Biomass heating

AM15: 2014

Biomass heating

CIBSE AM15: 2014

The Chartered Institution of Building Services Engineers
222 Balham High Road, London, SW12 9BS

Registered charity number 278104

ISBN 978-1-906846-51-0

Design, layout and typesetting by CIBSE Publications

Cover illustration: Pre-fabricated biomass boilerhouse operated by the West Highland Housing Association serving 50 houses and flats at Dunbeg near Oban, Argyll & Bute.

Note from the publisher

This publication is primarily intended to provide guidance to those responsible for the design, installation, commissioning, operation and maintenance of building services. It is not intended to be exhaustive or definitive and it will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

Any commercial products depicted or describer within this publication are included for the purposes of illustration only and their inclusion does not constitute endorsement or recommendation by the Institution.

Foreword

This Applications Manual concentrates on biomass systems with biomass boiler outputs in the range of 50 kW to 5 MW burning woodchips or wood pellets. The major application areas for biomass boilers will be for heating systems for existing buildings, and those with substantial heating and hot water loads throughout the year. Batch-fed boilers are briefly mentioned but it does not cover hot-air heaters, biomass gasifiers or biomass CHP systems.

The design of biomass boiler systems is considerably more complex than that of oil and gas boiler, heat pump and CHP systems, and requires an informed design approach. Integrating biomass boilers with oil and gas boilers with load circuits to form efficient and controllable hydronic systems requires a detailed understanding of the dynamics and subtleties of biomass boilers. Hence, this Applications Manual is designed to help readers understand biomass boiler systems to a level where they can make knowledgeable decisions on system design. With the exception of specific hydronic arrangements for integrating biomass boiler systems with oil or gas boilers in Chapter 7 and specific advice on health and safety requirements, this manual does not provide prescriptive solutions nor does it attempt to cover every eventuality. The primary readership of this manual is intended to be professional building services engineers in the UK.

Low-carbon related legislation and regulations are changing rapidly, and also vary significantly country by country. Reference is made throughout this manual to the UK's Renewable Heat Incentive (RHI) scheme and guidance is provided on measures which may be required to secure accreditation under the non-domestic RHI. Those installing boilers to provide heat to domestic properties, and seeking support under the domestic RHI, should refer to the appropriate guidance available on the Ofgem RHI website.

Readers must ensure that they are aware of, and conform with all legislation and regulatory requirements applicable to their project.

Colin Ashford – *Steering Committee Chair*

Principal author

David Palmer

Contributing authors

Colin Ashford
Jim Kinnibrugh
Graham Smith

Acknowledgements

— Carbon Trust for their extensive support to the early draft of this Applications Manual under the Biomass Heat Accelerator programme, together with the contribution of the initial authors.

— David Palmer for openly sharing his practical experience of achieving safe, efficient and reliable operation of biomass systems, identifying biomass best practice and applying academic rigour to the original material contained in this Application Manual.

— Graham Smith for his valuable input on controls and controllability of biomass heating installations.

— Jim Kinnibrugh for making available his extensive knowledge of European best practice on flues.

— Alison Campbell for applying her knowledge to make this Application Manual accessible to a general audience, and for preparing and reviewing the manuscript.

— Thanks to the following for helpful comments and guidance on the final draft of the publication: Phil Jones, Alexander Melichar, Edmund Ward (Ofgem), Matthew Woodcock (Forestry Commission).

Photographs and diagrams have been kindly supplied by:

— Alternative Heat, Biomass Energy Centre, Buccleuch Bioenergy, Campbell Palmer Partnership, Econergy, Fintry Development Trust, Forest Fuels, Herz, Hoval, Jim Kinnibrugh, KWB, Pentland Biomass, Reka, Remeha, Viessmann, West Highland Housing Association, Wöhler Messherät Kehrgerät GmbH, Wood Energy.

Editor

Ed Palmer

Peer reviewers

Dick Bradford
Walter Haag
Professor Brian Warwicker

CIBSE Technical Director

Hywel Davies

CIBSE Head of Knowledge

Nicholas Peake

1 Contents

1 Introduction and scope

1.1 Background

The rapidly increasing uptake of biomass as a low carbon technology has necessitated the production of this Applications Manual. Biomass for energy production is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. In the context of this Applications Manual biomass fuel is taken to be wood-based or woody material most frequently burned as woodchips or wood pellets. Ofgem refers to this as 'solid biomass' for the purposes of the Renewable Heat Incentive (RHI).

A biomass boiler is purpose-designed to burn woody biomass fuels (hereafter referred to as solid biomass) and usually comprises a combustion chamber and heat exchanger to provide low or medium temperature hot water. A biomass system includes fuel storage, a fuel extract and feed mechanism, bespoke boiler controls and hydronic arrangements to protect the biomass boiler from low return temperatures, to store excess heat and to achieve efficient operation. Many biomass boiler systems include flue gas cleaning and all require a flue system.

1.2 Scope

This Applications Manual focuses primarily on low temperature and medium temperature hot-water heating systems (LTHW and MTHW) within the range 50 kW to 5 MW nominal thermal output, burning woodchip, wood pellet or logwood fuel for the provision of space heating, process heating and hot water.

Typical applications include larger homes, offices, large residential buildings, hotels, leisure centres, schools, industrial space and process heating, and district heating networks. Extensive consideration is given to the integration of biomass boilers with oil and gas boiler systems, interfacing to both existing and new heating systems. While biomass systems from 1.5 MW upwards can provide saturated steam and from 3 MW upwards can heat thermal oil boilers for CHP, these are outside the scope of this Applications Manual.

The scope of this document is, necessarily, wide ranging because successful design, installation and operation requires knowledge of both component-level and system integration issues. The intrinsic nature of biomass heating plant (physically larger, more complex, a greater number of moving parts and the requirement for large plant space and fuel storage) necessitates that this Applications Manual covers areas not normally associated with the core skillset and responsibilities of building services engineers.

This document contains numerous references to UK legislation and the UK's RHI scheme up to June 2014 which are not applicable to installations outside the UK. The intended readership, described in Section 1.2.2 below, should ensure they comply with applicable local regulations and guidance.

Within the UK:

— Local authorities issue their own guidance and regulations on emissions, emissions assessments and flue heights.

— Different regulations exist within England and Wales, Scotland and Northern Ireland in areas such as emissions, the RHI and installation standards for biomass systems.

1.2.1 Purpose

The purpose of this Applications Manual is to enable the competent performance-in-use of a wide variety of biomass boiler installations by providing a detailed design process and technical guidance. It is based on many years' worth of accumulated experience in the field by some of the UK's most experienced biomass heating system designers, and from detailed analysis of biomass systems in use. It has been written to:

— Provide professional guidance on biomass heating system procurement, design and operation.

— Assist the understanding of the different types of biomass boilers available.

— Help designers select the most appropriate biomass system for a given application.

— Provide information on the knowledge, skills and experience required to achieve competent and efficient design and operation.

— Help identify the design input required from structural and civil engineers, building management system designers, and commissioning engineers.

— Provide information on other specialist areas such as fuel handling and flues.

— Clearly identify the differences from oil and gas boiler installations design.

1.2.2 Readership

The intended audiences for this Applications Manual are:

— Those involved in design, specification, installation and commissioning of biomass heating systems, including building services engineers, structural engineers, controls engineers and commissioning engineers.

— Non-engineering professionals such as architects and quantity surveyors.

— Planning, building control and environmental officers.

— Procurement, funding and client organisations.

— Facilities managers, maintenance engineers and those responsible for the operation of biomass systems.

— Suppliers of flues, thermal stores and pressurisation systems.

— Fire and rescue organisations.

This Applications Manual necessarily covers a wide range of topics. Persons directly involved in the design process should take benefit from all sections while others involved in the overall procurement process can use the activity specific notes below to gain initial familiarity. They can then explore other sections and seek advice as necessary.

1.3 Typical biomass boilerhouse project process

The time from initial identification of opportunity to a working installation for straightforward projects is typically around 45 weeks. For more complex projects, and those with funding constraints spanning financial years, up to two years is not unknown.

Small projects may only need a biomass designer working with an architect where the architect would undertake project management duties. The biomass designer, frequently a building services engineering professional, must be able to operate seamlessly with other professionals such as architects, structural engineers, quantity surveyors and project managers. Larger projects, especially those associated with district heating, will usually require a fully constituted and appropriately experienced design team. Table 1.1 shows a typical project timescale and advised reading within this manual.

1.4 Professional duties for the design of biomass boilerhouse projects

While CIBSE guidance does not usually include information on professional fees, biomass projects are unusual in that the fee structure, and percentage fees paid to design team professionals, can be significantly different to those encountered in a typical building services project. Biomass projects are heavily building services engineer led placing wider and more onerous duties and responsibilities onto the building services engineer, and with a greater percentage of the overall design fee going to the biomass designer. Typical fees are percentage (%) of project value for projects over £200 000. Note that for projects less than £200 000, fees will not be proportionally less, or reduced at all, as substantially the same duties have to be undertaken. The duties can be adjusted for new projects.

Project manager duties on smaller projects may be shared duties by the architect and quantity surveyor, rather than by a separately appointed project manager.

For convenience the following list of professional duties is presented in alphabetical order.

Architect (2.5%)

(1) Design the boilerhouse utilising information from the biomass designer.

(2) Design the fuel store taking information from the biomass designer and structural engineer.

(3) Obtain all permissions including those required under the Clean Air Act.

(4) Carry out contract administration.

Biomass designer (building services engineer – 7.5%)

The biomass designer should be a professional building services engineer with biomass system design experience appropriate to the project. The knowledge and experience needed to achieve competent design and operation of biomass systems are considerably wider than those required for the design of oil and gas systems. The biomass designer must have good knowledge at a professional engineering level of electrical and mechanical engineering, controls principles, biomass boiler characteristics and operation, thermodynamics, flues, system hydronics, plant dynamics and heat load control strategies. The client and/or project manager should ensure that the building services engineer appointed to undertake the biomass designer duties is appropriately experienced as detailed in following section; this includes a full understanding of this Applications Manual.

A departure from the usual duties of a building services engineer is the requirement to be able to design and specify flue systems which must be considered an integral part of biomass systems. A comprehensive knowledge of available flue system types and flue construction methods and procedures, including the theory and practice of test methods, is required. Much greater emphasis must be placed on flue design for a biomass system because, not only must the flue system produce sufficient draught to allow safe operation of the boiler under all operating conditions (including electrical power failure), but the flue height must be such as to satisfy the requirements of local authority environmental officers for the safe dispersal of pollutants, primarily NO_x and particulate matter (PM) in order to secure planning permission.

Clients should request evidence from potential biomass designers such as:

(1) Apart from feasibility studies, how many actual biomass system designs has the designer produced?

(2) How many of these designs have progressed to become actual working installations operating for more than 12 months?

(3) The names and addresses of the owners of the biomass installations for reference purposes.

(4) What are the seasonal efficiencies of each of the named biomass installations?

(5) What percentage of the annual heat energy requirement has been supplied by each of the named biomass installations?

If the potential biomass designer cannot provide the above information then their relevant experience/competence should be a cause of concern.

The specific duties of a biomass designer are:

Table 1.1 A typical project timescale and the advised reading within this Applications Manual.

Tasks	Typical duration in weeks	Activity
Initial identification of biomass heating opportunity. Undertake feasibility study to identify whole-life costs and benefits. Includes initial identification and discussions on planning and environmental issues.	4 to 7	Biomass designer advising client and working with planning consultant and architect. Must include initial liaison with flues specialist.
Obtain financial approval / outline planning	4 to 12	Biomass designer advising client and working with planning consultant and architect on larger projects.
Interview and appoint project team	4 to 6	Biomass designer defines tasks, duties responsibilities. Advises client and project manager.
Biomass designer identifies building heat demand profiles and biomass boiler size, thermal store size and required fuel storage capacity. Fuel suppliers identified together with their vehicular access requirements. Provide preliminary layouts and information to the structural engineer, architect, quantity surveyor, flue designer. Controls engineer specifies control arrangements.	6 to 10	Biomass designer with support from architect on larger projects. Commissioning specialist ensures suitability of access arrangements and test points.
Prepare bills of quantities	3 to 4	Architect working with project manager.
Generate tender documents. Include period for EU Official Journal contract advertising.	10 to 14	Project manager working with client
Prepare long-list and identify short-list of contractors. Hold bidder interviews, receive bids.	4 to 7	Architect / project manager working closely with biomass designer.
Appoint contractor, includes time for mobilisation	4 to 6	Project manager / architect
Civil engineering works plus architectural works construction time depends on size and imposed constraints.	8 to 18	Project manager / architect
Installation of building services	2 to 4	Project manager with checking by biomass designer. Initial checks by commissioning specialist.
Commissioning	1	Biomass designer alone on smaller projects, supported by commissioning specialist on larger projects
Completion, including thermal insulation of pipework and valves	1	Project manager
TOTAL	47 to 90	
Operation and maintenance	Ongoing	Facilities manager

(1) Identify client values on environmental friendliness /sustainability and use these to inform project decisions.

(2) Undertake biomass feasibility assessment – fundamental decision to determine if worth proceeding.

(3) Obtain information on and undertake whole-life cost analysis.

(4) Identify the contractual interface between existing building services and new works.

(5) Carry out energy analysis including heat load profiling, sizing of boiler, selection of boiler type, sizing of thermal storage.

(6) Select biomass fuel type and size the fuel store.

(7) Obtain topological data for the site and local terrain to identify minimum flue height necessary for proper dispersal of exhaust gases and access for fuel delivery.

(8) Identify preferred location for boilerhouse and flue.

(9) Evaluate potential fuel suppliers (multiple suppliers to ensure competition), including identification of delivery means and vehicle options.

(10) Produce either a performance specification for the boiler, or specify the boiler type and manufacturer. This should include response rates of the boiler, suitability for the proposed control strategy; minimum seasonal boiler efficiency and the minimum percentage of annual energy to be supplied by the biomass system.

(11) Obtain boiler performance data from potential boiler manufacturers.

(12) Determine whether any additional post combustion flue gas treatment is required.

(13) Specify the minimum flue height required for the dispersal of boiler fumes – may require dispersion modelling (this will need additional fees) if terrain elevations are local.

(14) Calculate the height and diameter of the flue to provide the minimum height required to provide the minimum draught required at the boiler under all operating conditions.

(15) Design the complete flue system including draught stabiliser, explosion relief, rainwater drainage, and access for cleaning and inspection.

(16) Design the biomass installation and interface(s) to existing building services systems.

(17) Calculate the combustion air requirement and the corresponding ventilation areas and inlet ventilator positions for both combustion air and boilerhouse ventilation.

(18) Design boilerhouse and fuel store safety systems including fire detection and suppression, carbon monoxide detection, and systems to ensure safe systems shutdown if the electrical power fails.

(19) Provide boilerhouse internal and external access and clearance space requirements to the architect.

(20) Specify the safety requirements and design the safety systems for the biomass installation in conjunction with the controls engineer.

(21) Specify the type and quality of fuel required using BS EN 14961-1 (2010).

(22) Specify the equipment required for on-site fuel quality monitoring and testing.

(23) Produce a maintenance schedule for the biomass system.

(24) Check the installation as construction proceeds for compliance with the specification.

(25) Detail the specific biomass requirements for commissioning.

(26) Direct the commissioning process and activities of all commissioning engineers from all contractors.

(27) Identify the training requirements for operational staff on site. (Training paid for by others).

Construction Design and Management (CDM) (1.5%)

CDM duties may be carried out by the quantity surveyor or a specialist CDM company.

Controls engineer (1%)

The controls engineer must be a professional building services controls engineer with extensive experience of system controllability and controls/building management system (BMS) specification, and with a good knowledge of bespoke biomass controls integrated into biomass boilers. A controllable hydronic system coupled with good integrated controls is essential for a successful biomass system, and building management systems integrators without extensive biomass system familiarity may not have the range and depth of experience required. At the very minimum, the controls engineer must have a good understanding of building physics associated with biomass systems hydronics. These duties are over and above those of a controls subcontractor.

(1) Review system controllability and principles of operation of the system and the selected boilers in association with the biomass designer.

(2) Identify possible control strategies to take account of any limitations in system design and sizing.

(3) Specify the overall control strategy.

(4) Ensure that control strategies are suitable for the safe operation of the biomass system taking into account e.g. electrical power failure, sudden removal of system load, fire detection and detection of CO.

(5) Specify the type of control system/BMS.

(6) Produce points list, valve schedules etc.

(7) Specify the user interfaces.

(8) Check contractor's proposals.

(9) Attend commissioning of the control system.

Quantity surveyor (2.5%)

(1) Produce a bill of quantities.

(2) Prepare the construction contract.

(3) Identify potential bidders pre-qualifying as necessary.

(4) Carry out a tender exercise, evaluate tenders with client and design team.

(5) Provide post-tender services: valuations of works, stage payments etc.

(6) If required by client, prepare contracts for system maintenance and fuel supply.

Structural engineer (1–1.5%)

(1) Check the need for any archaeological oversight.

(2) Check for contaminated land.

(3) Identify the ground conditions – arrange for test pits as required.

(4) Identify the location of existing underground services.

(5) Identify the location of any overhead services which cross or are near to the construction site.

(6) Arrange for any diversions of existing underground or overhead services.

(7) Design access road for fuel delivery vehicles.

(8) Design underground services – water, electricity, gas, drainage etc.

(9) Design the foundations for fuel store and flue.

(10) Design the boilerhouse structure.

Facilities manager[1]

(1) Implement the client's carbon impact reduction and payback policies.

(2) Ensure the fuel stock is adequate and that deliveries comply with the fuel specification using suitable fuel testing equipment.

(3) Maintain access for fuel delivery, and check the quality of delivered fuel including the appropriate rate of delivery for wood pellets.

(4) Ensure that maintenance activities are carried out in accordance the biomass boiler manufacturer's specification.

(5) Witness commissioning to gain initial familiarity with operation.

(6) Ensure the operation and maintenance manual is comprehensive and understandable. In particular that full descriptions of operating and maintenance procedures are detailed, together with comprehensive health and safety requirements and procedures.

(7) Ensure operating and maintenance personnel are adequately trained.

(8) Maintain logs of boiler performance and operation maintenance activities.

1.5 Key indicators for a successful installation

The key strategic-level indicators for successful projects are identified below with the detail contained elsewhere in this Applications Manual. These indicators are based on an analysis of a large number of biomass boilerhouses.

1.5.1 Performance-in-use

The metrics for competent operation of a biomass boiler house will depend on the boiler type and the load to be supplied. Typical key indicators for 'performance-in-use' are that:

(1) The biomass boiler should supply in excess of 90% of the total heating power requirement on an annual basis (% as defined at design optimisation, can be lower).

(2) The seasonal operating efficiency of biomass fuel heat input to metered heat output exceeds 85%. Note that this requires the moisture content and volume of biomass woodchips to be accurately recorded, or for the fuel supplier to guarantee gross heat in kW·h for fuel supplied.

(3) There should be no 'glazed crowns' or clinker in the fire-box which indicate unsatisfactory combustion conditions.

(4) Ash from biomass should not exceed the percentages stated in BS EN 14961-1 for the normative specification for the fuel (see 2.3.3).

1.5.2 Initial feasibility investigations

(1) Appoint a suitably experienced biomass designer (see 1.4 for required knowledge, skills and experience) to understand the client's objectives and to undertake initial site assessment to confirm that it is worth proceeding to a feasibility study.

(2) Undertake a feasibility study by an experienced biomass designer. This must include: detailed heat load profiles, ideally taken from half-hourly data, whole-life-cost (WLC) calculations, identification of backlog maintenance requirements if connecting to an existing installation, boilerhouse and flue positioning and height, environmental impact, access for fuel delivery and fuel costs and supply availability, suitability of any existing boilerhouse.

(3) Planning Department to confirm acceptability of flue height as determined by engineering calculations.

(4) Carry out an initial emissions assessment sufficient to confirm that permission is likely to be obtained for a biomass system.

(5) Carry out an initial check with potential fuel suppliers of the type, quality, availability, costs and deliverability of fuel to the site.

(6) Ensure feasibility report makes adequate provision for professional fees of suitably experienced persons.

The Biomass Energy Centre's *Guide to feasibility studies* (Palmer et al, 2011a) contains further useful information, particularly on biomass boiler selection. However, note that reference to using the Technical Memorandum D1 to size biomass flues is incorrect and should not be used.

1.5.3 Appointment of procurement team

(1) Ensure that the client and persons undertaking project manager tasks, duties and responsibilities fully understand and support the multi-disciplinary roles of the biomass designer (see Section 1.4 above).

[1] Although not part of the design, construction and commissioning processes, this role is included for completeness.

(2) Client requirements are to include compliance with all applicable 'performance-in-use' requirements (see 1.51 above) to the agreed performance level.

(3) Background checks of prospective professional team members include evidence-based checks on operational performance achieved on similarly sized projects. Section 1.5.1 above identifies suitable 'performance-in-use' metrics.

(4) If a multi-disciplinary consultancy offers to undertake the required duties, ensure that the team members are named and interviewed. The professional appointment contractual requirement should require that only named personnel will work on the project.

(5) Clients without biomass experience should use commercially impartial external consultants to ensure adequate knowledge, skills and experience checks on prospective team members.

1.5.4 Design engineering

(1) The biomass designer is to demonstrate optimisation of the size of the biomass boiler, fuel storage and thermal store, and of control arrangements using design tools such as the *Biomass decision support tool* (Carbon Trust, 2013).

(2) If a biomass boiler is being added to an existing heating system, the hydronic and controls interfaces must be clearly defined.

(3) Hydronic arrangements fully accord with all applicable guidance in Sections 5 to 8 of this Applications Manual.

(4) The control engineer must understand heat balance in system hydronics, that control requirements are properly defined, and the test requirements for proving correct operation are formally defined.

(5) The flue design avoids the use of flue fans in addition to those already incorporated into a boiler or required between a boiler and cyclone grit arrestor.

(6) The flue connection from boiler to flue stack is short, preferably within 1.5 to 2.0 m of boiler.

(7) The flue height and location must comply with local authority and environmental standards. This is especially important where multiple flues are present, e.g. biomass and fossil fuel. Air dispersion modelling may be required as part of the design process.

(8) The biomass designer must work with the project manager to ensure that the construction contractor cannot make any changes to specified equipment and systems unless explicitly approved by the biomass designer.

1.5.5 Construction and setting to work / commissioning

(1) The biomass designer is to check construction works and building services works for compliance with the engineering design.

(2) The flue construction is in accordance with the manufacturer's installation instructions, and properly pressure and leak tested. A flue test certificate must be available.

(3) The biomass boiler installation is to EU design criteria by the manufacturer or their appointed agents as fully compliant with their instructions. A boiler test certificate must be available.

(4) Heat meter installations are to be fully compliant with manufacturer's installation and operation instructions and, when applicable, RHI requirements.

(5) Commissioning is to prove operation of the control arrangements to achieve the design intent under all operating conditions.

(6) The biomass installer's duties include ensuring that the first 12 months' operation of the biomass system conforms fully to the design intent.

(7) The biomass boilerhouse operating staff are to be adequately trained and should have open access to well-informed and commercially impartial support.

(8) The construction works should include re-commissioning after 11 months of operation immediately prior to the final handover at 12 months.

2 Biomass fuels, combustion and emissions

Biomass for burning as a fuel includes wood, energy crops, agricultural crop residues, wood manufacturing by-products, clean recycled wood and farm animal litter. The selection of the fuel to be used can be complex as it depends on many factors. While cost is a key driver for fuel selection, the space available for fuel storage, access for fuel deliveries and the method of delivery are all key considerations.

While this manual is concerned primarily with woodchips and wood pellets, the potential for using other solid biomass fuels should be borne in mind when considering fuel types; a brief section is included on log fuelled systems. Burning of the following fuel types is not covered in this manual: straw, grains (barley, oats, oilseed rape, wheat, rice etc.), grain husks, oilseed rape, other agricultural residues, recycled wood containing glues and resins, farm animal litter and distillery draff. Guidance on burning other fuel types can be found on the Biomass Energy Centre website (www.biomassenergycentre.org.uk) and from numerous EU and UK official publications available via the internet.

2.1 Woodfuel composition

Wood comprises three main constituents, cellulose, hemicellulose and lignins, together with a number of trace elements. The three main constituents are complex structures of carbon, hydrogen and oxygen. Cellulose, 40–50% of the wood, is essentially a polymerised sugar formed into long chains and gives wood its strength. Hemicellulose, 20–35% of the wood, is similarly formed of sugars; it is generally a smaller molecule than cellulose, but has many more branches in its chemical structure. Lignins, 15–35% of the wood, have a very complex chemical form incorporating numerous five and six carbon aromatic ring structures. It is the unwanted side products formed during the combustion of lignins which gives rise to the characteristic smell of wood fires.

In addition to this, there are numerous trace elements taken up during growth. These include calcium, chlorine, nitrogen, phosphorus, potassium, silicon, sodium and sulphur. These minerals tend to be most prevalent in the bark, are concentrated in the ash during combustion, and will vary depending upon the elements' abundance (either naturally or as a contaminant) in the environment the tree was grown in. The ratios of the three main constituents differ between tree species, as do the ratios of sub-types within each constituent. However, as all are comprised of carbon, oxygen and hydrogen, there tends to be little variation in the overall quantities of the individual elements. A representative approximation of the composition of wood, ignoring trace elements is:

— carbon: 49% by weight

— oxygen: 45% by weight

— hydrogen: 6% by weight

giving rise to the generic chemical formula for wood of $C_1H_{1.4}O_{0.7}$.

2.2 Fuel characteristics

Moisture content and calorific value are the two most significant characteristics of solid biomass fuels (i.e. all woody fuels), but there are a range of other important characteristics which have an impact on the design and operation of biomass systems which need to be taken into consideration.

2.2.1 Woodchip fuel characteristics

2.2.1.1 Moisture content and calorific value

Woodchip is available with moisture contents between 20–55%, the moisture reducing the calorific value of the fuel in two ways. It forms a non-combustible mass within the fuel and requires energy from the fuel to boil it and convert it to water vapour so that it can escape up the flue. The greater the moisture content the less the energy is available from the fuel as the energy used to vaporise water is not available to provide heat from the boiler. For this reason net calorific values are used for all wood fuels and reflect European continental practice. Furthermore, as the majority of available boiler plant is manufactured in Europe this allows the performance of boilers to be assessed on a common basis.

Numerous woodchip calorific value calculators are available all of which calculate the lower heating value (LHV) of woody biomass fuels. The LHV of fully dried woodchips is usually between 18 and 18.5 MJ/kg (5.0 and 5.14 kW·h/kg) while there is no calorific value remaining at 88% moisture content. There is little practicable difference between softwoods and hardwoods. Calorific value is a linear function of the moisture content in the fuel (Kasimir et al, 2008):

$$LHV = UHV(1 - MC) - 2.447(MC - 9.01H(1 - MC) \quad (2.1)$$

where LHV is the lower heating value in MJ/kg, UHV is the upper heating value (usually taken as 20 MJ/kg for softwoods and 19.5 MJ/kg for hardwoods), MC is the moisture content in percent and H is the hydrogen content in percent (tree species dependent but usually taken as 6%).

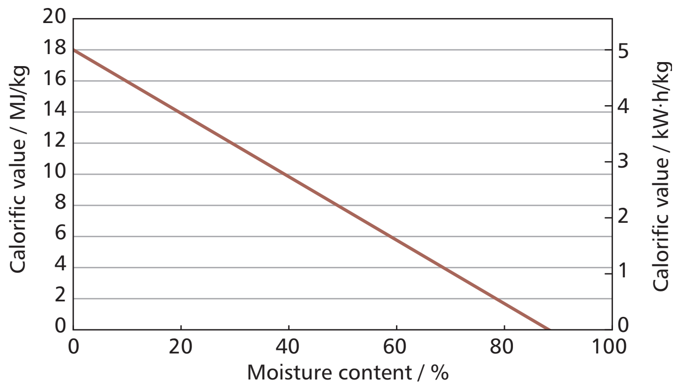


Figure 2.1 The calorific value of wood biomass fuels vs moisture content

In practice, woodchip characterised by moisture content can be divided into two bands: 15–35% moisture content; and 40–65% moisture content. A wide range of boilers, with low levels of ceramic lining and rated at up to 500 kW, is available to burn woodchips up to a maximum of 35% moisture content, while more thermally massive boilers are required to burn woodchips with a moisture content of 40% or above. Beyond 65% moisture content combustion is very difficult to maintain. The types and characteristics of boilers required to burn different fuels are covered in Chapter 4 of this Applications Manual.

2.2.1.2 Bulk density

When storing woodchips, a significant proportion of the occupied volume is empty space between the woodchips. The bulk density is a measure of the mass of a quantity of woodchips divided by the occupied volume, the higher the bulk density, the more mass of fuel exists in a given volume. The greater the moisture content of the fuel the greater the bulk density which has a hyperbolic relationship to volume (Kasimir et al, 2008):

$$Bulk\ density\ of\ softwood\ chips = \frac{150}{(1 - MC)} \quad (2.2)$$

where MC is the moisture content in percent.

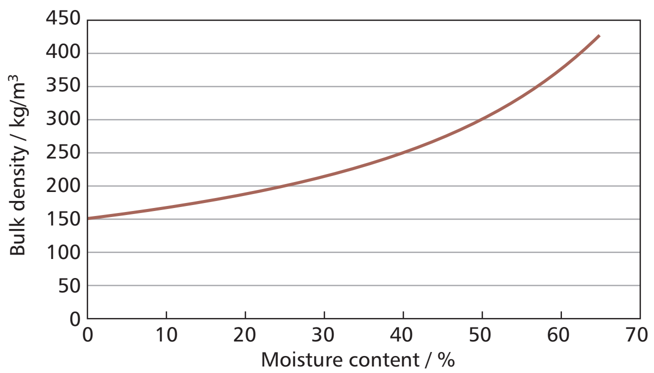


Figure 2.2 The bulk density of woodchips vs moisture content

Bulk density, unlike density, is not intrinsic to a material as the same piece of wood would have different bulk densities if processed into woodchips, logs or pellets. Moisture content also affects bulk density as each particle has a greater mass but does not occupy more space; this is an important consideration because fuels with higher moisture contents will have greater masses and, therefore, higher bulk densities.

2.2.1.3 Energy density

Energy density is a measure of the energy contained within a unit volume of fuel. Energy density is expressed in MJ/m^3 and can be derived by multiplying the calorific value in MJ/kg by the bulk density in kg/m^3 or, alternatively, the calorific value in kW·h/kg by the bulk density in kg/m^3:

$$\text{energy density} = \text{calorific value} \times \text{bulk density} \quad (2.3)$$

In practice the energy density does not vary greatly with moisture content over the most common range of woodchip moisture contents (20–35%) because the calorific value curve runs in the opposite direction to the bulk density curve, the two effects largely cancelling each other out resulting in the curve shown in Figure 2.3.

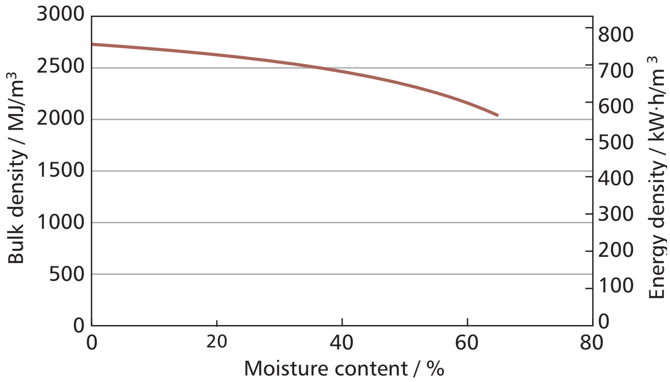


Figure 2.3 The energy density of woodchips vs moisture content

Energy density is an important variable as it can help designers to assess volumetric fuel consumption rates, the size of fuel storage and the frequency of deliveries required, and the annual fuel requirement.

2.2.1.4 Particle size and dimensions

Most boilers will be able to accept a maximum particle size which is, typically, defined by a combination of cross-sectional area and maximum length for wood chips. In general the smaller the boiler, the smaller the fuel feed system (usually based on augers) and the smaller the maximum chip size which can be accommodated. However, fuel feed systems incorporating a ram stoker can accept significantly oversized chips, these systems having a cutting knife at the fuel inlet to the boiler. Furthermore, outsize particles, or the presence of an excessive proportion of 'fines' (very small particles such as sawdust), are common causes of system blockages. For these reasons fuel standards exist to assist in the specification of fuel quality. These standards are covered in Section 2.3.

2.2.2 Wood pellet characteristics

Wood pellets, manufactured to BS EN 14961-2: A1 have a maximum moisture content of 10% and their calorific value can be calculated using equation 2.1, as for woodchips. Typically, the calorific value of wood pellets is between 4.6 and 4.8 kW·h/kg and their bulk density is between 600 and 650 kg/m^3.

2.2.2.1 Mechanical durability

The mechanical durability of wood pellets is a measure of the degree to which pellets remain intact during fuel delivery, storage and subsequent mechanical handling. Good quality pellets should have a mechanical durability of at least 97.5%, meaning less than 2.5% of the pellets will be broken down after handling, and have no more than 1% of fines. Small particles in the fuel may cause problems such as compaction in augers and smothering of the fire bed.

2.2.2.2 Pellet manufacture

The majority of wood pellets in Europe are manufactured using wet wood CHP plants, the resulting pellets being considered carbon neutral. Pellets are manufactured from the heart wood while the bark, small branches and brash are burned by the CHP plant. European wood pellet manufacturing capacity has been increasing at the rate of 1 million tonnes per annum and had reached 11 million tonnes per annum by the end of 2011. Cylindrical wood pellets are manufactured in diameters of 6, 8 and approximately 10 mm long.

Pellets are usually manufactured without the use of binders or adhesives, rather using the natural adhesives present in the wood to bind the pellets together in the presence of steam and high pressure in the pellet mill. The thermoplastic flow of the naturally occurring lignin and hemicelluloses, under the temperature and pressure conditions in the pellet press, causes the pellets to bind together.

2.2.3 The use of waste materials as fuel

Any material which has been classified as a waste under the European Waste Directive will require a permit from the relevant environmental regulator before it can be burned as a fuel. For this reason the forestry industry and manufacturers of wood products from raw materials produce co-products and by-products, but never produce waste: this allows materials such as bark to be burned.

If planning to use a recycled material as a biomass fuel it is important to establish whether the material contains any heavy metals, e.g. lead based paint, or has been contaminated by toxic organic compounds, e.g. organo-tin compounds used as sheep dip which could have contaminated the pallets on which they were supplied. The environmental regulator may require evidence demonstrating that the material it is proposed to burn does not contain any hazardous substances. Knowledge of the original source of biomass material is important for sustainability reporting requirements.

2.2.4 Contaminants in fuel

The contamination of, especially, wood chip fuel by foreign matter is a known and widespread problem, especially if clean recycled wood is used. The presence of, for instance, hinges, doorknobs and other metal items will jam fuel feed systems and can cause augers to snap. For this reason it is important that the fuel supplier uses state-of-the-art methods to separate wood from ferrous and non-ferrous metals. Appropriate screening will also ensure that other combustible and non-combustible materials are separated from the woody content. These procedures are practised by all quality fuel suppliers.

Another important consideration is where woodchip fuel is prepared. Wood to be chipped should always be stored in a clean concrete area and not on earth or open ground. Stones and other debris can be taken up into the fuel, and if timber is stored on sandy ground the silica content of the fuel can be increased to the point where slag formation becomes a major problem.

2.3 Fuel standards and testing

2.3.1 Fuel standards

From autumn 2014 biomass fuel used by RHI participants must meet a lifecycle greenhouse gas (GHG) emissions target of 34.8 g CO_2 equivalent per MJ of heat or 60% GHG savings against the EU fossil fuel average. Ofgem intends that biomass installations of <1 MW capacity will be able to use the default GHG emissions values outlined in the EU's *Report on Biomass Sustainability* (EC, 2010). Those installations above the 1 MW threshold will need to use actual values and are recommended to use the *UK Solid and Gaseous Biomass and Biogas Carbon Calculator* (Ofgem, 2012). From spring 2015 it is also planned that biomass fuel must meet land criteria, which will differ for different types of biomass. For wood fuel the criteria are outlined in the *UK Timber Standard for Heat and Electricity* (DECC, 2014b).

The *Biomass fuel procurement guide* (Carbon Trust, 2012) covers the specification and procurement of biomass fuel. This contains current guidance on fuel specifications and procurement as at 2014.

The Biomass Energy Centre, a division of Forest Research (part of the Forestry Commission) provides advice, information and guidance on a wide range of biomass fuels and conversion technologies, and full details of the following range of standards are available on their website.

2.3.2 CEN/TC 335

CEN/TC 335 allows all relevant properties of all forms of solid biofuels within Europe, including wood chips, wood pellets and briquettes, logs, sawdust and straw bales the fuel to be described. It includes both normative information that must be provided about the fuel, and informative information that can be included but is not required. The European Committee for Standardisation (CEN, under committee TC 335) published 27 technical specifications for solid biofuels during 2003–2006. As well as the physical and chemical characteristics of the fuel as it is, CEN/TC 335 also provides information on the source of the material. These technical specifications have now been updated to full European Standards (EN). The two primary technical specifications deal with classification and specification (BS EN 14961) and quality assurance for biofuels (BS EN 15234).

2.3.3 BS EN 14961-1 (2010)

EN 14961-1 covers the full range of solid biomass fuels including woodchips and wood pellets which are the primary focus in this manual.

The classification of solid biofuels is based on their origin, and the fuel production chain should be clearly traceable from source to the point of use. Normative specifications for wood chips include:

- origin
- particle size (P16/P31.5/P45/P63/P100)
- moisture content (M20/M25/M30/M40/M55/M65)
- ash content (A0.7/A1.5/A3.0/A6.0/A10.0).

Normative specifications for chemically treated wood or used wood include:

— nitrogen (N0.5/N1.0/N3.0/N3.0+).

Informative specifications for wood chips include:

— net energy content (lower heating value (LHV)) as MJ/kg or kW·h/m³ loose
— bulk density in kg/m³ loose
— chlorine content (Cl0.03/Cl0.07/Cl0.10/Cl0.10+)
— nitrogen (N0.5/N1.0/N3.0/N3.0+).

2.3.4 ÖNORM

While the EN 14961-1 standards have superseded all other European standards for solid biofuels across Europe, the Austrian ÖNORM standard is frequently referred to. ÖNORM is the Austrian Standards Institute and, while they are now adopting their own implementations of the EN 14961-1 standards, many Austrian boilers have been installed in the UK and specify fuel according to ÖNORM M 7133 for wood chips (*Woodchips for energy generation: quality and testing requirements*) and ÖNORM M 7135 for pellets.

2.3.5 Fuel supply to RHI accredited systems

All RHI participants using biomass feedstocks in their RHI accredited installation will need to comply with the sustainability requirements from the date the criteria come into force. There are two methods to meet the sustainability criteria and participants can switch between them:

— Sourcing wood fuel from the Biomass Suppliers List (BSL) and, subject to further detail, providing Ofgem with a quarterly declaration that the biomass fuel they have used was sourced from a supplier registered on the BSL and marked as sustainable.
— Those who produce wood fuel from the same estate as the installation must register on the BSL as a self-supplier: this applies to installations of <1 MW. They must then self-report to Ofgem on the sustainability of their fuel. This will involve making a quarterly declaration to Ofgem of the lifecycle GHG emissions associated with each consignment of fuel used in that quarter, and provide an annual independent audit of the lifecycle GHG emissions associated with biomass used in that reporting year.

Full guidance can be found in *New biomass sustainability requirements for the Renewable Heat Incentive* (DECC, 2014a).

2.3.6 Woodsure

Woodsure is an accreditation scheme for assessing the quality and suitability of wood chip, pellets, briquettes and hog fuel (shred). Woodsure accreditation means that these products have been tested to ensure they meet the EN and ÖNORM standards for woodfuel quality that have become the established measure in the European biomass industry. Woodsure accredited woodfuel assures customers that the fuel they are purchasing fulfils the appropriate specification for their equipment. It helps to guarantee a high standard and reliability in the supply chain.

2.3.7 Checking and testing fuel quality

The following subsections represent a range of relatively simple methods which may be employed to check fuel.

2.3.7.1 Moisture content

Simple

— ‘Touch test’: does the delivery feel wetter than it should? Is it showing signs of mould growth or other degradation?
— Bucket samplers, which can measure to an accuracy of ±1.5%.
— Moisture probes, which can measure moisture content up to 1 m depth in a woodchip pile to an accuracy of ±3%.
— Timber conductivity meters give an indication of the likely moisture content on logwood but cannot measure moisture content in the centre of a log.

More accurate

— The ‘oven-dry’ method: oven-drying of fuel at 105 °C and re-weighing until no further weight loss is detected. (CEN/TS 14774-1, 2 and 3:2009).
— When claiming the RHI a more established system needs to be in place especially for boiler systems >1 MW. See 2.3.4 below.

2.3.7.2 Particle size

Simple

— A visual check for unacceptable level of oversized particles such as shards, slivers, unchipped wood or anything that may cause blockages in the fuel handling system.
— A visual check for unacceptable level of undersized particles and dust content (note that dust can also cause blockages).

More accurate

— Put sample through handheld sieves to gauge the percentage of volume at each size (CEN/TS 15149-1, 2 and 3: 2006).

2.3.7.3 Contamination

Simple

— A visual check for foreign bodies, i.e. stones, plastic, nails, rubber etc.
— A visual inspection for chemical contaminants as evidenced by discolouration of material, e.g. heavy metal compounds as a result of treatment e.g. chromated copper arsenate (CCA) (identified by green colour), halogenated organic compounds, e.g. lindane (identified by yellow colour), creosote (identified by dark brown stain and smell), paint

flecks. For installations using recycled woody fuels, guidance on correct fuel preparation is provided in the UK's Wood Recycler's Association document PAS111: *Specification for the requirements and test methods for processing waste wood* (BSI, 2012).

More accurate

— Send a sample for laboratory testing at an independent test-house.

2.3.7.4 RHI requirement for fuel measurement and sampling

Where a biomass fuel could be contaminated with a fossil fuel and the installation is to be RHI accredited, Ofgem will require fuel measurement and sampling (FMS) to be carried out prior to accreditation and thereafter at regular intervals.

FMS is also required on boilers >1 MW where a non-biomass fuel is used for boiler ignition, e.g. a gas, oil or electric igniter.

2.4 Biomass combustion

Solid organic fuels are not flammable under ambient conditions and a chain of thermochemical conversion processes need to take place in order for solid biofuels to burn (DGS, Ecofys, 2005):

— *Stage 1:* Warming of the fuel (less than 100 °C). Biomass solid fuels are usually stored at between 0 and 25 °C, so before reactions can begin the fuel needs to be warmed. Stage 1 requires the combustion chamber to be hot above and around where the fuel enters the grate and most biomass boilers contain some refractory material for this reason. Boilers designed to burn wet wood chips have substantial refractory linings in large combustion chambers. The greater the quantity of refractory lining, the less responsive the boiler to changes in heat demand, the longer the time taken to reach ignition temperature and the greater the residual heat that will need to be dissipated when the boiler is switched off.

— *Stage 2:* Drying of the fuel (100–150 °C). Vaporisation of water trapped inside the fuel occurs above 100 °C.

— *Stage 3:* Pyrolytic decomposition of the wood components (150–230 °C). Pyrolytic decomposition begins at approximately 150 °C where the long-chain components of the solid fuels are broken down into short-chain compounds. The products of pyrolysis are liquid tars, gases such as carbon monoxide (CO) and gaseous hydrocarbons (C_mH_n). The pyrolytic decomposition of wood does not require any oxygen.

Stages 1–3 are endothermic (heat-absorbing) reactions. They take place in any fire and prepare the fuel for oxidation. Once the flash point has been reached, approximately 230 °C, exothermic (heat-producing) reactions commence with the input of oxygen. Wood can be externally ignited at approximately 300 °C, and undergoes spontaneous combustion from 400 °C.

— *Stage 4:* Gasification of the water-free fuel (230–500 °C). The thermal decomposition of dry fuel under the influence of oxygen commences at the flashpoint of approximately 230 °C, where gasification takes place mainly in the firebed of a solid fuel fire. The oxygen supplied in the primary air produces sufficient heat in reaction with the gaseous pyrolysis products to affect the solid and liquid pyrolysis products such as carbon and tar.

— *Stage 5:* Gasification of the solid carbon (500–700 °C). Combustible carbon monoxide is generated under the influence of carbon dioxide (CO_2), water vapour and oxygen (O_2). The gasification of solid carbon is an exothermic reaction producing both heat and light which can be seen as a visible flame.

— *Stage 6:* Oxidation of the combustible gases (700–1 400 °C). The oxidation of all combustible gases produced by the preceding process stages represents the end of the combustion reaction for the solid fuel. Most of the energy is produced at this stage when the combustible gases, mainly a mixture of carbon monoxide (CO) and hydrogen (H_2), are burned some distance away from the grate at a high temperature, while maintaining the temperature range on the grate required at Stages 1, 2 and 3 to convert the solid material to energy. The clean and complete combustion of the gas mixture is accomplished under the influence of secondary air.

Full conversion of solid fuels requires:

— Good mixing of the wood gas, produced at Stages 4 and 5, with the combustion air.

— The oxidation air at Stage 6 to be in excess of stoichiometric requirements (i.e. $\lambda > 1$).

— A sufficiently long dwell time for the wood gas/air mixture in the reaction zone.

— A sufficiently high combustion temperature.

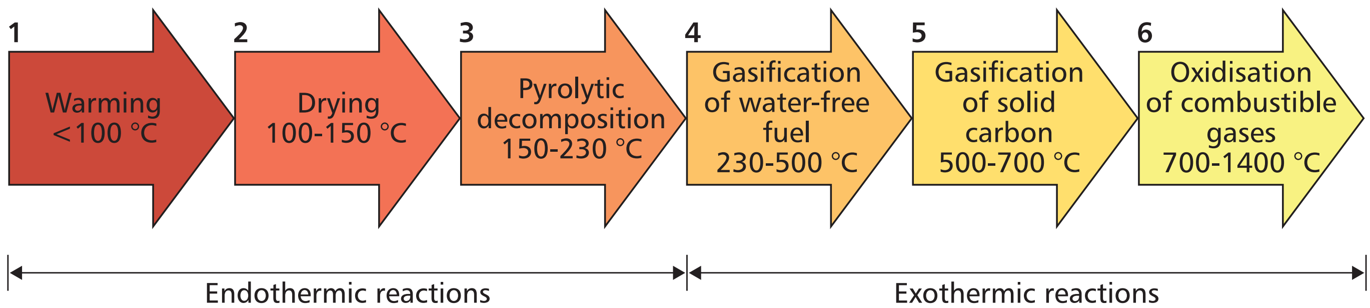


Figure 2.4 Stages of biomass combustion

The necessary conditions for complete and even combustion of the fuel, and resulting low emissions, are achieved by a spatial separation of the air supply to the firebed (primary air) and that to the gas combustion zone (secondary air); combustion air is discussed fully in Section 4.5.3. The requirement for combustion air is in addition to that for general boilerhouse ventilation, the requirement for which should be separately assessed.

Figure 2.5 A stepped grate

If a typical grated combustion system using a stepped grate automatic stoker is considered, then the area near the fuel feed will be predominantly drying, followed by the pyrolysis section with the carbon burn-out occurring at the end of the grate. The transition between sections is gradual, and the depth of firebed material will gradually reduce as mass is removed by pyrolysis and combustion of charcoal.

The surface area to volume ratio will affect the combustion rate. Fine fuels will have a faster rate of combustion and a more intense heat. Pellets have a greater mass within the surface area and will take longer to burn compared to the same sized chip. With all these variables, the feed rate of the grate must be set up correctly to avoid early burn off which will concentrate heat at one end of the grate.

A detailed treatment of the combustion of woody fuels can be found in the *Ignition Handbook* (Barbrauskas, 2003).

2.5 Combustion air

The complete combustion of the fuel and the combustible gases requires a sufficient supply of oxygen in the combustion air. If just sufficient oxygen is supplied for the complete combustion of fuel and combustible gases the fuel air mixture is deemed to be stoichiometric, and such a mixture is described as having an excess air ratio of 1. The excess air ratio is called λ, where $\lambda = 1$ for a stoichiometric mixture. Combustion air for wood fuelled boilers requires:

— *Primary air* which is introduced under the grate of a grated stoker or into the retort of an underfed stoker. This air rises up through the firebed reacting with the fuel in a limited oxygen environment. λ is always less than 1 in a primary combustion zone. The reduced oxygen content allows control of the gasification process in the boiler, and reduces the flame and firebox temperatures.

— *Secondary air* which is introduced above the firebed to react with the gases evolving from the firebed. Most of the energy in wood is converted to flammable gases by the pyrolysis process resulting in a larger requirement for secondary air in comparison with other solid or liquid fuels. Secondary air is likely to comprise some 80% of the total combustion air requirement, and an excess air ratio greater than 1 is always required with typical values of $\lambda = 1.5 – 2$. However, the provision of too much combustion air will result in lower flame temperatures and a cooler boiler. Heating the excess air to flue gas temperature also represents an energy loss, but less than that resulting from incomplete combustion.

Figure 2.6 Lambda sensor for measuring flue gas O_2 content

There must be sufficient time and turbulence in the combustion space above the firebed for the combustion of the evolved gases to take place. The complete burn-out of fuel and combustible gases requires temperature, time and turbulence. A minimum temperature of 850 °C must be maintained for a minimum of 0.5 seconds in a turbulent environment with a minimum Reynolds number of 2300.

Separate control of primary air (from beneath the grate) and secondary air (into the gas oxidation zone) is required to maintain the lower grate temperature for Stages 1–3 while ensuring that a sufficiently high temperature and turbulence exist to oxidise the wood gases completely at Stage 6. A lambda sensor measuring flue gas O_2 content is used to ensure the correct supply of primary and secondary combustion air, with the boiler exhaust fan regulating combustion chamber pressure to ensure it is negative, i.e. the primary and secondary air fans modulate on flue gas O_2 content with the boiler exhaust fan modulating to maintain negative pressure.

2.6 Ash characteristics and slag formation

2.6.1 Ash characteristics

The ash content of solid biomass fuels is much lower than that of coal and is typically between 0.5 and 5% by weight of the dry fuel. Ash is a by-product of solid biomass combustion and derives principally from the minerals which predominate in the bark or, in the case of small diameter fuel such as straw, throughout the biomass material, together with some unburned carbon. Fuels with a high bark content, and those containing a high percentage of silica, will produce more ash.

The exact proportion of ash produced is dependent on the chemical composition of the fuel. Wood pellets usually produce the lowest proportion of ash together with dry woodchips (~0.5%), while wetter woodchips, and woodchips produced from whole trees, will produce up to 1.5% ash. Fuel derived from softwood grown in sandy areas will also produce higher ash outputs, while high silica fuels derived from agricultural residues and non-debarked trees could produce up to 5% ash.

Approximately 98% of the ash produced is bottom ash from the grate with the remaining 2% emitted as fly ash. Any heavy metals present in the fuel will predominately precipitate out in the fly ash; this fact has been used as a method of decontaminating land containing heavy metal residues. Fly ash is usually captured by a flue gas clean-up system or by a fly ash drop-out chamber within the boiler. Under some circumstances wood ash from combustion appliances can be spread on the soil under the relevant environmental regulators guidelines. This does not relate to domestic boilers for which the restrictions do not apply.

The quality of ash produced by a biomass system can provide a good indication of the health of a system. In particular a change in the quantity of ash produced, its colour, density, particulate size and moisture content, can provide an early indication of a change in combustion conditions or a problem within the boiler. It is recommended that a sample of ash be taken when a boiler is first commissioned and is retained as a reference sample. Any subsequent change in boiler performance or the characteristics of the ash produced can then be evaluated against the reference sample.

Figure 2.7 Ash from a newly commissioned 400 kW boiler operating for 12 hours (100 mm across)

2.6.2 Slag formation

Depending upon the chemical constituents of the ash, it may soften, forming glasses from silicas within it. The temperature at which this occurs is the ash fusion temperature, and varies between fuels as differing trace elements affect the melting point. Slag formation occurs when naturally occurring silica (sand), or unwanted silica in the fuel, converts to glass. For example, while pure silica melts at 1700 °C, chlorides present in the fuel can reduce this to as low as 773 °C, making it important to keep the temperature on the grate below 750 °C in this instance.

Once ash has melted it will cool and solidify to form a solid clinker. The firebed temperature must be controlled to below the ash fusion temperature to prevent clinkering, and some types of boiler require water-cooled grates and/or flue gas recirculation to manage the firebed temperature. High silica fuels, such as straw, present a particular problem as they often also contain high concentrations of chlorides, and specially designed boilers are usually required to allow such fuels to be burned.

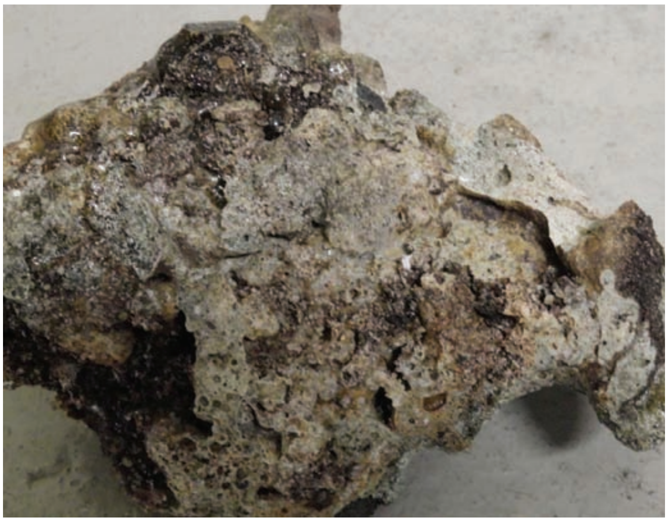


Figure 2.8 A 150 mm lump of glassy slag formed on a grate operating at too high a temperature

Biomass containing fresh, green matter such as leaves, needles and brash will contribute to an increase in the concentration of chlorine and will affect the ash melting temperature in addition to producing much higher NO_x and PM emissions. Burning such material will increase the maintenance burden on the boilers and heat exchanger surfaces.

2.7 Emissions

The principal emissions from biomass boilers are:

— the gas phase emissions of carbon monoxide (CO), carbon dioxide (CO_2), water vapour and nitric oxide (NO) and nitrogen dioxide (NO_2) collectively known as NO_x, and

— particulate matter including salts, soot, condensable organic compounds and volatile organic compounds. Collectively these are known as PM.

Careful control of the air supplies to the primary and secondary combustion zones are required to minimise the formation of all NO_x and particulates. However, as complete oxidation of the wood gases requires a slightly higher combustion temperature than in fossil fuelled boilers, the quantity of NO_x produced by biomass boilers per unit of heat generated is usually greater than that from gas fuelled boilers.

Other airborne toxic fumes are created by the incomplete combustion of biomass fuel. Incomplete combustion produces benzene-related polyaromatic hydrocarbons

(PAH) which give wood-smoke its distinctive aroma, but they are carcinogens and chronic exposure to them can ultimately be fatal.

2.7.1 NO_x

The reduction of fuel nitrogen to molecular nitrogen is favoured in the fuel rich primary combustion zone. The minimum total fixed nitrogen (TFN = HCN + NH_3 + NO + NO_2 + $2N_2O$) emission from the primary combustion zone is reached for a stoichiometric ratio (λ) of 0.7 to 0.8 at a temperature of 700–750°C with a mean residence time of 0.5 s (Keller, 1994). After the reduction zone the combustion is completed in the secondary combustion (burnout) zone by injection of excess air.

The following two graphs show the influence of moisture content on flame temperature, and how NO_x production increases with increasing flame temperature. From these it can be seen that the drier the biomass fuel, the hotter the flame and the greater the potential to produce NO_x. For this reason, and to protect boiler internals from damage (particularly ceramic linings), a key feature of boiler design is to ensure that combustion temperatures are maintained at, typically, no more than 1 200 °C. Flue gas recirculation (see Section 4.5.3.5) will permit the combustion of drier fuels without causing excessive NO_x formation in gases or clinkering of ash, and is essential if dry fuels are to be burned in a boiler designed to burn wetter fuels. The following diagram shows the influence of water content (w) on the calculated adiabatic flame temperature of wood combustion with ambient air as function of the stoichiometric ratio λ (total pressure 1 bar, dry wood as $CH_{0.7}O_{1.4}$) (Salzmann, 2001).

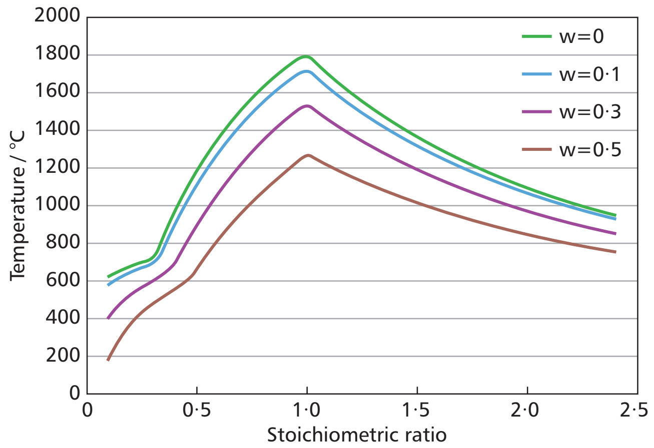


Figure 2.9 Influence of water content on the adiabatic flame temperature as a function of λ

Figure 2.10 below also shows that herbaceous biofuels, which include straw and grasses, produce more NO_x than wood and that recycled materials containing adhesives, such as chipboard, produce even higher levels of NO_x. Hence, in areas where the background NO_x level may already be of concern, such as in cities and where an Air Quality Management Area has been declared, the preferred fuel is woodchips or pellets manufactured from virgin wood which does not contain any bark or brash.

Wood pellets are usually manufactured from heartwood and will produce the lowest NO_x emissions. Woodchips, which are manufactured from whole trees including the bark, and logs will have higher emissions than wood pellets but lower emissions than herbaceous biofuels.

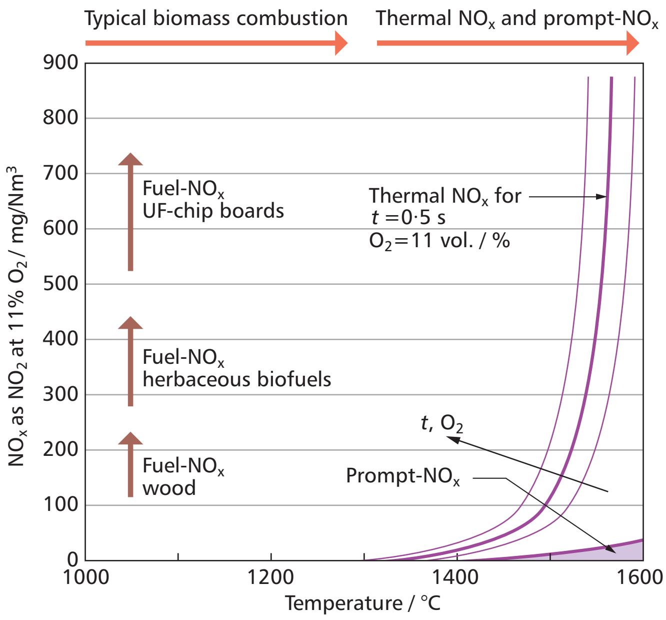


Figure 2.10 Influence of temperature on NO_x emissions for biomass combustion

NO_2 is known to cause sensitisation of the respiratory system, hence exposure to combustion gases must be avoided at all times. NO_2 is a pollutant deriving from complete combustion of biomass fuel and is always present in flue gases (Nussbaumer, 1997).

2.7.2 Particulate matter

Particulate matter (PM) from biomass combustion are tiny particles which include fly ash, black carbon, tars and benzopyrenes. Since the 1970s PM from all sources have been known to have adverse health effects. PM smaller than 10 μm aerodynamic diameter, PM_{10} can settle in the bronchi and alveoli (and so is referred to as the thoracic fraction) while PM smaller than 2.5 μm ($PM_{2.5}$ the respirable fraction) can pass through the lungs and into the bloodstream. Many of the tars and benzopyrenes are carcinogens, and are now known to contribute to cardiovascular disease.

PM_{10}s are formed as a result of incomplete combustion (see Section 2.8 below) (Nussbaumer, 2011). Salts, soot, condensable organic compounds (COC) and volatile organic compounds (VOC) are deemed primary aerosols while secondary aerosols can also be formed as secondary organic aerosols (SOA) and secondary inorganic aerosols (SIA). Soot is formed from tars via polyaromatic hydrocarbons (PAH) as an intermediate product. VOC resulting from incomplete combustion act as precursors for SOA, while NO_X and SO_X from nitrogen and sulphur in the fuel act as precursors for nitrates and sulphates. Figure 2.11 shows the mechanisms for PM production.

2.7.3 Regulated levels of PM and NO_x

PM is formed in three ways:

— Incomplete combustion at low temperature can lead to condensable organic compounds (COC) as

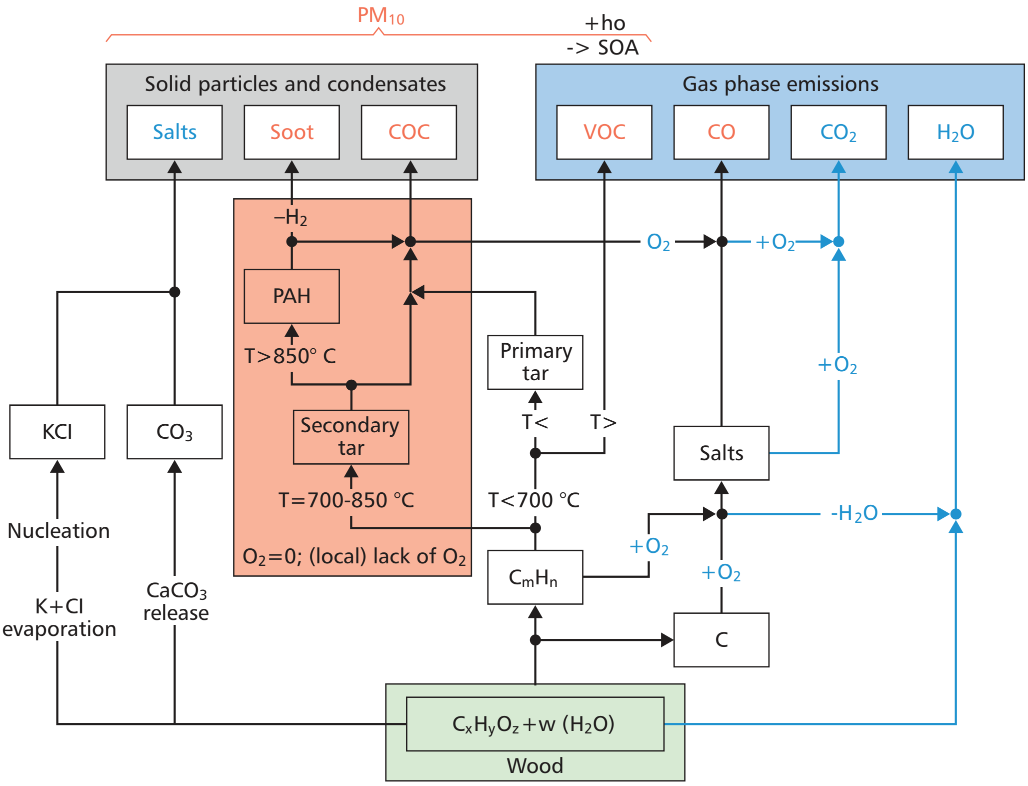


Figure 2.11 Pathways to the formation of PM (Nussbaumer, 2011)

pyrolysis products and also called tar, which form primary organic aerosols and contribute to brown carbon in the ambient air.

— Incomplete combustion at high flame temperature but with a local lack of oxygen or flame quenching can lead to soot formation resulting in nearly elemental carbon (EC) finally contributing to black carbon (BC) at ambient temperature.

— Mineral matter, including alkali metals and chlorine in the fuel, leads to the formation of inorganic fly ash particles mainly consisting of salts such as chlorides and oxides. In addition, other metals may also be available in certain concentrations.

In 2013 the UK introduced legislation which requires the maximum concentrations of 30 g/GJ for PM and 150 g/GJ for NO_x for boilers to be accredited for the RHI. Boiler manufacturers have to provide laboratory testing certificates to demonstrate boilers meet these standards, utilising of post combustion cleaning if required, for a boiler to be accredited under the RHI.

Boiler testing results are in normalised mg/m³ of flue gas (i.e. corrected to a flue gas density at 0 °C and 1013.25 mbar at normal temperature and pressure). These data have to be converted to g/GJ of net heat input for RHI purposes, but the normalized densities are a function of excess O_2 content in the flue. The conversion can be carried out following the advice provided in the Defra report *Conversion of biomass boiler emissions concentration data for comparison with the Renewable Heat Incentive emission criteria* (Defra, 2011). The conversions from concentration (CN) in mg/m³ to emissions factor (EF) in g/GJ and vice versa can be carried out using the following formulae. A dilution factor (DF) is defined as:

$$DF = \frac{21\% - O_2}{21\%} \quad (2.4)$$

where O_2 is the oxygen concentration in the flue gas in %, giving:

$$EF = \frac{CN \times 253}{DF \times 1000} \quad (2.5)$$

and:

$$CN = \frac{EF \times 1000 \times DF}{253} \quad (2.6)$$

Table 2.1 shows concentrations of PM and NO_x corresponding to the emissions factors of 30 g/GJ and 150 g/GJ respectively for various flue gas O_2 concentrations.

Table 2.1 PM and NO_x concentrations in mg/m³ for excess O_2, excess air and λ corresponding to RHI emissions standards

O_2 concentration in flue	0%	6%	10%	11%	12%
Excess air	0%	28.6%	47.6%	52.4%	57.1%
Stoichiometric ratio (λ)	1.0	1.29	1.48	1.52	1.57
PM	119	85	62	56	51
NO_x	593	423	311	282	254

The Mayor of London has recently published *Sustainable Design and Construction Supplementary Planning Guidance* (GLA, 2014) under the London Plan 2011 Implementation

Table 2.2 Exposure limits and health effects of airborne toxins produced during biomass combustion

CO	PM	PAH	Benzene	NO_2
		Exposure levels*		
10 mg/m³ (8 ppm) 8 hr workplace exposure limit	PM10 20 μg/m³ PM2.5 10 μg/m³ Annual mean level outdoor**	No safe level of exposure can be recommended	No safe level of exposure can be recommended	200 μg/m³ (0.1 ppm) 1 hour average. 40 μg/m³ (0.02 ppm) annual average
		Critical outcomes from the World Health Organisation (2005, 2010)		
Acute exposure –related reduction of exercise tolerance and increase in symptoms of ischaemic heart disease	Excess pulmonary disease and cardiovascular disease mortality	Lung cancer	Acute myeloid leukaemia, aplastic anaemia, bone marrow failure, genotoxicity	Respiratory symptoms, bronchoconstriction, increased bronchial reactivity, airway inflammation and decreases in immune defence leading to increased susceptibility to respiratory infection

* HSE document EH40 (HSE, 2011) specifies legally binding exposure limits in the UK.
** Outdoor guideline included because of the increased likelihood of PM escaping into the plantroom. There is no WHO indoor air guidance for PM.

Framework which impose some stricter emissions concentrations than those required for accreditation under the RHI.

2.7.4 Carbon monoxide (CO)

Carbon monoxide (CO) is created by the incomplete combustion of carbon and is well known to be lethally toxic. Less well known is that sustained sub-clinical exposure (which produces no symptoms) can result in incremental damage to the brain and other organs. Chronic, sub-clinical exposure to CO causes cumulative damage to oxygen-using organs in the body, hence the World Health Organisation (WHO) recommends a 24 hour exposure limit of 7 mg/m³ (6 ppm). Sub-clinical exposure is that which produces no symptoms, i.e. <50 ppm in the case of CO.

Biomass pellets in the period up to 8 weeks after manufacture will give off gas producing CO. CO concentrations at lethal levels have been measured in inadequately ventilated pellet stores and the holds of bulk carrier ships transporting wood pellets. The concentration of CO may also be such as to form an explosive atmosphere. Hence ATEX regulations apply to any electrical equipment installed in pellet stores.

2.7.5 Benzene and PAH

Benzene, created by the incomplete combustion of the hydrocarbon vapours in the oxidation phase (see Figure 2.4). It is produced during pyrolytic decomposition and gasification and causes cancer in both humans and animals.

PAH are potent atmospheric pollutants consisting of fused aromatic rings and are chemically related to benzene. They too are the product of incomplete combustion in the oxidation phase. Pyro(a)benzene is particularly dangerous and is the component in tobacco smoke which causes lung cancer.

2.7.6 Summary of the health effects of exposure to airborne toxins

Table 2.2 summarises the health effects of the most important toxins produced during biomass combustion.

The correct flue heights must be applied in the design and construction phases of a biomass project to ensure toxic emissions are adequately dispersed at sufficient height to prevent occupants of buildings in the vicinity of biomass installations suffering chronic exposure. Planning and Development Control Departments must ensure that flue heights are adequate.

Table 2.3 provides useful references for health effects of different toxins.

2.8 The effects of burning out-of-specification fuels

2.8.1 Too wet

If wet fuel is not dried sufficiently by the boiler (because the fuel moisture content is outside the fuel tolerance range of the boiler) incomplete gasification and oxidation will occur and black smoke will be produced. In addition, the tars released at combustion Stage 2 (see Section 2.4) will gradually coat the heat exchanger surfaces resulting in reduced heat exchange efficiency and the eventual failure of the boiler. Tar accumulation is also one reason why many manufacturers recommend minimum running periods for their boilers to ensure that combustion chambers and heat exchangers reach full working temperature to drive off the

Table 2.3 Health effects references

Topic	Reference
Deposits	Jansson et al (2011)
PM	Lave et al (1973) Mokdad et al (2004)
PM by fuel type	IEA (2008)
CO	Téllez et al (2006)
NO_2	WHO (2010), pp 215–216
Benzene	WHO (2010), pp 24–32
PAH	WHO (2010), pp xx–xxi, 317–313
Heat	CIBSE Guide A 8.2.6 (CIBSE, 2009)
Emissions	EEA (2013)

heavy volatiles deposited during the heat-up phase. The energy used to evaporate the moisture is not available to the appliance user.

2.8.2 Too dry

If the fuel is too dry for the boiler, grate (Stage 2) and oxidation zone (Stage 4) temperatures can be too high, resulting in the formation of slag and a higher concentration of NO_2. This latter issue can be addressed by installing flue gas recirculation to primary air. This allows dry fuel to be used in a boiler designed to burn wet fuel by maintaining the primary gas flow rate while reducing its O_2 content, thus reducing the gasification rates (Stage 3) on the grate.

2.8.3 Safety considerations

As with all fuels some excess air above that required for stoichiometric combustion is required to obtain full combustion of the fuel. Failure to obtain full combustion, by provision of inadequate air, will result in a significant presence carbon monoxide in the flue gases. This is a major boiler efficiency loss in the calorific value that it carries away but, more importantly, presents a significant explosion risk in that the lower explosive limit in the flue gases can be reached very quickly after load is removed from a boiler. The Combustion Engineering Association and Carbon Trust's *Health and safety in biomass systems: Design and operation guide* (CEA, 2011) provides comprehensive guidance on all aspects of health and safety related to the design and operation of biomass systems and should be referred to as the definitive text on this subject.

Participants in the non-domestic RHI also have ongoing obligations, including to ensure that the fuel used is in accordance with that specified on a valid RHI emissions certificate for their plant. The use of other fuels, or the use of fuels at a moisture content exceeding the certificated moisture content, will be a non-compliance which would be subject to sanctions.

3 Fuel delivery, storage and extraction

The delivery and storage of biomass fuels is a subject area thoroughly covered by many publications. This chapter provides an introduction to fuel delivery and storage, but for detailed information the reader should access the information freely available from the Biomass Energy Centre, Carbon Trust (Carbon Trust, 2009) and others (DGS, Ecofys, 2005) (Van Loo et al, 2008) (ÖNORM M 7137). The methods of transporting, handling and storing wood fuels depend on the fuel type. This Applications Manual is concerned primarily with wood chips and wood pellets. Wood pellets are delivered in closed tanks, pneumatically blown into the storage and then stored in a dust-sealed environment. Woodchips are usually transported in trucks or trailers and tipped direct into an open silo.

3.1 Woodchips

3.1.1 Woodchip delivery

Wood chips are typically delivered in containers of 30 m^3 or trucks with a capacity of up to 100 m^3. The fastest delivery times (and therefore, the lowest delivery costs) are achieved if loads can be tipped into underground silos as in Figure 3.1, or onto a walking floor, with tipping a 100 m^3 load taking between 5 and 10 minutes. When tipped, woodchips do not flow freely, requiring the delivery vehicle or trailer to tip at a very steep angle to ensure fuel is emptied into the silo. An alternative is to use a walking floor trailer as the fuel store with extraction onto a transfer auger or conveyor.

Figure 3.1 Woodchip being tipped into an underground silo

While blown delivery into a fuel store is possible (see Figure 3.2), it is not recommended because of much longer unloading times (30–60 minutes for 80 m^3) and the noise and dust associated with blown delivery. Blown deliveries are most suitable if the fuel store is remote from occupied buildings. Hook-lift containers offer an alternative delivery and storage method in which containers are delivered pre-filled, unloaded at the site and connected to the wood fuel feed system.

Figure 3.2 Blown delivery of woodchips

Another option is a fast-fill auger system (see Figure 3.3) which allows woodchips to be tipped into a trough from where they are augered vertically before being delivered into the silo by a further horizontal auger. The disadvantage of using a fast-fill auger system is that, contrary to what the name suggests, it can take an hour or more to fill even a moderately sized silo.

Figure 3.3 Fast fill auger and fuel reception trough

3.1.2 Woodchip storage

3.1.2.1 Underground silos

The key considerations when designing an underground silo are:

— The groundwork for an underground silo requires a considerable amount of working space around the silo area. Not only does the excavation need to be larger than the final size of the silo to allow for shuttering, concrete and tanking, but simultaneous access is required for an excavator and a lorry.

— Ventilation is essential, especially when the woodchips are >30% moisture content.

— The silo lid should open to at least 80% of the silo plan area so that dead space in the silo is minimised. However, as there is a limit to how far back a lorry can tip, a large silo should be rectangular in shape. This has implications for the method of fuel extraction (see Section 3.1.3).

— The silo has to be designed to withstand the impact of a lorry as it reverses up against the silo wall for tipping.

— The silo lid (see Figure 3.4) has to be insulated on the underside to prevent condensation and corrosion.

— An underground silo should be 'tanked' against water ingress, and the lid should overlap an upstand to prevent rainwater ingress.

— In the event of water ingress it is advisable to design the concrete base with a run-off gully to a sump into which an automatic sump pump should be installed. For ease of maintenance the sump may be installed outside the silo although an access pit will be required in this case.

— An openable steel grating (see Figure 3.5) should be installed beneath the silo lid to prevent people from falling into the silo. The grating should be lockable and fitted with a trapped key mechanical/ electrical interlock system as described below.

— A trapped key interlock system has a key operated electrical switch which is installed in the power supply to the fuel extract mechanism, and is usually located in the boilerhouse. If the key is removed the electrical supply to the extract mechanism is isolated and the key can then be used to open the grating above the fuel silo. On opening the grating the key is trapped in the lock so that the grating has to be closed and locked before the key can be returned to the boilerhouse and electrical power restored to the fuel extract mechanism.

— A fuel extract mechanism will be required in the silo which may be a walking floor, sweeping arm extractor or a rotating auger; these are discussed in Section 3.1.3. A walking floor will require a horizontal concrete base whereas the other extract systems will require either a horizontal or sloping floor of up to 15° constructed from marine ply to be installed above the concrete base. The use of marine ply provides some buffering against variable fuel moisture content, although the storage of wet woodchips (>40% MC) can results in the warping and rotting of a fuel floor. The design of the fuel floor must take into account the moisture content of the proposed fuel and be constructed of a suitably durable material.

— It is also usual to line the walls of the silo with marine ply. Where a sloping fuel floor is to be installed a supporting framework will be required, and the design of this may need to be undertaken by a structural engineer. The construction of the fuel silo will need to comply with the relevant technical standards on the bulk storage of woody biomass fuel.

— Fuel level sensing in the silo can be achieved by the installation of ultrasonic or laser level sensors which can be connected to a BMS to allow the user to monitor fuel level without the need to access the silo.

— Most fuel silos will be classified as confined spaces where the Confined Spaces Regulations 1997 will apply.

Figure 3.4 Underground silo showing lid and safety grille

Figure 3.5 Close-up showing the safety grille on an underground silo

3.1.2.2 Hook-lift containers

Hook-lift containers are delivered by a hook-lift capable vehicle (see Figure 3.6) as commonly used for industrial waste collection. A typical site installation will have two containers to the fuel extract mechanism with at least one spare off-site. At the time of delivery, one container will be in use, one container will be empty and ready for replacement, and one container will have been filled at the wood fuel depot ready for delivery. For easy operation during change-over, space for all three containers has to be provided at the site. The capital cost of such a system can be much greater than that of an underground fuel silo, and more space is required, but where an underground silo is not possible this system provides an alternative. Hook-lift containers should be firmly attached to the fixed part of the extract system to prevent their being pushed backwards in the event of a fuel jam or fuel freezing in the container.

Figure 3.6 Hook lift container being delivered

3.1.3 Woodchip fuel extraction

3.1.3.1 Walking floor

Fuel handling in underground silos for industrial and large commercial installations is most successfully achieved with a walking floor system. Walking floors can be installed in underground silos where fuel is tipped onto them from above, or can be installed at ground level where they have to be designed to take the weight of a delivery vehicle which drives onto the floor and tips as it drives off (see Figure 3.7). Fuel is moved to one end of the walking floor from where it drops onto a cross-feed auger and then a rising auger for transfer to the boiler. Another variation is the use of a front loading shovel to tip fuel onto a walking floor installed at ground level. Hook-lift containers are always fitted with walking floors, while the cross-feed auger is part of the permanent installation onto which the hook-lift container attaches. Walking floors can also be found on large woodchip delivery vehicles where a combination of a tipping trailer and a walking floor is required to ensure all fuel is extracted from the delivery vehicle.

Where a walking floor is installed, the tolerance of the concrete floor beneath the walking has to be within ±1 mm in order to avoid chips passing under the rams and lifting them.

Figure 3.7 Woodchip fuel delivery from a walking floor trailer

Figure 3.8 Woodchip fuel on a walking floor

3.1.3.2 Sweeping arm extractor

One or more sweeping arm extractors can be installed within a silo. Silos with a single sweeping arm system must be square, whereas those with two sweeping arm systems must be rectangular with an aspect ratio of 2:1. The sweeping arms are sprung to allow them to get into the corners of the silo so the length of the arms should be at least √2 times the width of the silo. The silo is fitted with an outfeed auger beneath the marine ply floor with woodchips being swept onto the auger through a slot in the floor (see Figure 3.9).

Silo depths of up to 4 m are possible although consideration should always be given to how a jam in the outfeed auger can be cleared in the event that the silo is full of fuel. The greater the fuel depth the more fuel has to be removed by a grab crane in the event of a fuel jam. Sweeping arm extract systems are suitable for wood chips up to G50 size grade, although the use of smaller grades of fuel is likely to result in more reliable operation.

Figure 3.9 Sweeping arm extractor and fuel extract auger in a square silo

3.1.3.3 Sweeping auger extractor

A sweeping auger which rotates around the silo in the same manner as a sweeping arm but incorporates the fuel extract auger within the sweeping mechanism. A variation on this system is a sweeping auger that can also move in a vertical as well as the horizontal plane. When the silo is full it sweeps in a circle at a steep angle to the horizontal, and gradually reduces its angle to the horizontal as the silo empties. Fuel stores with sweeping auger extractors have horizontal fuel floors.

3.2 Health and safety in woodchip stores

3.2.1 Fire safety design in all types of wood fuel stores

The *Building Standards Technical Handbook* in Scotland contains specific provisions for the fire proofing of wood fuel stores which, in essence, require a one hour fire separating wall between biomass fuel bulk storage and any other building even when the bulk storage is contained within a boiler-house. Until such regulation comes into force in the rest of the UK the Scottish Standards may be used as guidance.

3.2.2 Access control to woodchip stores

The access control system detailed in Section 3.1.2.1 above is required to ensure than personnel are unable to enter a woodchip store when the fuel extract mechanism is operative. The danger is that the sweep arms, augers or another extract mechanism, including walking floors, could operate and trap and injure personnel working in the store.

3.2.3 Dangerous mould growth on wet woodchips

Moulds can be found wherever moist, damp conditions exist, with moulds such as aspergillus and penicillium (both common outdoor fungi) associated with woodchip piles. Mould growth on woodchips can occur when the moisture content (MC) of woodchip exceeds 30%, and results in a reduction in both calorific value and woodchip quality. Respiratory exposure to the spores produced from these moulds is known to cause respiratory irritation, a disease commonly referred to as ‘farmers lung’. Symptoms include fever, chills and muscle aches (flu-like symptoms), and in some rare situations workers who have been sensitized to moulds have developed allergic-like reactions. There are no occupational exposure limits established for moulds at this time.

To reduce the risk of mould growth, woodchips to be stored for periods longer than one month should be stored at a MC of 30% or less. For systems which burn wet woodchips, fuel stores should be turned-over at an interval of less than one month. Where a woodchip fuel store containing wet woodchip is to remain unused for a period of greater than one month, the fuel store should be emptied either by feeding the fuel through the biomass boiler or by mechanical means prior to the chips being either dried or disposed of safely.

Should mould growth be found on woodchips (see Figure 3.10), a risk assessment should be carried to evaluate the options for managing the hazard. Options to be considered include feeding the entire contents of the fuel store into the biomass boiler to be burned or removing them to be disposed of. On no account should personnel enter the fuel store without suitable respiratory protection.

Even though woodchips may have been at a MC<30% when delivered into the fuel store, if an underground fuel store has uninsulated metal lids, condensation can form on the underside of the lid and drip onto the top of the woodchip pile permitting mould growth. The photograph below shows otherwise dry woodchip which had been allowed to remain in a fuel store for a long period covered in mould filaments. Any form of water ingress to the fuel store can contribute to this problem.

Figure 3.10 Mould growth on woodchip

3.3 Wood pellets

3.3.1 Wood pellet delivery

Wood pellets are usually delivered pneumatically from a specialist delivery vehicle, although they can be tipped. Recent design practice has been to fabricate pellet stores as sealed structures which require pressure relief during fuel filling, with the dust produced being captured in a bag filter from a pressure relief pipe. However, a recent HSE safety alert (see Section 3.4.2.1 below) on pellet stores now makes it necessary to ventilate stores adequately to prevent the build-up of toxic gases, in particular carbon monoxide (CO), within the store. In a ventilated store dust will escape from the through the vents during delivery unless extraction by a separate extract fan is applied to the silo. Specialist pellet delivery vehicles in the UK are supplied with the necessary pellet blowing and extract equipment to connect to fuel feed and vent pipes on the silo using two separate hoses.

3.3.1.1 Fuel delivery and pressure relief pipework

Great care must be taken in the delivery of wood pellet fuel to ensure that pellets do not break up and produce dust. The fuel delivery rate should be limited to 12 tonnes per hour per delivery pipe to ensure pellets do not degrade during delivery. A number (minimum 2) of 100 mm diameter fuel feed and pressure relief pipes manufactured from smooth bore stainless steel and fitted with Camlock connectors are required to connect the fuel fill and pressure relief pipes on the fuel store to the delivery vehicle. The number of bends in the pipework must be kept to a minimum, be smooth and of a large radius at least 5 times the pipe diameter. It is usual for the pipes to be alternated for fuel delivery and pressure relief, and the pipes should extend into the fuel store by different amounts to allow both the closest and farthest points of the store to be filled.

Recognising the need to ensure that pellets are not degraded during delivery, a notice should be fixed to the filling points stipulating the maximum rate at which pellets should be delivered for that installation. The notice should also state that failure to comply with this requirement could result in the complete removal of and replacement of the shipment at the fuel provider's expense. If delivery drivers are required to sign in and out of the site, by recording time in, time out and the quantity of fuel delivered, the user can readily check that fuel has been delivered at an acceptable rate.

Figure 3.11 External view of wood pellet fuel fill and pressure relief pipes

Figure 3.12 Close-up of a Camlock connector

Pellet impact mats must be installed in front of each pipe (see Figure 3.3) to prevent pellets from hitting any hard surfaces and breaking up producing dust. Usually made of rubber, they need to be large enough to ensure that no pellets impact on the wall behind the mats.

Figure 3.13 Internal view of pellet store, showing fuel fill pipes (left) and pellet impact mats (right)

3.3.2 Wood pellet storage

Silos similar in construction to those used for woodchips, and employing similar extract mechanisms, may be used for wood pellets; please refer to the woodchip storage section above. In addition to these wood pellets may be stored in above ground silos with v-shaped floors or in grain type silos. For small installations pellets may be stored in bag silos (Carbon Trust, 2013).

In order to purchase pellets at the lowest cost, whenever possible wood pellet storage should be sized to accept a full pellet tanker of fuel. Large pellet delivery vehicles hold between 23 and 26 tonnes requiring a storage volume of up to 40 m^3, and pellet tankers hold typically 16 tonnes of fuel requiring a storage volume of 24 m^3. With a 20% residual fuel allowance as a re-ordering level, a pellet store requires a volume of 50 m^3 from a large delivery vehicle or 30 m^3 from a pellet tanker in order to accept a full load. While smaller installations will not require this volume of fuel storage, the designer should always establish both the minimum order weight and minimum economic order weight before sizing a pellet store. In the longer term it may be more economically advantageous to install a larger pellet store able to accept at least 50% of a tanker load.

The many considerations for pellet store design are contained in a guide available from the Biomass Energy Centre (Brites, 2009).

3.3.2.1 V-shaped pellet stores

Manufactured from marine plywood or stainless steel, a v-shaped fuel floor is installed on a supporting framework with the fuel store. The angle of static repose for wood pellets is approximately 40°, hence the sloping 'v' floor should be installed at a minimum angle of 45° to ensure pellets are able to flow down the floor to an extract auger running along the base of the 'v'. It is usual for the 'v' section itself to slope downwards, along with the extract auger, towards the fuel outlet point from the store.

Figure 3.14 V-shaped pellet floor under construction showing fuel fill pipes at top

3.3.2.2 Gravity hoppers

Grain-type silos can be used to store wood pellets, especially if external fuel storage is required. Fuel can be blown into the top of a silo via a rising fuel feed pipe and is extracted from a 45° cone at the bottom of the silo. In order to prevent pellets being crushed within the silo 45° cones should be installed internally at 3 m intervals up the silo. Pellet outlets should be installed around each cone as well as at the base of each cone to distribute pellets evenly throughout the silo.

3.3.3 Wood pellet extraction

The mechanisms for extracting woodchips (walking floor, sweeping arm and sweeping auger) can also be used for wood pellets in addition to the common methods of a fixed auger at the bottom of a v-shaped fuel store and gravity outfeed from a conical bottom on a silo. Typically, pellets will drop into a dropbox from where they are transported by auger to the boiler.

3.4 Health and safety in wood pellet stores

3.4.1 Explosion risk from dust in pellet stores

Should wood pellets break up on delivery forming dust, and the concentration of dust be such as to form an explosive concentration of dust in air, any ignition source could cause a dust explosion. The design procedure must be to avoid both an explosive concentration of dust and eliminate potential ignition sources.

The use of an extract fan on the non-filling fill pipe during pellet delivery will remove dust from the silo as it forms to maintain the concentration of dust below the lower explosive limit. The dust must be trapped in a filter bag. The avoidance of electrostatic charge building up on metal components requires all metal pipework to be continuously electrically bonded and sections of pipework electrically bonded to earth to discharge any electrostatic build-up as a result of pneumatic delivery. The pellet tanker must also be electrically bonded to earth during fuel delivery. For reasons of electrical safety plastic pipework must not be used.

To eliminate ignition sources further, pellet stores should not contain any mains electrical equipment such as lighting, switches or motors. Should it be unavoidable to install mains powered equipment then it must meet the appropriate Explosive Atmospheres (ATEX)[2] specification and must be connected using an approved fully enclosed wiring method. Electrical conduit should not be used as dust can become trapped in it. However, low voltage electrical equipment up to 24 V, such as infra-red level sensors, may be used to measure the depth of pellets in a store.

Health and safety considerations
Design, construction and operation of fuel stores must specifically identify and avoid or minimise explosion risks.

Large pellet stores may require explosion relief panels or blast dampers on the upper surfaces of the store, typically on the roof of the silo, in the event of a dust explosion. A designer's risk assessment process should determine whether explosion relief panels are required and, if so, seek specialist advice.

No source of ignition may be allowed in the vicinity of the delivery operation and all metallic parts of the store, the delivery lorry, the delivery hose and the fixed delivery pipes and connectors must be equipotentially cross-bonded to the building's earth. This must be done by a qualified electrician with minimum 4 mm^2 copper cable.

3.4.1.1 Explosion danger from gases in pellet fuel stores

There is a risk of explosion from gases in pellet fuel hoppers and stores. Fatty acids in wood pellets oxidise producing carbon monoxide, hexanal and methane which are all flammable gases. This is a very slow, natural process of wood decomposition but one which is greatly accelerated by the pellet manufacturing process.

Therefore pellet fuel hoppers/stores must have a notice placed prominently by any openings and must have the relevant hazard warning signs for asphyxiation and explosion displayed. See also HSE Bulletin number OPSTD 3-2012: *Risk of carbon monoxide release during storage of wood pellets*.

3.4.2 Asphyxiation danger from toxic gases in pellet stores

In 2012, the HSE issued a safety alert, HSE Bulletin OPSTD 3-2012: *Risk of carbon monoxide release during storage of wood pellets*. The essential content of the Bulletin was:

[2] Explosive Atmospheres Directives 94/9/EC (ATEX 100) and 99/92/EC (ATEX 137), The Dangerous Substances and Explosive Atmosphere Regulations 2002

The HSE has issued an alert to operators, maintenance personnel and members of the public on the dangers associated with bulk feed hoppers/tanks normally used with Wood Pellet Boilers. This alert follows a fatal accident where a home owner entered a bulk wood pellet storage hopper/tank and was overcome by carbon monoxide (CO) gas. CO is a colourless, odourless and tasteless gas that is highly toxic.

Wood Pellet Boilers are commonly used in homes and businesses as an alternative to oil or gas fired boilers. Wood pellets, the fuel source for these units, are normally housed in a large sealed hopper/tank that is either fitted with screw feeder (auger) connected to the boiler, or the hopper/tank is mounted over the boiler for gravity feeding. Due to the enclosed nature of these hoppers/tanks the atmosphere inside can become oxygen depleted and a toxic atmosphere can accumulate.

3.4.2.1 HSE advice

The HSE website tells all operators, maintenance personnel and users of this equipment to do the following:

— *DO NOT ENTER or place your head into the wood pellet hopper under any circumstances. The unit can contain toxic gases.*

— *Ensure that your wood pellet hopper/tank and boiler has been installed and commissioned by a competent person. If in doubt, contact the supplier and/or manufacturer and request assistance.*

— *Ensure that the boiler is cleaned and serviced by a competent person at the frequency required by the manufacturers' instructions.*

— *If any problems are encountered with the unit, such as, system not heating correctly, flue gas is flowing into boiler room, turn unit off and seek assistance immediately.*

— *No personnel should enter the hopper/tank unless fully trained and competent in confined space entry procedures. The hopper/tank should be fully ventilated and controls put in place to ensure safe entry (see Guidance on the* Confined Spaces Regulations 1997*).*

— *Ensure the boiler room is well ventilated at all times to ensure no inadvertent build-up of toxic gases.*

Health and safety considerations
Boilerhouse and fuel store design, operation and maintenance personnel MUST be fully informed of the risks from toxic gases. The client must be notified formally of these risks.

3.4.2.2 Advice from the Swiss and German Pellet Fuel Trade Associations

The Swiss and German Pellet Fuel Trade Association safety advice for pellet stores larger than 10 tons capacity as of November 2012 is:

— Unauthorised entry forbidden. Keep doors locked.

— Smoking, fire and other ignition sources forbidden.

— Danger of death from odourless carbon monoxide and from oxygen depletion.

— Take care to sufficiently ventilate the store before entering – keep the door open when inside.

— Only enter store if under the supervision of another person outside.

— Danger of injury from moving machinery.

— Filling must be carried out in accordance with the instructions of the heating installer and the pellet supplier.

— Pellet fuel must be protected from moisture.

— Store must be permanently ventilated via ventilation cowls on the delivery and air extract pipes mounted in an outside wall.

3.5 Fire protection and prevention in fuel transport mechanisms

Fuel transport from the fuel silo to the boiler will usually be by an auger or a ram stoker. A potential hazard with a continuously fed biomass boiler is for the fire to burn back along the fuel feed from biomass boiler to fuel store. In all cases a number of fire safety features will be incorporated which are described in the following sections. These features apply to both woodchip and wood pellet systems, and will also apply to systems using granulated or particulate fuels such as grain. The photographs in the following sections show these features and where they are likely to be installed on a system.

3.5.1 Auger fuel transport systems

The following sections describe fire safety devices moving from fuel store to biomass boiler in the order in which they are usually installed.

3.5.1.1 Rising auger

Fuel extraction and transport systems employing augers use a rising auger from the fuel silo or fuel store to the safety device on the biomass boiler, either a rotary valve or flap valve. A fire is most likely to reach a fuel store from the boiler and the reason for a rising auger is because fire will not readily travel downwards along an auger from the boiler to a fuel store. Designers should always incorporate a rising auger into the fuel transport mechanism design as the first line of defence against burn-back from biomass boiler to fuel store.

3.5.1.2 Mains water drenching

In order to extinguish a fire in the fuel transport auger a direct acting mains water drench valve can be installed; this is good practice and should be installed whenever possible. Larger systems with wide in-feeds require additional burn-back certification from the equipment manufacturers/suppliers. Direct acting drench valves use a mechanical thermostat activating a mechanical linkage via a Bowden cable which opens a valve allowing water at mains pressure to flood the transport auger. This system will continue to flood the auger until it is reset manually.

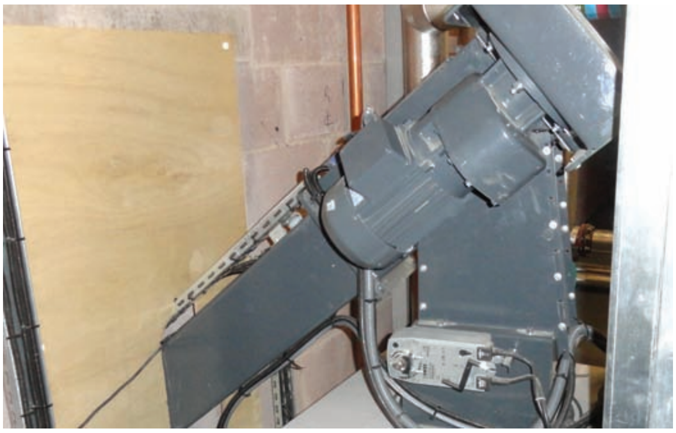


Figure 3.15 Rising auger showing rotary valve in fuel feed system

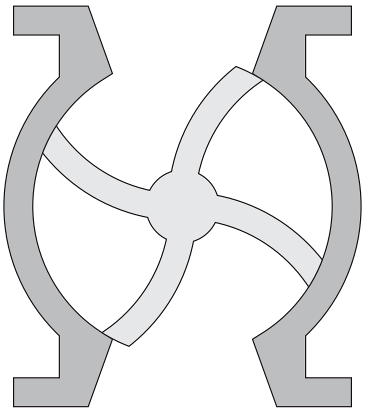


Figure 3.16 Internal drawing of a rotary valve

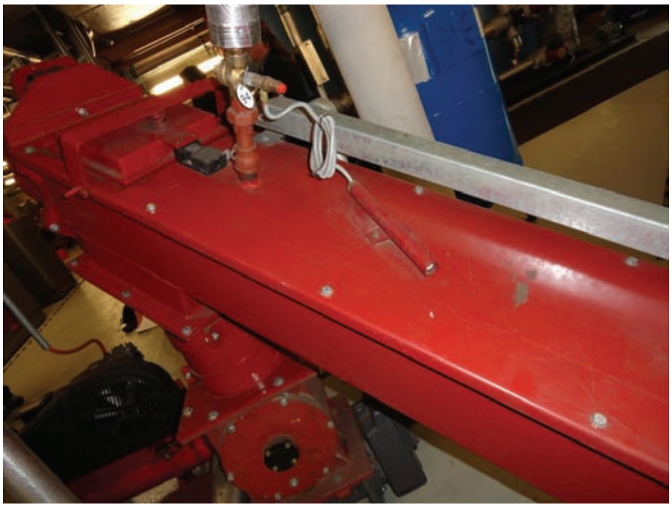


Figure 3.17 Mains water drench valve with flap valve housing below

3.5.1.3 Rotary valves

Fuel from the top of a rising fuel transport auger will drop onto either a rotary valve or into a fuel box on the boiler. Where a rotary valve is used it will be inserted between the drop section at the end of the rising transport auger and a horizontal fuel feed auger to the boiler. A rotary valve has metal dividing segments which both meter fuel onto the fuel feed auger and prevent burn-back from the fuel feed auger through the rotary valve. A rotary valve will always provide isolation between the rising auger and fuel feed auger, whether moving or stationary.

3.5.1.4 Boiler feed auger temperature sensing

A thermostat or bi-metal strip is often placed on the boiler feed auger to sense the temperature within the auger casing. If the temperature rises to a preset level, typically 80 °C, an electrical contact will open to remove the enable signal to the boiler or otherwise shut the boiler down.

3.5.1.5 Water bottle drenching

On smaller systems a water drench bottle is sometimes installed in lieu of, or in addition to, a mains water supplied drench valve to extinguish a fire in the fuel feed auger. Consisting of a small water tank at high level feeding a nozzle in the fuel feed stopped with a wax plug, the wax plug melts at a pre-determined temperature emptying the water bottle into the fuel feed auger. Water bottles can also be activated by direct acting mechanical thermostats and valves as described in 3.5.1.2.

Figure 3.18 Water bottle and direct acting drench valve on fuel feed system

3.5.1.6 Burn-back flaps

Where fuel drops from a rising auger into a dosing silo on the biomass boiler, a burn-back flap will be installed on the inlet to the silo. The fuel level within the dosing silo is monitored by an ultrasonic or laser level detector, the signal from which is used to open the burn-back flap and operate the rising auger to refill the dosing silo. In this case the fuel feed auger is internal to the biomass boiler and will be a further rising auger to a moving grate or a horizontal auger to an underfed stoker (see Section 4.2.2). In the event of fire reaching the dosing silo the flap valve is disabled.

3.5.2 Ram stoker fuel transport systems

On larger boilers, especially those employing a walking floor fuel extract system, a flap valve or vertical rising gate will be found on in the inlet to the boiler. The ram stoker serves the functions of both the rising auger and fuel feed auger, with the faceplate of the ram itself serving as a burn-back prevention device. A mains water drench is always installed through the casing of the ram stoker close to the boiler flap valve or rising gate.

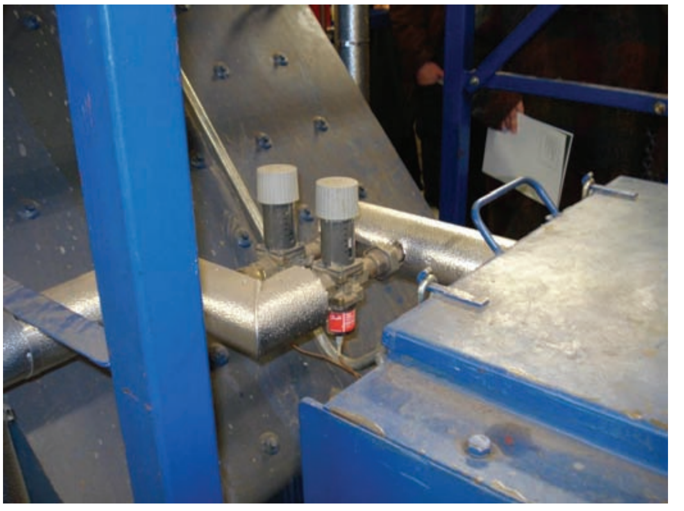


Figure 3.19 Photograph of ram stoker showing mains water drench valves

4 Biomass boiler types and characteristics

4.1 Introduction

This chapter provides a detailed overview of biomass boilers, with the emphasis on automatic fuel feed boilers in the size range 50 kW to 5 MW; boilers are classified by type, and the characteristics of boilers are explained. This chapter also covers boiler maintenance and emissions abatement systems. Design engineers need a thorough understanding of the types, characteristics and features of these types of biomass boilers if they are to select the best boiler for application and then to integrate it successfully into a heating system. A boiler is generally ordered and delivered as a package, complete with all its ancillaries. Biomass boilers can vary considerably both in complexity and the specific elements of its design and the system designer will need to use their judgement to select the appropriate plant for each application.

Biomass boilers may be classified by the type of stoker, type of ignition or fire tube orientation. Many combinations of stoker type, ignition type and fire tube orientation are offered by boiler manufacturers together with a range of associated features. Armed with an understanding of boiler types, the design engineer should be able to interpret manufacturers' information to identify whether a boiler being offered is appropriate for a particular application.

General descriptions of biomass boiler types can be found in a number of publications including:

— CTG012 *Biomass heating A practical guide for potential users* (Carbon Trust, 2009), and

— B*iomass heating: a guide to medium scale chip and wood pellet systems* (Palmer et al, 2011b).

4.1.1 Automatic feed boilers

This Applications Manual is concerned primarily with automatic fuel feed biomass boilers where the firebed is automatically fed with fuel. Automatic feeding systems, as described in the previous chapter, may be used with wood pellet, woodchip and other fuels such as grain, sawdust and chopped straw. Fully automatic fuel feed plant permits a biomass boiler to function in a manner similar (though in many respects very different) to conventional fossil fuelled plant without intervention from the building user. This is the most common approach for biomass in building services applications.

4.1.2 Batch fed systems

Wood stoves and log boilers are batch fed systems for which the user has to load a fire box manually. While batch fed log boilers are available in sizes up to a few hundred kW, the majority of these systems are rated at less than 50 kW and are not covered in depth by this Applications Manual; a brief description of log boiler systems is given in Section 4.7. A number of sources of detailed information on wood stoves and log systems are available including *Biomass heating: a guide to small log and wood pellet systems* (Palmer et al, 2011c), and *Planning and installing bioenergy systems: A guide for installers, architects and engineers* (DGS, Ecofys, 2005).

4.2 Boiler classification by type of stoker

Biomass boilers can be categorised as either overfed or underfed stokers. A number of variations exist within the overfed type. Underfed stokers have been developed from coal boiler technology whereas overfed stokers have been designed specifically for biomass installations.

4.2.1 Overfed stokers

Overfed stokers supply fuel onto a grate from above, the fuel being pushed onto the grate by either an auger or stoking ram. A number of distinct and different grate types can be fed from an overfed stoker, which are described below.

4.2.1.1 Stoker burner boilers

Stoker burner boilers are the simplest boilers having a relatively small grate, or a cast iron tube in which the firebed is set, attached directly to the end of the feed auger, the force pushing the firebed along the grate and the ash being pushed off the open end of the grate. Stoker burners are generally used in smaller boilers although some Swedish and Finnish boilers up to 1 MW have been manufactured.

Figure 4.1 Cutaway drawing of stoker burner boiler

Combustion air is usually supplied by a single fan which provides both the primary and secondary combustion air. As a result, the design of these boilers is a compromise between the requirement for a low temperature on the grate to prevent slag formation and the need for a higher temperature in the secondary combustion zone to ensure complete combustion of the wood gas produced. The potential for overheating of the grate is very high, so manufacturers of these boilers often include a water cooling circuit within the grate to prevent slag formation and excessive grate erosion. The water cooling circuit, which requires a grate cooling pump, is taken as a bleed from the return circuit to the boiler and is fed back to the return inlet to the boiler.

A stoker burner requires wood pellets or woodchips of less than 30% moisture content and of a consistent small particle size to maintain even combustion; heat from the fire dries and starts the pyrolysis process in the wood as it is pushed forwards. A small fuel inventory on the grate allows these boilers to respond quickly to changes in load. However, the potential for burn-back along the fuel feed auger is very high in this type of boiler necessitating it to be emptied on boiler shutdown, and some boiler designs incorporate a flap valve immediately prior to the grate to prevent burn-back, avoiding the need to empty the fuel feed auger on shutdown.

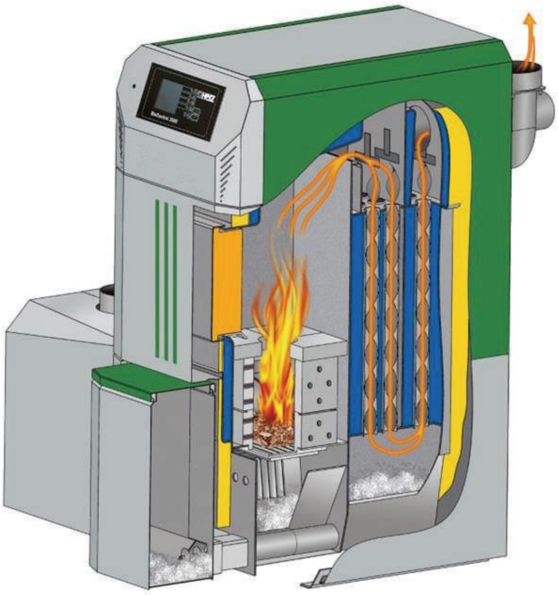


Figure 4.2 Stoker burner boiler with a tipping grate

Some stoker burner boilers with automatic ignition systems (see Section 4.3.1) incorporate a tipping grate which allows ash to be tipped off the grate into the ashpan on firebed burnout. This ensures the grate, and particularly the primary combustion air holes on the sides of the grate, is ready to accept a new load of fuel for the next ignition sequence.

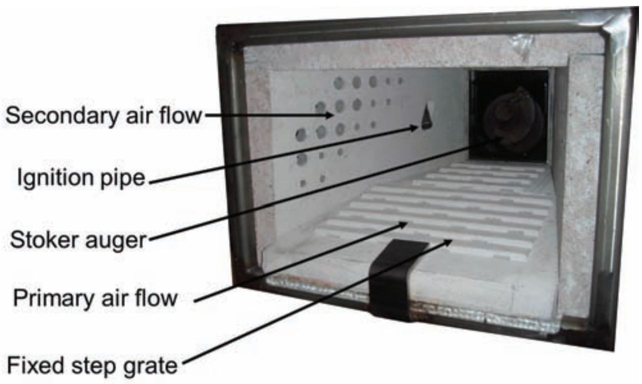


Figure 4.3 Construction of a stoker burner

Advantages

- Typical turndown ratio of 4:1 when burning dry fuels.
- The simplest type of boiler with the lowest capital cost.
- A low fuel inventory permits a fast response to load demands.
- Very low fuel consumption if boiler is of the manual ignition type (see Section 4.3) and operating in slumber mode.

Disadvantages

- Primary and secondary air cannot be controlled independently on most stoker burner boilers and can result in incomplete combustion of wood gas with accompanying low boiler efficiency.
- Clinker and slag may form on an overheated grate damaging the grate and jamming ash removal augers.
- Often require grate cooling.
- These boilers have the lowest tolerance to variations in wood quality, requiring consistent woodchip size and moisture content.
- Black smoke is readily produced when the fuel moisture content is too high.
- Small changes in fuel specification can have a large impact on boiler performance.

4.2.1.2 Stepped grate boilers

Stepped grate boilers, also referred as moving grate boilers or inclined grate boilers, allow the greatest flexibility in boiler design. These boilers are available throughout the size range from 10 kW domestic boiler to 10 MW industrial scale boilers. Fuel is introduced at the top of the grate by either an auger feed or hydronic ram and is moved forward by the longitudinal scraping action of the grate bars. Powered by either electric motors or hydraulic rams, the bars oscillate backwards and forwards with adjacent bars being out of phase. The grate is stepped and sloped downwards towards the ashpan at the opposite end. Drying occurs at the top, pyrolysis in the middle and charcoal burnout at the bottom of the grate. The angle of the grate is designed to optimise the drying and combustion process, and is greater on boilers designed to burn wet fuel while the grate can be almost horizontal on boilers designed to burn dryer fuels. Grate bars usually contain a high percentage of chromium to provide a high degree of corrosion resistance.

Boilers designed to burn woodchip of up to 55% moisture content will have the slowest response to load changes of all the biomass boiler types, because of their high thermal mass resulting from the much greater level of refractory lining required to enable them to burn wet fuel. Very dry fuels may also be burned when the boiler may have little or no refractory lining. Fine fuels such as sawdust and small grains may be burned if the grate is specifically designed with small clearances between grate bars and small primary combustion air holes in the design. Primary air is supplied from beneath the grate and rises between the grate bars. Secondary air is introduced independently some distance

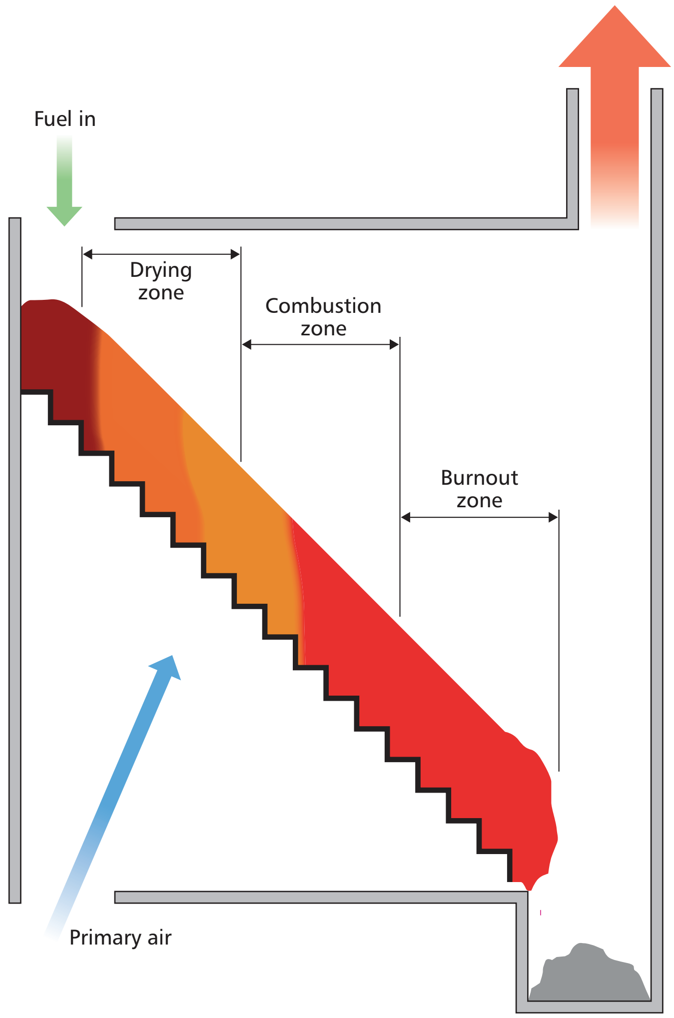


Figure 4.4 Combustion zones in a stepped grate boiler

above the firebed to burn off wood gas, and on the largest boilers tertiary air fans can be included to ensure the complete combustion of all wood gases before they exit the combustion chamber.

Figure 4.5 Stepped grate in an overfed stoker boiler

Typical turndown ratios for burning wood chip are 3:1 at 30% moisture content falling to 2:1 at 55% moisture content. With wood pellet fuel, higher turndowns of up to 3.5:1 are possible. The very latest boiler design from Europe, employing a very small stepped grate of a similar size to that found in stoker burner boilers, will burn woodchips at up to 40% moisture content with a turndown ratio of 4.8:1.

Many of the available stepped grate boiler designs have the highest fuel inventories of all biomass boilers and, coupled with the high mass refractory linings (see Section 4.5.1), makes them the least responsive to fluctuating load demands. Flue gas recirculation (see Section 4.5.3.5) is required to limit the combustion temperature on the grate if drier fuels are to be burned on a boiler designed to burn wet fuels.

Figure 4.6 Combustion on a stepped grate

Advantages

— Can be designed for a wide tolerance of fuel types and particle sizes.

— Can accept fuel up to 55% moisture content.

— Clinkering and slag formation is minimised by the moving grate design.

— Refractory linings can often be modified to allow fuel of a different moisture content to be burned.

— The ability to vary primary and secondary air supplies allows combustion to be optimised.

Disadvantages

— On systems with large grates, a slow response to load variations because of high fuel loading.

— On manual ignition boilers, slumber mode heat output can be up to 30% when burning wet fuels.

— The boiler efficiency in slumber mode is very low.

— Long warm up and cool down times on boilers with substantial refractory linings.

— An emergency heat exchanger (see Section 4.5.1.4) may be required to cool the boiler in the event of a power failure.

4.2.1.3 Chain grate boilers

A variation on the stepped grate boiler; as its name implies the grate comprises a continuously moving chain link belt.

Fuel is conveyed slowly through the boiler, being dried by the refractory lining where it enters the boiler and with ash falling off the end of the belt. Primary combustion air is supplied form beneath the belt. Chain grate boilers can accept a range of different biomass fuels up to 30% moisture content, but at a size depending on the capacity of the feed auger.

4.2.1.4 Moving grate rotary combustion chamber boilers

Another variation on the moving grate boiler is one in which the wood gases produced on the grate are ducted to a separate secondary combustion zone comprising a rotary combustion chamber. The rotating secondary combustion chamber produces thorough mixing of the wood gases and the secondary combustion air resulting in complete combustion and high boiler efficiency. The ability to achieve a consistent and optimum secondary combustion temperature together with complete combustion results in low particulate NO_x emissions. This type of boiler can handle fuel with a moisture content of up to 40%.

Figure 4.7 Cutaway drawing of a rotary combustion chamber boiler

4.2.2 Underfed stokers

In an underfed stoker boiler the fuel is pushed up through an inverted retort cone to form a dome of fuel on which combustion takes place within the combustion chamber. The auger enters beneath the combustion chamber and, because combustion occurs on the top of the fuel dome, the fuel feed auger may not need to be emptied on boiler shut down and the risk of burn-back along the auger is greatly reduced. Underfed stoker boilers can burn wood pellets and woodchips up to 30% moisture content, and are available in boilers up to 5 MW capacity.

Figure 4.8 Underfed stoker grate

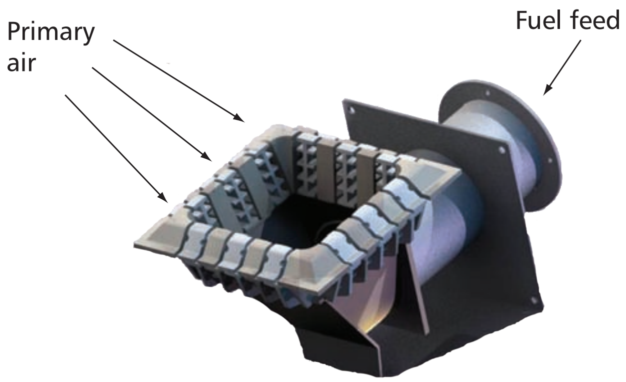


Figure 4.9 Cutaway drawing of an underfed stoker boiler

Primary combustion air is feed in around the base of the fuel dome and rises through the fuel dome to where pyrolysis occurs. Char burnout occurs round the edge of the fuel dome where ash falls outwards into an ash pan. A variation on the fixed retort burner is the rotating grate which assists in the removal of ash from the combustion dome.

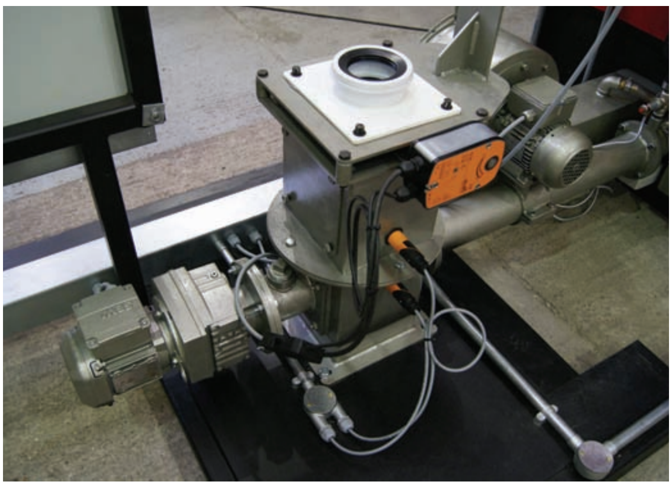


Figure 4.10 Underfed stoker auger mechanism

Advantages

— Simple grate mechanism.

— Good separation between primary and secondary combustion air.

— Wide range of boiler sizes available.

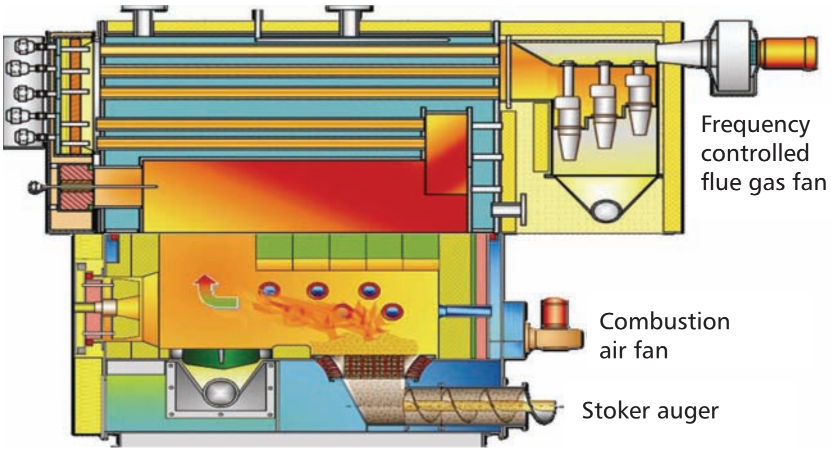


Figure 4.11 Cutaway drawing of an underfed stoker boiler

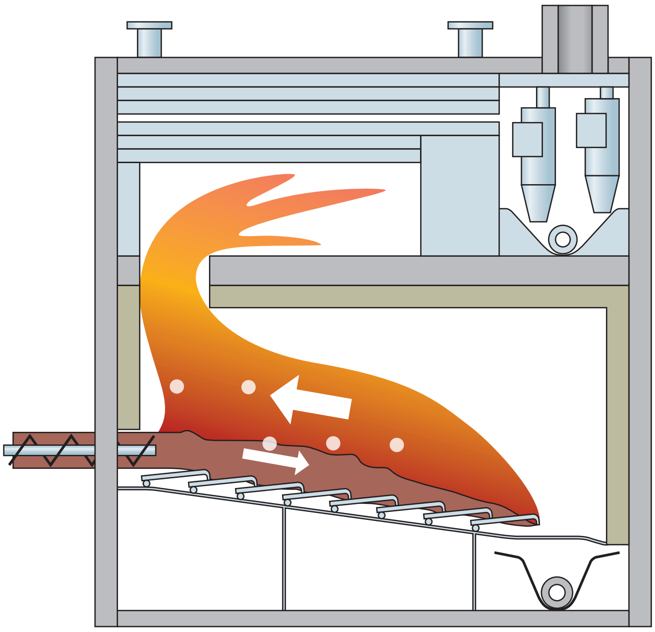


Figure 4.12 Reverse flame boiler

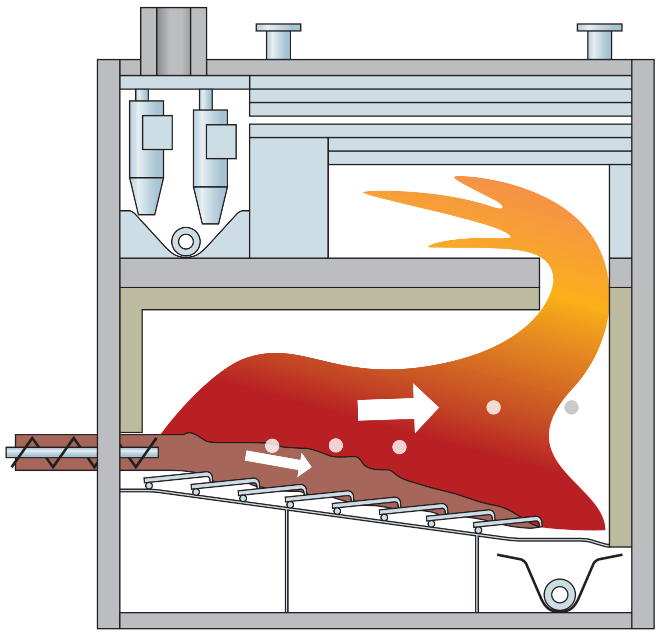


Figure 4.13 Forward flame boiler

Disadvantages

— Extensive refractory lining can limit turndown ratio.

— If not set up and controlled correctly, high temperatures on the surface of the fuel dome can result in clinker formation and boiler flame out.

— Generally limited to 30–35% moisture content in fuel.

4.2.3 Combustion chamber gas flows

Three types of gas flow above the grate are possible as illustrated by the sketches in Figures 4.12 to 4.14.

A reverse flame boiler is most suitable for wet fuels (40–55% MC), the reverse flame helping to dry the incoming fuel and remove water vapour from the combustion chamber. Particularly good mixing of secondary combustion air with the wood gas is required to ensure complete combustion of the wood gases. This configuration is most commonly found on stepped grate boilers.

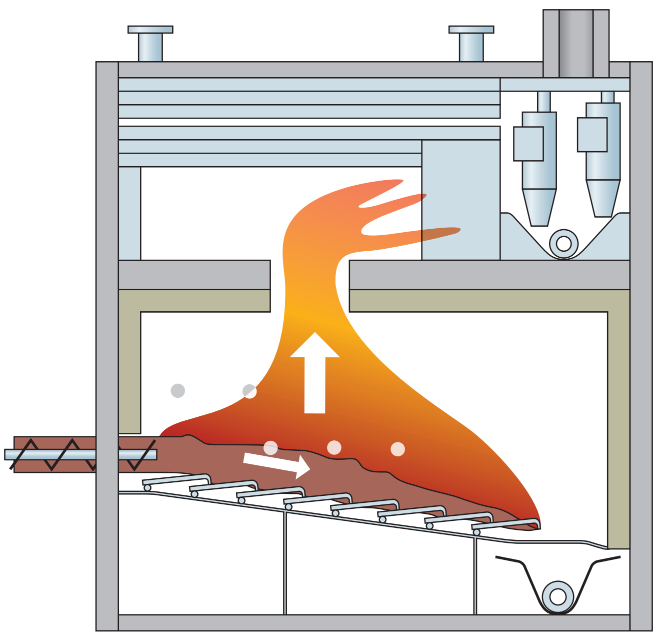


Figure 4.14 Mixed flame boiler

A forward flame boiler is used for dry fuels (10–20% MC). NO_x levels are reduced through contact between the wood gas and the charcoal bed at the bottom of the grate, and the residence time of gases in the combustion chamber is increased. This configuration can be found on stepped grate, chain grate and underfed stokers. A greater degree of entrainment of fly ash can occur in this configuration.

Mixed flame boilers are most commonly encountered on underfed stokers and on vertical tube boilers, see Section 4.4.2.

4.3 Boiler classification by ignition type

A common understanding of the meaning of the term 'automatic ignition boiler' is a boiler whose firebed can be set by means of an ignition system, typically an electric hot air gun, or an auxiliary gas or oil burner. However, depending on the boiler design the ignition system is used either to fire the boiler as required, or to establish combustion when a boiler is first switched on. In a biomass context this leads to two very different boiler types:

— Boilers which fire as required are referred to throughout this Applications Manual as 'automatic ignition boilers'.

— Boilers in which the firebed is maintained continuously following ignition are referred to throughout this Applications Manual as 'slumber mode boilers'.

In the context of this Applications Manual an automatic ignition boiler is one in which the firebed is not continuously maintained and where combustion is established only as required to meet heat demands on the boiler. The operation of an automatic ignition boiler is closer to, but different from that, of a conventional oil or gas boiler in that the heat demand at the boiler is a function of the demand not just from the load circuits but also from a buffer vessel or thermal store. Slumber mode boilers are ignited manually or by an ignition system, and then enter a slumber mode to keep the firebed alight continuously when the demand falls below their minimum output.

Whether or not a boiler can be equipped with an ignition system is primarily a function of the moisture content of the fuel to be burned. Those boilers which are designed to burn drier fuels, or which are limited to drier fuels, can often be found with an ignition system. This section covers the very different considerations when designing systems with either automatic ignition or slumber mode boilers.

4.3.1 Ignition systems

Two types of ignition systems are available:

— A conventional auxiliary gas, LPG or oil burner fitted to the side of the firebox where the burner will fire until the firebox reaches a minimum temperature and combustion is self-sustaining. This arrangement is typical for larger boiler plant.

— Electric hot air blowers usually employed on smaller boilers, again operating until combustion is self-sustaining.

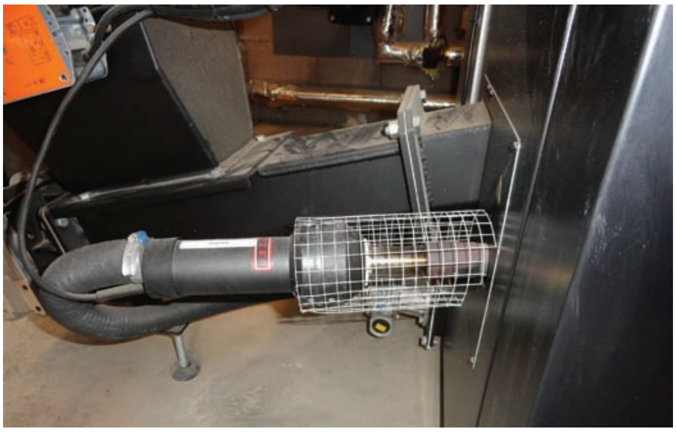


Figure 4.15 Electric igniter

Health and safety considerations
The surface temperature of electric ignitions systems can exceed 400 °C. To prevent accidental contact electric igniters should be fitted with a wire safety cage as shown in Figure 4.15.

In both cases fuel is dried and raised to its auto-ignition temperature at which point the ignition system cuts off.

Ignition systems can be found on boilers burning fuel at up to 45% moisture content. By virtue of the different characteristics of the three basic boiler types described in Section 4.2, stoker burners and underfed stokers are frequently found with ignition systems, while they are not so common on stepped grate boilers.

4.3.2 Automatic ignition boilers

Automatic ignition boilers do not maintain the firebed continuously, but fire to meet load demands on the boiler. Unlike conventional oil or gas boilers, the load demand sensed at the boiler results primarily from a thermal store and not from the system load. Typically, an automatic ignition boiler will fire to satisfy the demand and the firebed will be allowed to burn out. Depending on the boiler, a demand will result from the need to maintain the boiler's flow temperature to within a few degrees of the flow temperature setpoint, or to maintain the temperature within a thermal store.

4.3.2.1 Explosion risk from automatic ignition boilers

Like oil boilers, biomass boilers require the combustion chamber to be purged of wood gas before an ignition sequence is started. The timing of this purge is based on the boiler design and fuel moisture content, but an explosion risk exists if fuel with a moisture content greater than that for which the boiler has been designed is used. Should too wet a fuel be fed into an automatic ignition boiler the ignition system may fail to bring the fuel to its auto-ignition temperature before the ignition cuts off. In this case partially ignited fuel will be left pyrolysing on the grate producing both carbon monoxide and hydrogen. Should the boiler start sequence not adequately purge the combustion chamber of these gases before the ignition sequence restarts, an explosion is likely to occur. This is a well-documented problem which designers and users must acknowledge. It is incumbent on designers to advise users of this risk, and then for users to advise fuel suppliers of the maximum acceptable fuel moisture content for their system. Users should never accept fuel which is too wet for an automatic ignition boiler.

Health and safety considerations
Never use fuel in an automatic ignition boiler which has a moisture content greater than the boiler is designed to accept

4.3.2.2 Response to load changes within the boiler's modulating range

The fuel feed rate, and primary and secondary combustion air supply rates will be varied to match the load demand on the boiler within the boiler's modulation range. For as long as the load demand is within the modulating range the boiler will fire continuously, and it is within the boiler's modulating range that the boiler will operate at its maximum efficiency, and with minimum emissions, because the combustion chamber temperature can be optimised and maintained during continuous firing.

Designing a biomass system where the boiler is sized at well below the peak load, and a thermal store is provided to help meet peaks in load, will allow the boiler to operate continuously, or for very long periods. This is a crucial reason not to oversize a biomass boiler. The design of thermal storage is covered in detail in Chapter 5 of this manual.

4.3.2.3 Boiler operation below minimum turndown

Most biomass boilers operate based on satisfying the water flow temperature from the boiler. In the case of automatic ignition boilers, once the boiler has reached its maximum flow temperature no more fuel will be fed onto the grate and the primary and secondary air fans will either modulate down or switch off depending on the boiler control system. Once the boiler flow temperature has fallen by, typically, 3 °C the primary and secondary air fans will resupply combustion air, and fuel will be fed onto the grate. If the firebed has extinguished, the automatic ignition system will operate until the fire has been re-established.

On overfed stoker boilers the fuel feed auger will normally remain full of fuel for as long as the load system is enabling the boiler, the auger emptying only when the boiler shuts down fully.

4.3.2.4 Seasonal efficiency and emissions

The seasonal efficiency of an automatic ignition boiler is determined largely by its firing profile. It is possible to achieve a net efficiency of up to 90% by designing an undersized boiler to fire continuously supplying a thermal store. An automatic ignition boiler operating without a thermal store may fire at frequent intervals, with its efficiency dropping every time it needs to reset the fire using the automatic ignition system. Boiler emissions are at their peak during an automatic ignition sequence because of incomplete combustion on the grate resulting in the release of unburned volatile material, including tars, from the flue.

4.3.3 Slumber mode boilers

The majority of stepped grate boilers are of the slumber mode type. Where an ignition system is not fitted, manual ignition may be by means of a gas lance which is pushed into the firebed, although the traditional method of manually setting a fire using paper or fire lighters is commonly used. Irrespective of whether a load demand exists the firebed remains alight at all times until the boiler is shut down by the user. The boiler enters a slumber (or kindling) mode when the flow water temperature from the boiler is satisfied, with fuel feed being reduced to the minimum required to keep the fire alight; primary and secondary combustion air may be removed completely or significantly reduced in slumber mode. Again, the fuel feed auger does not empty. The thermal response to a load demand to producing a heat output is usually faster than from an automatic ignition boiler because the firebed is already established.

4.3.3.1 Response to load changes within the boiler's modulating range

As with automatic ignition boilers, the fuel feed rate, and primary and secondary combustion air supply rates will be varied to match the load demand on the boiler within the boiler's modulation range; the same considerations of boiler efficiency and boiler emissions apply.

It is even more important when designing a biomass system using an slumber mode boiler that the boiler is not oversized and spends as much of its time as possible operating within its modulating range. Again, small boilers operating into thermal stores will produce the most efficient operating solution with the minimum of emissions.

4.3.3.2 Boiler operation below minimum turndown

A slumber mode boiler will enter slumber mode when the flow temperature is satisfied and the boiler reaches its minimum turndown. The minimum of fuel is fed onto the grate to maintain the firebed and, depending on how the boiler's controls have been configured, the boiler back-end loop (see Chapter 7) may circulate water within the loop or the back-end valve may be cracked open to allow water to circulate into a buffer vessel or thermal store. In the former case all of the energy produced to keep the boiler alive is wasted as heat up the flue, whereas circulating water into a buffer vessel or thermal store will capture some of the heat produced.

4.3.3.3 Explosion risk from slumber mode boilers – boiler response to sudden load changes

Slumbering fuel on a grate produces carbon monoxide and hydrogen (the primary fuel gases resulting from pyrolysis). In the depleted oxygen atmosphere of slumber mode operation, the gas-air mixture in the combustion chamber may exceed the lower explosive limit for these gases. While biomass boiler control systems allow for this, and flue systems must be designed to supply sufficient draught to minimise the risk of an explosive mixture in the combustion chamber, the boiler's control system is less suited to respond to a sudden reduction in load.

If a slumber mode boiler is operating at full load and that load is suddenly removed, the gas-air mixture will rapidly exceed the lower explosive limit and continue to rise until the fuel inventory on the grate has been reduced significantly. The risk of an explosion is very high because the grate and boiler will be at maximum temperature with a lot of burning fuel. Even a small increase in primary combustion air could cause an explosion, and opening the firebox door in this situation will almost certainly guarantee a flash-over. Even in normal operation, an explosion can result from a boiler coming out of slumber mode. Boiler specifications should include the requirement for a sight glass in the firebox door in order that the firebed can be viewed without the need to open the firebox door. Modern systems employ an interlock to prevent the operator from opening the firebox access door when it is unsafe to do so. This feature is programmed into the control system of larger boilers which place the boiler into a safe mode allowing the access door to be opened after a suitable time delay.

Health and safety considerations
Never open the firebox door of a slumber mode boiler when the boiler is operating in slumber mode

Health and safety considerations
Design the building's control system to avoid sudden load reductions being imposed on the boiler

When designing a control system for load circuits, e.g. a building management system, it is incumbent on the designer to design out the potential for sudden and large loads reductions on the boiler. For example, the loads on a large building should not all be removed at the same time at cease of work, but be staggered across the last 1 or 2 hours of the working day. The use of a thermal store provides a high degree of resilience to sudden load changes as it achieves hydronic separation between the boiler and load circuits. Nonetheless, if the thermal store is fully charged when a sudden load reduction occurs with the boiler firing at peak output, this will reflect back to the boiler causing it suddenly to enter slumber mode with the attendant explosion rise detailed above.

Figure 4.16 Unburned gases produced in slumber mode

Prior to the photograph in Figure 4.16 being taken, the boiler was firing and the O_2 content of the flue gas was checked for safety before the boiler firedoor was opened. While the firedoor was open the boiler dropped into slumber mode and immediately began to produce visible smoke containing unburned fuel.

4.3.3.4 Seasonal efficiency and fuel consumption in slumber mode

Any large boiler burning wet fuel will be of the slumber mode type. While automatic ignition boilers are usually found on individual smaller buildings, manual ignition boilers are typically found in larger buildings and on heat networks as well as in industrial applications where a 24-hour heating profile exists. The use of slumber mode boilers in, for example, office blocks and schools results in grossly inefficient boiler operation and low seasonal efficiency. Even where a slumber mode boiler is used on a district heating scheme, seasonal efficiency will be low if the boiler's minimum output is greater than the standing losses on the network. An internal Carbon Trust report on biomass boilers' seasonal efficiency showed most boiler systems working well below their design efficiency (Carbon Trust, 2009b).

Unless the boiler is well matched to the load profile throughout the year, it is good practice to turn off slumber mode boilers in summer where they would otherwise operate for only a few hours a day. A modern building constructed to the current technical standards is unlikely to be a suitable candidate for biomass as its combined heating and hot water load profile is likely to be very low from spring through to autumn. While a small automatic ignition boiler operating into a thermal store may produce an acceptable seasonal efficiency, operating a slumber mode boiler, which fires for 10 hours a week and slumbers for 158 hours a week, will result in an exceptionally low seasonal efficiency with significantly increased fuel consumption and greater cost than a fossil fuel system.

4.4 Boiler classification by firetube orientation

A further method of classifying biomass boilers is by fire tube orientation. Both horizontal and vertical tube boilers are commonly employed, although 500 kW is the maximum size for vertical tube boilers. Heat exchangers are of a conventional shell and tube arrangement, using fire tubes in a water shell for both types of boiler.

4.4.1 Horizontal tube boilers

Horizontal tube heat exchangers can be found on all three main boiler types, the heat exchangers usually being located above the combustion chamber. Size for size, horizontal tube boilers tend to have larger boilerhouse footprint than vertical tube boilers but require less headroom.

Figure 4.17 Horizontal tube boiler

Fly ash and soot accumulation in horizontal tube boilers is a significant consideration, with tubes requiring regular manual cleaning even when an automatic cleaning system is installed (see Section 4.5.6).

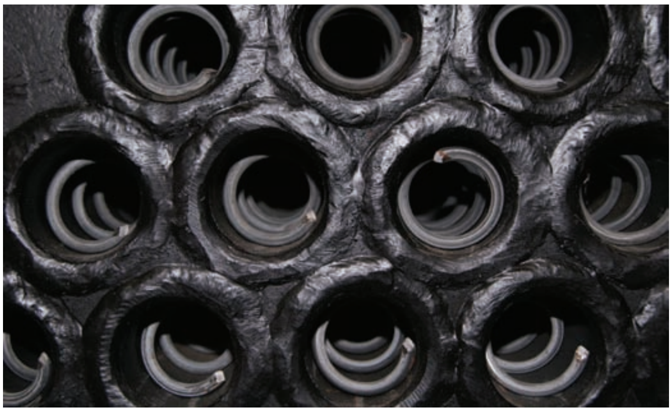


Figure 4.18 Horizontal fire tubes

4.4.2 Vertical tube boilers

Vertical tube heat exchangers can, again, be found on all three main boiler types, the heat exchangers usually being located behind the combustion chamber. However, these boilers tend to have relatively small grates making them responsive to load changes and with the highest achievable turndown ratios. While the maximum rating for vertical tube boilers is currently 1 MW, outputs have been increasing gradually over the last decade.

The same problem of soot and fly ash accumulation occurs in vertical tube boilers, but automatic and continuous cleaning of firetubes is possible avoiding the need for manual intervention (see Section 4.5.7). Maintenance access from above is usually required on vertical tube boilers so, relative to horizontal tube boilers, they are taller and require much more headroom in the boilerhouse.

Vertical tube boilers predominate at sizes up to 200 kW using either underfed stokers or overfed stokers onto a stoker burner or stepped grate. Those boilers which use underfed stoking usually have a fuel dosing silo attached to the boiler with the underfed auger running from the bottom of this bin to the underfed retort or grate. The dosing silo will usually incorporate fuel level sensing (ultrasonic or laser infra-red) to allow it to be filled automatically from the main fuel store.

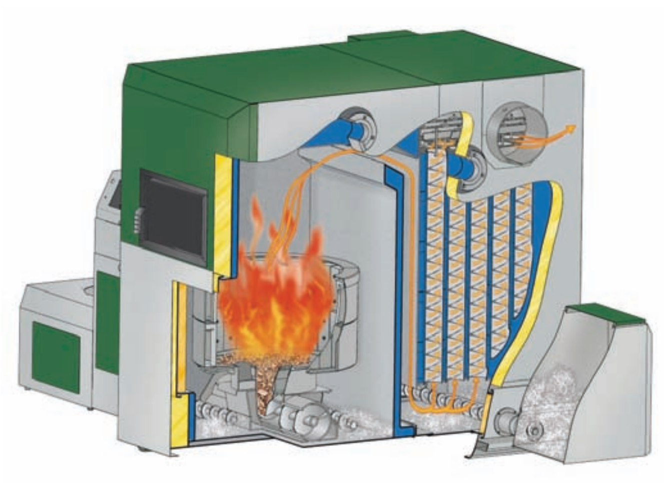


Figure 4.19 Underfed stoker vertical tube boiler showing flue gas path and ash removal

4.5 Boiler features and characteristics

4.5.1 Firebox and refractory lining

Conventional gas and oil fired boilers usually use a wet firebox, where the firebox lies within the water shell, often in a reverse flame configuration. However, the large quantity of gas that evolves from a wood fuelled firebed requires a large firebox and combustion chamber to ensure that it is fully burnt. The size of a biomass firebox makes a wet firebox impracticable, and the large size also means that more material is required in the shell to withstand a given pressure. To limit material and cost, low temperature hot water biomass boiler shells are generally designed for 3 bar pressure rather than the 6 bar of their fossil fuelled counterparts.

Figure 4.20 Cylindrical refractory lining in a 400 kW underfed stoker boiler showing fuel feed auger beneath grate, primary air holes in the grate and secondary air holes in the refractory

The majority of biomass boilers use a refractory lined dry firebox, the refractory lining protecting the boiler wall from the high combustion temperature. When up to operating temperature, the refractory lining exchanges radiant heat with the incoming fuel to dry the fuel, and with the combusting gases to maintain the temperature of the combustion reaction. The hot gases then pass into the heat exchanger to heat the boiler water. In horizontal tube boilers the water shell is usually positioned on top of the firebox and in vertical tube boilers it is often positioned behind the firebox.

Figure 4.21 Arch of refractory lining above firebed with horizontal fire tubes at top

The quantity and location of refractory lining varies considerably between manufacturers and between horizontal and vertical boilers. As a general rule, the wetter the fuel to be burned the greater the quantity of refractory lining required and the slower the thermal response of the boiler.

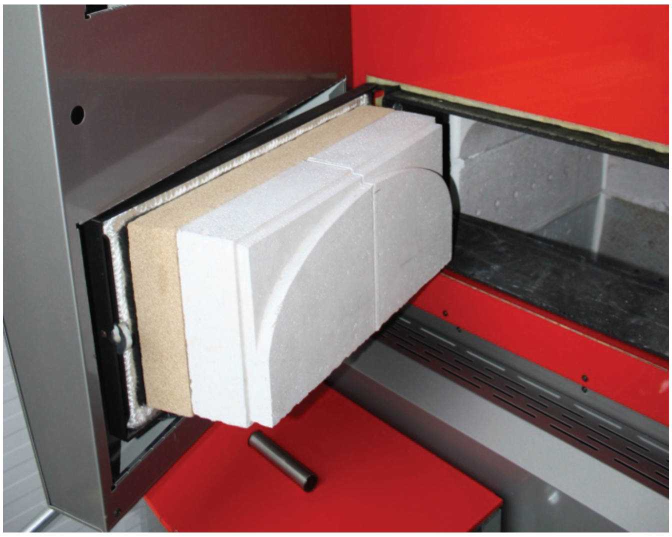


Figure 4.22 Refractory lining on boiler door

Figure 4.23 Refractory lining in underfed stoke boiler

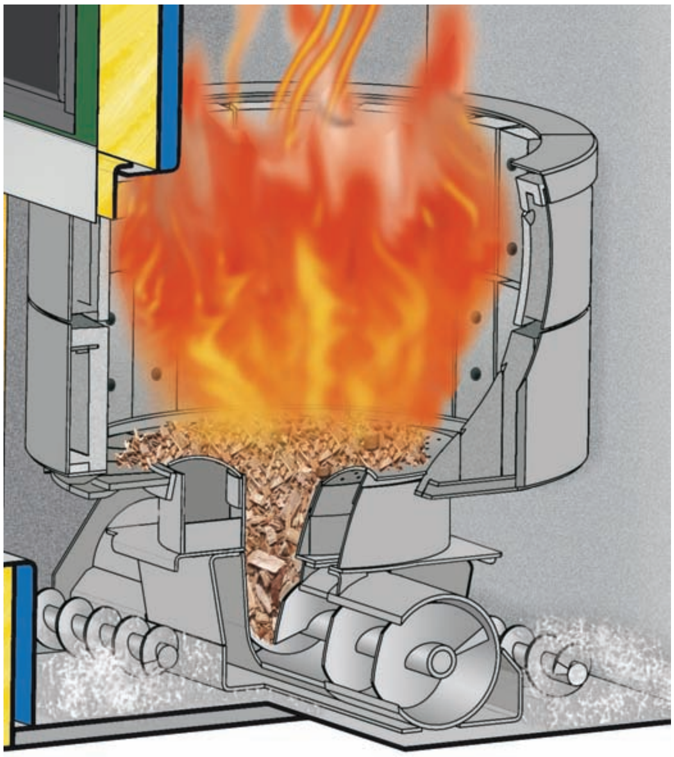


Figure 4.24 Cylindrical combustion chamber with underfed stoker auger and ash augers

4.5.1.1 Reasons for refractory lining

The key reasons for using a refractory lining are to:

— Dry fuel prior to combustion.

— Raise the fuel temperature to the auto-ignition point for pyrolysis.

— Provide a stable combustion chamber temperature.

— Provide a sufficiently high combustion chamber temperature to ensure complete combustion of wood gases.

4.5.1.2 Factors influencing the quantity and positioning of refractory lining

The following factors influence the quantity and position of refractory lining:

— The fuel moisture content.

— The size of the grate and the associated fuel inventory.

— The design of primary and secondary combustion zones.

— The geometric relationship of refractory lining to the grate.

4.5.1.3 Removal of residual heat on boiler shutdown

The presence of a refractory lining and a fuel load on the grate means that a significant quantity of heat has to be removed from a boiler prior to shutdown. The boiler's own control system will reduce the fuel inventory on the grate as the boiler modulates to its minimum output from where the residual heat can be dissipated into a buffer vessel (see Chapter 5). In general terms, the larger the grate and the greater the refractory lining the larger the buffer vessel required. Heat must be removed from the boiler until the fuel has been burned off the grate and sufficient heat has been removed from the refractory lining to keep the water in the boiler below the boiling point with an adequate flash margin. On overfed stokers the boiler fuel feed auger usually needs to be emptied and the fuel burned off on the grate. In the event of a loss of electrical power an emergency heat exchanger may be needed to remove residual heat safely as described in the next section.

4.5.2 Emergency heat exchangers

In the event of a sudden boiler shutdown as occurs, for example, during a power failure, the heat contained in the unburned fuel and the refractory lining has to be removed quickly. This is often accomplished by the use of an emergency heat exchanger located within the boiler. This safety device is operated if the water within the boiler exceeds the manufacturer's design maximum temperature. It is operated, independently of a power supply, by a direct acting valve which allows mains water to pass through a heat exchanger within the boiler removing the excess heat. As it is only utilised in an emergency situation, the mains water passes through the heat exchanger once and the outflow is dumped to drain.

Figure 4.25 Emergency heat exchanger pipework with direct-acting valve and temperature probe sensor withdrawn from its pocket

It is important that the water supply to the boilerhouse has sufficient pressure and capacity to supply the required volume flow rate to the emergency cooling system. A minimum water pressure of 3 bar is required and the recommended supply pipe sizes are:

— DN32 for boilers up to 300 kW

— DN40 for boilers of 300 kW to 1 MW

— DN50 for boilers of 1 to 2 MW

If the mains water supply pressure is insufficient, or if the mains water supply could be subject to disruption, the designer should take advice from the boiler manufacture on how to provide an emergency water supply.

On boilers which are not fitted with an emergency heat exchanger, and on which the manufacturer's maximum design temperature could be exceeded in an emergency shutdown situation, the designer must implement any measures required to achieve a safe shutdown from the boiler manufacturer.

Health and safety considerations
The designer should ensure the boiler is prevented from exceeding its maximum design temperature in the event of a power failure or emergency boiler shut down

4.5.3 Combustion chamber pressure and combustion air

4.5.3.1 Combustion chamber pressure control

The combustion chambers of modern fossil fuelled boilers are usually well sealed against leakage of combustion products from the boiler. However, the very nature of biomass boilers, with augers and stokers penetrating into the combustion chamber, means that it is not possible to seal a biomass boiler's combustion chamber against leakage from the firebox back along the feed system. Hence, the combustion chamber pressure of all biomass boilers must be negative at all times. On small boilers the negative pressure can be as little as –10 Pa while on large boilers it can be several hundred Pascals negative. Should combustion chamber pressure be lost a very dangerous situation can develop rapidly in that wood gases, including carbon monoxide and hydrogen, will leak into the boilerhouse presenting both asphyxiation and explosion risks.

The primary means of maintaining a negative combustion chamber pressure in biomass boilers is through an induced draught fan which draws air through the firebox, maintaining the firebox below atmospheric pressure. The induced draught fan may be set up to a fixed speed during commissioning, or be variable speed and controlled from a firebox pressure sensor. The induced draught fan may be located in smaller boilers which do not require flue gas abatement equipment, or after the flue abatement system. The induced draught fan is controlled in concert with the primary and secondary combustion fans (see Sections 4.5.3.3 and 4.5.3.4).

Figure 4.26 Combustion chamber pressure sensors

4.5.3.2 Maintaining negative combustion chamber pressure under emergency shutdown conditions

The primary means of maintaining a negative combustion chamber pressure under failure conditions is the flue, and in this respect the design of a biomass flue is even more critical than that for fossil fuelled systems; flue design is covered in depth in Chapter 10. The designer must ensure that the asphyxiation and explosion risks associated with the worst case operating condition of sudden boiler shutdown are designed out at the earliest stage. For example, the flue system must provide a positive draught under all conditions, and no part of the flue should impose a load on the vertically rising flue section. Measures which can be taken to reduce the potential for a sudden boiler shutdown include the use of standby generators and uninterrupted power supplies on flue and cyclone fans. However, it is recommended that the designer should not rely on such means as the primary measure, but should aim to design the flue system to ensure the safe evacuation of wood gases from the combustion chamber in the event of an emergency shutdown.

Health and safety considerations

The designer should aim to ensure that the flue system is able to evacuate wood gases from the combustion chamber in the event of an emergency boiler shutdown

4.5.3.3 Primary combustion air – sub-stoichiometric

Primary combustion air is supplied beneath the grate or into the side of the firebed. In order to produce wood gas by pyrolysis air must be supplied sub-stoichiometrically, $\lambda = 0.7–0.8$. In the simplest boilers primary air is drawn through the boiler by the flue or cyclone fan, the primary air supply rate being adjusted by manually operated dampers on the side of the boiler. In these boilers the primary air dampers have to be adjusted every time the fuel moisture content changes. The majority of boilers have one or more primary air fans which can either be pulsed on and off or speed-controlled by variable speed drives, the mark-space ratio or fan speed being adjusted by the boiler control system respectively. Accurate primary air control is required in order to optimise pyrolysis and combustion efficiency. Some manufacturers use flue gas recirculation (see Section 4.5.3.5) as standard to maintain an accurate λ value and optimise combustion efficiency. On stoker burner boilers it is common to find both primary and secondary air supplied by a single combustion air supply fan.

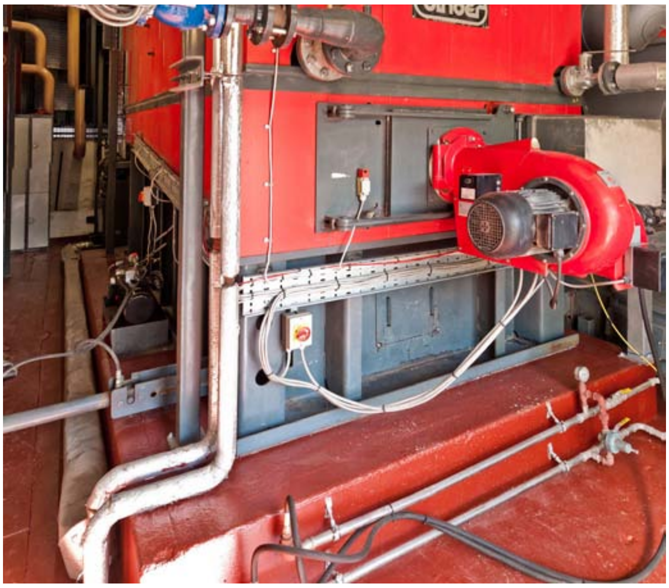


Figure 4.27 Primary combustion air fan on underfed stoker boiler

Figure 4.28 Primary combustion air fans on a 2 MW overfed stoker boiler

4.5.3.4 Secondary combustion air – super-stoichiometric

Secondary combustion air is supplied above the firebed to combust the wood gases produced. The complete combustion of wood gases requires accurate temperature and excess air control in the upper combustion chamber. Air must be supplied super-stoichiometrically, approximately $\lambda = 1.5$, to ensure complete combustion. A typical excess O_2 level in a biomass boiler flue is between 8 and 12% corresponding to $\lambda = 1.42$ to 1.63, the excess air ratio being monitored by a lambda sensor measuring the excess O_2 level in the flue. The excess air ratio also serves to limit the production of thermal NO_x, i.e. the NO_x formed by the combining of atmospheric N_2 and O_2. As before, on the simplest boilers, air can be supplied via manually operated

Figure 4.29 Secondary combustion air fans on a 2 MW overfed stoker boiler with fuel feed at bottom

Figure 4.30 Exhaust gas recirculation duct and fan on a 1.5MW biomass boiler

dampers, but the majority of boilers use one or more secondary air fans controlled as described above.

4.5.3.5 Exhaust (flue) gas recirculation

The purpose of exhaust gas recirculation is to limit the firebed temperature in order to prevent clinker formation on the grate and damage to the grate, and to improve and regulate the mixing of combustible gases and air. The flue gas is taken from the cleaned gases after the flue abatement processes, and is mixed with the fresh combustion air prior to introduction into the firebed. A disadvantage of exhaust gas recirculation is that it increases the flue gas volume in the boiler requiring even more excess secondary combustion air to ensure complete combustion of the wood gases. To prevent condensation within the boiler, flue gas recirculation should be operated continuously.

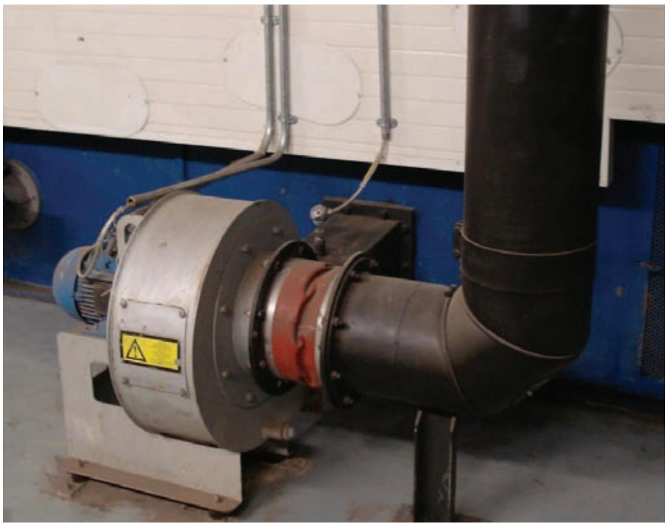


Figure 4.31 Exhaust gas recirculation fan feeding exhaust to plenum beneath firebed

4.5.4 Return water temperature control and temperature bandwidth

On condensing gas boilers the objective is to return water to the boiler at less than 55 °C in order that some of the moisture will condense out of the flue gases to increase boiler efficiency. On oil boilers the minimum return temperature needs to be 60–65 °C to prevent acidic flue gases from condensing in the boiler tubes and flue, and to control this oil boiler systems incorporate either a gravity or pumped back-end loop on the boiler. The same consideration applies to biomass boilers, where a back-end loop is always installed to protect the boiler as shown below.

4.5.4.1 Biomass boiler return water temperature

The minimum return temperature required for a biomass boiler is a function of the moisture content of the biomass fuel and the design of the boiler. The typical return temperatures required are:

— Wood pellets (moisture content 8%): 55 °C

— Woodchips (up to 35% moisture content): 60–65 °C

— Woodchips (50% moisture content): 65–75 °C

On start-up a boiler will circulate water within the back-end loop until both the return water temperature is above the minimum required and the flue gas temperature is above the dew point temperature; this is described in detail in Sections 5.2.1 and 5.3.1. A key function of the boiler control system is to increase the flue gas temperature as rapidly as possible to avoid the condensable volatile organic substances from condensing in the flueways. This is more important in horizontal tube boilers where salts and chlorides can become trapped in the fly ash and soot laying in the boiler tubes, for if this happens the boiler tubes will corrode. This is the primary reason for the need to clean boiler tubes at regular intervals including brushing on horizontal tube boilers. The control of return water temperature is covered in more depth in Section 8.1.1.

4.5.4.2 Temperature differential/bandwidth across the boiler

The temperature difference between the flow and return on a biomass boiler is referred to as the temperature differential or temperature bandwidth. The temperature bandwidth can usually be set between 5 and 20 °C, the choice of bandwidth depending on a number of factors including the minimum return temperature required, the desired flow temperature, the back-end loop flow rate and the temperature difference across a buffer vessel or thermal store.

4.5.4.3 Dynamic return temperature control

The designer must endeavour to avoid a situation in which the boiler's return temperature setpoint exceeds the boiler flow temperature. For example if the boiler's flow and return temperature setpoints are 85 °C and 75 °C respectively, and load greater than the boiler can supply (i.e. greater than the boiler's rated output) has been placed on the boiler resulting in an actual boiler flow temperature of 73 °C, the boiler return temperature setpoint will exceed the boiler flow temperature and cause the boiler to shut down.

Some boiler manufacturers incorporate a feature to prevent this happening by adjusting the return temperature setpoint to maintain the temperature bandwidth under all circumstances.

4.5.5 Grate design

Biomass boiler grates, irrespective of the type of boiler in which they are installed, all have the same purpose, i.e. as a bed on which to dry and then pyrolyse fuel. They must be designed to withstand temperatures in excess of 800 °C without distortion and aggressive materials within the fuel such as silica and corrosive chemicals. Whether the grate is a single fixed component, or a moving or rotating grate, the grate must be designed to allow primary air to enter the firebed from below and/or from the sides. The spacing of grate components will be determined by the type of fuel being burned, with grates designed to burn sawdust and grain having a very close tolerance with grate components overlapping to provide small clearances. All grates are manufactured with a proportion of chromium steel, with grates burning aggressive fuels having up to 60% chromium content.

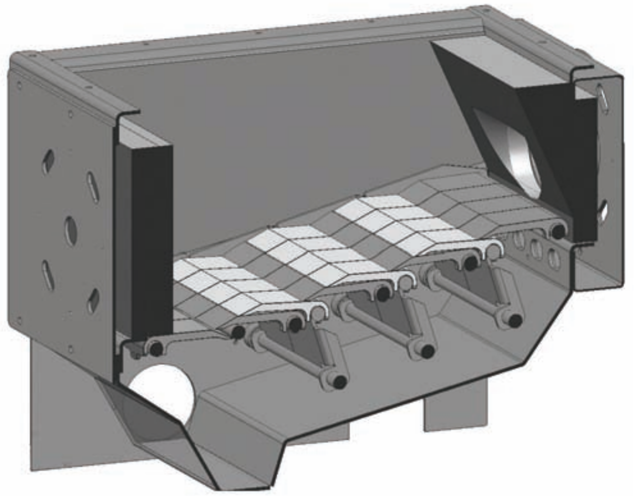


Figure 4.32 Moving grate

Figure 4.33 Moving grate in an overfed stoker boiler

4.5.5.1 Water cooled grates

In order to avoid clinkering on the grate, some stoker burner and stepped grate boilers incorporate a water cooling circuit within the grate. A bleed from the return water circuit to the boiler is pumped through the grate cooling circuit to rejoin the return water immediately prior to the boiler. In addition to the prevention of clinker formation, grate cooling prolongs the life of the grate and cools the ash before it is deposited into the ashpan below.

Figure 4.34 Connections to a water cooled grate showing cooling pump

4.5.6 Ash removal from beneath the grate

Ash will either be pushed off the grate or fall off the grate into an ashpan below. In all but the smallest boilers ash is usually removed by an ash auger located in the ash pan. On smaller boilers this extends into wheeled ash bin and, on larger boilers, to an ash conveying auger which transports the ash to an external ash container. Boilers are designed to ensure that, for all normal fuels, the temperature of the ash entering the ashpan never exceeds the ash fusion temperature otherwise a glassy slag will form which can snap or jam an ash auger. However, fuels with a high chloride content may have a very low ash fusion temperature and could result in problems both on the grate and in the ashpan.

Figure 4.35 External ash bin on a 3 MW biomass boiler

4.5.7 Fire tube cleaning

The regular cleaning of firetubes is essential on biomass boilers. Not only does soot and fly ash accumulate, which reduce the heat transfer coefficient in the boiler, but salts and condensable organic volatiles become trapped in the soot and fly ash which remain in contact with the firetube walls until the tubes have been cleaned. Every time the boiler cools down these substances will condense within the firetubes causing corrosion.

4.5.7.1 Manual and compressed air cleaning of horizontal tube boilers

Horizontal tube boilers accumulate soot and fly ash much more readily than vertical tube boilers. When designing an installation using a horizontal tube boiler, sufficient clearance must be available in front of boiler, greater than the length of the firetubes, to allow manual cleaning by brushing.

Figure 4.36 Compressed air cleaning nozzles on a horizontal tube boiler

Compressed air pulse cleaning is commonly used on horizontal tube boilers and on large vertical tube boilers. Requiring an external air compressor, compressed air is injected into air nozzles installed on ends of the fire tubes in a timed sequence at regular intervals. The use of this system does not avoid the need for manual cleaning, but reduces the frequency at which manual cleaning is required.

4.5.7.2 Spiral turbulators on vertical tube boilers

The majority of vertical tube boilers employ a mechanical cleaning system which is built into the firetubes. Manual cleaning is not possible on these boilers and neither is it required. Turbulators within the firetubes spin the flue gases to deposit particulates on the firetube walls. The turbulators are rotated or shaken mechanically at regular intervals to clean deposits from tube walls which drop into ashpan.

Figure 4.37 Turbulator shakedown mechanism on a vertical tube boiler

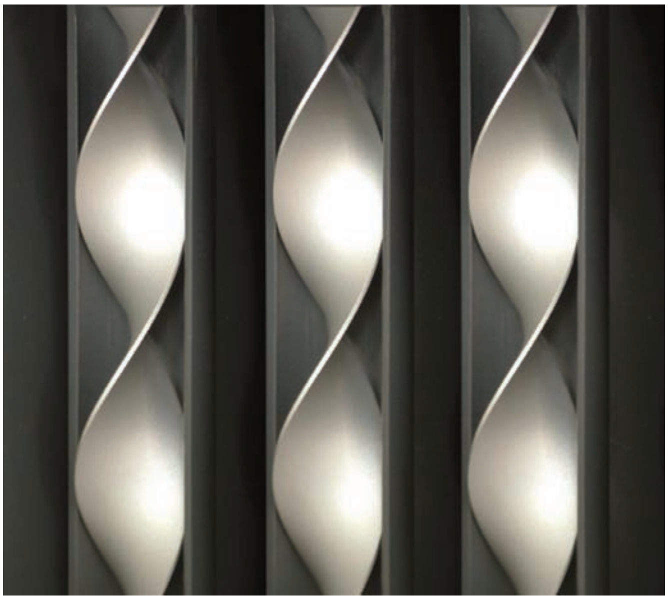


Figure 4.38 Cut-away showing turbulators in vertical firetubes

4.5.8 Electrical consumption of biomass boiler systems

4.5.8.1 Power supply requirements

For all but the very smallest biomass boiler systems a 3-phase electricity supply is either required or highly desirable. While biomass boilers are generally available wired for single phase operation up to a maximum of 200 kW, above this size all biomass boilers require a 3-phase electricity supply. However, the high torque required for fuel extract systems means that even at sizes below 200 kW a 3-phase supply is required. It is possible to generate a 3-phase supply for a fuel extract motor by using an electronic inverter which converts single-phase to 3-phase electricity.

4.5.8.2 Boiler control panels

Some manufacturers build their boiler control panel into the boiler housing but some supply their panels as separate units for wall mounting. Ideally, separate control panels should be positioned near the entrance door to accord with good building practice. Care has to be taken to position the control panel at a safe distance from the biomass boiler firebox door in order to avoid exposure to radiated heat and dust when opening a firebox door. Manual controls, such as reversing switches for augers, should be positioned so that the effect of the control can be observed while operating it.

4.5.8.3 Electrical consumption of boiler system components

Unlike fossil fuel boilers, where the only electrical components are the control panel, one or two small valves and a burner fan, biomass boiler systems have a number of relatively high consumption components. Fuel extract and feed systems need motors for rotary extractors and augers, or walking floors and ram stokers, the latter two items requiring a hydraulic pack with relatively high electricity consumption. The consumption of a rotary extractor and out feed auger on a sloping floor at 15° is twice that of the same equipment on a horizontal floor. Electrical equipment on the boiler includes a rotary valve, several fans and, on large boilers, an induced draught fan after the cyclone grit arrestor which can also be a heavy electricity consumer. The electricity consumption of biomass boilers is not insignificant, and must be taken into account when calculating annual running cost and net CO_2 savings. The biomass boiler system sizing tool includes the calculation of biomass boiler electricity consumption and can provide a good estimate of electricity use. The algorithms used to calculate the electrical consumption of biomass boiler system components can be found in the Carbon Trust's *Biomass Boiler System Sizing Tool User Manual* (Carbon Trust, 2013).

4.5.9 The boiler control system

4.5.9.1 Equipment controlled by the boiler control system

It is usual for biomass boiler manufacturers to supply a control system bespoke to each model of boiler, even if this is a relatively basic controller. A system typically controls all mechanical and electrical components from the fuel extract system in a silo to the grit arrestment system after the boiler. Designers should ensure that boilers incorporate a sufficient level of control for efficient and safe operation. The following are lists of the equipment typically controlled, although not all of this equipment will be found on every system:

Fuel system

- fuel extract auger
- walking floor
- fuel transfer auger
- ram stoker
- rotary valve
- flap valve.

Boiler

- fuel feed auger
- stepped grate motor
- rotary grate motor
- tipping grate operation
- grate cooling pump
- ash removal auger
- primary air fan motor(s)
- secondary air fan motor(s)
- flue fan motor
- cyclone fan motor.

4.5.9.2 Sensors connected to the boiler control system

Control of the above equipment is based on several sensors on the boiler:

- combustion chamber pressure
- flue gas temperature
- lambda (O_2) level
- water flow temperature
- water return temperature
- buffer vessel high level temperature (start sensor)
- buffer vessel low level temperature (stop sensor)
- ash bin level
- fuel dosing bin level.

4.5.9.3 External connectivity

As a minimum a biomass boiler's control system will accept an enable signal from another control system and produce a common fault signal when any monitored boiler component fails. An increasing number of boilers provide an external interface in the form of a MODBUS or similar connection which allows external monitoring of conditions within, but not control of, the boiler.

4.6 Flue gas cleaning

Both particulate and gaseous components are present in biomass flue gases, and very different technologies are required to remove or abate particulates and gases. A number of publications exist describing the various technologies and their effectiveness in considerable detail (Van Loo et al, 2008) (Carlsson, 2008), while a brief introduction is provided in this Applications Manual.

4.6.1 Particle control technologies

Biomass combustion gives rise to both fly ash and small particles from sub-micron to 10 μm (PM_{10}) in the flue gases. Depending upon the environmental regulations in force where the boiler is to be installed, differing degrees of post combustion treatment may be required. The particle control technology required depends on particle size, gas flow, collector efficiency, the electrical and chemical properties of the particles, and whether tars are present in the flue gas. Common forms of post combustion particulate removal on systems of up to 5 MW are cyclone grit arrestors, bag filters and ceramic filters. Electrostatic precipitators may be used but are very expensive and likely to be found only on the largest systems. Figure 4.39 shows the collection efficiencies for various particle control technologies.

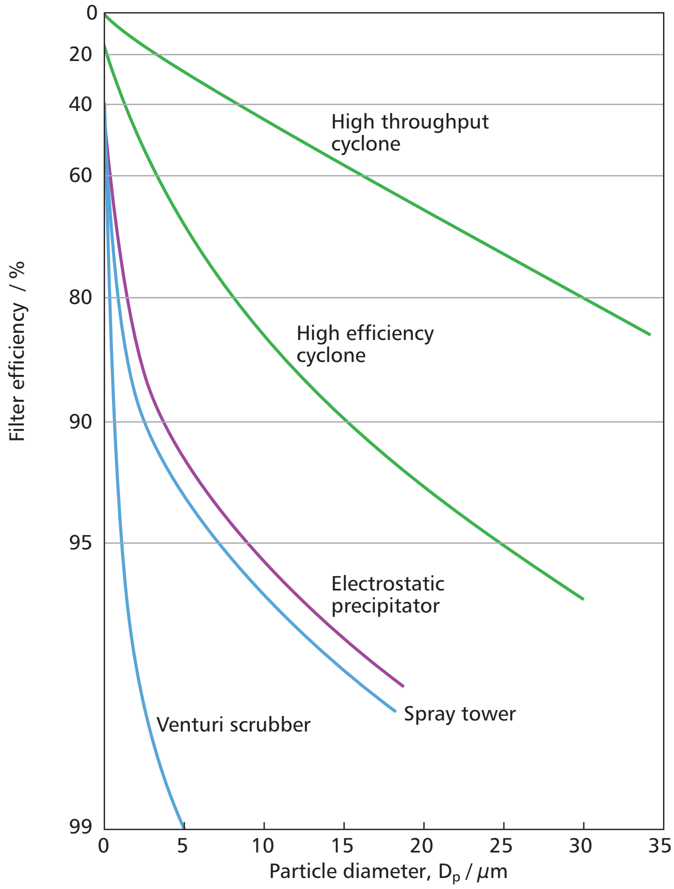


Figure 4.39 Collection efficiencies for various particulate control technologies

A wet scrubber or a filter with permanently wetted surfaces must be used when tar is present in the flue gas, but these technologies are too expensive for use in the smaller scale systems covered by this Applications Manual. A different range of technologies is required to remove NO_x and other gases from the flue gas stream.

4.6.1.1 Cyclone grit arrestors

Boilers rated at less than 300 kW are not usually fitted with any form of post-combustion particle arrestment, while the primary abatement plant on boilers greater than this size will usually take the form of a cyclone grit arrestor for larger non-sticky (tar-free) particles, and multi-cyclones for the removal of much smaller particles down to 5 μm. The cyclone takes the form of a chamber in which the particulate and flue gas mix is spun at high velocity, the resulting centrifugal forces throwing the particulates onto the cyclone walls from where they drop to the bottom for collection and removal. The removal of particulate matter smaller than 10 μm microns using cyclones is about 80% efficient, while cyclone efficiency drops off rapidly as the particle size decreases. Multi-cyclones can achieve 90% efficient at particle sizes down to 5 μm. On boilers with an integral cyclone a single ash bin may be used to collect the cyclone fly ash and firebed bottom ash.

Figure 4.40 Cyclone grit arrestor

4.6.1.2 Bag filters

In a bag filter particle-laden gases are forced through filter bags and then removed from the bags by gravity. Initially, particles collect on the bag fibres and then accumulate on previously collected particles, bridging the fibres. Gradually the collected particles form a layer of dust cake that acts as a packed bed filter for further particles, and simultaneously the pressure drop increases across the filter to the point where it becomes too great to allow sufficient gas flow. The dust must be then removed into the hopper at the bottom by shaking, pulse jet cleaning or gas flow reversal.

Bag filters can achieve very high collection efficiencies for a wide variety of very small particles, can operate over a wide range of volumetric flow rates and produce moderate pressure drops; efficiencies of 99% are possible for particles down to 1 μm. However, they must be operated at temperatures lower than that at which the fabric is destroyed, must not be used where gas or particle constituents may attack the fabric or prevent proper cleaning, such as tars.

The selection of filter materials to withstand the high temperature of biomass flue gases is a critical consideration. A popular material is P84 polyimide fibre as it has a continuous working temperature of 260 °C, has a high chemical resistance, and is also resistant to abrasion. Fine stainless steel mesh with a stronger stainless steel supporting frame is also used to achieve a longer working life. High temperature synthetic material filters can be up to 99.9% efficient over a particle size range of 0.05 μm to 5 μm. The presence of water vapour in biomass flue gases creates a potential condensation problem which can cause blinding of the filter media, and some filter manufacturers provide electric pre-heaters to heat the filter material prior to introducing the flue gases.

4.6.1.3 Ceramic filters

A filtration system recently introduced to the UK comprises ceramic cylinders closed at one end through which flue gases pass from inside to outside as shown in Figure 4.41. Ceramic filters can operate at temperatures up to 250 °C and can remove up to 96% of particulates down to 2.5 μm. The introduction of biomass boilers into Air Quality Management Areas (AQMA) will require the use of technologies such as ceramic filtration if particulate emissions have been included in the declaration of the AQMA concerned.

Figure 4.41 Ceramic filter unit showing filter elements (inset)

4.6.1.4 Electrostatic filters

Electrostatic filters can operate at 99% efficiency at particle sizes of 1 μm and above. Particulates are electrically charged and then separated from the gas stream in an electrostatic field to an electrode. The electrode is cleaned periodically by vibration causing the dust to drop into a collection unit below. Electrostatic filters for biomass boiler applications can operate at temperatures up to a maximum of 250 °C and are particularly suitable for high flue gas flow rates. However, they are sensitive to variable particulate loading and variable flue gas flow rates while being physically large relative to a biomass boiler. They are usually found only on larger installations.

4.6.2 Gas control technologies – removal of NO_x

The primary method of NO_x control in biomass boilers up to 5 MW is through combustion optimisation to minimise the amount of NO_x emitted in the flue gases as described in Section 4.5.3.4. Maintaining low NO_x levels depends heavily on combustion optimisation and the use of fuel at the correct moisture content. Fuel which is wetter than the boiler is designed or set-up to handle will result in both higher NO_x and higher PM levels. NO_x also undergoes atmospheric transformations leading to or contributing to the formation of additional PM. Further NO_x reduction is extremely difficult and expensive requiring the use of selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR), neither of which works efficiently at the low flue gas temperatures present in biomass boilers. Hence, neither SCR nor SNCR should be considered suitable post-combustion cleaning technologies for biomass systems.

4.7 Log boiler systems

Log boilers are batch-fed systems which differ from automatic and manual ignition woodchip and wood pellets in some key areas. Log boilers must always be connected to an accumulator tank which has a minimum capacity of 50 litres of water per kW of boiler rating.

Figure 4.42 Cut-away of a large log boiler

All log boilers should be configured using the following simple hydronic arrangement up to the accumulator:

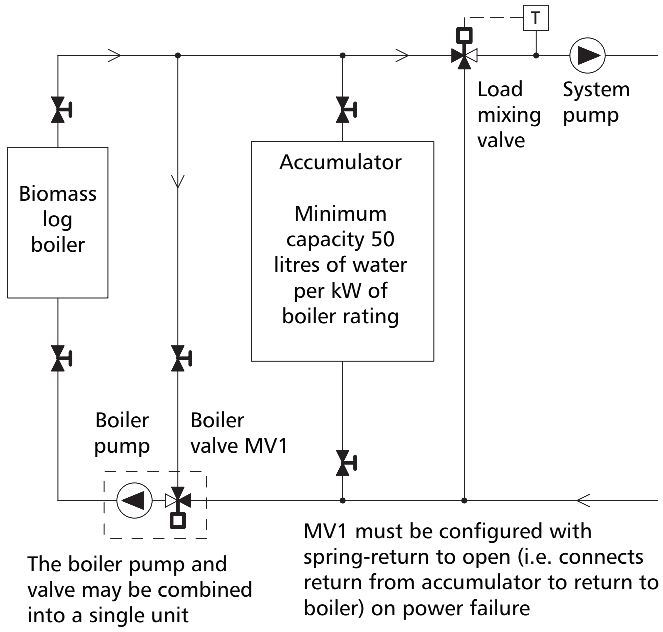


Figure 4.43 Typical log boiler configuration

The boiler back-end protection valve, MV1, and the boiler pump may be supplied as an integral unit which provides an automatic thermal bypass between the accumulator and boiler return in the event of electrical power failure. If the boiler pump and back-end valve are supplied as separate units, MV1 must default to a 'straight-through' configuration to connect the accumulator to the return on the boiler. This will allow gravity circulation between the boiler and accumulator to remove heat safely in the event of an electrical power failure.

Log boilers generally require fuel to be have a moisture content of <20% at the centre of the logs. Boilers which have passed emissions tests to meet RHI requirements may have passed only because fuel with a moisture content of <15% or less was used to enable the boiler to meet the emissions standards. In this case the user will be required to ensure that fuel has a moisture content no higher than that stated on the boiler test certificate to continue to receive RHI payments. As many log boiler operators will be self-suppliers under the 2014 RHI fuel quality regime, they will be required to maintain records of fuel moisture testing using a method approved by Ofgem. Fuel moisture content testing using a two-pronged moisture meter on the surface of a log will measure the moisture content in the surface layer only. Ofgem may require a sample of logs to be cut open and the moisture content measurement taken in the centre of the log to demonstrate that the fuel meets the RHI requirements.

Log boilers are particularly prone to tar formation in the combustion chamber, and to tars condensing in the flue. This usually results from burning fuel with a moisture content greater than that recommended by the boiler manufacturer. Where tars accumulate in the flue there is a high likelihood of a flue fire which can result in the destruction of the boiler system and boilerhouse. Another consequence of burning fuel which is too wet for the boiler is that the boiler efficiency can drop to 50% or less.

Health and safety considerations
Under no circumstances should fuel be burned with a moisture content greater than that recommended by the boiler manufacturer

4.8 Packaged boilerhouses

Containerised boilerhouses for commercial use have become popular for boiler <500 kW capacity, in particular in the size range up to 199 kW. The particular advantages of containerising a boilerhouse are:

- A complete biomass system can be constructed, tested and commissioned at a contractor's premises.
- The need for a permanent architect-designed boilerhouse is avoided.
- Preparatory works, including the provision of utility services, heating connections and concrete foundation is simplified.
- On-site installation is rapid and less dependent on weather.
- A containerised solution is usually less expensive than one requiring a separate boilerhouse and complete system build on site.
- Providing all aspects of the interface between the containerised system and works external to the container are clearly defined, contractual arrangements are simplified.

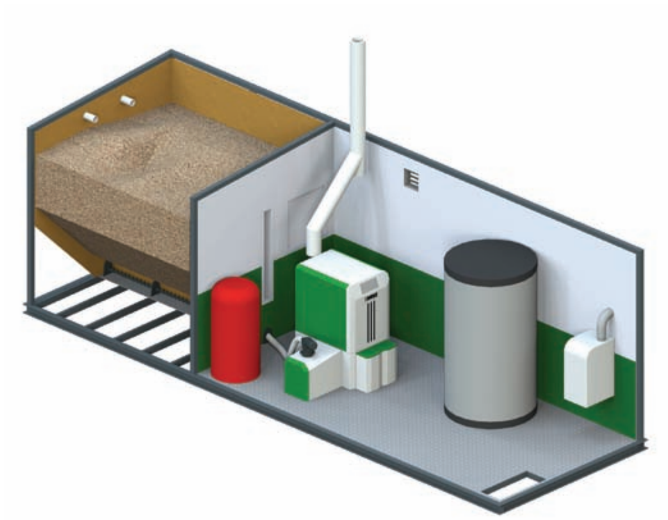


Figure 4.44 Cut-away 3-D drawing of a packaged wood pellet boilerhouse with 199 kW boiler

A standard road vehicle is 2.5 m wide and containerised systems can be road transported:

- To a width of 3 m without making any special arrangements.
- To a width of 3.5 m providing the police are notified.
- Wider than 3.5 m but less than 3.75 m with an escort and police notification.
- Wider than 3.75 m with a police escort.

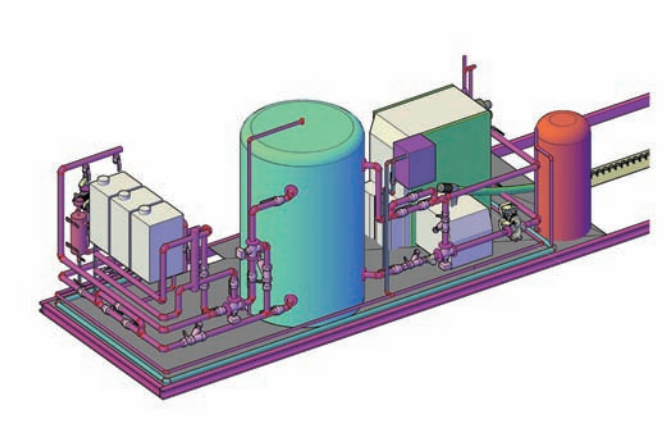


Figure 4.45 3-D pipe layout for a 199 kW biomass boiler and 3 × 120 kW LPG boilers

Figure 4.46 Packaged boilerhouse operating on woodchips (woodchip store on left)

4.9 Biomass hot air systems

There are two methods of producing hot air from biomass, in a modified wood burning boiler or in a dust burner.

4.9.1 Modified biomass boilers

A number of manufacturers supply adapted systems to produce hot air which can then be used directly or indirectly (via a heat exchanger) to provide space or process heating. Some systems use grates which can accept a range of fuel types and fuel moisture contents while others are designed to burn fine materials at moisture contents up to 15%. Systems start at 200 kW and range up to 20 MW.

System control is akin to biomass boilers where the fuel feed rate is adjusted to match the load demand based on load sensing.

4.9.2 Biomass dust burners

Biomass dust burners are designed to burn sawdust or other fine biomass material in a dust burner comprising dust fed through a nozzle at high pressure surrounded by several concentric rings of combustion air also at pressure. A flame of up to 10 m is produced from particles of up to 1 mm diameter. Systems are available from 500 kW up to 150 MW. While a heat exchanger can be used to convert it to an indirect system, many industrial and agricultural hot air requirements can be meet by a direct dust burning system.

System control is by modulating the dust stream into the burner nozzle where load sensing can be used to provide the control signal.

As with all dust handling, system design must take account of the hazards associated with dust storage and handling. Flash detection will be required on the fuel feed system and explosion relief panels on storage silos.

4.10 Small-scale biomass CHP systems

Electricity generation using Stirling engines running on hot gas from biomass burners have been under development for some time in the UK and Europe. The hot side of the Stirling engine is placed in the hot gas stream from a biomass burner with the cold side in ambient air. To date this technology has not been particularly successful because of fouling of the hot side heat exchanger surface. Should this problem subsequently be resolved this technology could offer biomass electricity generation at scales as low as 50 kW_e.

5 Designing with buffer vessels and thermal stores

5.1 Definition of terms

See also page 99 for a full glossary.

Automatic ignition boiler: An automatic ignition boiler is one in which an automatic ignition system fires each time the boiler starts-up, akin to the way in which fossil fuel boilers operate.

Auxiliary boiler: Used to make up the difference between the biomass system output and the peak load.

Back-end valve: A 3-port mixing valve in the hydronic circuit attached to the biomass boiler used to ensure a minimum return water temperature to the boiler at all times.

Back-up boiler: Used to provide 100% back-up to the biomass system.

Buffer vessel: Used to improve biomass system efficiency by capturing residual heat from a biomass boiler on shutdown, and to provide start and stop signals to automatic ignition boilers to ensure efficient and stable boiler operation

Building balance temperature: The temperature at which the sum of the casual gains equals the heat demand on a building.

Casual gains: Heat gains from people, lighting, equipment and insolation.

Initial ignition slumber boiler: Some slumber or kindling mode manual ignition boilers have an ignition system for the purpose of initiating combustion the first time the boiler is lit. Thereafter, the boiler remains lit going into slumber or kindling mode when the load falls below the minimum output of the boiler.

Load mixing valve: A 3-port valve on the outlet from a buffer vessel or thermal store which serves to minimise the draw from the buffer vessel or thermal store by supplying only the amount of hot water required to meet a load. A load mixing valve is essential on constant temperature circuits which contain hot water calorifiers or fan convectors where a diverting circuit circulates water at a constant flow rate to the load irrespective of heat demand. A load mixing valve also allows a biomass boiler in combination with a buffer vessel or thermal store to operate at a higher temperature than the load circuits, effectively increasing the thermal capacity of the buffer vessel or thermal store.

Peak pre-heat load density: The peak pre-heat load density = (peak heat load × heat-up allowance) / (the serviced area of the building).

Slumber or kindling mode: Biomass boilers which do not have automatic ignition systems modulate down to a slumber mode when the heat demand is below their minimum output. The minimum of fuel is fed onto the grate to keep the fire alight.

Thermal store: Used to enable a relatively small boiler to provide a large proportion of the annual energy demand from biomass. Typically a thermal store is much larger than a buffer vessel and often incorporates the functions of a buffer vessel within it. A thermal store also provides start and stop signals to automatic ignition boilers to ensure efficient and stable boiler operation.

Figure 5.1 Three 10 000 litre thermal stores on a 400 kW biomass system

Utilisation factor: the extent to which the installed plant is utilised is defined as:

$$\text{Utilisation factor} = \frac{\text{Hours per year full load equivalent operation}}{8760} \tag{5.1}$$

5.2 Systems with buffer vessels

Various terms are used interchangeably to describe water filled vessels connected to biomass boilers. In the context of this Applications Manual, ‘buffer vessel’ and ‘thermal store’ are the only terms used. A buffer vessel is used to improve biomass system efficiency by capturing residual heat from a biomass boiler on shutdown, while a thermal store is used to enable a relatively small boiler to provide a large proportion of the annual energy demand from biomass; both provide start and stop signals for automatic ignition boiler control systems. Typically, a thermal store is much larger than a buffer vessel and usually incorporates the functions of a buffer vessel within it. Unfortunately, the important distinction between these two terms is often blurred, with the term buffer vessel frequently being used to describe any form of water vessel attached to a biomass boiler. The term ‘accumulator tank’ is sometimes used for both ‘buffer vessel’ and ‘thermal store’, especially in relation to log burning systems: the term ‘accumulator tank’ is not used in this Applications Manual. Table 5.2 on page 57 compares the different features of buffer vessels and thermal stores.

Buffer vessels:

— Are usually 2-port devices across the flow and return from the biomass boiler.

— Dissipate heat from a biomass boiler on shutdown.

— Prevent water boiling in a biomass boiler on shutdown.

— Prevent the connected heating system from going over-temperature/over-pressure.

— Improve biomass boiler efficiency by capturing heat which would otherwise be lost by radiation from the boiler and convection up the flue.

— Provide some heat to supply the load as the biomass boiler heats up.

— Increase the return temperature to the biomass boiler when a very low load return temperature is present. Return temperature control is covered in detail in Section 8.1.1.2.

5.2.1 Automatic ignition boiler operation with a buffer vessel

Figures 5.2 to 5.8 show the sequence of operation from boiler start-up to boiler shutdown for an automatic ignition boiler when a 2-port buffer vessel is connected across the boiler[3].

Figure 5.2 shows the cold system before start-up.

The biomass boiler heats up to minimum return temperature plus the boiler differential temperature, Figure 5.3. The biomass boiler heats up until the minimum return temperature as seen at the boiler return is achieved. At this point the flow temperature from the biomass boiler will be the minimum return temperature plus the temperature differential set on the boiler control panel. For example, if the minimum return temperature is 65 °C and the boiler differential is set to 10 °C the boiler flow temperature will be 75 °C.

Once the boiler's minimum return temperature has been exceeded, the back-end valve begins to open and the buffer vessel begins to charge to the boiler minimum return temperature plus boiler differential, Figure 5.4. Once the buffer vessel has charged fully to 75 °C water returns to the boiler at this temperature and the boiler flow temperature becomes 85 °C, while the buffer vessel sits at 75 °C.

Once the biomass boiler has reached operating temperature (in this example 85 °C) a demand from the load circuits can be serviced, the load mixing valve opens sufficiently to satisfy the load and the system pump operates, Figure 5.5. If the biomass boiler operates at a temperature greater than that required for the load, the load mixing valve opens proportionately to achieve the desired load circuit temperature.

When there is no longer a load demand the load mixing valve is in the fully recirculating position and the boiler discharges its residual heat into the buffer vessel, Figure 5.6. For as long as the biomass boiler is enabled it remains online, firing intermittently for brief periods to maintain its flow temperature. It is usual practice for an automatic ignition boiler to remain enabled throughout the heating season, although most automatic ignition boilers cool down when there is no demand, typically overnight. However, once the biomass boiler has been disabled it discharges any further residual heat into the buffer vessel when it cools down, Figure 5.7.

On the next demand for heat if the biomass boiler is cold, and if there is residual heat in the buffer vessel, the buffer vessel will discharge into the load while the system pump switches on and the boiler heats up, Figure 5.8. However, as buffer vessels are devices with a low thermal capacity it is common for the buffer vessel to be fully discharged before the biomass boiler has reached operating temperature.

On the next demand for heat the cycle commences again from Figure 5.5.

5.2.2 System pump sizing and control

A biomass boiler configured with a buffer vessel is unable to meet a load greater than the output of the boiler. If the system pump was to be sized for a duty greater than the biomass boiler output, once the buffer vessel has been depleted flow temperature dilution will occur. The buffer vessel would fill with water at system return temperature and cooler water from the buffer vessel would mix with the flow from the biomass boiler resulting in a reduced system flow temperature.

When using a biomass boiler and buffer vessel configuration, either the biomass boiler must be sized to provide 100% of the load (a practice not advocated in this Applications Manual) or an auxiliary, usually fossil fuel, boiler is required to meet loads greater than can be supplied by the biomass boiler alone.

5.2.3 Automatic ignition boiler start from cold

When starting an automatic ignition biomass boiler from cold[4], the boiler should be started sufficiently ahead of a load demand so that the buffer vessel is not fully depleted before the back-end valve opens to allow the biomass boiler to supply the load. If the buffer vessel is depleted before the boiler is fully online, either the flow temperature will be depleted or an auxiliary, usually fossil fuelled, boiler will need to meet the load demand. This is a common cause of excessive fossil fuel consumption on hybrid systems where the biomass boiler is disabled at the end of each heating period. The pre-heat time required for the biomass boiler prior to the first load demand of the day will depend on the boiler's thermal response, which is itself a function of the mass of ceramic lining and water content of the biomass boiler. Should it not be possible to arrange for an automatic control system to start the biomass boiler sufficiently ahead

[3] The sequence of operation for a boiler operating in slumber mode is as described in this section except that the boiler remains alight and at operating temperature at all times. It does not cool down until manually switched off.

[4] On a load system with a heat demand profile during the working day only, typically an automatic ignition boiler starts from cold once a day, the buffer vessel having retained its heat overnight.

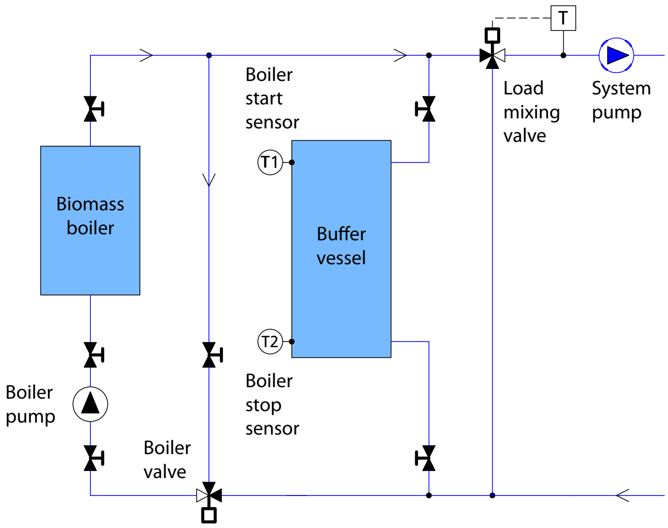


Figure 5.2 System cold

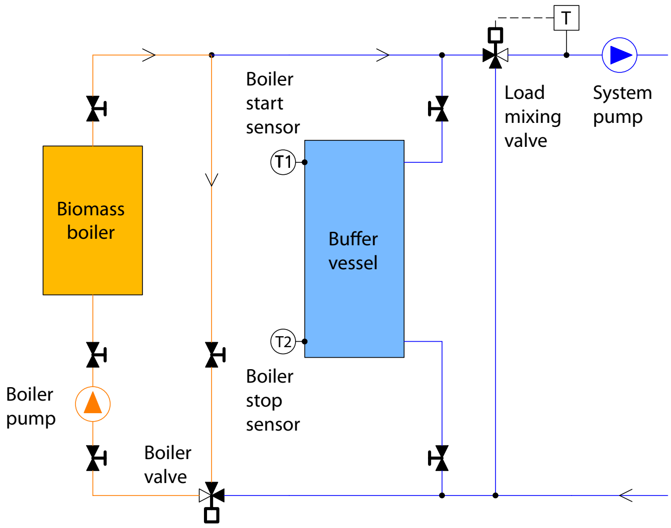


Figure 5.3 Biomass boiler heats to minimum return temperature

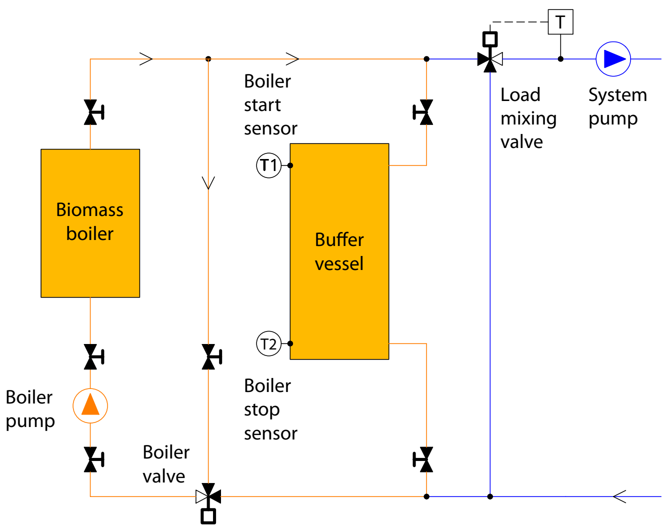


Figure 5.4 Buffer vessel heats to minimum return temperature

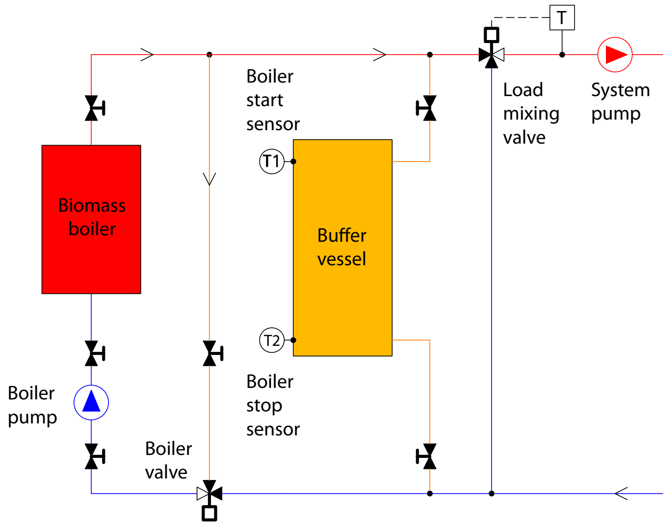


Figure 5.5 Biomass boiler heats to operating temperature

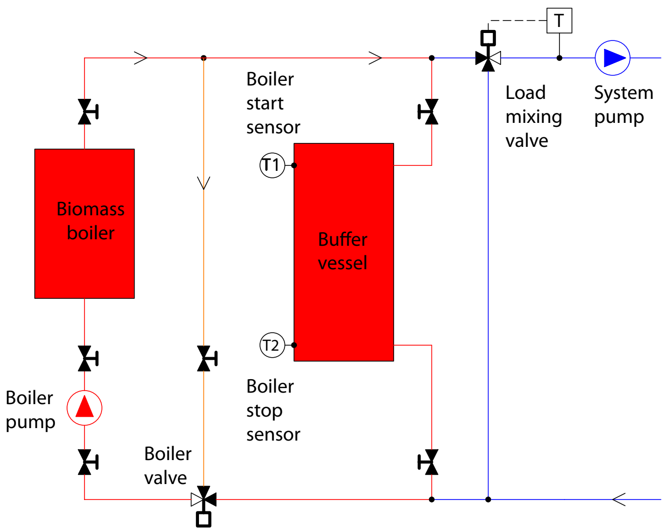


Figure 5.6 System satisfies load

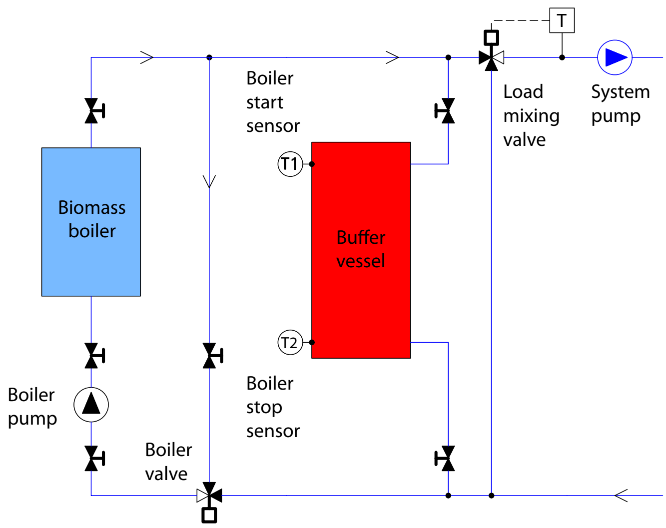


Figure 5.7 Boiler discharges residual heat into buffer vessel

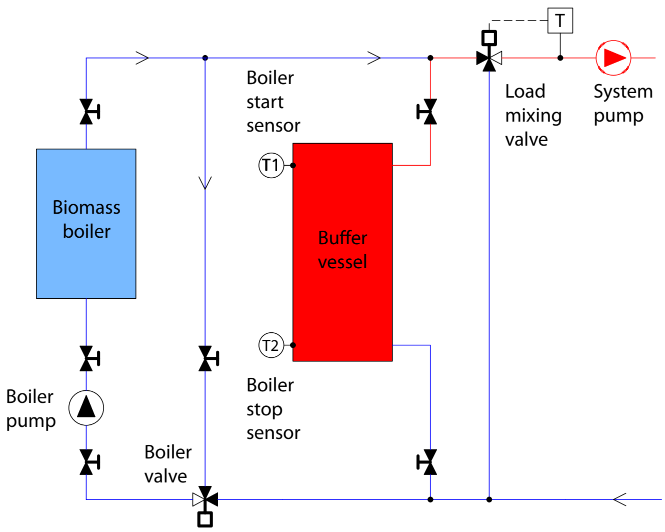


Figure 5.8 Buffer vessel retains heat to help meet next load demand

of the load demand then it is necessary to increase the size of the buffer vessel, or use a thermal store.

In buildings controlled by a building management system (BMS) using optimum start, it is normally possible for the BMS to send a start signal to the biomass boiler sufficiently ahead of the optimum start time that the biomass boiler is up to temperature to deliver heat by the time the optimum start brings on the load circuits.

5.2.4 Buffer vessel sizing

The majority of manufacturers of automatic ignition biomass boilers require the use of a buffer vessel, with the manufacturer specifying the minimum size of buffer vessel required to absorb excess heat on boiler shutdown. The capacity ratio required for a buffer vessel, measured in litres per kW of biomass boiler rating, is dependent on many factors:

— The type of biomass boiler grate, e.g. underfed stoker, moving grate or stoker burner, which determines the fuel load on the grate.

— Whether the biomass boiler is an automatic ignition boiler or one which operates in slumber mode.

— The fuel load on the grate to be burned off prior to biomass boiler shutdown or entering slumber mode.

— Whether a feed auger needs to be emptied onto the grate and the fuel burned off prior to biomass boiler shutdown.

— The mass of ceramic lining from which heat has to be removed prior to biomass boiler shutdown.

— The type of fuel being burned.

— The temperature difference across the buffer vessel.

— The time to reach operating temperature on automatic ignition biomass boilers.

Rules of thumb should not be used for sizing buffer vessels as capacity ratios vary considerably depending on the particular combination of the above factors. However, some typical capacity ratios for a temperature difference of 20 °C are:

— Underfed stoker boiler burning woodchips: 5–10 l/kW

— Underfed stoker boiler burning pellets: 10–15 l/kW

— Moving grate boiler burning woodchips: 20–40 l/kW

— Moving grate boiler burning pellets: 30–60 l/kW

— Stoker burner boiler: 10–15 l/kW

A set of equations was developed for calculating buffer vessel sizes for a wide range of boiler types as part of the development of the *Biomass Decision Support Tool* (Carbon Trust, 2013). These enable buffer vessel sizes to be calculated for any biomass boiler ΔT (see Table 5.1).

For guidance on the appropriate level of refractory lining refer to Chapter 4.5.1.

5.3 Systems with thermal stores

The reader should read the introduction to Section 5.2 and refer to Table 5.2 for a comparison of buffer vessels and thermal stores. The use of thermal stores is strongly recommended. Thermal stores:

— Allow biomass boilers to operate continuously for long periods.

— Improve the operating efficiency and utilisation factor of biomass boilers.

— Can incorporate a buffer vessel at the bottom of a thermal store if the biomass boiler 'stop' temperature sensor is appropriately positioned.

— Enable a biomass boiler to be reduced in size while meeting up to 100% of the load from biomass at external temperatures down to the design winter temperature.

— May be 2-port or 4-port devices connected in specific hydronic configurations.

5.3.1 Automatic ignition boiler operation with a 4-port thermal store

Figures 5.9 to 5.13 show the sequence of operation from boiler start-up to boiler shutdown when a 4-port thermal store is connected across the biomass boiler.

Figure 5.9 shows a cold system before start-up.

The biomass boiler heats up to minimum return temperature, Figure 5.10.

The back-end valve opens and the thermal store charges to operating temperature. Depending on the minimum return temperature and biomass boiler temperature differential, the thermal store may heat up in cycles until the hot interface at the design flow temperature reaches temperature sensor T2. This leaves the lower part of the storage vessel available as a buffer vessel sitting at the boiler return temperature, Figure 5.11.

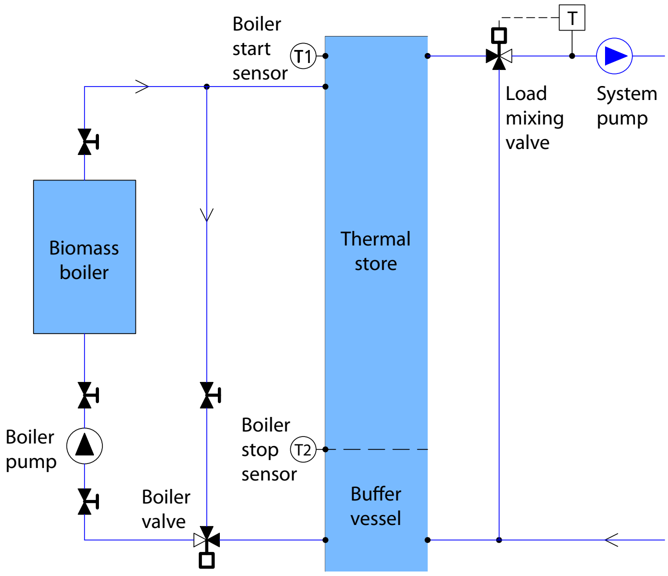


Figure 5.9 System cold

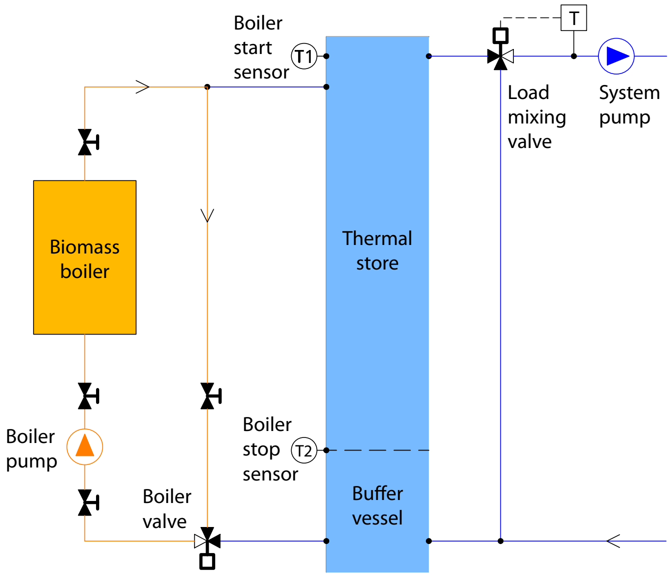


Figure 5.10 Biomass boiler heats to minimum return temperature

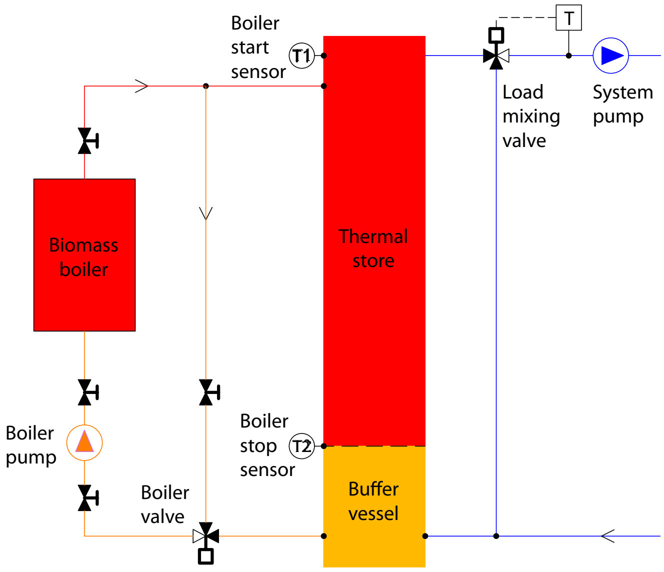


Figure 5.11 Thermal store heats to minimum return temperature

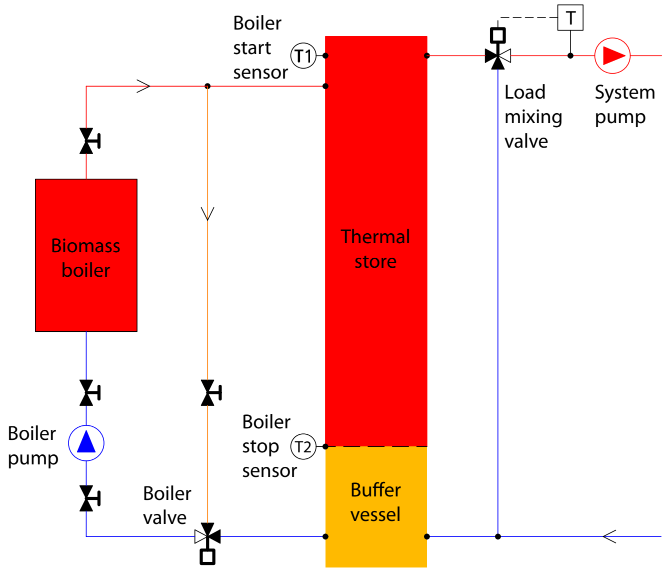


Figure 5.12 Biomass boiler heats to operating temperature

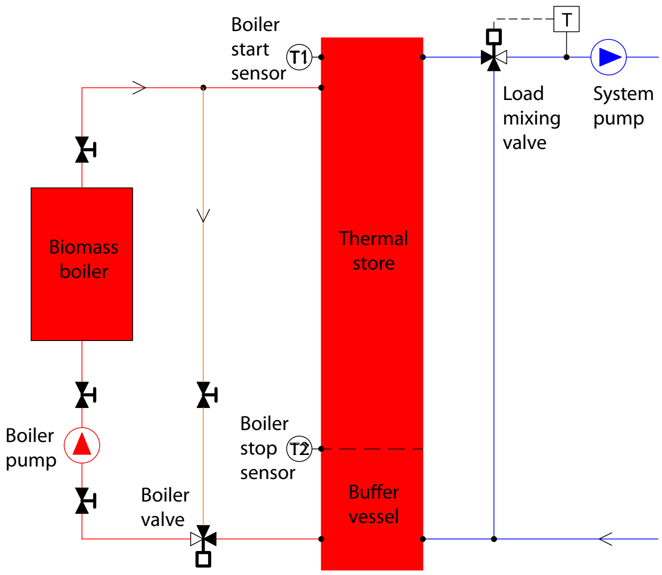


Figure 5.13 System satisfies load

Table 5.1 Formulae for calculating buffer vessel sizes for automatic ignition boilers

Fuel	Boiler type	Fuel feed mechanism	Refractory lining	Buffer vessel formula (l/kW)	Turndown ratio
Woodchips	Stoker burner	Auger	Low	$V = 89.17\Delta T^{1.0031}$	3.5:1
	Stoker burner	Auger	High	$V = 120.4\Delta T^{1.0015}$	3:1
	Moving grate	Auger	Low	$V = 202.19\Delta T^{0.9982}$	3:1
	Moving grate	Auger	High	$V = 371.06\Delta T^{1.0011}$	2.5:1
	Moving grate	Ram stoker	Low	$V = 158.27\Delta T^{0.997}$	3:1
	Moving grate	Ram stoker	High	$V = 374.1\Delta T^{1.0009}$	2.5:1
	Underfed stoker	Auger	Low	$V = 57.946\Delta T^{1.006}$	3.5:1
	Underfed stoker	Auger	High	$V = 89.17\Delta T^{1.0031}$	3:1
Pellets	Stoker burner	Auger	Low	$V = 223.46\Delta T^{0.9989}$	4:1
	Stoker burner	Auger	High	$V = 255.64\Delta T^{1.0002}$	3.5:1
	Moving grate	Auger	Low	$V = 249.53\Delta T^{1.001}$	3:1
	Moving grate	Auger	High	$V = 463.45\Delta T^{1.0003}$	2.5:1
	Moving grate	Ram stoker	Low	$V = 124.62\Delta T^{0.9991}$	3:1
	Moving grate	Ram stoker	High	$V = 338.1\Delta T^{0.9989}$	2.5:1
	Underfed stoker	Auger	Low	$V = 57.946\Delta T^{1.006}$	3.5:1
	Underfed stoker	Auger	High	$V = 130.27\Delta T^{0.9955}$	3:1

On a demand from the load the system pump switches on, the load mixing valve opens and modulates to meet the load from the thermal store plus biomass boiler, Figure 5.12.

Once the load is satisfied the system pump switches off, the load mixing valve closes and the biomass boiler discharges residual heat into the buffer vessel portion of the thermal store[5], Figure 5.13.

5.3.2 Automatic ignition boiler operation with a 2-port thermal store

Biomass operation with a 2-port thermal store has the features of operating with a 2-port buffer vessel plus some of those of a 4-port thermal store. A particular advantage of using a 2-port thermal store is that, unlike a 4-port store, there is no flow through the thermal store when the load is less than the biomass boiler output if the boiler valve is fully open and the flowrate of the system pump is the same as that of the boiler pump. In all other situations if the biomass boiler is running and the load is less than the biomass boiler output, then with a constant speed boiler pump there will be flow down in the store. With a load greater than the biomass boiler output there will be flow up the store. Hence, there is a similar potential for de-stratification resulting from turbulence as in a 4-port thermal store.

The disadvantage of using a 2-port thermal store is that there is limited hydronic separation between the biomass boiler and the load circuit, with interaction between the biomass boiler pump and system pump. Once the thermal store is depleted the system pump must be slowed down to match the biomass boiler output.

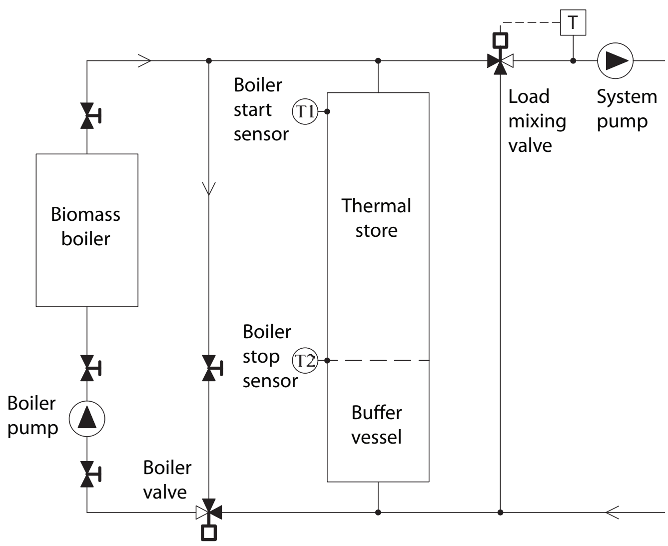


Figure 5.14 Biomass boiler with 2-port thermal store

The only differences between a biomass boiler with a buffer vessel and one with a 2-port thermal store are the much larger capacity of the vessel and the position of temperature sensor T2 to prevent the biomass boiler filling the vessel completely with water at flow temperature, Figure 5.14.

5.3.3 System pump sizing and control

In order to meet system loads which are greater than the biomass boiler output, the system pump will need to run at a speed to match the full load whenever the load demand is greater than the biomass boiler output, i.e. when there is a net discharge from the thermal store. However, once the thermal store is depleted, as sensed by temperature sensor T1, the draw from the thermal store will need to be reduced so that there is no net discharge from it. To achieve this

[5] Depending on whether the biomass boiler is an automatic ignition or slumber mode boiler, the boiler will either switch off and cool down until the next demand for heat or will enter slumber mode remaining at operating temperature. Biomass boilers operating in slumber mode are covered in Section 4.3.3.

either the system pump speed will need to be reduced to match the biomass boiler output, which requires the use of a variable speed pump, or the load mixing valve will need to be controlled appropriately to ensure the temperature as measured by sensor T1 does not continue to reduce. While the turndown ratio of a variable speed pump is typically 5:1, and can be up to 10:1, the turndown ratio of a load mixing valve can be up to 50:1. The use of a variable speed pump in this position should be seen as an energy efficiency measure while the load mixing valve is required to ensure good flow temperature control and to minimise depletion of the thermal store. Good practice is to use both a variable speed pump and a load mixing valve.

5.3.4 Initial ignition slumber boiler operation with a 4-port thermal store

Figures 5.15 to 5.19 overleaf show the sequence of operation from biomass boiler start-up to its entering slumber mode when a 4-port thermal store is connected across an initial ignition slumber biomass boiler. Figure 5.15 shows the cold system.

The biomass boiler heats up to minimum return temperature, Figure 5.16.

The back-end valve opens and the thermal store charges to operating temperature, but in this case there is no need for buffer vessel provision at the bottom of the thermal store. Only a small portion at the bottom of the thermal store is at return water temperature, Figure 5.17.

With a load demand from the system the system pump switches on, the load mixing valve opens and the load is met from thermal store plus biomass boiler, Figure 5.18.

Once the system load drops below the biomass boiler minimum output, and the biomass boiler has charged the thermal store fully, the biomass boiler enters slumber mode, Figure 5.19.

When an initial ignition slumber boiler enters slumber mode a small amount of fuel is fed onto the grate to keep the fire alight. The amount of fuel required depends on the fuel moisture content and the size of the biomass boiler. For a dry fuel such as wood pellets the slumber mode fuel consumption can be as low as 0.5% of the consumption at peak load for a large biomass boiler, and for woodchips at 35% moisture content the slumber mode fuel consumption can be 2% or more of the peak load consumption. However, for any biomass boiler there is a minimum amount of fuel required on the grate to keep the fire alive and for smaller boilers the slumber mode fuel consumption increases inversely with the boiler size. The slumber mode fuel consumption can be 5% or more of the peak load consumption on boilers rated at less than 100 kW. Hence, whenever possible, a small boiler should be an automatic ignition boiler. This can be seen in the current European trend towards the automation of boilers up to 500 kW because of the low net efficiency, typically 65%, of small initial ignition slumber boilers.

Depending on whether or not the heat generated in slumber mode can be dissipated within the boiler, the boiler pump may switch on and the boiler valve open at regular intervals to dissipate heat into the thermal store or external circuit. This is more likely to occur if fuels at up to 35% moisture content are being burned, and the designer needs to ensure there is always a load into which such heat can be dissipated. Whether or not the boiler pump remains on during slumber mode is manufacturer dependent, and this must be considered when selecting a particular make of biomass boiler.

5.4 Systems with neither a buffer vessel nor a thermal store

Some boiler manufacturers offer boilers which are promoted as not requiring a buffer vessel. In practice there is always a small buffering requirement, typically 1–2 l/kW of boiler rating, which can often be met by the water volume in the connected load circuits. However, this passes the requirement for ensuring an adequate buffering capacity to the designer of the load system, or to the existing load circuits. Great care must be exercised to ensure that both an adequate water volume is always available under all operating conditions, and that an adequate minimum temperature differential is presented to the boiler by the load circuits at all times.

When designing a system with neither a buffer vessel nor thermal store, in depth consideration must be given to the control of auxiliary or back-up boilers. The absence of either a buffer vessel or thermal store means that the facility to control auxiliary or back-up boilers using a temperature sensor on the vessel is not available, making control of such boilers problematic. While it is possible to initiate operation of a fossil fuel boiler based on the depression of the flow temperature below a setpoint, it is much more difficult to ensure that boiler ceases to fire when no longer required to meet the load.

5.5 Stratification and temperature difference across buffer vessels and thermal stores

Thermal storage vessels, whether buffer vessels or thermal stores, should be designed for stratified operation. Unless they are of very large diameter, a vertical vessel is required to achieve good stratification. Fully mixed stores, e.g. typical hot water calorifiers, are heated from the bottom causing mixing of water with the result that the top of the store may not reach maximum temperature until it is charged to capacity; such fully mixed stores are not appropriate for biomass systems. The design intent with a stratified store is to ensure that water at the design temperature is available at the top of the store at all times by charging from the top using a low velocity (non-mixing) inlet, and with the hot-cold interface moving down the store as it charges. Figure 5.20 shows a net charge into the thermal store.

The heat storage capacity of a thermal store is a linear function of the temperature difference across the store and its volume:

$$E = m c_p \Delta T \div 3600 \tag{5.2}$$

where E is energy (kW·h), m is water content (kg), c_p is specific heat of water (4.2 kJ·kg^{-1}·K^{-1}) and ΔT is the temperature difference across the thermal store (K).

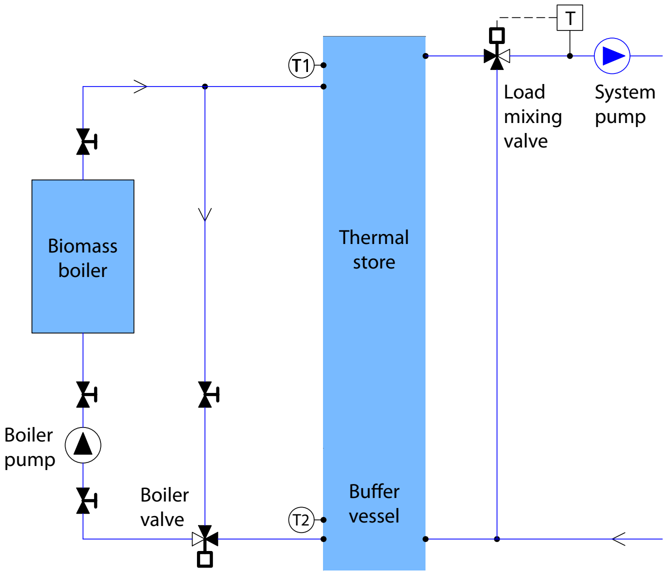


Figure 5.15 System cold

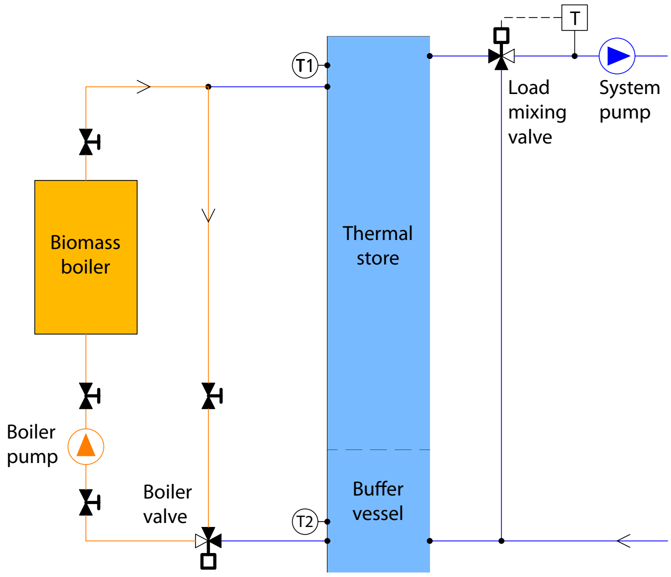


Figure 5.16 Biomass boiler heats to minimum return temperature

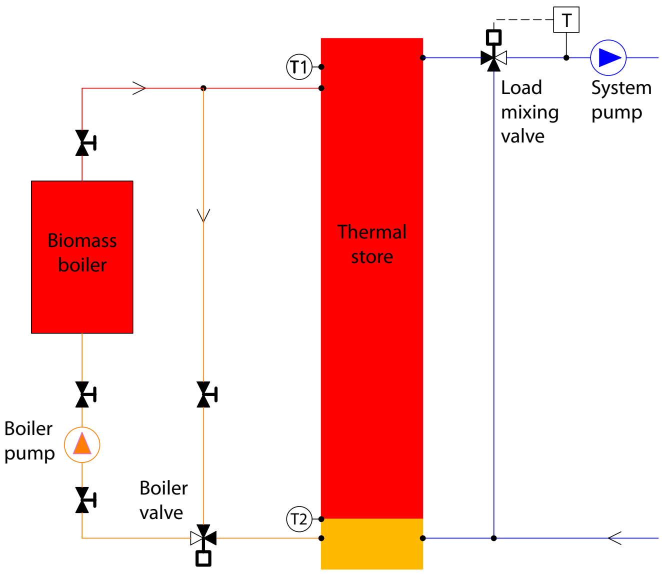


Figure 5.17 Biomass boiler charges thermal store to operating temperature

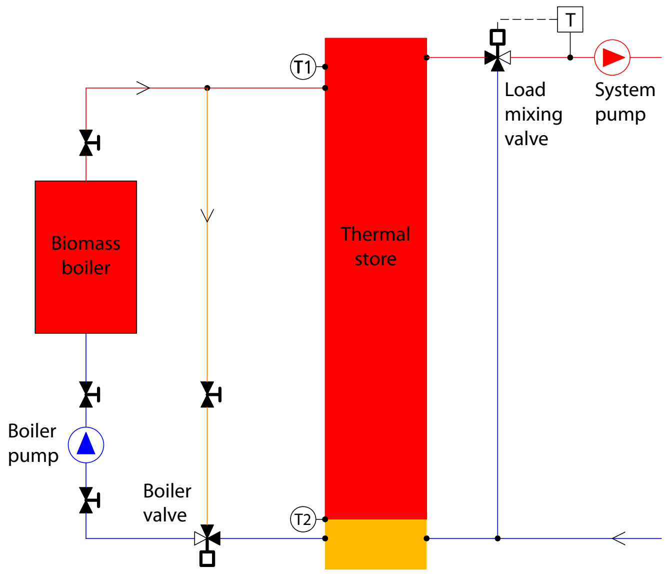


Figure 5.18 System satisfies load

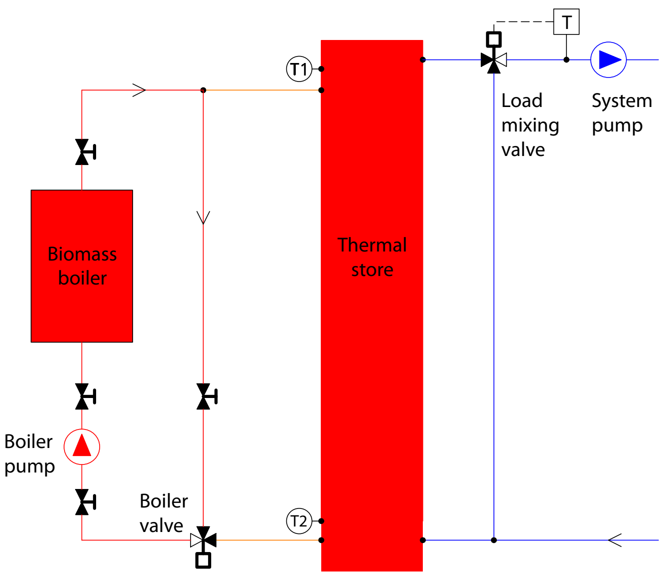


Figure 5.19 Biomass boiler discharges residual heat into thermal store

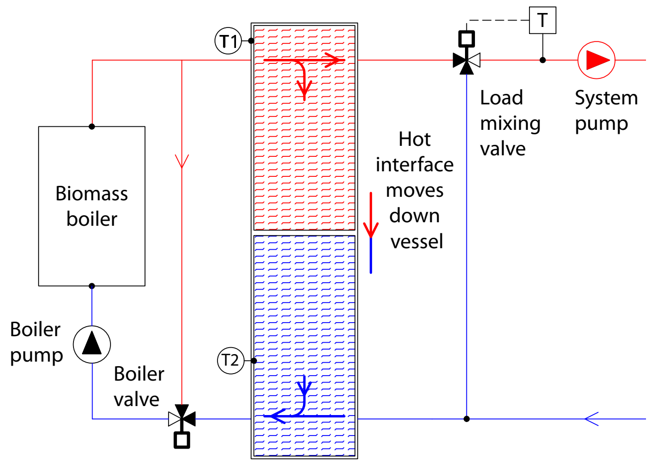


Figure 5.20 Stratified thermal store showing movement of hot-cold interface

Operating the thermal store at the highest possible temperature will minimise the size of store required and, importantly, minimise the capital cost of the storage and of the building to house it. The maintenance of stratification is crucial to the performance of a biomass boiler/thermal store combination. To achieve this, and to mix the flow water down to the desired load flow temperature, a 3-port load mixing valve is required on the outlet from the store to minimise the circulation through the store at low loads. This valve can be controlled by a temperature sensor on the flow line to the load as shown in Figure 5.21.

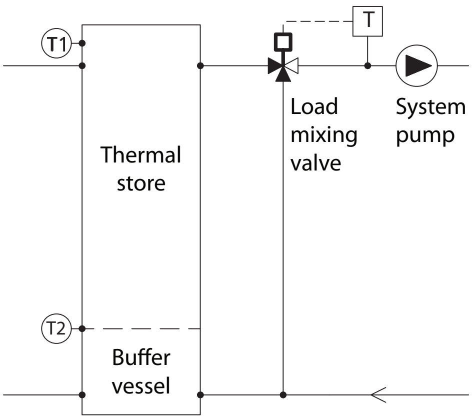


Figure 5.21 Load mixing valve

5.5.1 Thermal store water inlet design

To minimise turbulence and, hence, mixing within the thermal store, the velocity and distribution of water entering either as hot flow from the biomass boiler or cold return from the load circuits must be controlled. Inlets must be designed to minimise turbulence and this can be achieved by sparge pipes, which distribute water horizontally across the store, or by expanding inlets which direct water into the domes at the top and bottom of the thermal store. Low injection velocities can be achieved by either method.

5.5.2 Heat losses

Thermal stores require proportionately more insulation than hot water calorifiers to ensure that a store fully charged at the end of one day still has most of its energy available at the beginning of the following day, or week. Heat losses should be calculated during the design process so that an appropriate level of insulation can be specified; it is not sufficient to leave the selection of insulation thickness to the thermal store manufacturer. The insulation thickness on external stores will need to be greater than that for internal stores to achieve the same heat loss primarily because of lower external temperatures. In all cases a low emissivity outer layer is required to minimise the radiative heat loss. The significant level of insulation required on external stores means that the outside surface heat transfer coefficient makes a very small contribution to the overall heat loss irrespective of the wind speed.

The heat loss from a thermal store may be calculated using:

$$Q_{loss} = \lambda \cdot A \cdot \left(\frac{T_{in} - T_{out}}{r_{out} \cdot ln\left({r_{out}}/{r_{in}} \right)} \right) \qquad (5.3)$$

where

Q_{loss} = the heat loss of the thermal store (W)

λ = the thermal conductivity of the insulation material ($W \cdot m^{-1} \cdot K^{-1}$)

A = the total surface area of thermal store (m^2)

T_{in} = the mean water temperature in the thermal store (°C)

T_{out} = the outside ambient air temperature (°C)

r_{out} = the outside radius of thermal store, including insulation (m)

r_{in} = the radius of uninsulated thermal store (m).

5.5.3 Space requirements

The space required for thermal storage can be minimised, and the stratification maximised, by designing thermal stores which are as tall and thin as possible. Thermal stores can be connected in series to achieve the effect of one very tall but narrow store. A crucial trade-off is that between the capital cost of a biomass boiler and thermal storage against the annual percentage of energy obtainable from biomass. While a range of possible combinations of boiler and thermal store will exist for any given load pattern as discussed in Section 6.2, providing the temperature drop across a store is as large as possible (it must be greater than the usual 11 °C) it is generally more economical to install larger thermal storage than to increase boiler capacity; however, the additional cost of a building to house thermal storage must be taken into account.

5.5.4 Combined buffer vessel and thermal store

When using a thermal store with a biomass boiler which also requires a buffer vessel, the minimum buffer vessel volume must be added to the thermal storage volume desired. The buffer vessel portion of the combined store must be held at the boiler return temperature in order that it is available for use as a buffer vessel. This can be achieved by positioning the boiler 'stop' temperature sensor at a point above the buffer vessel as previously shown in Figures 5.9 to 5.13.

5.6 Positioning of temperature sensors on buffer vessels and thermal stores

The control scheme for the biomass boiler must be taken into account when deciding on the position of temperature sensors on both buffer vessels and thermal stores. Two control schemes are common, simple on-off boiler control using two temperature sensors, or proportional control of boiler modulation achieved through multiple temperature sensors. Figures 5.2 to 5.19, covering both buffer vessels and thermal stores, show typical positions for the start sensors (T1) and stop sensors (T2) for on-off control while Figure 5.22 shows sensor positions for proportional control of a biomass boiler from a thermal store. Using this control scheme the biomass boiler fires at minimum output when the cold interface rises past sensor T5 and, as the cold interface moves up past each of the sensors in turn, the boiler firing modulates until full output is demanded by sensor T1.

Figure 5.22 shows a biomass boiler controlled by 5 temperature sensors, although the actual number of sensors required varies between biomass boiler manufacturers.

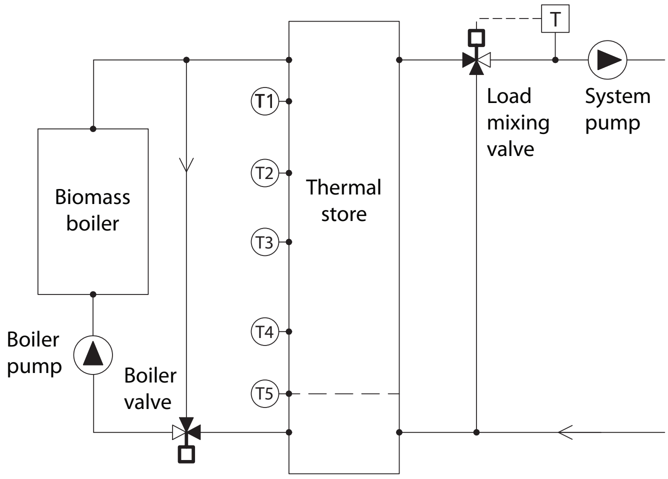


Figure 5.22 Thermal store with multiple boiler temperature control sensors

5.6.1 Positioning the upper (start) sensor for 2-sensor control on buffer vessels and thermal stores

The position of the upper sensor, T1, to start the biomass boiler depends on the boiler's ignition type (automatic ignition or initial ignition), the time it takes for the boiler to reach operating temperature and the rate of depletion of the buffer vessel or thermal store at maximum load.

Assuming the boiler has previously been started from cold as described in Section 5.2, the time for the boiler to reach operating temperature, and hence the position of sensor T1, for both 2-sensor and proportional control systems, will depend on whether the boiler is of the automatic or initial ignition slumber type. Initial ignition boilers respond quickly to changes in load so T1 can be positioned nearer to the top of the buffer vessel or thermal store, while automatic ignition boilers starting from cold will take longer to reach temperature requiring T1 to be positioned further down the vessel.

The important consideration is that the temperature at the top of the thermal store does not dip significantly below the boiler setpoint flow temperature in order to ensure the load is satisfied under all conditions.

5.6.2 Positioning the lower (stop) sensor for 2-sensor control on buffer vessels

The biomass boiler stop sensor, T2, on a buffer vessel should usually be positioned near the bottom of the vessel to ensure the vessel is fully charged to the boiler's minimum return temperature.

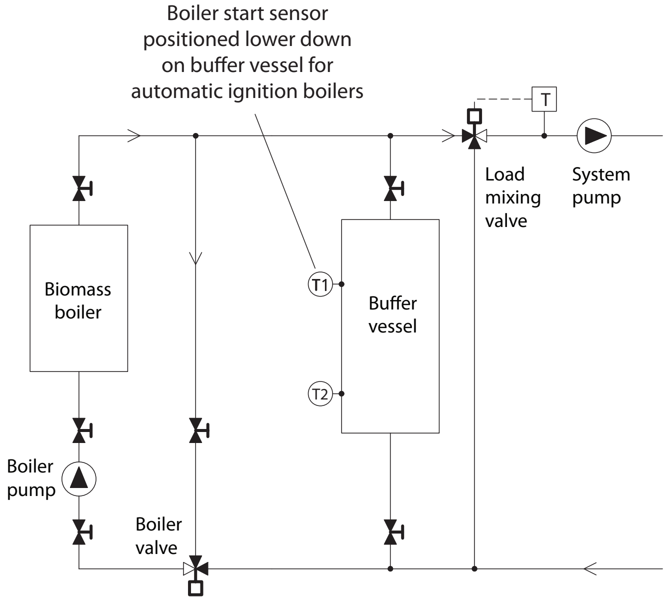


Figure 5.23 Temperature sensor positions for 2-sensor boiler control

5.6.3 Positioning the lower (stop) sensor for 2-sensor control on thermal stores

To calculate the position of the boiler stop sensor on a thermal store, the calculated buffer vessel volume required at the bottom of the store should be translated into a vertical height up the vessel and the boiler stop sensor, or the lowest proportional control sensor, should be located at this point as shown in Figure 5.24.

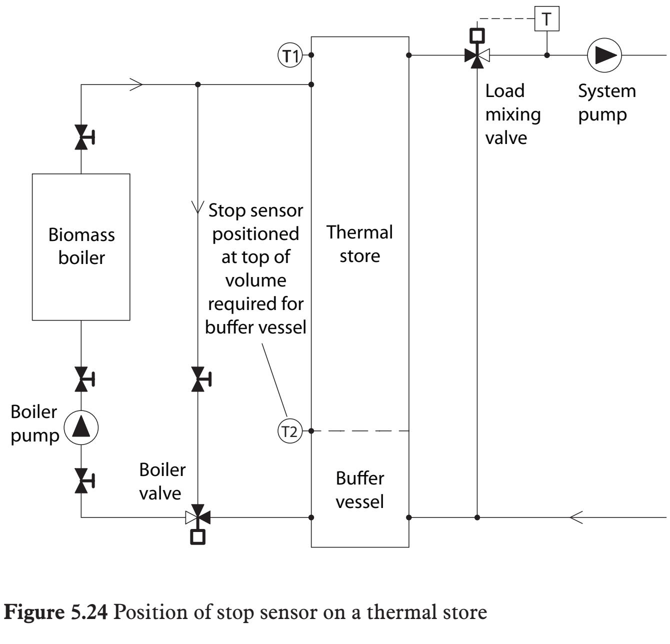


Figure 5.24 Position of stop sensor on a thermal store

5.6.4 Pre-fabricated vs bespoke thermal stores

A range of pre-manufactured ready-to-use thermal stores up to 5 000 litres are available from a number of manufacturers, and these come with the temperature sensor pockets already installed in a number of positions on the store. If using an off-the-shelf thermal store the designer needs only to select the temperature sensors'

Table 5.2 Comparison of buffer vessels and thermal stores

Operating feature	2-port buffer vessel	2-port thermal store	4-port thermal store	Section
Dissipates heat from a biomass boiler on shutdown to: – prevent boiler overheating – avoid the safety valve operating – prolong boiler life by minimising stresses in the boiler casing	Yes	Yes, but temperature of thermal store could rise above maximum design temperature	Yes. If a thermal store is designed with an additional water volume equal to that required for a buffer vessel, no additional temperature rise will occur	5.2.1, Figure 5.22 5.3.1
Improves boiler efficiency by capturing residual heat from a boiler on shutdown. Stored heat is used to contribute to the next heat demand	Yes	Yes	Yes	
Enables a higher biomass boiler flow temperature than load system temperature to achieve greater heat storage in a smaller volume. Used in conjunction with a load mixing valve	No	Yes	Yes	
Allows a rapid response to load changes as heat demands are met from storage	Yes, but for a very short period only	Yes	Yes	
Enables stable biomass boiler control by providing biomass boiler start and stop signals	Yes	Yes	Yes	
Improves the biomass boiler utilisation factor by allowing a relatively small boiler to operate continuously or for long periods	No	Yes	Yes	
Enables modulating turndown of biomass boiler operation as the store charges, reducing the amount of heat to be dissipated during a controlled shutdown	Yes, if multiple temperature sensors are installed at intervals up the vessel plus a boiler control system to modulate boiler output based on the height of the hot/cold interface in the vessel	Yes, if multiple temperature sensors are installed at intervals up the store plus a boiler control system to modulate boiler output based on the height of the hot/cold interface in the store	Yes, if multiple temperature sensors are installed at intervals up the store plus a boiler control system to modulate boiler output based on the height of the hot/cold interface in the store	Figure 5.21
Enables a higher peak output from a biomass boiler system via a higher flow rate in the load circuit, with the biomass boiler operating continuously	No	Yes, for as long as heat is available in the store	Yes, for as long as heat is available in the store	
Increases the return temperature to the biomass boiler when a very low load return temperature is present	Yes	Yes	No	
Turbulent mixing	None except when the vessel switches from charging to discharging (because the flow reverses) or vice versa	None except when the vessel switches from charging to discharging (because the flow reverses) or vice versa	Yes, where flow from the boiler enters the store and the return from load circuit enters the store. Careful design of inlets is required to minimise turbulence	5.5.1
Allows an automatic ignition biomass boiler to start and heat-up while a store supplies the load	No	Yes. Temperature and capacity of store determine the period for which a store can provide heat without the biomass boiler being online	Yes. Temperature and capacity of store determine the period for which a store can provide heat without the biomass boiler being online	
Avoids the need for a fossil fuel boiler to augment the biomass system during the load pre-heat period, and allows an optimum start signal from a BMS to start the load circuit pumps without the need to start an automatic ignition biomass boiler prior to the optimum start time. The biomass boiler heats up while the store discharges to meet the load	No	Yes. Providing the heat storage capacity of the store, in combination with the biomass boiler, is large enough to provide the heat required for the load pre-heat period	Yes. Providing the heat storage capacity of the store, in combination with the biomass boiler, is large enough to provide the heat required for the load pre-heat period	7.2.2
Hydronic segregation between biomass boiler and load circuits if a low loss header is not present	Yes if connections suitably sized	Yes if connections suitably sized	Yes. A 4-port thermal store acts as a common header	8.3

positions which most closely match the design requirements.

Larger thermal stores are usually bespoke manufactured in which case the designer can specify the position of the temperature sensors as well as the type of inlets and outlets (sparge pipe, expanding inlets etc.) required.

5.7 Comparison of buffer vessels and thermal stores

Table 5.2 lists the differences between 2-port buffer vessels, 2-port thermal stores and 4-port thermal stores. Refer to the section numbers in the table for a more detailed description of each operating feature.

6 Sizing a biomass boiler and suitability of biomass

6.1 The principles of sizing a biomass boiler and thermal store

The capital cost of a biomass boiler system is, typically, ten times that of a fossil fuelled boiler system. Furthermore, the low turndown ratio of biomass boilers, typically between 2:1 and 3.5:1, means that most biomass systems will be significantly mismatched with respect to summer loads. Hence it is very important not to oversize a biomass boiler system. The key principal of sizing a biomass boiler and thermal store combination is to design the system using a small boiler in relation to the peak load while operating it continuously, and hence at high efficiency, to charge a thermal store: energy is stored overnight to meet peak loads the following day. The extent to which the boiler size can be reduced in relation to peak load is wholly dependent on the shape and duration of the daily load profile.

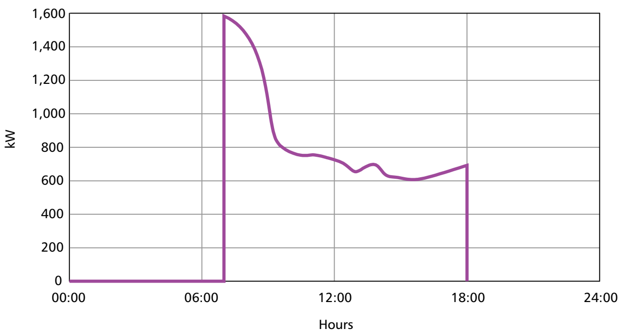


Figure 6.1 Load profile for a building heated during normal working hours

A thermal store, in combination with a biomass boiler, should be designed to meet the desired percentage of energy from biomass (when an auxiliary boiler is incorporated) or 100% of the annual energy requirement if a biomass system only is to be installed. A thermal store collects energy from the biomass boiler when the demand from the load is less than the boiler's output and releases it, in combination with the biomass boiler, when the load demand is greater than the boiler's output: it serves as a peak lopping and load smoothing device. The shape of the heat load profile has the greatest influence on the size of thermal storage required. Figure 6.1 shows a profile for a building heated during normal working hours while Figure 6.2 shows that for a continuously heated building.

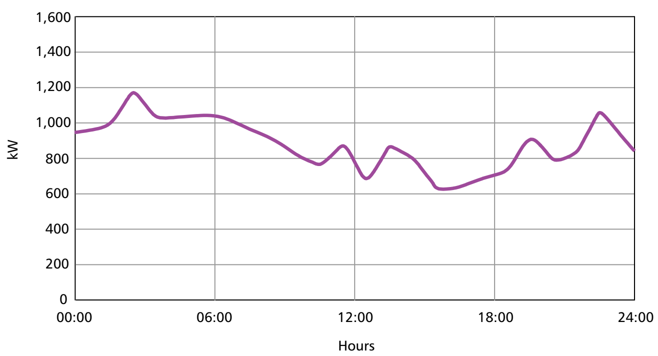


Figure 6.2 Load profile for a continuously heated building

It is self-evident that a small biomass boiler in combination with a large thermal store could meet the demand shown in Figure 6.1 (operating overnight to charge the thermal store) while there is little scope for using a thermal store with the relatively flat profile of a continuously heated building which would require a boiler sized at the average load of the profile in Figure 6.2.

6.2 Sizing a biomass boiler and thermal store

The process of sizing a biomass boiler and thermal store is best explained through a worked example.

Step 1 – Create the design winter day load profile

The first step is to create a load profile for the building or load system for the design winter day, i.e. the day on which the average outside temperature equals the design winter temperature for the geographical location of the building. The profile can be created using dynamic building simulation, heat metered measurements of the load, or by applying the winter design day external temperature profile to a simplified method, e.g. to the CEN 13790 standard. It is important to use the most accurate profile generation method available if the resulting system performance is to be acceptable.

Figure 6.3 shows a typical load profile for a large building heated for extended working hours for the design winter day. In this profile the domestic hot water calorifiers charge at the same time as the initial demand for heating resulting in a very large start-up peak. Traditionally, fossil fuelled boilers are sized to meet a profile with all loads starting simultaneously, plus a safety factor, which results in boilers which are massively oversized for most of the year.

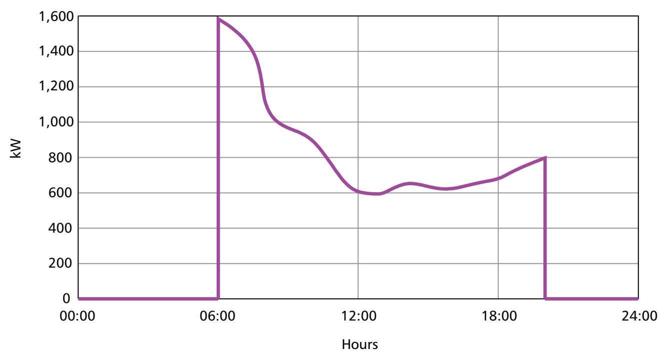


Figure 6.3 Load profile for a building heated for extended working hours

Step 2 – Adjust the profile by moving DHW calorifier charging to avoid the start-up peak, and stagger the start-up for other loads

Most domestic hot water calorifiers can be charged at times other than the morning start-up peak, with charging being either distributed during the working day or occurring overnight. In this example the heating demand profile can be modified with a reduction of 300 kW in the peak load in this example by delaying calorifier charging. When sizing a boiler and thermal store this reduction in peak load results in a significant reduction in biomass boiler size. Where possible, all other loads should have staggered starts to reduce the size of the start-up peak. The default load profile should be modified to take account of shifts in calorifier charging and other load start-ups as shown in Figure 6.4.

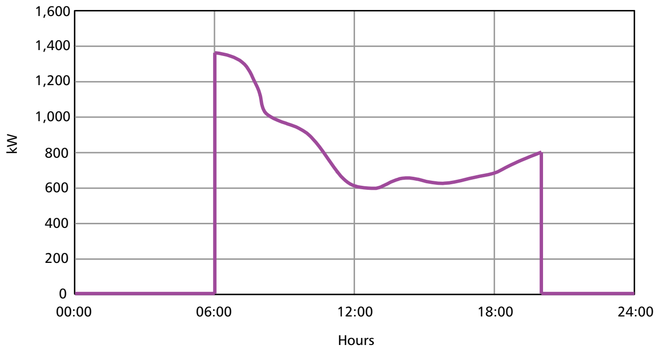


Figure 6.4 Load profile of Figure 6.3 modified by shifting hot water calorifier charging

Step 3 – Examine boiler/thermal store combinations

The modified load profile is used to examine combinations of biomass boiler and thermal storage to identify a pragmatic system taking into account capital costs, space requirements and the desired percentage of annual energy from biomass. If 100% of the annual energy is required from biomass, the boiler/thermal store must be able to supply 100% of the energy required on the design winter day. The optimum combination of boiler and thermal store from an energy storage perspective occurs at the point where the energy stored by the boiler overnight (the grey area beneath the boiler line) meets the demand above the boiler output the following day (the grey area above the boiler line).

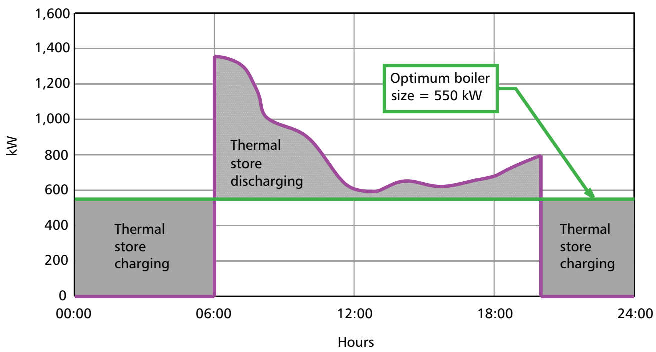


Figure 6.5 Load profile from Figure 6.4 served by a 550 kW boiler and 110 000 litre thermal store

In Figure 6.5 a 550 kW biomass boiler runs continuously to charge a thermal store overnight and discharges to meet peak load the following day. This is the minimum biomass boiler size to meet 100% annual energy from biomass. In this example a 600 kW biomass boiler would be selected (the closest standard boiler size representing 44% of the peak load) together with a thermal store of 110 000 litres if operated at a temperature difference of 30 °C. However, this is a very large thermal store and increasing the size of the boiler to, for example, 800 kW produces the following balance, Figure 6.6, again to provide 100% of the annual energy from biomass. While the thermal store size would be reduced to 44 000 litres the capital cost would be significantly greater while the minimum boiler output would also increase.

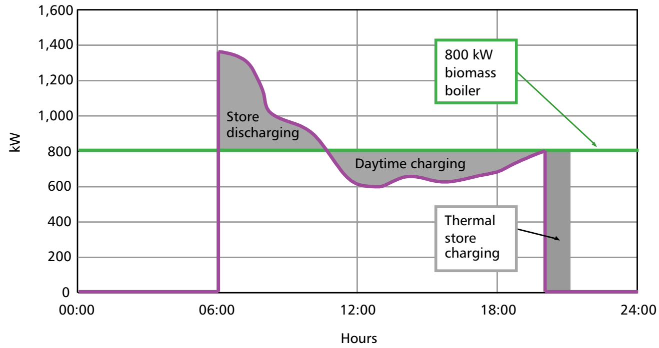


Figure 6.6 Load profile of Figure 6.4 served by a 800 kW biomass boiler and 44 000 litre thermal storage

Step 4 – Consider adding an auxiliary boiler

A pragmatic compromise would be to select a biomass boiler of 700 kW (52% of peak load) together with a 650 kW fossil fuel auxiliary boiler and a 30 000 litre thermal store. In this case the system would be still be able to produce 95% of the annual energy from biomass, yet have significantly reduced capital costs.

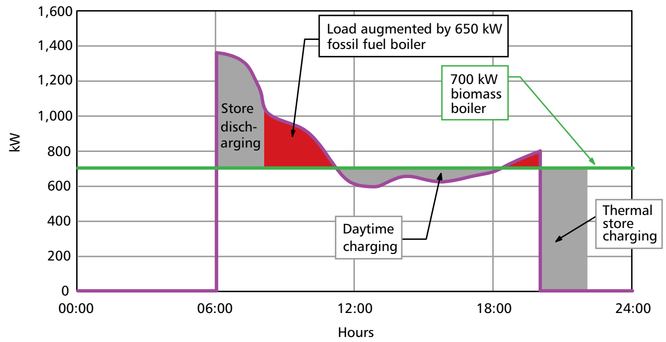


Figure 6.7 Load profile of Figure 6.4 served by a 700 kW biomass boiler, 30 000 litre thermal store and 650 kW auxiliary boiler

Step 5 – Matching summer loads

It is essential that the performance of a biomass system is checked against the summer load profile to determine to what degree the biomass boiler may be mismatched because of its low turndown ratio. For this example the summer load is predominantly hot water requiring 300 kW to charge hot water calorifiers for no more than 2 hours per day. The minimum output from the biomass boiler should, ideally, be no more than this. For the 700 kW biomass boiler selected the minimum output will be between 200 and 350 kW depending on the boiler type and fuel – this is acceptable. However, should a biomass boiler sized at or close to the peak load have been selected the minimum boiler output would be between 400 and 700 kW. While this would have matched the peak load it would have been significantly oversized for much of the year because the mean load for the subject building is 300 kW or less for 6 months of the year. Significant cost and efficiency penalties would result.

A useful and intuitive method of checking a biomass boiler's suitability for summer operation is to construct an annual load duration curve for the load system. This is covered in depth Section 6.3.

Step 6 – Estimation of the percentage of annual energy produced by a biomass system

The assessment of the annual energy contribution from a biomass system when it has been designed to use an auxiliary boiler for peak lopping is not straightforward. A sophisticated approach involving analysis using data generated by a dynamic building simulation programme or an analysis of loads versus the frequency of occurrence of temperatures is required to produce an accurate assessment. Some rules of thumb which give an indication of the likely performance of a hybrid biomass and fossil fuelled system are:

— For a system employing a buffer vessel only, a biomass boiler sized at 50% of the peak load is likely to be able to supply 80–85% of the annual energy from biomass.

— For a system using a thermal store a biomass boiler rated at 30% of the peak load is likely to be able to supply 95% or more of the annual energy from biomass.

Great care must be taken when using rules-of-thumb as the achievable performance is heavily dependent on the shape of the winter design day heat load profile. However, for many typical existing buildings, a biomass boiler rated at 30% of peak load with a thermal store and auxiliary boiler(s) is probably not too far from the optimum solution and should achieve efficient biomass boiler operation and enable the system to be effectively controlled. However, care must be taken to ensure the boiler is sized on the peak heat load profile and not on the size of the existing fossil fuel boilers, which are often oversized.

It is recommended that appropriate calculations always be carried out. A tool such as Carbon Trust's *Biomass Boiler System Sizing Tool* (Carbon Trust, 2013) carries out all the calculations required and allows what-if analyses to be undertaken to examine combinations of biomass boiler, thermal store and auxiliary boiler to identify the most appropriate and cost effective solution.

It is always desirable to calculate the size by two different methods, by rules of thumb and more sophisticated methods. Whilst the later should be far more accurate, errors due to incorrect data entries are more likely. If both methods produce reasonably close answers there will be more confidence that the calculations are correct. If there are significant differences a double check on both sets of calculations is recommended.

6.3 Annual load duration curves

The use of annual load duration curves is usually confined to district heating networks where they are useful in determining the appropriate mix of heat generators, but in the context of biomass boiler sizing they offer a method of examining a biomass boiler's peak and minimum loads in relation to the annual load duration curve for the load system. An annual load duration curve is a cumulative frequency distribution of load, so that any point on the curve of fractional heating load represents the number of hours in the year for which the heating demand will be greater than the value indicated. For the examples in this section, Figures 6.8 and 6.9 are based on the same design winter day load profile as shown in Figures 6.4 to 6.7 which have a peak load of 1.34 MW; also shown are the biomass boiler maximum and minimum outputs. In Figure 6.8 a boiler rated at 75% of the peak output (1 MW) with a turndown ratio of 3:1 has a minimum output in excess of the cumulative load curve for almost 7 000 hours a year. While this boiler in combination with a 30 000 litre thermal store would provide 99% of the annual energy from biomass, by inspection it can be seen that this boiler should not be used in summer, and probably for much of the heating season as well.

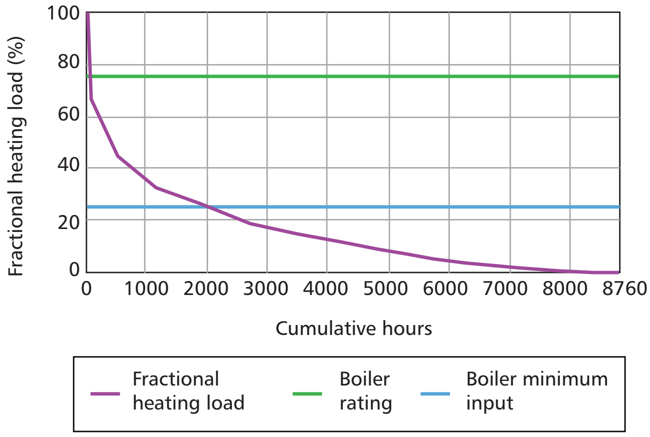


Figure 6.8 Annual load duration curve for boiler rated at 75% of peak with a 3:1 turndown

If a more pragmatic combination of a 700 kW biomass boiler, 650 kW auxiliary boiler and 30 000 litre thermal store was selected it can be seen from Figure 6.9 that the biomass boiler would still be too large for the load profile for over 4 000 hours a year. This combination would provide 95% of the annual energy from biomass.

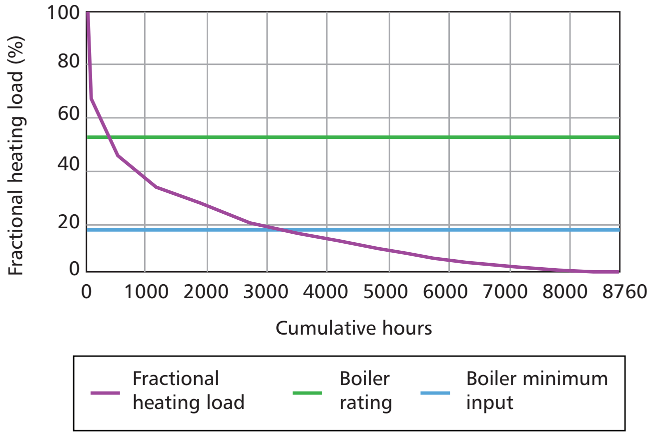


Figure 6.9 Annual load duration curve for boiler rated at 52% of peak with a 3:1 turndown

In order for the biomass boiler to be a reasonable match to the load profile for most of the heating season its size would need to be reduced to 30% of the peak load or 400 kW, as shown in Figure 6.10. If a thermal store of 30 000 litres is used together with a 950 kW auxiliary boiler, the biomass boiler would supply 78% of the annual energy from biomass.

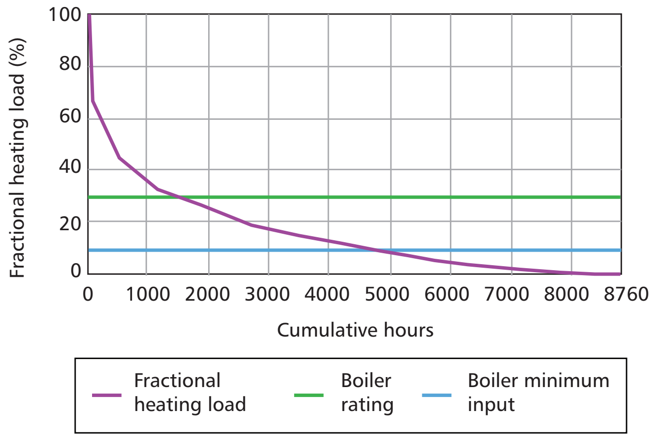


Figure 6.10 Annual load duration curve for boiler rated at 30% of peak with a 3:1 turndown

The examples in this section have been generated using the Sochinsky Method which creates a close approximation to the actual annual load duration curve when the annual frequency distribution of loads is not known, as is usually the case during the design process unless sophisticated energy modelling is employed. As a rule of thumb, the user should aim for 5 000 hours of annual operation with load above the minimum biomass boiler output.

6.4 Suitability of biomass

Not all loads are suitable for connection to a biomass system, and not all biomass systems are suitable for a given load. The boiler may fire for only a few hours a day in a modern, well insulated, building because much of the heat load is met from casual gains. If biomass is used for such an application, a small automatic ignition boiler (relative to the peak load) and a proportionately large thermal store are required. Consideration of the shape of the design day heat load profile coupled with a calculation of the building's balance temperature is usually sufficient to indicate if biomass is suitable. Other indications are a low boiler utilisation factor, a low peak heat load density (W/m^2) and a very long financial payback on the biomass system.

Should the indicators described in 6.4.1 to 6.4.5 suggest that biomass is not suitable, a project review should be carried out to determine whether biomass should be installed.

6.4.1 Shape of the load profile

The shorter the duration of a building's load profile (considering a range of monthly profiles throughout a year) the less suitable the building is likely to be for biomass. A short load profile will result in a low to very low biomass boiler utilisation factor if the boiler is sized at more than 50% of peak load.

6.4.2 Building balance temperature

A building's balance temperature is the temperature at which the sum of the casual gains equals the heat demand on the building. It can be calculated using a simplified method by comparing the sum of the casual gains (measured in kW) against the heat load in kW/K to identify the outside temperature at which the heat load matches the casual gains. While older building stock will have balance temperatures of 18 °C or more, the balance temperature for modern buildings will be 12 °C or less. The progressive improvement in building construction standards and associated regulations means that building balance temperatures will continue to fall into the future. It is recommended that suitability for biomass be checked whenever the balance temperature is 12 °C or less because such buildings frequently require cooling, rather than heating, for much of the year. Such buildings will also have low peak load densities.

6.4.3 Utilisation factor

The Tier 1 boundary in the Renewable Heat Incentive for boilers of less than 1 MW is based on a utilisation factor of 15%, the principle being that every biomass system should be able to achieve a utilisation of at least 15%. A utilisation factor of less than 15% is an indication that an application may not be suitable for biomass, so the utilisation factor should be calculated in every case. The utilisation factor can usually be improved significantly by decreasing the size of the boiler, while the effect on utilisation factor of increasing the size of the associated thermal storage is an order of magnitude lower. The calculated biomass boiler utilisation factors for the examples in Figures 6.8 to 6.10 are 21%, 30% and 57% respectively.

6.4.4 Peak pre-heat load density

The peak pre-heat load density (the peak pre-heat demand on the design winter day divided by the serviced area of a building) of old draughty buildings can be as high as 200 W/m^2 whereas that for modern buildings constructed to current standards is typically 50–60 W/m^2. It is recommended that the suitability for biomass heating be checked whenever the peak pre-heat load density falls below 80 W/m^2.

6.4.5 Other factors

There are a number of other factors which mitigate against the suitability of biomass. These include:

- Sufficient space to install a biomass system (see Chapter 2).
- Fuel delivery vehicle access (see Chapter 5).
- Environmental factors such as noise, the Clean Air Act or the existence of an Air Quality Management Area (see Chapter 4).
- The ability to install a suitable flue which could be influenced by physical or planning constraints (see Chapter 10).

6.5 Biomass system design for efficient operation

6.5.1 Boiler selection to match load profile

The selection of the correct boiler type with the most appropriate features to match the load profile is of critical importance. Manual ignition boilers are suitable for district heating networks, hospitals, leisure centres with swimming pools and other high heat or steam users where a continuous load is present. In all other cases, where load profiles are of short or medium duration, and also where a biomass boiler is required to meet summer loads, if possible an automatic ignition boiler should be selected. In all cases a thermal store should be used, rather than a buffer vessel, to minimise the biomass boiler size and increase overall system efficiency.

6.5.2 Proper control of auxiliary and back-up boilers

Where one or more fossil fuel boilers is used to augment the output of a biomass boiler (auxiliary boiler) or to provide back-up to the biomass boiler (back-up boiler) the fossil fuel boiler(s) must be actively controlled. Auxiliary boilers must be controlled to ensure they fire at a rate commensurate with the additional load demand, and then only for as long as needed. Back-up boilers must be controlled so that they fire only on biomass boiler failure, and then for only as long as they are required.

6.5.3 Achievable direct efficiencies

The most commonly used measure of biomass boiler efficiency is the direct efficiency, defined as:

$$\text{Direct efficiency} = \frac{\text{Heat output from the biomass boiler}}{\text{Energy input to the biomass boiler}} \qquad (6.1)$$

A well-designed system using an automatic ignition boiler operating into a thermal store with well controlled auxiliary or back-up boilers can achieve a direct efficiency of up to 90%, whereas a well-designed manual ignition boiler operating into a thermal store with well controlled auxiliary or back-up boilers can achieve a direct efficiency of up to 80%. However, if a manual ignition boiler is applied to a daily short duration load the system efficiency can drop to as low as 50%. If auxiliary or back-up boilers are then, in addition, not well controlled, the direct efficiency can drop below 10%.

7 Connecting biomass boilers in parallel or series

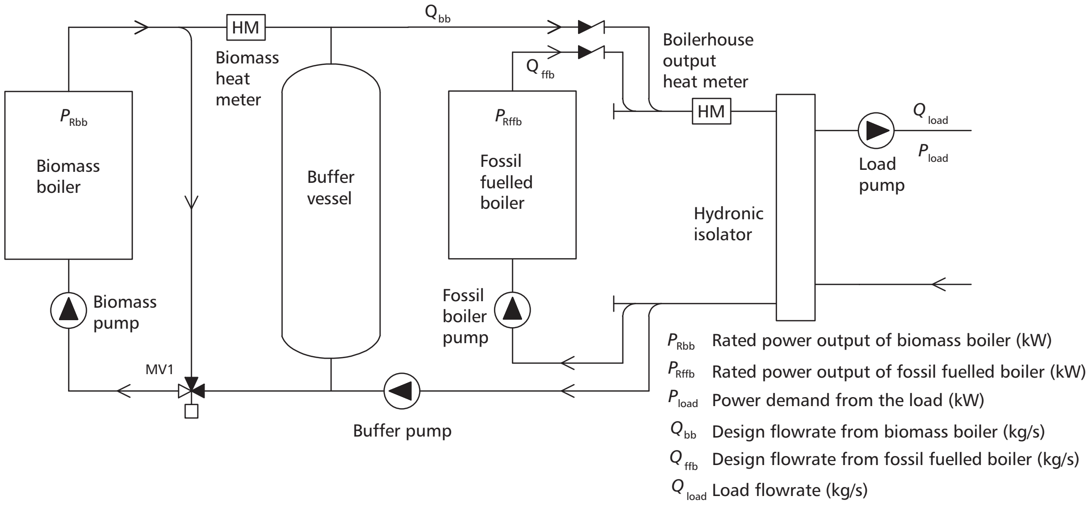


Figure 7.1 Typical parallel connected system

This chapter covers the arrangements of biomass boilers connected in either parallel or series with fossil fuelled boilers. To aid understanding, a typical parallel connected system is analysed, including an example typical of widely installed parallel arrangements. This is followed by a preferred parallel connected arrangement which overcomes the limitations identified for the typical parallel arrangement. A similar process is applied to typical and preferred series connected arrangements. All other options for connecting biomass boilers, buffer vessels and thermal stores can be derived from these arrangements. The chapter concludes with a detailed comparison of the performance of typical parallel and series connected arrangements which are compared to the ideal performance which can be achieved only by using either the preferred parallel or series arrangements.

Commonly implemented hydronic arrangements of biomass and fossil fuelled boilers are analysed with respect to engineering physics. These arrangements are shown to produce low biomass boiler utilisation with the consequent unnecessary and additional fossil fuel use. When it is desired to give priority to one type of heat source, e.g. biomass, significant problems are shown to occur when connecting dissimilar heat sources. This is unlike implementations using multiple fossil fuelled boilers when the division of flows between boilers is of little consequence. The analyses presented here also apply to the connection of any renewable heat source to fossil fuelled boilers including heat pumps, CHP units, geothermal sources and solar thermal systems. However, none of these other renewable energy sources are considered further in this Applications Manual.

RHI guidance published in 2013 includes *Metering Placement Examples* (Ofgem, 2013b) containing detailed advice on where heat meters are required for RHI purposes. System configurations for RHI accreditation are described as either ‘standard’ or ‘multiple’, with many of them not requiring any heat metering in the boilerhouse, or a biomass heat meter only. Competent control of the preferred configurations in this chapter requires a boilerhouse output heat meter which may be in addition to that required for the RHI. The biomass heat meters shown, whether or not required by the RHI, allow the operator to measure heat output and thereby to calculate the direct biomass boiler efficiency by taking the ratio of the measured heat output divided by the calculated energy content of the delivered biomass fuel.

7.1 Typical parallel connected system

A typical parallel connected system consists of a biomass boiler, with or without a buffer vessel, connected in parallel with one or more fossil fuelled boilers as shown in Figure 7.1.

The following assumptions have been made:

- The boiler pumps for both the biomass boiler and the fossil fuelled are fixed speed.
- The buffer pump operates at the same flow rate as the biomass pump.
- The fossil fuelled boiler is controlled on flow temperature. On a modulating[6] boiler this will cause the output to reduce as the flow temperature is satisfied, while on a boiler fitted with a hi-lo burner the burner will be staged based on flow temperature.
- The pump flowrates (Q) are determined by each boiler’s output rating at the design temperature drop across the load circuit using the formula:

$$Q = P \div (c_p \times \Delta T) \tag{7.1}$$

where P is boiler output rating, c_p is the specific heat capacity of water (kJ·kg^{-1}·K^{-1}) and ΔT is the design temperature drop across the load circuit.

[6] The term modulating boiler refers to one which has a modulating burner capable of continuously variable output from the boiler’s minimum output up to 100% of its rated power output.

— The design temperature drop across each boiler is the same, and the same as that across the load circuit.

If $P_{load} \leq P_{bb}$ a signal from the boilerhouse output heat meter is used to disable the fossil fuelled boiler and its pump, and the biomass boiler meets the full load demand. However, if $P_{load} > P_{bb}$ the load demand is shared between the biomass and fossil fuelled boilers, which also means that the flow rate through each boiler will be in proportion to the rating of each boiler. In this case the power supplied by the biomass boiler can be determined by:

$$P_{bb} = \frac{P_{load} \times Q_{bb}}{(Q_{bb} + Q_{ffb})} \quad (7.2)$$

A signal from the boilerhouse output heat meter is used to enable the fossil fuelled boiler, with modulating control either by the boiler's internal control system or from the heat meter. The only operating points at which the biomass boiler can supply its full power output to the load are when:

— $P_{load} \leq P_{bb}$ as described above

or

— $P_{load} = P_{loadMAX}$ because both biomass and fossil fuelled boilers are operating at their peak outputs.

Notes:

— A hydronic isolator is shown, rather than multiple primary connections onto a low loss header, because it provides a single point of connection to allow a boilerhouse output heat meter to be connected.

— The drawing shows just one fossil fuelled boiler, but it can be configured as one or more boilers connected in parallel across the input to the hydronic isolator.

— The load pump can be one or more pumps on one or more secondary circuits each connected across the secondary of the hydronic isolator.

— Refer to Chapter 5 for a description of how the buffer vessel operates with respect to the biomass boiler.

There are a number of significant limitations with this typical configuration:

— Enabling of the fossil fuelled boiler using return temperature can be problematic[7] and may better be accomplished using the boilerhouse output heat meter.

— When the load is just greater than the biomass boiler peak output, the fossil fuelled boiler will fire and its pump will switch on. Even if the biomass and fossil fuelled boilers are of equal power output the demand on the biomass boiler will immediately drop to 50% of its peak output. However, as the biomass boiler will be unable to react sufficiently quickly to the additional output on the system, the biomass boiler is likely to go over-temperature producing an unwanted temperature spike on the primary circuit.

— The smaller the ratio of the biomass boiler output rating to the fossil fuelled boiler output rating, the lower the percentage of load supplied by the biomass boiler. when $P_{load} > P_{bb}$.

— Fossil fuel use will be much greater than either expected or is necessary as shown in Figure 7.2.

— A low percentage of energy from the biomass boiler will impact severely on its utilisation, reducing the energy produced, increasing the payback period on the biomass system and, if it is in receipt of the RHI, reducing payments from the RHI scheme.

— The modulating range of the fossil fuelled boiler will be insufficient to supply the full range of load demands above that supplied by the biomass boiler. In particular, when the additional load demand is less than the minimum output of the fossil fuelled boiler, that boiler will switch on and off producing large over-temperature spikes on the system. While this can happen on systems employing fossil fuelled boilers only, it is a particular problem on a system with a mix of biomass and fossil fuelled boilers.

— If $P_{load} \leq P_{bb}$ and the load pump is a fixed speed pump sized for the full load flow, reverse flow will occur in the hydronic isolator because $Q_{load} > Q_{bb}$ resulting in flow temperature dilution to the load circuit.

— If a buffer vessel is not installed, the directly connected biomass boiler, with neither buffer vessel nor thermal store, requires control coordination between the load pump, load circuits and the biomass boiler. If the biomass boiler is of the:

  — automatic ignition type, the load pump must run-on, and a load must be available, for a sufficient period to remove residual heat from the biomass boiler; or

  — manual ignition type, the load pump must run continuously, and a load must be available continuously, to remove and dissipate the heat produced during slumber mode, i.e. when the demand on the biomass boiler is less than its minimum output.

7.1.1 Example calculation for a typical parallel arrangement

The following example illustrates the problem of connecting a biomass into a system incorporating fossil fuelled boilers based on the above hydronic arrangement. In this example a 199 kW biomass boiler is connected in parallel with two 500 kW fossil fuelled boilers – a typical

[7] In order to ensure that the fossil fuelled boiler does not fire until absolutely necessary, it is common practice to allow the return temperature to fall several degrees below the load design return temperature before enabling a fossil fuelled boiler. This practice can result in a significant depression of the flow temperature to the load circuits while the fossil fuelled boiler continues to fire until the system flow temperature has been satisfied. This can result in the demand on the biomass boiler being depressed below the minimum output forcing this boiler either to switch off (automatic ignition biomass boiler) or to enter slumber mode (manual ignition biomass boiler). As fossil fuelled boilers are much more responsive than biomass boilers, the fossil fuelled boiler may then supply all of the load demand because the biomass boiler is unable to respond sufficiently quickly to changes in load demand.

current arrangement used to secure the highest RHI tariff for the biomass boiler. With ideal control of both the enabling and modulation of the fossil fuelled boilers the following output profile for the biomass boiler can, theoretically, be achieved. The reality of less-than-ideal control of the fossil fuelled boilers, and in particular the absence of modulation when hi-lo burners are in use, could result in much lower utilisation of the biomass boiler than shown in the graph below. Whenever at least one fossil fuelled boiler is required to meet the load in addition to the biomass boiler, unnecessary additional fossil fuel consumption will result except when the load demand exactly matches the biomass output plus one or more fossil fuelled boilers operating at full output.

Referring to Section 6.3, approximately 80% of the energy consumption occurs within 40% of the peak load, i.e. 480 kW for this example. It can be seen from Figure 7.2 that a large fossil fuel contribution will be required to meet the load in the region up to 480 kW. This is a significant limitation of the typical parallel connected arrangement.

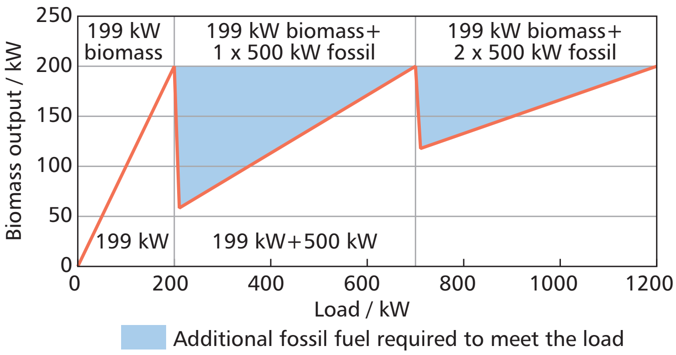


Figure 7.2 Theoretical biomass output for a typical parallel connected system with biomass output limited by flow sharing

The assumptions made are:

— The buffer pump operates while the biomass boiler is heating up and thereafter operates with the biomass boiler to deliver heat to the boilerhouse.

— Each fossil fuelled boiler is not enabled until required by the load demand – i.e. ideal control.

— Each boiler's pump is not switched on until the associated boiler is enabled.

— Each fossil fuelled boiler is modulated exactly to meet the additional load demand.

— No unwanted forward or return flow will occur through disabled fossil fuelled boilers.

— The biomass boiler can produce an output from zero to its maximum power. In reality this is unlikely to be the case because of its minimum turndown output, typically 28–35%. Once switched-off or in slumber mode the biomass boiler will be very slow to respond resulting in a fossil fuelled boiler being enabled to meet the load demand.

7.2 Preferred parallel connected system

The following hydronic configuration, together with its accompanying controls description, is offered as the preferred solution for connecting a biomass boiler in parallel with fossil fuelled boilers. This configuration, when adequately controlled, overcomes most of the limitations identified for the typical parallel connected system (Figure 7.3).

The key features of this preferred configuration and the associated control arrangements are:

— The biomass boiler is able to operate continuously, thus maintaining the combustion chamber at the minimum temperature required for efficient combustion.

— The biomass boiler is able to operate within its modulating range charging the thermal store. This further optimises the biomass boiler efficiency by preventing the boiler from switching off (automatic ignition boiler) or dropping into slumber mode (manual ignition boiler).

— The thermal store helps to ensure that as much heat as possible is generated from the biomass boiler and stored for future use.

— A biomass boiler rated at significantly below the peak load can, together with the thermal store, meet peak loads without the need for fossil fuelled boiler support.

— Optimisation of the biomass boiler's utilisation factor[8] by operating a small biomass boiler for extended periods into a large thermal store.

— The ability to operate the biomass system at a higher temperature than the load circuits, or fossil fuelled boiler, to allow greater energy storage with the thermal store or, conversely, a smaller thermal store for a given energy storage requirement.

— The provision of a signal from a temperature sensor at the top of the thermal store to disable the fossil fuelled boiler for as long as heat is available in the thermal store.

— The thermal store is designed to accept the full load flow rate through the secondary side of the store to ensure that the biomass boiler, in combination with the thermal store, has the opportunity to satisfy the full load demand for as long as heat is available in the store.

— The thermal store can be operated at a higher temperature than the load design flow temperature, when the mixing valve MV2 will modulate to maintain the design flow temperature. This reduces the draw from the thermal store, reduces turbulence within the thermal store, and also reduces the speed at which the hot-cold interface moves up the store during periods of high load demand.

— The thermal store itself acts as a hydronic separator ensuring that the biomass heat meter is hydronically isolated from other equipment. This ensures it

[8] Utilisation factor = Hours per year full load equivalent operation / 8760

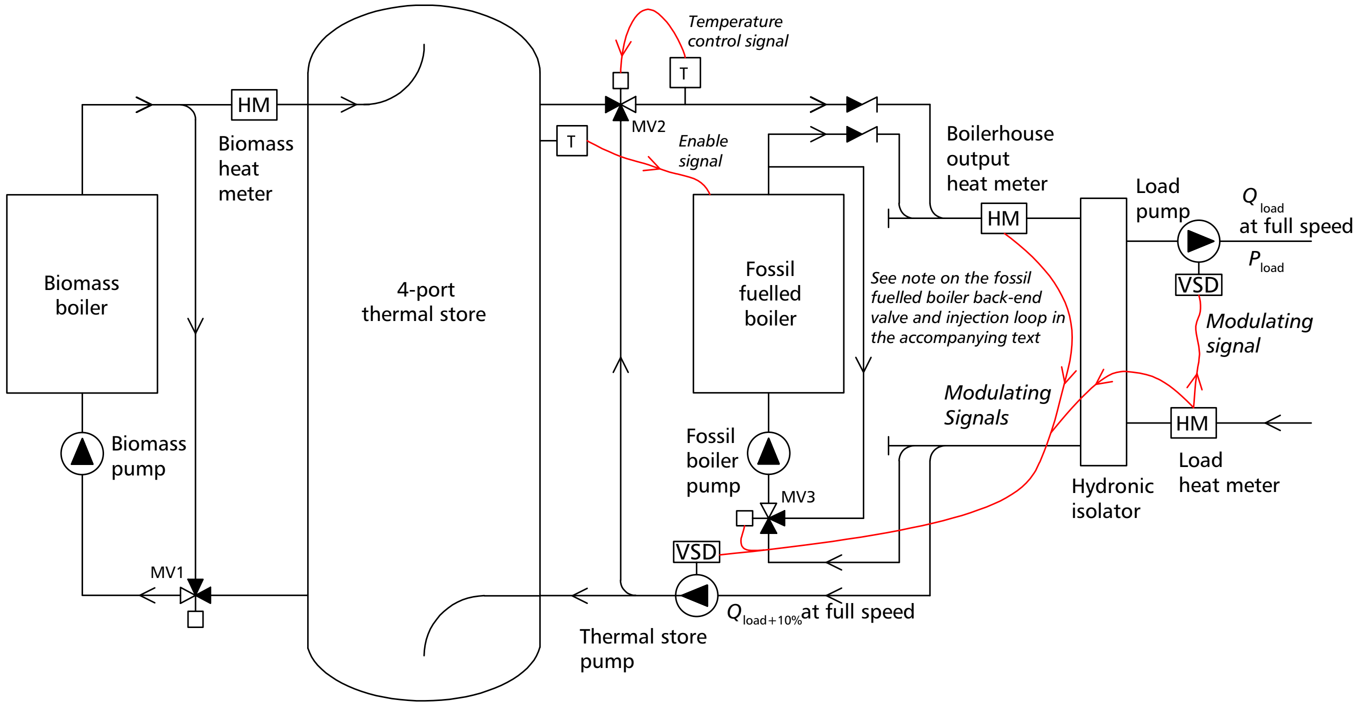


Figure 7.3 Indicative hydronic arrangement for the preferred parallel connected system

cannot be influenced by either the fossil fuelled boiler or the load circuits.

— To ensure forward flow along the hydronic separator at all times the flow rate of the thermal store pump must be 10% greater than that of the load pump. The load pump in this example will usually represent a combination of constant temperature and variable temperature load circuits.

— On constant temperature load circuits, control of the variable speed load pump is based on the temperature difference across the load to maintain the design load temperature difference under all operating conditions. Most constant temperature circuits in existing buildings are constant flow with 3-port valves, but can be converted to variable flow by regulation of the bypass port relatively easily to achieve a turndown to 25%.

— On variable temperature load circuits, the flow rate from the hydronic isolator is determined by the position of a 3-port compensated circuit valve (not shown), as the load pumps on these circuits are within the mixing loops.

— The flow rate of the variable speed thermal store pump can then be controlled at 10% above the total flow in the load circuits by comparing the flow meter outputs from the load and boilerhouse heat meters.

— Variable speed control of the thermal store pump, together with MV2, ensures the correct draw from the thermal store to meet the load demand whilst maintaining stratification in the store.

— A back-end injection loop, connected in parallel with the hydronic isolator, to allow just sufficient heat to be provided from the fossil fuelled boiler to meet any additional load demand beyond that provided by the biomass boiler and thermal store.

The 3-port valve[9] MV3 can be modulated with a turndown of up to 50:1 to meet additional loads. Modulation of this valve is based on comparing signals from the load heat meter and boilerhouse output heat meter to match heat supply to load. The control system ensures load matching at all times when the load demand cannot be met entirely from the biomass boiler and thermal store.

— If the fossil fuelled boiler is of the type which can accept a variable flow rate through the boiler, the back-end injection loop is not required and the fossil fuelled boiler pump speed is controlled by the load matching algorithm described above.

— If the fossil fuelled boiler is a gas condensing boiler it should be selected to allow a variable flow rate through the boiler; in this way the back-end injection loop can be dispensed with. However, the boiler will begin to operate in condensing mode only if its return temperature is below 54 °C, with 90% latent heat recovery possible only when the return temperature is 34 °C (boiler type dependent).

— On constant temperature load circuits, control of the variable speed load pump is based on the temperature difference across the load to maintain the design load temperature difference under all operating conditions. This minimises the flow rate in the load circuit which then allows the thermal store pump to operate at a corresponding flow rate.

— On variable temperature load circuits, the flow rate from the hydronic isolator is determined by the position of the 3-port compensated circuit valve as the load pump on this circuit is within a mixing loop.

[9] The Scottish Technical Standards require boilers to be isolated when not in use to minimise parasitic energy consumption

— Variable speed control of the thermal store and load pump minimises pumping electrical consumption.

— The use of a hydronic isolator[10] prevents interaction between primary and secondary pumps, and should be used for all connections. In particular when retrofitting a system to an existing plantroom with split headers, a hydronic isolator should be installed to convert that plantroom to one with hydronically separated primary and secondary circuits to facilitate the control strategies detailed above.

— A hydronic isolator also provides a single point flow connection to which a boilerhouse output heat meter can be connected.

— Note that the boilerhouse output heat meter and the load heat meter, while they will be of similar capacity, are shown on the flow and return lines respectively. They must be specified and installed on the correct lines.

— The drawing shows just one fossil fuelled boiler, but it can be configured as one or more boilers connected in parallel across the input to the hydronic isolator.

— The load pump can be one or more pumps on one or more secondary circuits each connected across the secondary of the hydronic isolator. In this case each constant temperature circuit pump must be a variable speed pump controlled on the temperature difference across its load circuit.

7.2.1 Biomass systems designed to meet less than the peak load

Many biomass systems (biomass boilers in combination with thermal stores) are designed with the intention of the biomass system supplying just the baseload or a proportion of the peak load only, and in this situation the biomass boiler will not be able to operate at its full output when connected in parallel as described above. There are many reasons for designing on this basis including limiting system capital cost, the availability of the highest rate of RHI tariffs if the biomass boiler is rated at 199 kW or less, the physical space available in a plantroom for a boiler and thermal store, and the availability of space for fuel storage.

When a system is designed to meet only part of the total load the peak flow rate through the biomass system will be less than the full load flow rate, biomass boiler utilisation will reduce and fossil fuel consumption will increase. The reduction in biomass boiler utilisation depends upon the flow rates of biomass and fossil fuelled boilers, and the daily load profile. If the biomass part of the system has a maximum flow rate less than 70% of the maximum secondary system total flow rate, a significant reduction in biomass boiler utilisation will result as shown in Figure 7.2 in the previous section. In this situation the biomass boiler will supply its full output to the load up to the limit of the biomass system output. Thereafter the fossil fuelled boiler will be controlled as described above.

[10] Note that little publicly available design information exists on hydronic isolators. A suggested approach is: 1) the flow velocity along the isolator at maximum primary load, with no secondary load, is 0.15 m/s; 2) the flow velocity in the primary and secondary stub pipes is no more than 0.5 m/s at full load.

7.2.2 Biomass system start-up and operation

In order to avoid fossil fuel use during system start-up the main control system, typically a BMS, should send an enable signal to the biomass boiler's own control system sufficiently ahead of an expected heat load demand that the thermal store is fully charged. With a small biomass boiler and a large thermal store this pre-start can be up to one day.

7.2.2.1 Automatic ignition boilers

The timing of the enable signal for an automatic ignition boiler depends on whether:

— The biomass system is being started for the first time in a heating season when the thermal store will have cooled to ambient temperature when a long pre-heat period will be required.

— The biomass system is being restarted after being shutdown for a weekend, overnight or following maintenance when a shorter pre-heat period will be required.

— The combination of biomass boiler and thermal store has been sized such that the biomass boiler has to run continuously recharging a thermal store overnight.

If it is intended that the fossil fuelled boiler is not to run on initial start-up an additional disable signal from the control system will be required (if the thermal store is cold the fossil fuelled boiler will be enabled automatically because the enable signal is based on low temperature at the top of the thermal store).

The firing of the biomass boiler will be based on temperature sensors on the thermal store as described in Chapter 5.

The biomass boiler itself will have a safety device to prevent overheating. This may be in the form of a safety heat exchanger fed by cold water or a temperature relief valve. In either case the boiler controls will prevent any further fuel being fed to the boiler which will shut down. A manual reset will then be required. Refer to Section 4.5.2 for details of emergency heat exchangers.

7.2.2.2 Manual ignition boilers

Manual ignition boilers are not usually enabled from a remote control system, rather a fire is set on the grate and then the boiler's own control system is switched on, the actual sequence being boiler type dependent. The boiler will need to be ignited manually at an appropriate time prior to heat being required. Thereafter:

— Once lit, the boiler will operate continuously, dropping into slumber mode when there is no demand on the boiler.

— Boiler control is usually by flow temperature operating, typically, on a 3 °C temperature differential. Whenever the flow temperature drops below its setpoint value by 3 °C the boiler comes out of slumber mode and recharges the thermal store until the setpoint flow temperature is satisfied.

— It is essential that provision is made for heat to be dissipated from the biomass boiler at all times.

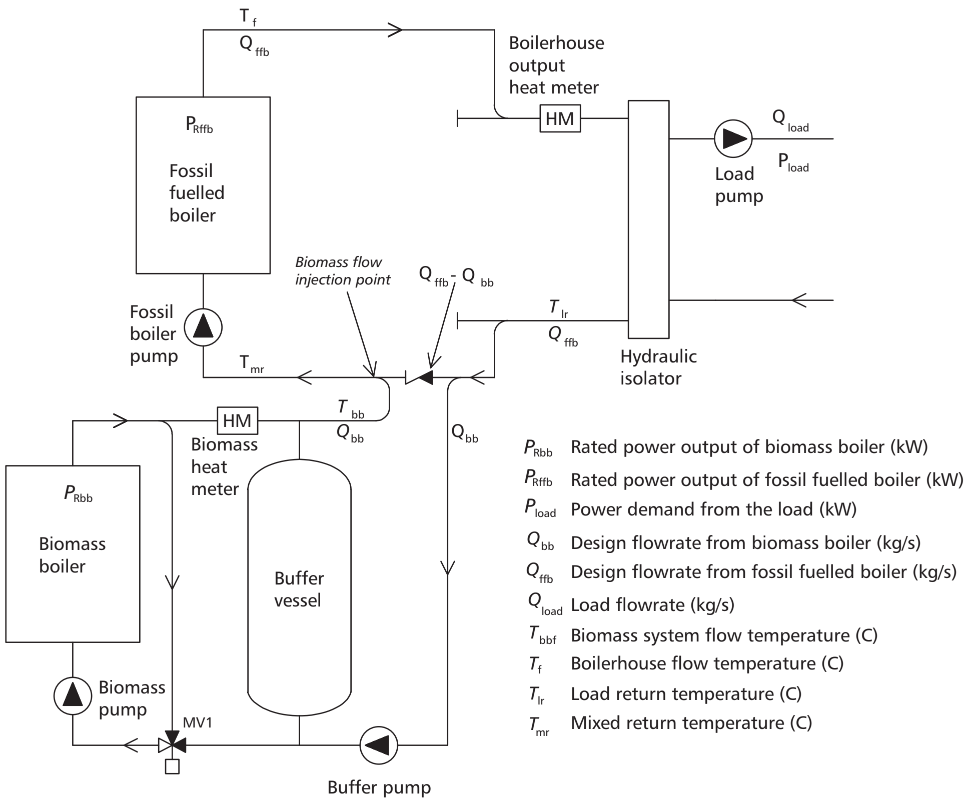


Figure 7.4 Typical series connected arrangement

This will require controls coordination between the thermal store pump, MV2, the load pump and load circuits.

— If the thermal store temperature approaches the maximum permissible biomass boiler flow operating temperature, MV2 must open fully, the thermal store pump and load pump must operate at full speed and the load circuits must be controlled to accept heat. This is a safety critical design consideration.

Health and safety considerations
When using a manual ignition boiler, ensure that the heat generated in slumber mode can be safety dissipated under all load and operating conditions

— The biomass boiler itself will have a safety device to prevent overheating. This may be in the form of a safety heat exchanger fed by cold water or a temperature relief valve. In either case the boiler controls will prevent any further fuel being fed to the boiler which will ultimately cause the firebed to burn out. A manual restart will then be required. Refer to Section 4.5.2 for details of emergency heat exchangers.

On both types of boilers common fault signals will be generated from a variety of boiler alarm and faults.

7.3 Typical series connected system

Another commonly implemented hydronic arrangement of biomass and fossil fuelled boilers is the series connected biomass boiler (Figure 7.4) which is analysed with respect to engineering physics. As with the typical parallel connected arrangement, this is also shown to produce low biomass boiler utilisation with the consequent unnecessary and additional fossil fuel use. Series connection is rarely considered or necessary when using multiple fossil fuelled boilers. However, when connecting dissimilar heat sources, such as biomass and fossil fuelled boilers, when it is desired to give priority to one type of heat source, again significant problems are shown to occur.[11]

The assumptions made are:

— The boiler pumps for both the biomass boiler and the fossil fuelled are fixed speed;

— The fossil fuelled boiler is controlled on flow temperature. On a modulating[12] boiler this will cause the output to reduce as the flow temperature is satisfied, while on a boiler fitted with a hi-lo burner the burner will stage based on flow temperature.

— The pump flowrates are determined by the each boiler's output rating at the design temperature drop across the load circuit using equation 7.1.

— The design temperature drop across each boiler can be different the same.

Unlike parallel connected systems the fossil fuelled boiler pump operates continuously irrespective of whether an output from the fossil fuelled boiler is required. If $P_{load} \leq P_{bb}$ and $T_{bb} = T_{mr}$ the full output of the biomass system is

[11] As with parallel connected systems the analysis presented here also applies to the parallel connection of any renewable heat source to fossil fuelled boilers including heat pumps, CHP units, geothermal sources and solar thermal systems. None of these other renewable energy sources are considered further in this manual.

[12] The term modulating boiler refers to one which has a modulating burner capable of continuously variable output from the boiler's minimum output up to 100% of its rated power output.

available: this can occur only if $Q_{bb} = Q_{ffb}$, i.e. if the full load flow passes through the biomass boiler. This is analogous to the parallel connected system described in Section 7.1. In this situation a signal from the boilerhouse output heat meter is used to disable the fossil fuelled boiler but not its pump. If these conditions are not met:

— If $P_{load} > P_{Rbb}$ the biomass boiler is unable to supply the full load demand and the fossil fuelled boiler is enabled.

— If $Q_{ffb} > Q_{bb}$, irrespective of whether $P_{load} > P_{Rbb}$, flow temperature dilution occurs at the point where the flow from the biomass boiler is injected into the primary return, marked as the biomass flow injection point on the schematic.

Notes on the schematic diagram:

— A hydronic isolator is shown, rather than multiple primary connections onto a low loss header, because it provides a single point of connection to allow a boilerhouse output heat meter to be connected;

— The drawing shows just one fossil fuelled boiler, but it could be configured as one or more boilers connected in parallel.

— The load pump can be one or more pumps on one or more secondary circuits each connected across the secondary of the hydronic isolator.

7.3.1 Analysis of typical series connected systems

The analysis of this arrangement produces the following equations created using nodal analysis. The power balance at the biomass flow injection point is:

$$(Q_{ffb} - Q_{bb}) \times T_{lr} + Q_{bb} \times T_{bb} - Q_{ffb} \times T_{mr} = 0 \quad (7.3)$$

rearranging for T_{mr} gives:

$$T_{mr} = \frac{(Q_{ffb} - Q_{bb}) \times T_{lr} + Q_{bb} \times T_{bb}}{Q_{bb}} \quad (7.4)$$

From this it can be seen that if the biomass boiler and primary circuit flow rates are the same $T_{mr} = T_{bb}$.

Analysing the power supplied split between the biomass boiler and the fossil fuelled boiler, the load return temperature:

$$T_{lr} = T_f - \frac{P_{load}}{Q_{ffb} \times c_p} \quad (7.5)$$

The load demand:

$$P_{load} = Q_{ffb} \times c_p \times (T_f - T_{lr}) \quad (7.6)$$

The power supplied by the biomass boiler up to the power output limit of the biomass boiler:

$$P_{bb} = Q_{bb} \times c_p \times (T_f - T_{lr}) \quad (7.7)$$

The power supplied by the fossil boiler:

$$P_{ffb} = Q_{ffb} \times c_p \times (T_f - T_{mr}) \quad (7.8)$$

Equating equations 7.6 and 7.7 and rearranging:

$$\frac{P_{load}}{c_p \times Q_{ffb}} = \frac{P_{bb}}{c_p \times Q_{bb}}$$

which gives:

$$P_{bb} = \frac{P_{load} \times Q_{bb}}{Q_{ffb}} \quad (7.9)$$

In order to avoid the need for the fossil fuelled boiler, T_f must be equal to T_{mr}. Substituting T_f for T_{mr} in equation 7.3:

$$T_{mr} = \frac{(Q_{ffb} - Q_{bb}) \times T_{lr} + Q_{bb} \times T_{bb}}{Q_{bb}} = T_f \quad (7.10)$$

and rearranging for T_{bb} produces:

$$T_{bb} = \frac{Q_{ffb} \times T_f - (Q_{ffb} - Q_{bb}) \times T_{lr}}{Q_{bb}} \quad (7.11)$$

This is the minimum flow temperature required from the biomass boiler in order to achieve the maximum output from biomass up to the limit of the biomass boiler's output rating without the need for addition heat from the fossil fuelled boiler.

Referring to Figure 7.5, the upper graph shows the effect on the biomass boiler output of altering the ratio of primary circuit flow rate (Q_{ffb}) to biomass flow rate (Q_{bb}) for a 199 kW biomass boiler and a 500 kW fossil fuelled boiler. The graph was generated by setting the fossil fuelled boiler ΔT to 10 °C and varying the biomass boiler ΔT from 5–20 °C in 5 °C steps to produce flow rate ratios of 1.25 to 5 respectively. For example, with a 199 kW biomass boiler operating at a ΔT of 5 °C[13] the flow rate through the boiler is 9.52 kg/s whereas a 500 kW fossil fuelled boiler operating at a ΔT of 10 °C has a flow rate of 11.9 kg/s giving rise to a flow rate ratio of 1.25:1.

The lower graph in Figure 7.5 shows the biomass boiler flow temperature required to ensure all of the power produced by the biomass boiler is used up to its rated output for a range of primary circuit flow rate (Q_{ffb}) to biomass flow rate (Q_{bb}) for a the same combination of biomass and fossil fuelled boilers. The same combination of biomass boiler ΔT and flow rate ratios were used as for the upper graph for a system setpoint flow temperature of 80 °C. The lower graph also shows the typical maximum permitted operating flow temperature for biomass boilers of 90 °C.[14]

[13] Many biomass boilers can be set to operate at differential temperatures of 5 °C to 20 °C, with 5 °C being the lowest permissible ΔT to avoid excessive flow rates and pressure drops through a boiler.

[14] The maximum operating temperature for the widely installed biomass boilers is 90 °C. Biomass boilers able to operate at higher flow temperatures are available at higher cost. Furthermore, the Pressure Systems Regulations may apply when operating at higher temperatures because of the greater system pressures required to prevent the formation of flash steam.

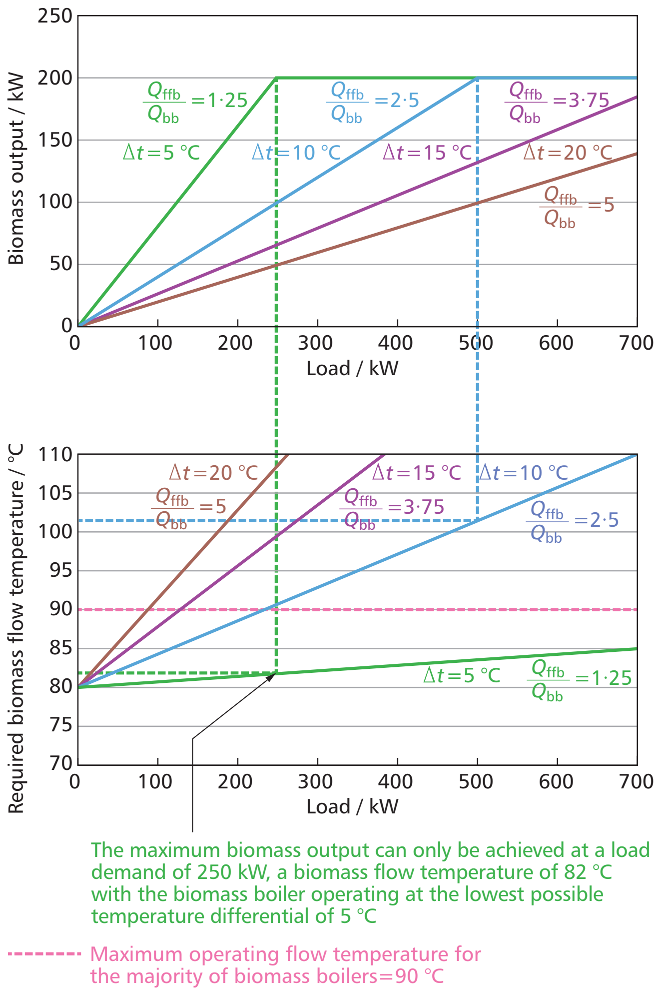


Figure 7.5 Biomass boiler output vs biomass boiler flow rates and boiler flow temperatures for a typical series connected system

Like typical parallel connected systems, typical series connected systems have their limitations, but they also have some advantages over typical parallel systems; these limitations and advantages are most easily understood by considering this example.

7.3.2 Example calculation for a typical series arrangement

The following example illustrates the performance of the optimum connection of a biomass boiler in a system incorporating fossil fuelled boilers based on the series hydronic arrangement above. In this example a 199 kW biomass boiler is connected in series with a 500 kW fossil fuelled boiler – which is also a typical current arrangement used to secure the highest RHI tariff for the biomass boiler. With ideal control of both the enabling and modulation of the fossil fuelled boiler the following output profile for the biomass boiler can, theoretically, be achieved. The reality of less-than-ideal control of the fossil fuelled boilers, and in particular the absence of modulation when hi-lo burners are in use, could result in much lower utilisation of the biomass boiler than shown in the graph below. In this particular example output from the fossil fuelled boiler is required to meet the load in addition to the biomass boiler while the load is still within the biomass boiler's output range of 199 kW.

Figure 7.5 shows biomass boiler output for different ratios of primary circuit to biomass boiler flow rates with, below, the required biomass boiler flow temperature to achieve optimum biomass boiler utilisation.

Referring to Figure 7.5:

— The permissible operating region for the biomass boiler is significantly constrained if high biomass utilisation is to be achieved. The green line on the upper graph shows that, with the combination of 199 kW biomass boiler operating at a ΔT = 5 °C and a 500 kW fossil fuelled boiler operating at a ΔT = 10 °C (resulting in a flow rate ratio of 1.25:1), the biomass boiler cannot produce its full output until the load demand exceeds 251 kW. Following the dotted green line down to the graph below until it intercepts the corresponding sold green line shows the required biomass flow temperature vs load demand, then following the next dotted green line to the left shows that for a flow rate ratio of 1.25:1 the biomass boiler needs to operate at a flow temperature of 81.8 °C.

— If the flow rate ratio is set to 2.5:1, as shown on the blue lines on the graphs, it can be seen that the maximum output achievable from the biomass boiler is only 92 kW at a flow temperature of 89.9 °C for a load demand of 230 kW.

— At flow rate ratios greater than about 2:1, high biomass boiler utilisation is not possible without operating at excessive biomass boiler flow temperatures.

— A series connected fossil fuelled boiler which is permanently in circuit results in high parasitic losses and is energy inefficient, and this configuration is not permitted by the Technical Standards in Scotland. Good practice design requires thermal isolation of this boiler which can be achieved using a controlled bypass.

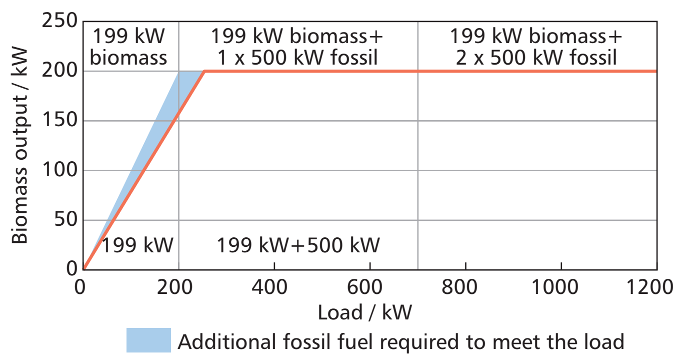


Figure 7.6 Typical series connected boilers showing region where fossil fuel use is required

For this example, two 500 kW fossil fuelled boilers are connected in series with a 199 kW biomass boiler. Fossil fuel consumption will occur in the shaded region because the biomass boiler cannot deliver it full output until the load demand is in excess of 251 kW. The assumptions made are:

— Each fossil fuelled boiler is not enabled until required by the load demand – i.e. ideal control.

— Each boiler's pump is not switched on until the associated boiler is enabled.

— Each fossil fuelled boiler is modulated exactly to meet the additional load demand.

— No unwanted forward or return flow will occur through disabled fossil fuelled boilers.

— The biomass boiler can produce an output from zero to its maximum power. In reality this is unlikely to be the case because of its minimum turndown output, typically 28–35%. Once switched off or in slumber mode the biomass boiler will be very slow to respond resulting in a fossil fuelled boiler being enabled to meet the load demand.

The complexity of designing a series connected system is such that designers need to carry out a suitable analysis in order to achieve the highest possible biomass boiler utilisation within permissible design and operating parameters. The above equations allow designers to analyse proposed designs for competent operation.

7.3.3 Advantages of the typical series connected arrangement over the typical parallel connected arrangement

The advantages of typical series connected systems over typical parallel connected systems are:

— Operating the biomass and fossil fuelled boilers at different ΔTs can allow both boilers to be set to operate at the same flow temperature and the same flow rate. For example, with a load circuit design ΔT of 20 °C, and with a 500 kW fossil fuelled boiler designed to operate at the same ΔT, operating the biomass boiler at a ΔT of 8 °C would result in a flow rate ratio of 1:1 and allow the biomass boiler to operate at a flow temperature of 80 °C.

— The flow rate ratio can be minimised by setting the greatest possible fossil fuelled boiler ΔT and operating the biomass boiler at no more than 5 °C ΔT.

— Unlike the typical parallel connected system, where the ΔT across both the biomass and fossil fuelled boilers has to be the same, the ability to operate series connected boilers at different ΔTs provides greater scope for the system designer to achieve higher utilisation of the biomass boiler.

— 100% utilisation of the biomass boiler is possible with a flow rate ratio of 1:1, unlike typical parallel connected systems where a 1:1 flow rate ratio can result in a biomass boiler utilisation of only 50% as shown in Figure 7.1.

— The flow rate ratio can also be minimised by selecting a larger biomass boiler while taking into account the advice on boiler sizing contained in Chapter 6.

— The fossil fuelled boiler will not fire if the temperature of the water arriving at its return connection is at or above its flow setpoint temperature. This means that heat load control of the biomass and fossil fuelled boilers using heat meter outputs is not required for a typical series connected system.

— If a biomass system is to be operated at a higher temperature or pressure than the primary loop, a plate heat exchanger can be inserted where the biomass system injects into the primary loop. The plate heat exchanger must be rated for the biomass boiler output and the chosen biomass system flow rate.

— Typically, 80% of a building's energy consumption occurs within 40% of the peak load. Comparing Figures 7.2 and 7.6 which show boiler capacity to meet a peak load of 1200 kW, the 40% point is 480 kW. Significantly less fossil fuel would be required to meet the load in the region up to 480 kW using series connected fossil fuel boilers than would be required using parallel connected fossil fuel boilers for the typical arrangements.

7.4 Preferred series connected system

The hydronic configuration shown in Figure 7.7, together with its accompanying controls description, is offered as the preferred solution for connecting a biomass boiler in series with fossil fuelled boilers. This configuration, when adequately controlled, overcomes all of the limitations identified for the typical series connected system and, as such, offers the best overall solution for integrating biomass boiler systems into boilerhouses.

The key features of this preferred configuration and the associated control arrangements are:

— Unlike the typical series connected arrangement, where the biomass system injects into the primary loop, with this connectivity the biomass system is in the primary loop while the fossil fuelled boiler injects into the primary loop afterwards. This gives priority to the biomass system and would be used for new build systems whereas the typical series connectivity is more suited for retrofitting to existing boilerhouses.

— The biomass boiler is able to operate continuously thus maintaining the combustion chamber at the minimum temperature required for efficient combustion.

— The biomass boiler is able to operate within its modulating range charging the thermal store. This further optimises the biomass boiler efficiency by preventing the boiler from switching off (automatic ignition boiler) or dropping into slumber mode (manual ignition boiler).

— The thermal store helps to ensure that as much heat as possible is generated from the biomass boiler and stored for future use.

— A biomass boiler rated at significantly below the peak load can, together with the thermal store, meet peak loads without the need for fossil fuelled boiler support.

— Optimisation of the biomass boiler's Utilisation Factor by operating a small biomass boiler for extended periods into a large thermal store.

— The ability to operate the biomass system at a higher temperature than the load circuits or fossil fuelled boiler to allow greater energy storage with

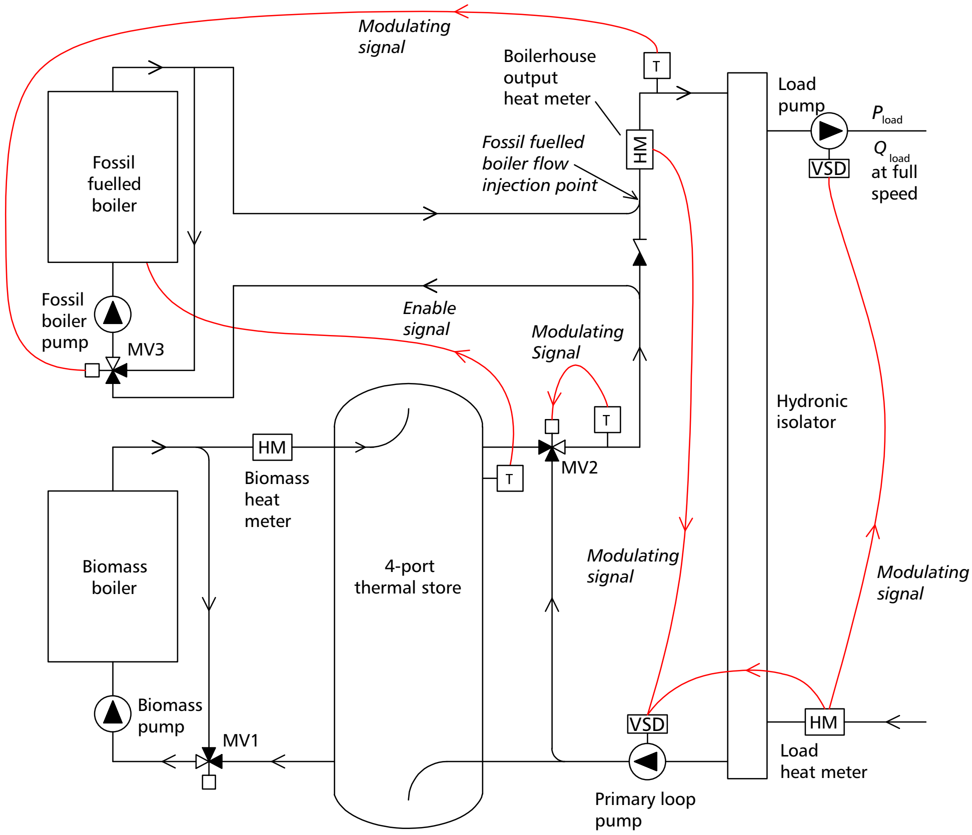


Figure 7.7 Indicative hydronic arrangement for the preferred series connected system

the thermal store or, conversely, a smaller thermal store for a given energy storage requirement.

— The provision of a signal from a temperature sensor at the top of the thermal store to disable the fossil fuelled boiler for as long as heat is available in the thermal store.

— The thermal store is designed to accept the full load flow rate through the secondary side of the store to ensure that the biomass boiler in combination with the thermal store has the opportunity to satisfy the full load demand for as long as heat is available in the store.

— The thermal store can be operated at a higher temperature than the load design flow temperature, when MV2 will modulate to maintain the design flow temperature. This reduces the draw from the thermal store, reduces turbulence within the thermal store, and also reduces the speed at which the hot-cold interface moves up the store during periods of high load demand.

— The thermal store itself acts as a hydronic separator ensuring that the biomass heat meter is hydronically isolated from other equipment. This ensures it cannot be influenced by either the fossil fuelled boiler or the load circuits.

— To ensure forward flow along the hydronic separator at all times the flow rate of the primary loop pump must be 10% greater than that of the load pump. The load pump in this example will usually represent a combination of constant temperature and variable temperature load circuits.

— On constant temperature load circuits, control of the variable speed load pump is based on the temperature difference across the load to maintain the design load temperature difference under all operating conditions. This can be accomplished using a heat meter on each constant temperature load circuit.

— On variable temperature load circuits, the flow rate from the hydronic isolator is determined by the position of a 3-port compensated circuit valve (not shown), as the load pumps on these circuits are within the mixing loops.

— The flow rate of the variable speed primary loop pump can then be controlled at 10% above the total flow in the load circuits by comparing the flow meter outputs from the load and boilerhouse heat meters.

— Variable speed control of the primary loop pump, together with MV2, ensures the correct draw from the thermal store to meet the load demand whilst maintaining stratification in the store.

— An injection loop to allow just sufficient heat to be provided from the fossil fuelled boiler to meet any additional load demand beyond that provided by the biomass boiler and thermal store. The 3-port valve[15] MV3 can be modulated with a turndown of up to 50:1 to meet additional loads. Modulation of this valve is based on the primary flow temperature measured just prior to the hydronic isolator to maintain the setpoint flow temperature. Unlike parallel connected systems, it is not necessary to use a heat meter to control the output of the fossil fuelled boiler.

— The use of a high efficiency fossil fuelled boiler, rather than a condensing boiler, in a series connected system. As a biomass system should

[15] The Scottish Technical Standards require boilers to be isolated when not in use to minimise parasitic energy consumption

have priority over fossil fuelled boilers, the opportunity for condensing operation is limited to periods when the biomass system has failed and the primary loop bypasses the thermal store with MV2 fully closed. If the fossil fuelled boiler is intended to be a back-up boiler, condensing could only commence if the primary loop return temperature is below 54 °C.

— The use of a hydronic isolator[16] prevents interaction between primary and secondary pumps, and should be used for all connections. In particular when retrofitting a system to an existing plantroom with split headers, a hydronic isolator should be installed to convert that plantroom to one with hydronically separated primary and secondary circuits to facilitate the control strategies detailed above.

— A hydronic isolator also provides a single point flow connection to which a boilerhouse output heat meter can be connected.

— Note that the boilerhouse output heat meter and the load heat meter, while they will be of similar capacity, are shown on the flow and return lines respectively. They must be specified and installed on the correct lines.

— If a biomass system is to be operated at a higher temperature or pressure than the primary loop, a plate heat exchanger can be inserted where the biomass system connects into the primary loop. In this case the plate heat exchanger must be rated at the full load demand and the full load primary flow rate.

7.4.1 Biomass systems designed to meet less than the peak load

Unlike the situation with parallel connected biomass boilers designed to supply just the baseload or a proportion of the peak load, biomass systems in series connected arrangements can be designed to operate at their full output as discussed in the previous section. The reasons for designing for baseload or part load operation include limiting system capital cost, the availability of the highest rate of RHI tariffs if the biomass boiler is rated at 199 kW or less, the physical space available in a plantroom for a boiler and thermal store, and the availability of space for fuel storage.

7.4.1.1 Biomass system start-up and operation

In order to avoid fossil fuel use during system start-up the main control system, typically a BMS, should send an enable signal to the biomass boiler's own control system sufficiently ahead of an expected heat load demand that the thermal store is fully charged. With a small biomass boiler and a large thermal store this pre-start can be up to one day.

[16] Note that little publicly available design information exists on hydronic isolators. A suggested approach is: 1) the flow velocity along the isolator at maximum primary load, with no secondary load, is 0.15 m/s; 2) the flow velocity in the primary and secondary stub pipes is no more than 0.5 m/s at full load.

7.4.1.2 Automatic ignition boilers

The timing of the enable signal for an automatic ignition boiler depends on whether:

— The biomass system is being started for the first time in a heating season when the thermal store will have cooled to ambient temperature when a long pre-heat period will be required.

— The biomass system is being restarted after being shutdown for a weekend, overnight or following maintenance when a shorter pre-heat period will be required.

— The combination of biomass boiler and thermal store has been sized such that the biomass boiler has to run continuously recharging a thermal store overnight.

If it is intended that the fossil fuelled boiler is not to run on initial start-up an additional disable signal from the control system will be required (if the thermal store is cold the fossil fuelled boiler will be enabled automatically because the enable signal is based on low temperature at the top of the thermal store). The firing of the biomass boiler will be based on temperature sensors on the thermal store as described in Chapter 5. Prior to the load pump being started, for series connected arrangements the primary loop pump must operate at full speed irrespective of whether the difference between the load heat meter and the boilerhouse output heat meter is producing a difference signal to run this pump. As soon as heat from the thermal store is circulating in the primary loop the heat meters can take over control of the primary loop pump speed.

The biomass boiler itself will have a safety device to prevent overheating. This may be in the form of a safety heat exchanger fed by cold water or a temperature relief valve. In either case the boiler controls will prevent any further fuel being fed to the boiler which will shut down. A manual reset will then be required. Refer to Section 4.5.2 for details of emergency heat exchangers.

7.4.1.3 Manual ignition boilers

Manual ignition boilers are not usually enabled from a remote control system, rather a fire is set on the grate and then the boiler's own control system is switched on, the actual sequence being boiler type dependent. The boiler will need to be ignited manually at an appropriate time prior to heat being required. Thereafter:

— Once lit, the boiler will operate continuously, dropping into slumber mode when there is no demand on the boiler.

— Boiler control is usually by flow temperature operating, typically, on a 3 °C temperature differential. Whenever the flow temperature drops below its setpoint value by 3 °C the boiler comes out of slumber mode and recharges the thermal store until the setpoint flow temperature is satisfied.

— It is essential that provision is made for heat to be dissipated from the biomass boiler at all times. This will require controls coordination between the primary loop, MV2, the load pump and load circuits.

— If the thermal store temperature approaches the maximum permissible biomass boiler flow operating temperature, MV2 must open fully, the primary loop pump and load pump must operate at full speed and the load circuits must be controlled to accept heat. This is a safety critical design consideration.

Health and safety considerations
When using a manual ignition boiler, ensure that the heat generated in slumber mode can be safely dissipated under all load and operating conditions.

— The biomass boiler itself will have a safety device to prevent overheating. This may be in the form of a safety heat exchanger fed by cold water or a temperature relief valve. In either case the boiler controls will prevent any further fuel being fed to the boiler which will ultimately cause the firebed to burn out. A manual restart will then be required. Refer to Section 4.5.2 for details of emergency heat exchangers.

On both types of boilers common fault signals will be generated from a variety of boiler alarm and faults.

7.5 Performance comparison of the different arrangements

The example used in the analysis of the typical parallel arrangement produced the boiler operating pattern shown in Figure 7.2 above.

The equivalent example used in the analysis of the typical series arrangement produced the operating pattern shown in Figure 7.6 above.

While the examples both comprised a 199 kW biomass boiler plus two 500 kW fossil fuelled boilers, it can clearly be seen that fossil fuel use in the typical series arrangement will be significant less than that for the typical parallel arrangement. However, both the preferred parallel and series arrangements can be designed to avoid fossil fuel use altogether resulting in the ideal biomass output profile, Figure 7.8. This performance can be achieved by sizing the biomass boiler and thermal store to provide 100% of the heating energy required at the winter heating design outside air temperature. The critical success factor is the use of a correctly sized thermal store based on sizing the biomass boiler and thermal store using the design winter day load profile for the installation being served.

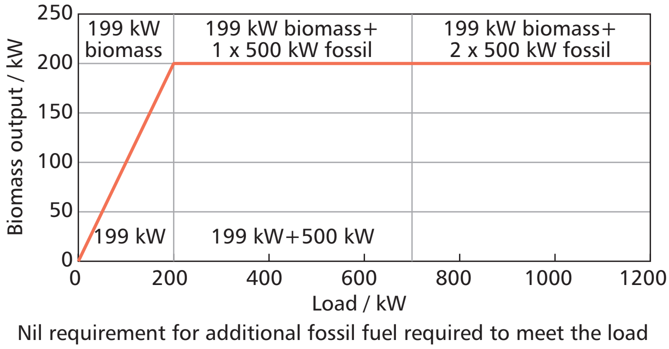


Figure 7.8 Ideal biomass boiler utilisation achieved by using either the preferred series or parallel arrangements

8 Controls, pressurisation and headers

8.1 Control systems

All biomass systems will require a minimum of two different control systems, one a bespoke system from the biomass manufacturer and the other an external system, frequently a BMS. Integration between these systems is rarely possible because biomass manufacturers are very protective of the specific and unique controls required for a particular boiler. This places a demand on the system designer to use an external system to the greatest extent possible to secure the best performance from a biomass system. In addition to the control requirements identified in Chapters 5 to 8, well-designed, integrated and commissioned control systems should collectively achieve the following:

- Maximisation of biomass system efficiency.
- Realisation of the target annual percentage of energy from the biomass system.
- Maximum utilisation of the biomass boiler.
- Maximum utilisation of thermal storage.
- Prevention of unnecessary auxiliary or back-up boiler operation.
- Safe operation.

The biomass designer must recognise the differences between fossil fuel systems and biomass systems in terms of the additional controls requirements related to the very slow response of most biomass boilers, the need for thermal storage and techniques to achieve good control of auxiliary or back-up boilers.

Commissioning of an external control system must be closely coordinated with the commissioning of the biomass boiler and its own control system. In addition to standard commissioning duties, checks for the competence of biomass specific control algorithms must be made, with proof of correct operation of thermal storage, buffer vessels and low-loss headers. Due to the slow response of biomass boilers, and time for thermal stores to heat and deplete, commissioning of the biomass operational aspects should include assessment of BMS logs under a range of thermal loads.

8.1.1 Minimum return water temperature control

Return water temperature control to the biomass boiler is accomplished by modulating the back-end valve. The designer must always be aware of the conditions required to achieve a desired flow temperature from the biomass boiler which must take account of the return water temperature and the temperature drop across the biomass boiler:

$$T_f = T_{bw} + T_r \tag{8.1}$$

where T_f is the desired flow temperature, T_{bw} is the temperature bandwidth across the biomass boiler (boiler temperature differential) at full load and T_r is the return temperature for the biomass boiler at the design condition.

T_{bw} can usually be set between 5 °C and 20 °C, with 10 °C being a common design figure. For all types of biomass boilers the selected value of T_{bw} will be achieved only when the biomass boiler is at full load; when operating at less than full load T_{bw} will be lower.

The minimum return temperature setpoint, T_{rmin}, should be set on the biomass boiler control panel as advised by the biomass boiler manufacturer for the specific fuel being used. For any biomass boiler T_{rmin} will vary with the fuel moisture content; the wetter the fuel the higher the value of T_{rmin} required. Depending on the specific biomass boiler, either the biomass boiler flow temperature or the temperature bandwidth will be set on the biomass boiler's control panel. It is important to check that the return temperature set on the biomass boiler's control panel is at least equal to T_{rmin}, i.e.:

$$T_r \geq T_{rmin} \quad \text{at all times} \tag{8.2}$$

When selecting a boiler, and also when preparing for commissioning, the designer should specify T_f, T_{bw}, T_r and T_{rmin} to ensure the biomass system operates correctly.

Decisions on the selection and setting of these parameters should not be left to the biomass contractor unless under a design and build contract, even then the designer should ensure that the design and build contractor has correctly identified the T_{rmin} required.

8.1.1.1 System design when low return water temperatures are present

Some commonly encountered situations result in low to very low return temperatures. District heating networks, and networks with commercial glasshouses, can produce low to very low return water temperatures as can instantaneous hot water generators based on plate heat exchangers. A key objective of the district heating network designer is to minimise network pipe sizes by maximising the temperature difference across the network. On district heating networks it is common for water to be returned to the boilerhouse at 55 °C or less which conflicts with the need for return temperatures greater than this for a biomass boiler. Glasshouses present a particular challenge because the return temperature from them can be as low as 30 °C even though water needs to be stored at a much higher temperature to minimise thermal storage volume.

The biomass boiler's control system will always ensure that the minimum return temperature to the boiler is maintained when the return temperature is below T_{rmin} which is achieved by recirculation within the back-end loop through modulation of the back-end valve. In this situation the biomass boiler flow temperature, T_f, will be $T_{rmin} + T_{bw}$ which may not produce a sufficiently high flow temperature. In this situation careful design is required to ensure that the biomass boiler can supply the desired minimum flow temperature. The temperature bandwidth,

T_{bw} should usually be set as high as possible on a system with a low return temperature in order to minimise the return temperature required and maximise the flow temperature available.

On systems of 1 MW and above burning wet fuel (>45%), heat recovered in a flue gas condenser can be fed into the biomass boiler return line using a heat exchanger located outside the biomass boiler's back-end loop. By this means the return temperature to the biomass boiler can be increased by up to 10 °C, but this solution is both expensive and maintenance intensive and, in the case of a wet scrubber, produces an effluent sludge requiring waste disposal.

8.1.1.2 The role of a 2-port thermal store in return temperature control of low temperature systems

When a load system has been designed for a low return temperature it is important to have a 2-port thermal store across the biomass boiler output prior to the load mixing valve in order to improve the return temperature to the biomass boiler. The explanation for this is best illustrated by means of two worked examples, one without a buffer vessel or thermal store (Figure 8.1) and the other with a thermal store (Figure 8.2) The examples are based on a 500 kW biomass boiler supplying glasshouses, with the following criteria:

- Biomass boiler rated at 500 kW
- Load circuit absorbing 500 kW
- T_f = 85 °C
- T_{bw} = 15 °C
- T_r = 70 °C
- Load flow temperature = 50 °C
- Load return temperature = 30 °C

Figure 8.1 shows the temperatures and flow rates in each part of the circuit. The heat flow in each part of the circuit is 500 kW, but the flow rate into the load mixing valve is only 2.16 kg/s because the temperature difference between the inlet to this valve and the return circuit is 55 °C. In particular note that a portion of the return water at 30 °C arrives at the back-end valve where it mixes with water from the bypass leg at 85 °C. To do this the back-end valve needs to be 73% closed.

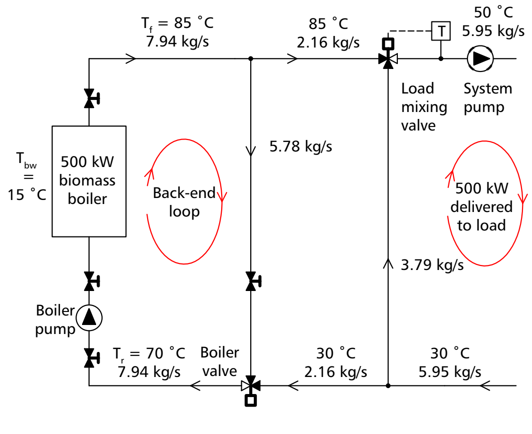


Figure 8.1 Biomass circuit without a buffer vessel or thermal store

If a 2-port thermal store is employed, as the load mixing valve operates to achieve the desired load flow temperature a back pressure will be imposed on the biomass boiler from the flow line. This diverts a proportion of the flow from the biomass boiler through the thermal store because it will present a lower hydronic resistance path to the flow from the biomass boiler than the partially closed load mixing valve. In the example in Figure 8.2 it has been assumed that at a 64% closure of the load mixing valve the back pressure would be such as to divert approximately 64% of the flow through the thermal store. Assuming the thermal store to be fully charged under the operating conditions being considered, water at 85 °C from the thermal store will mix with the return water at 30 °C to deliver a mixed return flow at 65 °C to the back-end valve. The back-end valve will now operate at 24% closure, a better operating point giving the valve greater control authority. If the biomass boiler is burning a wet fuel it will require a T_{rmin} of about 65 °C, and this method of improving the return water temperature to the back-end valve will ensure this valve can open fully should it need to do so.

This method of increasing return water temperature to the back-end valve will not work as well with a 2-port buffer vessel or a 4-port thermal store (which will usually have a volume of water acting as a buffer vessel at the bottom of the store), as both of these devices store water at a temperature lower than flow temperature.

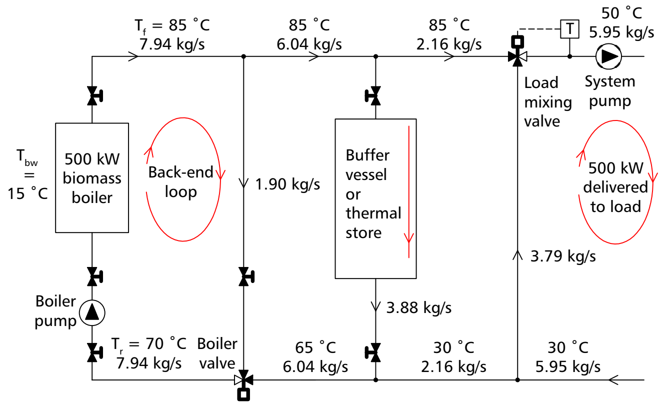


Figure 8.2 Return water temperature control using a 2-port buffer vessel

8.1.1.3 Use of a series connection condensing boiler to increase return temperature

Another way to increase circuit return temperature to the biomass boiler is to incorporate a back-up/auxiliary boiler in a series injection loop as described in Section 7.4.

8.2 Pressurisation and system isolation

8.2.1 Introduction to pressurisation regimes

The majority of heating systems encountered in building services design use either a pressurisation set with expansion vessels, or have a gravity-feed open-vented pressurisation regime, and operate at a maximum temperature of 82 °C. It is only on very large buildings with a system water content of 25 000 litres or more than anything other than a simple pressurisation set is likely to be encountered. However, the use of large thermal stores on biomass systems at higher temperatures means that water expansion volumes of greater than 800 litres are commonly encountered requiring the use different types of pressurisation system.

Gravity pressurisation from a header tank with expansion back into the tank

Many existing installations use this traditional pressurisation system while new systems are likely to use this only in a domestic setting. Issues with gravity pressurisation are heat loss from the tank, oxygenation of the heating water and pumping-over if the tank is too small.

Factors affecting the choice of pressurisation system, and whether the biomass system needs to be isolated from the load system, are:

- Biomass system operating temperatures and pressures.
- Load system operating temperatures and pressures.
- Biomass and load system water and expansion volumes.
- The type of pressurisation system on an existing load system (for retrofits).

8.2.1.1 Pressurisation set

In a conventional pressurisation set (PressSet) a pumped unit pressurises the system to a minimum cold fill pressure. As the system heats to operating pressure water expands to fill expansion vessels which operate at the same pressure as the system. The system pressure increases as the system heats up with the expansion vessels designed to accept up to about 35% of their volume (the acceptance level). A PressSet is typically used for temperatures up to 95 °C (up to 120 °C if an intermediate cooling vessel is used between the pressurisation unit and the expansion vessels), and a water expansion volume of up to 800 litres. A system pressure rise of up to 2.5 bar from the cold fill pressure can be expected depending on the expansion vessel acceptance level.

8.2.1.2 SpillPress

A SpillPress pressurisation set uses a pumped unit to pressurise the system to a minimum cold fill pressure. Once the system operating pressure has been reached further expansion water is pumped under control into expansion vessels to a much higher acceptance level than for a PressSet, and with the expansion vessels operating at higher pressure than the system operating pressure. A SpillPress can be used at temperatures up to 120 °C and for water expansion of up to 2 000 litres. The system pressure rise is less than for a PressSet, and at up to 0.5 bar a SpillPress is suitable for converting gravity systems to pressurised systems.

8.2.1.3 SpillSet

A SpillSet uses a pumped unit to pressurise the system to a minimum cold fill pressure and, once at operating pressure, spills the expansion water into a covered spill tank operating at atmospheric pressure. As the system cools down, water from the spill tank is pumped back into the system to maintain the minimum system pressure. A SpillSet can be used for temperatures up to 120 °C and for water expansion up to 20 000 litres. The disadvantages of SpillSets are that the expansion water cools down in the spill tank losing heat and reducing system efficiency while also absorbing oxygen from the air. Hence, a SpillSet should be used only if absolutely essential and then with a double layer ball blanket on top of the water in the spill tank to minimise oxygen uptake. The system pressure rise above cold fill pressure can be negligible.

8.2.2 Flash margins and maximum temperature

In order to maintain an adequate flash margin on systems operating above the traditional 82 °C, the system cold fill and operating pressures must be increased as the design operating temperature is increased. Unless unavoidable, the maximum design operating temperature should be limited to 110 °C to avoid the system falling within the remit of the Pressure Systems Safety Regulations 2000 which covers systems operating at 120 °C and above: a system operating at 110 °C could reach 120 °C in the event of a sudden system depressurisation.

8.2.3 Retrofitting a biomass system

When retrofitting a biomass system to an existing building, load process system or district heating system it is crucially important not to upset the hydronic balance or to over-pressurise the existing system. There are particular considerations when connecting to gravity pressurised systems, and great care must be taken if converting such a system to a pressurised one. The flow chart at Figure 8.3 is designed to assist with the retrofitting of a biomass system operating at a maximum of 90 °C to a load system also operating at a maximum of 90 °C, identifying when the biomass system needs to be isolated from the load system using a heat exchanger. Similar considerations apply for biomass and/or load systems operating at higher temperatures and pressures.

It is essential to flush existing load systems thoroughly before connecting a biomass system as a retrofit installation. Failure to do so, particularly if using a heat exchanger for an indirect connection, could result in total system failure.

8.2.4 Isolation of the biomass system from the load system

There are several reasons for using a heat exchanger to isolate the biomass system from the load system on both new build and retrofit installations. Plate heat exchangers are now commonly used when:

- The biomass and load system operating temperatures and/or pressures are different.
- The expansion volume on the biomass system is too great for a directly connected biomass and load system without a significant upgrade to the existing pressurisation system.

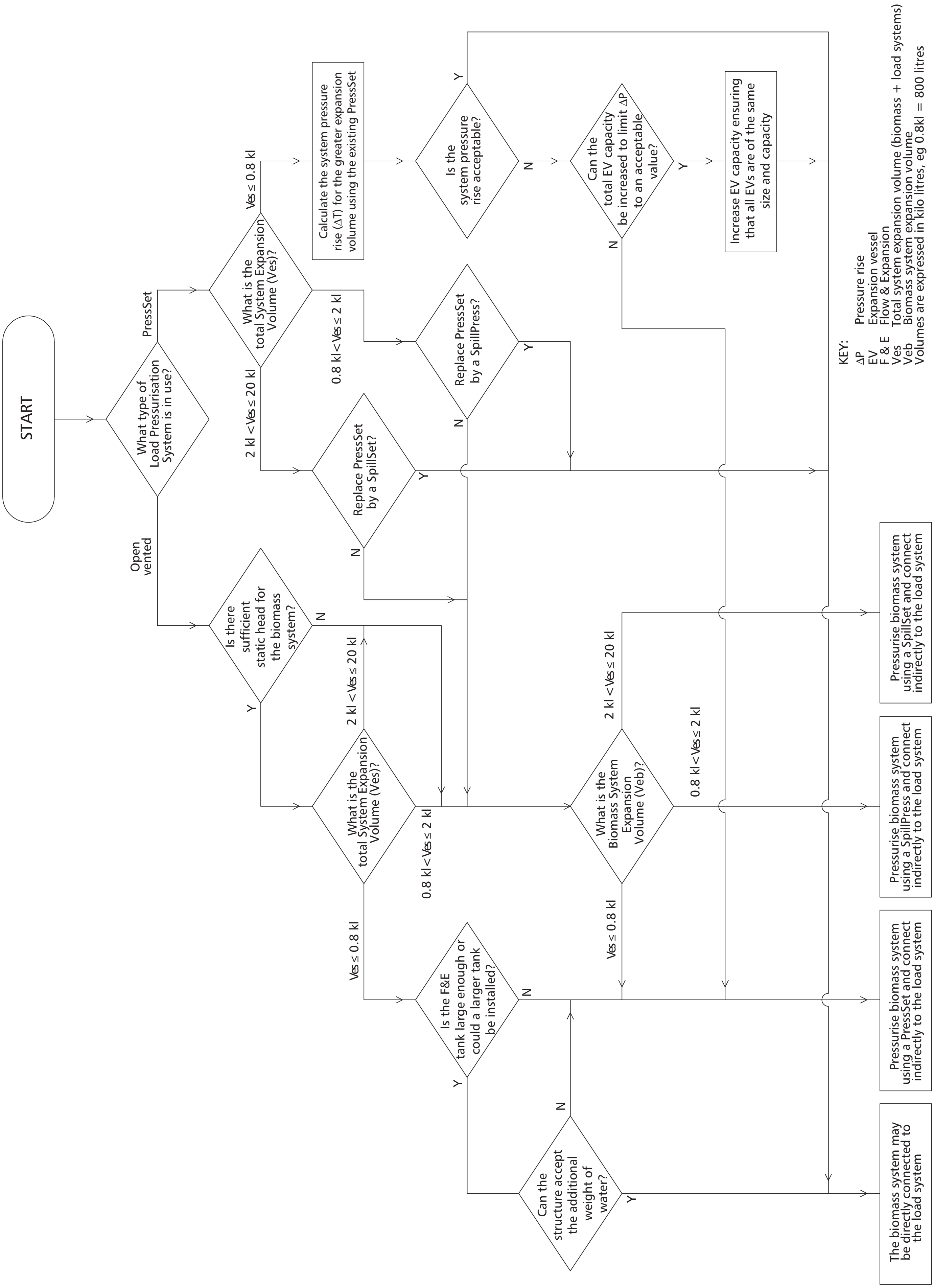


Figure 8.3 Pressurisation system selection flowchart for low temperature hot water systems

- It is important that a failure of the biomass system does not affect the operation of back-up fossil fuel systems and/or load systems.
- A responsibility demarcation between a biomass system and other heat producing equipment is required.
- Isolation is required between a biomass district heating system and the load buildings or systems.

When retrofitting a biomass system a simple method of connection is to remove one existing boiler and replace it by a plate heat exchanger. If the hydronic balance of the existing load system is not to be disturbed the pressure loss on the secondary side of the plate heat exchanger must match the pressure loss of the boiler which has been removed, and the design temperature drop must be the same as that for the existing load system.

8.2.4.1 The use of heat exchangers when biomass system temperature is greater than load system temperature

In order to minimise the size of thermal storage required the biomass system should be operated at higher temperature than the load system with the required outlet temperature from the thermal store being achieved by using a load mixing valve as described in Section 7.4. Should this lead to the biomass system having to operate at a higher pressure than the load system it is usually necessary to separate the biomass from the load using a plate heat exchanger. In this case the thermal mixing valve should be controlled by a temperature sensor on the secondary flow from the plate heat exchanger to ensure that the design flow temperature on the load system is not exceeded. Where the biomass system temperature is much higher than the load system temperature a direct acting safety valve may also be required on the secondary flow in the event of a heat exchanger internal failure.

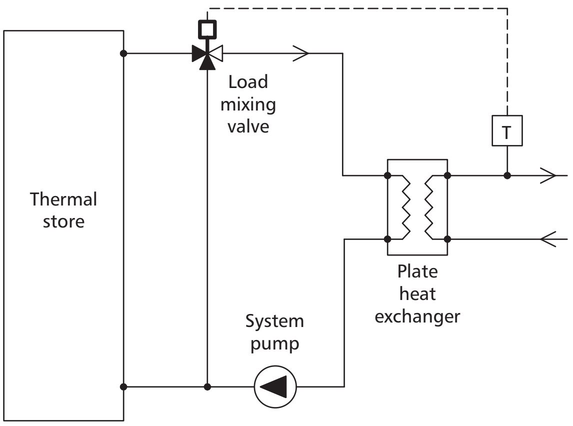


Figure 8.4 Plate heat exchanger for biomass system physical isolation

8.2.4.2 Counter-flow and parallel flow heat exchangers

Plate heat exchangers are usually designed to operate as counterflow devices in which case there is a temperature drop between the primary and secondary flows and a temperature rise between the secondary and primary returns. While heat exchangers can be designed for temperature drops of as little as 1 °C from primary flow to secondary flow and rises of 1 °C from secondary return to primary return, this would result in very large and very expensive heat exchangers. Pragmatic values are 2 to 3 °C on both the flow and return sides. This is not to be confused with the system temperature differential which would normally be a minimum of 11 °C or 20 °C for more recent circuits. When specifying heat exchangers consideration must be given to the minimum return temperature to the thermal store as a large temperature rise across the heat exchanger on the return side will reduce the effective storage capacity of the thermal store when using a counter flow heat exchanger. This problem can be overcome using parallel flow heat exchangers, but again this can result in large and expensive units.

Figure 8.5 shows the pattern of temperature drops and rises across a counterflow heat exchanger.

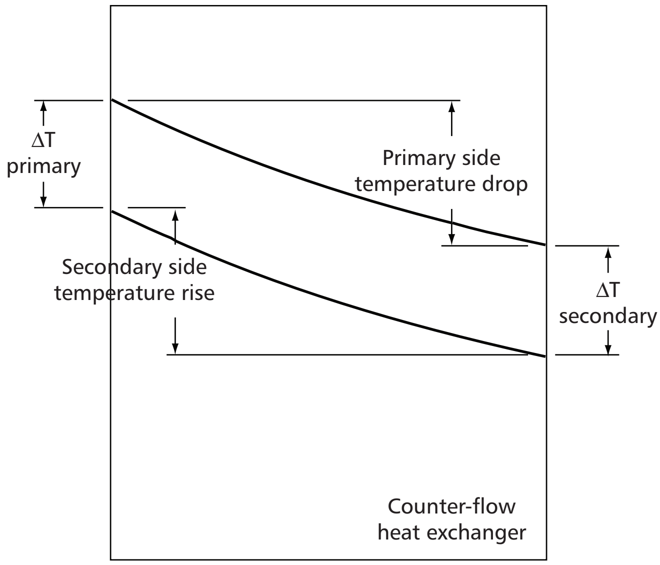


Figure 8.5 Temperature drops and rises in a counterflow heat exchanger

Note that a temperature rise occurs between the secondary return and the primary return which will increase the temperature at the bottom of the thermal store. If the return side temperature rise is too large the heat storage capacity of the thermal store could be reduced significantly. This problem can be addressed by using a parallel flow heat exchanger, but it results in a physically larger and more expensive heat exchanger.

8.3 Low loss headers

8.3.1 Historical background

Low loss headers, often referred to as common headers, are advocated as design best practice because they enable boilers to be controlled in their own constant flowrate circuit while flowrates in load circuits vary. The preferred hydronic circuit arrangements in CIBSE Guides B and H show boilers and load circuits connected by a low loss header. While the principles of hydronic separation between primary and secondary circuits were published in the USA in the 1950s, most of the current advice on low loss header design is contained in boiler manufacturers' literature because the use of a low loss header is essential when connecting multiple boilers to a primary circuit.

The principal function of a low loss header is to provide hydronic isolation between primary circuits (containing heat generators) and secondary (load) circuits. Water will flow in a closed circuit only if there is a pressure difference across the circuit; this is usually created by a pump, but can also be produced by a temperature difference across the circuit (e.g. in gravity heating).

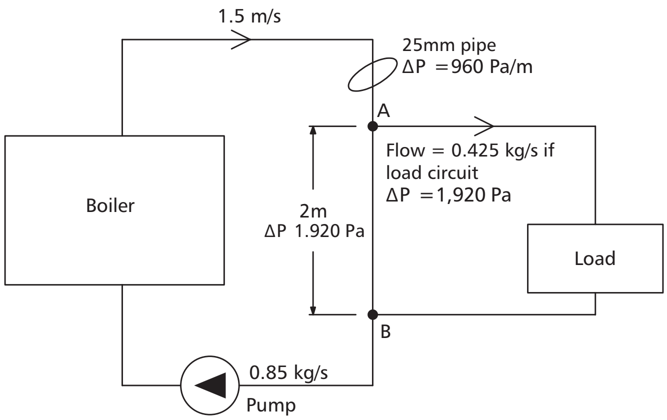


Figure 8.6 Significant induced flow in a load circuit

Consider the circuit above comprising a boiler and pump in a primary circuit, and a secondary circuit attached across the primary pipe. If the primary circuit has a flow rate of 0.85 kg/s at a velocity of 1.5 m/s in a 25 mm pipe the pressure loss in the circuit will be 960 Pa per metre length of primary pipe (ignoring bends and fittings). If the secondary circuit connection points A and B are 2 m apart a pressure difference of 1 920 Pa will appear across the secondary (load) circuit. Then, if the pressure loss in the secondary circuit is also 1 920 Pa, 50% of the flow will pass through the load. However, if points A and B are practicably close together, say 100 mm apart, the pressure difference across the secondary circuit will be only 96 Pa producing much less flow in the load circuit and a pump will now be required to produce the required flow in the secondary circuit.

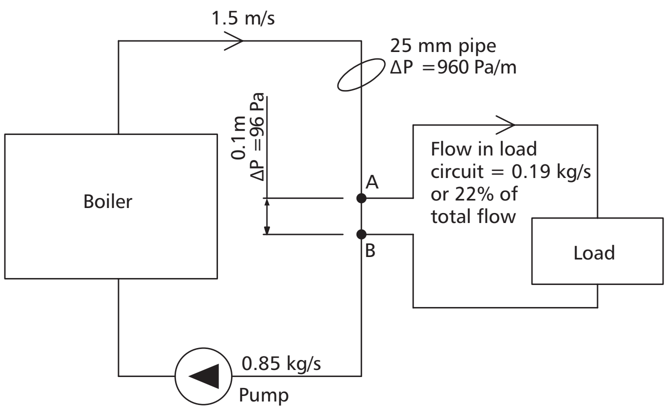


Figure 8.7 Reduced unwanted flow by placing flow and return connections close together

This configuration was the basis of all the early primary-secondary pumping originating in the USA but, as can be seen, even with the secondary flow and return pipes very close together, an unwanted flow of 5% of the primary flow can still be produced in the load circuit in this example. A low loss header, perhaps better referred to as a 'low pressure loss header', achieves hydronic isolation by reducing the pressure loss along the header to a very low value, and this is the basis of low loss header designs used in the UK.

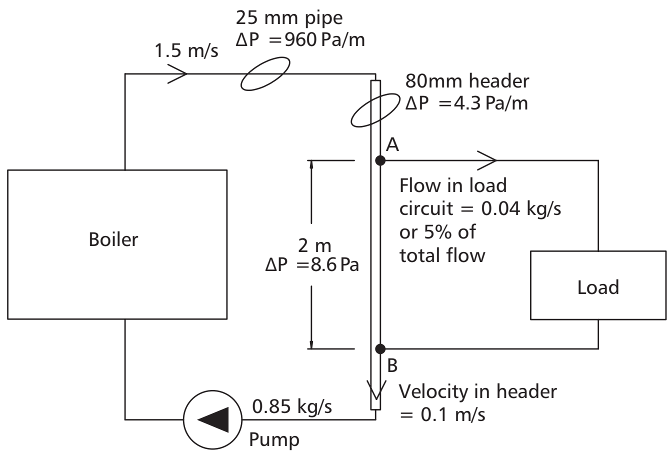


Figure 8.8 Use of a low loss header to reduce unwanted flow in the load

Above is the same circuit but with an 80 mm header which reduces the pressure drop to 4.3 Pa/m at a flow velocity of 0.16 m/s. With the secondary circuit connections again spaced 2 m apart, the unwanted flow in the load circuit is now just 0.4% of the primary flow. If the header diameter is selected on the basis of a maximum flow velocity of 0.2 m/s at full load it results in a header diameter typically 3 times that of the largest pipe connected to the header.

An immediate consequence of low flow velocity in the header is the potential for sludge and debris to collect in the header. For this reason a low loss header should always be mounted vertically with a sludge trap and drain cock at the bottom as shown in Figure 8.9.

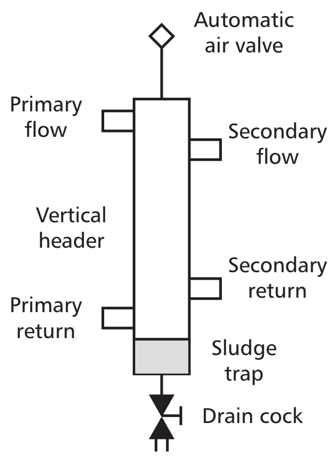


Figure 8.9 Essential components of a vertical low loss header

A vertical header will often produce a high point in the system, so an automatic air valve should be installed on top of the header. The lowest connection point on the header must be above the level at which sludge collects.

8.3.2 Header length and separation distance between circuits

An aspect of low loss header design on which limited information is available is how to determine the overall length of the header and the spacing between connections onto the header. Many boiler manufacturers provide guidance in relation to these aspects of header design for their own boilers, and some general rules inferred from their data are:

— The greater the output of the boilers, the larger the header diameter and the longer the header needs to be.

— The greater the system design temperature drop, the lower the flow rate, the smaller the header diameter and the shorter the header.

— The greater the total load, the more widely spaced the secondary connections need to be.

— For a constant flow temperature system on the load side the secondary connections should be inside the primary connections.

— For a constant return temperature system on the load side the secondary flow connection should be above the primary flow connection.

The majority of boiler manufacturers recommend a single pair of primary connections and a single pair of secondary connections, with the multiple boilers connected in reverse return and separate flow and return headers connected to the secondary ports on the low loss header as shown in Figure 8.9. While this satisfies the boiler manufacturer's requirement to provide hydronic separation between primary and secondary circuits, this approach does not allow the connection of an additional heat source such as a biomass boiler or heat pump on the primary side, nor the use of multiple connections on the secondary side to circuits operating at different flow temperatures. Boiler manufacturers' installation guides mostly show load circuits connected as shown in Figure 8.10.

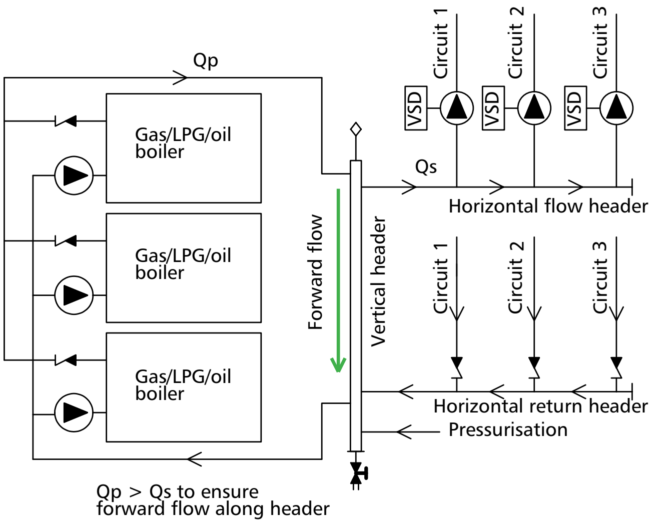


Figure 8.10 Boiler manufacturers' preferred low loss header connections

Separate flow and return headers are connected to the ports on the secondary side of the low loss header, and not along the header itself. This allows a relatively short low loss header to be mounted vertically while the flow and return headers can be mounted horizontally. However, UK design practice is to allow multiple primary and secondary connections as shown in Figures 8.11–8.13 in the following sections.

8.3.3 Constant flow temperature vs constant return temperature

The direction of water flow along the header depends on the ratio of primary flowrate (Q_p) to secondary flowrate (Q_s). If $Q_p > Q_s$ flow will be in the forward direction, Figure 8.11.

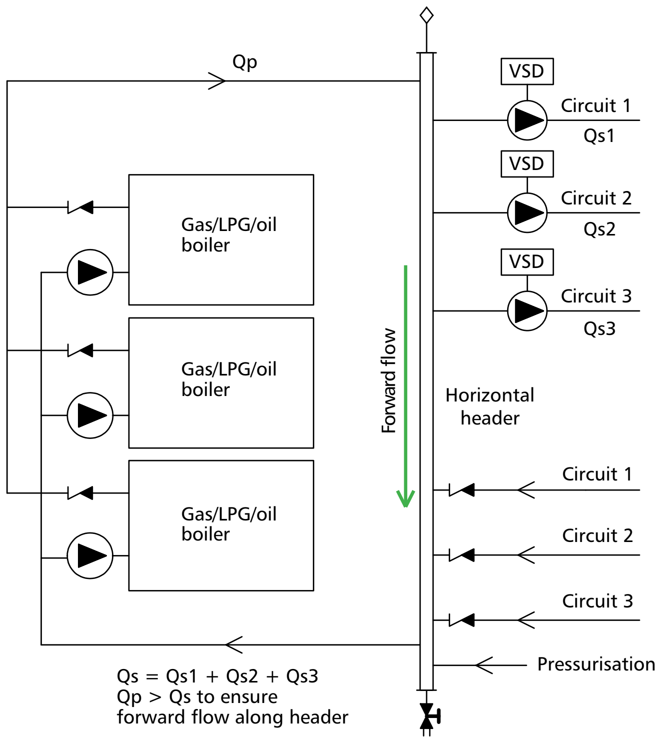


Figure 8.11 Forward flow when total primary flowrate > total secondary flowrate

The majority of designs require water to arrive at each secondary circuit at the same temperature it has left the boiler(s), i.e. at a constant flow temperature, which, in turn, requires $Q_p > Q_s$ under all operating conditions to ensure reverse flow, and the resulting flow temperature dilution, cannot occur. Three individually pumped boilers are shown which, operated in sequence, should achieve an overall turndown of up to 12:1. Hence, to satisfy the condition $Q_p > Q_s$ at low loads, flow modulation of the secondary circuits is required with an overall turndown ratio of at least this value. If all, or the majority, of the secondary flow is on a single constant temperature (CT) circuit this will require both large and small capacity variable speed secondary pumpsets in parallel because the best available turndown on a variable speed pump is 10:1. On variable temperature secondary circuits the mixing valve will achieve the necessary modulation. Splitting large CT secondary circuits into several smaller pumped circuits, each fitted with a variable speed pump, can avoid the cost and complexity of large parallel pumpsets on a single circuit, and provide zoning and better overall system control. That $Q_p > Q_s$ at all times is particularly important when multiple secondary circuits are connected because partial reverse flow along the header can occur diluting the flow temperature of those secondary circuits lower down on the header, Figure 8.12.

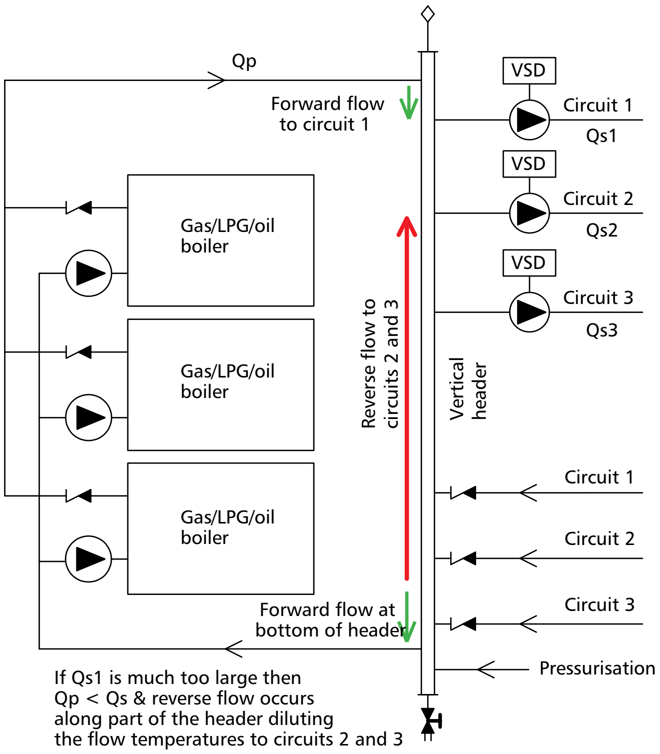


Figure 8.12 Unintended partial reverse flow when total secondary flowrate > total primary flowrate

When $Q_p > Q_s$ the mixed return temperature to the boilers at the bottom of the header will vary depending on load, but if a fixed, and low, return temperature is required, e.g. for condensing boilers, $Q_s > Q_p$ at all times and the flow along the header will be in the reverse direction to achieve a constant return temperature, Figure 8.13.

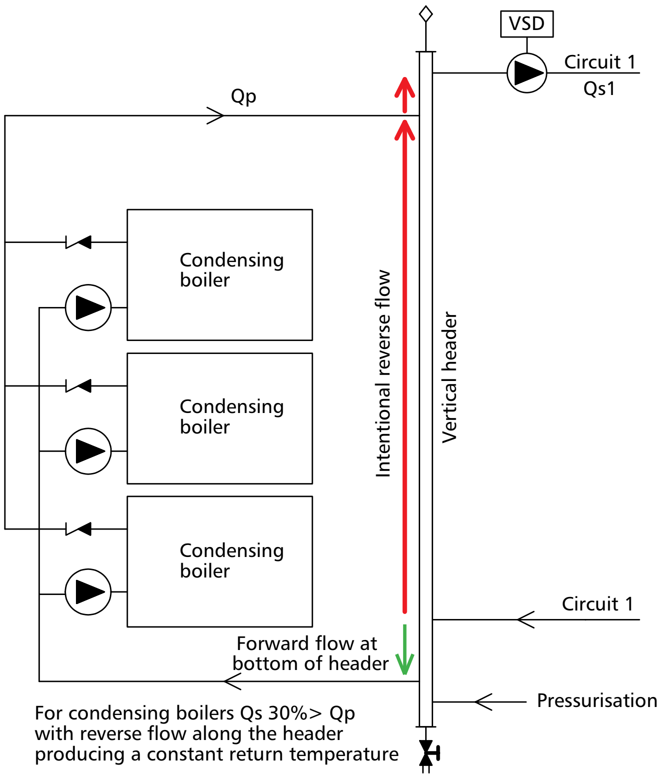


Figure 8.13 Design to achieve a constant return temperature

Note that the secondary connection in this sketch has the secondary flow take-off at a position higher than the primary flow connection making the primary flow connection the point at which mixing between primary flow and secondary return occurs. To achieve continuous condensing operation in condensing boilers the return temperature must be below the minimum temperature required for condensing to commence (54 °C at 10% excess air) and be maintained at or below this value at all times, while 90% latent heat recovery does not occur until the return temperature is 34 °C. The flow temperature at the secondary circuits will be diluted by the recirculating flow along the header and system designer needs to take account of this. The secondary flow mixed circuit temperature can be calculated by nodal analysis, as can temperatures in any low loss header system whether constant flow or constant return temperature. One condensing boiler manufacturer recommends that Q_s should be 30% greater than Q_p at full load.

A measure sometimes employed to avoid reverse flow along a low loss header is to insert a non-return in the middle of the header between the last secondary circuit flow take-off and the first secondary circuit return, Figure 8.14.

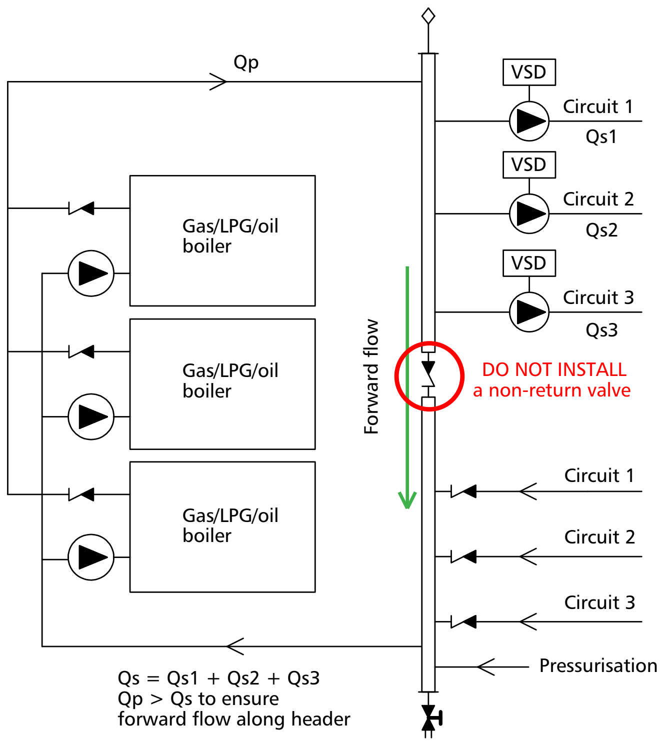


Figure 8.14 Inappropriate use of a non-return valve converts a low loss header to a split header

Unfortunately this does not produce a sound engineering solution as the use of such a non-return valve is used a substitute for good design and circuit control. The result is, effectively, to split the header back into separate flow and return headers. If the header is intended to operate at a constant flow temperature and $Q_p < Q_s$, the excess secondary flow will be directed back to the boilers causing the very primary-secondary flow interactions the low loss header was supposed to avoid.

Figures 7.3 and 7.7 in the previous chapter show the preferred configurations for parallel and series connection of a biomass boiler and fossil fuel boiler on the primary side of the low loss header. Note the use of a 4-port device (thermal store or buffer vessel) to maximise the energy available from the biomass boiler, provide a control signal to hold-off fossil fuel boilers when heat is available in the thermal store/buffer vessel, and to provide hydronic separation between the low loss header and the biomass heat meter. Note that heat meters are not to be positioned at the highest or lowest points of a circuit, nor close to pump inlets or partly opened valves to minimise heat metering errors.

8.3.4 Low loss header system pressurisation

In order to prevent unintended primary-primary, primary-secondary or secondary-secondary circuit interactions, no point on the header should be at positive pressure with respect to any other point on the header by more than a few Pa. To achieve this the header should be designed as the neutral point of the hydronic circuit with system pressurisation connected near the bottom of the header above the sludge trap as shown in the previous figures. The inlet of every pump should be connected to the header which places them on the return to boilers and on the flow to each secondary circuit. Placing pumps in other than this configuration will result in unintended and unwanted circulation between circuits with unpredictable, and potentially disastrous, consequences.

8.3.4.1 Low-loss header design rules

Key to understanding how to design low loss headers is to define what the design needs to achieve and then to select the most appropriate header configuration. The key considerations include:

— Is the system to be designed for constant flow temperature or constant return temperature?

— Do all of the load circuits operate at the same temperature, or is there a mix of higher temperature (e.g. AHU and DHW calorifier coils) and lower temperature (e.g. underfloor heating and oversized radiators) circuits?

— Are multiple boilers to be used on the primary side?

— Is a biomass boiler to be included in the boiler mix?

— What turndown ratio will result on the primary side of the header?

— Will all load circuits operate at the same temperature difference?

Close attention must be paid to low-loss header design to ensure reliable operation if it is to provide hydronic isolation between primary circuits, primary and secondary circuits and secondary circuits. A low loss header and its associated circuits should be designed as follows:

— *Rule 1: The flow along the header must always be in a forward direction.*
This requires the total of flows form the primary circuits to be greater than the total of flows of the secondary circuits at all times.

— *Rule 2: The flow velocity along the header should not exceed 0.15 m/s at full load.*
A rule of thumb to achieve this is to ensure that the diameter of the header is at least 3 times that of the largest pipe attached to the header.

— *Rule 3: The header should be mounted vertically.*
At low flow velocity any sludge in the hydronic system will accumulate in the header. The header must be mounted vertically in order to trap sludge at the bottom and be able to drain it. Any air in the system will rise to the top of the header where it can be removed with an automatic air valve.

— *Rule 4: The header should operate at neutral pressure.*
To achieve this, the suction (inlet) side of all pumps in the system should be connected directly to the header. This is consistent with good practice design where boiler pumps should pressurise boilers to avoid kettling and secondary load pumps pressurise load circuits.

— *Rule 5: System pressurisation should be directly onto the header.*
The pressurisation connection should be above the level at which sludge could collect and below the lowest primary circuit connection. This ensures that every pump is pressurised on its inlet to avoid cavitation.

— *Rule 6: Heat meters should be positioned in the flow from boilers to the low loss header while avoiding installation at the highest point in the circuit to prevent air locking and metering errors.*
Positioning in the flow avoids meters being installed on or near pump inlets, or on the inlet to a biomass boiler's back-end valve.

9 Heat metering

Heat metering is installed on biomass installations for a number of reasons:

— To measure the heat output from the biomass boiler to allow fuel supply companies to sell heat by the kW·h.

— To measure the heat output from the biomass boiler for use in calculating the direct efficiency of the boiler (by dividing the measured heat output of the boiler by the energy content of the biomass fuel consumed over the same period as the measurement).

— To meet the requirements of the Renewable Heat Incentive (RHI).

— To provide control signals to initiate the firing of back-up and auxiliary fossil fuel boilers.

— To allow billing of heat to users on heat networks.

Heat meters comprise a flow meter, temperature sensors and an electronic integrator. Flow sensors can be of the ultrasonic, impeller or turbine, fluid oscillator or magnetic-inductive type. The choice of sensor depends on the type of measurement required, in particular to take account of the viscosity of the heating medium, the mounting position, the measuring precision required and cost.

9.1 Heat metering for measurement and control

Key considerations when selecting and installing heat meters are:

— The class of meter which defines its accuracy (Class 2 being required for the RHI).

— The need for a pair of temperature sensors matched to an accuracy of 0.01 °C.

— The need for the flow meter, temperature sensors and data integrator to be matched.

— Meter calibration must be specific to the boiler system fluid – normally 'water' but can be for mixtures such as 30% glycol.

— The provision of test point temperature sensor pockets next to each heat meter temperature sensor pocket, to allow measurement of the accuracy of the temperature sensors using an external temperature measurement device for calibration and audit purposes. These must be installed in the vertical plane to allow them to be oil filled.

— The essential requirement for laminar flow through the flow meter to ensure consistent measurement accuracy. This is usually achieved by ensuring a minimum of 10 straight pipe diameters (of the same diameter as the meter inlet) before the flow meter and a minimum of 5 straight pipe diameters after the flow meter, but this is manufacturer dependent. Depending on the installation and meter manufacturer, the minimum requirement could be greater, with 20 pipe diameters before the meter.

— The provision of isolating valves either side of the meter, outside the minimum straight pipe lengths before and after the flow meter, and a bypass valve around the meter to allow removal of the meter for repair or calibration. However, while some manufacturers do not require the clearances detailed above they specify that isolating valves should not be placed close to the flow meter.

— The inclusion of 'stool pieces' (short lengths of pipe) on one side of the meter to allow meters of different physical dimensions to be installed in place of the originally installed meter.

— Ideally, installation of flow meters on vertical sections or, if not, on a horizontal section which drains to a lower point to prevent sludge build-up in the meter and in its associated pipework and valves. A flow meter should not be installed on the highest point of a circuit where air could collect.

— To achieve the necessary accuracy a water density correction calculation is carried out within the integrator, and this will be based on either the flow or the return temperature as measured by the corresponding temperature sensor. If the integrator is programmed to use the flow temperature for the density calculation the flow meter must be installed on the flow line. Similarly, if the integrator is programmed to use the return temperature for the density calculation the flow meter must be installed on the return line. The line on which a flow meter should be installed should be marked on the integrator. This is a requirement for the RHI but may not be required for control only.

— Some manufacturers specify minimum system pressures at the flow meter in order to avoid measurement errors as a result of cavitation or air in the water. While it is unlikely that cavitation will occur within the flow meter, measurement errors can result from bubbles generated by cavitating pumps or regulating valves upstream of the flow meter.

— Dissolved air in water can come out of solution if the pressure drops, and for this reason a flow meter should not be installed on a pump inlet to minimise the risk of bubbles forming within the flow meter.

— The type of pressurisation system being employed. Greater care is required with meter selection when installing meters on open vented systems to ensure sufficient pressure is available at the meter and dissolved air cannot come out of solution within the meter.

— If the system is gravity pressurised on an open vented system, the cold fill pipe, or combined fill and expansion pipe, must not be installed on the same part of the return circuit as a heat meter to avoid addition to or subtraction from measured flows.

— Installation at a position where only uni-directional flow can occur. Ultrasonic flow meters, for example, produce a positive output in both the forward and reverse directions making the outputs additive. For this reason heat meters should never be installed on a 2-port buffer vessel or 2-port thermal store where reverse flows occur.

— Installation of the meter in a position where it can be readily and safely maintained and removed.

— The requirement for an output not just for heat data recording but also for system control. When required for control in addition to heat metering, a meter having a MODBUS, BACNET or 0–10 V analogue output should be used where possible, rather than a standard pulsed output.

— A low pulse factor to achieve as high a resolution as possible.

— The installation of heat meters powered by mains electricity rather than battery operated units.

9.2 Ultrasonic, flow oscillation and turbine heat meters

9.2.1 Heat metering of systems containing glycol

The most frequently installed heat meters for biomass systems use ultrasonic flow sensing. If the system contains a glycol-water mixture, only a limited number of manufacturers supply ultrasonic heat meters calibrated to work on systems containing glycol. While the MID heat metering standard was developed for meters on district heating networks, there is no standard for heat meters on systems containing glycol. If a biomass heating system contains glycol, for example if a system is designed to be switched off for periods in the winter, one option is a fluid oscillation flow meter. Like ultrasonic meters they have no moving parts, but the glycol concentration can be input into these meters, some of which are specifically manufactured for use on circuits containing glycol. Designers must ensure that heat meters they specify can be used on circuits containing glycol, and that the glycol concentration can be entered into the integrator.

9.2.2 System pressure and open vented systems

The accuracy of ultrasonic heat meters is impaired if air bubbles pass through an ultrasonic meter. Dissolved air is not a significant issue in a well-designed closed pressurised system which is fitted with automatic air eliminators and has been chemically dosed to remove oxygen. However, in open vented systems air enters the system continuously meaning that air can come out of solution at any point where a sudden pressure drop occurs. Furthermore, where the heating header tank is less than 10 m above the heat meter the pressure on the meter will be less than 1 bar making most ultrasonic meters unsuitable. When combined with the pressure drop through the meter, and taking into the account the influence of suction from circulating pumps, the pressure at a meter on a typical open vented circuit will be significantly less than 1 bar. Again, flow oscillation meters will operate at lower pressures without loss of accuracy and are not affected by the presence of air bubbles in the meter. Similarly, turbine meters (traditional water meters) have no minimum pressure requirement and may be used on low pressure or open vented systems. Designers must ensure that heat meters selected for use on open vented systems are suitable for the application.

9.2.3 Cavitation in heat meters

Cavitation occurs on any hydronic circuit when the pressure at a given point in the system falls below the water vapour pressure at the temperature the circuit is operating at. To ensure cavitation does not occur in heat meters they should:

— Not be installed on pump inlets. The examples in this manual show heat meters on biomass boilers installed on the flow circuit to keep the meter inlet away from the biomass boiler pump.

— Not be operated at a flow rate greater than the maximum specified by the meter manufacturer to ensure the flow remains laminar.

— Be installed on circuits with the minimum static pressure recommended by the meter manufacturer.

9.3 Heat metering and the Renewable Heat Incentive

The *Renewable Heat Incentive Guidance Volume One* (Ofgem, 2013a) contains the specific requirements for heat metering for the RHI in Chapter 7 of Volume 1 together with the *Meter Placement Examples* (Ofgem, 2013b) document of October 2013. To be eligible for the RHI the metering must be installed as per these documents, which may require metering over and above that for heat measurement and control purposes. In addition to the guidance on the use of heat meters for system control in this document, designers must follow the RHI guidance for an installation to comply with the RHI requirements.

9.4 Heat metering of systems connected to low loss headers

Heat metering errors can be caused by incorrect sizing and configuration of low-loss headers. Under particular combinations of demand-side water flows and pump status, reverse flows can occur in heat metered circuits. Since many heat meters do not account for flow direction, this can result in heat meter increment from non-biofuel sources. The guidance in Chapter 8 on low-loss headers should be followed. Key issues are to ensure that the flow velocity in the header is always less than 0.15 m/s, and to position pipe entries and exits on the low-loss header such that there is minimal induced flow in other circuits.

9.5 Use of heat meters for flow rate commissioning

Commissioning should include specific checks on hydronic flows in biomass boilers to prove minimal or zero interaction under all operational modes. Building management system (BMS) data should record heat-meter flows and temperatures. This data can be used at commissioning, and should be a specific check in early operation.

9.6 Use of M-Bus data

Most major makes of heat meter have an M-Bus (Meter Bus) interface available. This can read kW, kW·h, flow rate, flow and return temperatures. All of these parameters should be logged on the BMS to facilitate continuous performance monitoring and to facilitate forensic investigation of system operation should that be required.

10 Flues

10.1 Introduction to biomass flues

The purpose of a biomass flue system is to take the gaseous combustion products from a biomass boiler and discharge them at height with sufficient efflux velocity to protect the environment and human health. Exhaust gases from biomass combustion include compounds classified by the World Health Organisation as having no safe lower exposure limit for humans. Flues for biomass systems must:

— Produce adequate draught to remove gaseous combustion products (see Chapter 2) from a biomass boiler under all operating conditions.

— Disperse gaseous combustion products to comply with UK outdoor air quality regulations.

— Ensure that gaseous combustion products do not enter occupied spaces and thus compromise indoor air quality.

Mainland Europe has a long history of biomass use which has resulted in design and test processes to achieve correct and safe operation of flue systems. To produce a flue design with the ability to remove combustion products from a biomass boiler under all weather conditions and accounting for the topography of a given site requires specific knowledge, skills and experience – attributes which are required of a biomass or specialist flue designer. The knowledge required includes the use of flue design software, British and European technical standards and the extensive library of documentation on local air quality management and emissions assessment produce by Defra, the Institute of Air Quality Management and UK local authorities. The UK Clean Air Act is under revision at the time of publication (2014), and designers should always check the applicability and currency of the information contained in this chapter.

A biomass boiler must always operate under negative combustion chamber pressure to ensure that combustible and toxic gases cannot escape into the boilerhouse: this requires a negative pressure flue. Of particular importance is that a flue can maintain negative pressure when a boiler is operating in slumber mode (see 4.3.3) or in the event of an electrical power failure. Negative pressure in the flue is produced by the buoyancy of the flue gases, although with a typical maximum flue gas temperature of 150 °C buoyancy may create pressure differences across the flue of only a few Pascals (Pa). This process, known as the stack effect, is related to the effective height of the flue, i.e. the vertical distance between the axis of boiler flue outlet and the chimney terminal.

The use of a flue fan to achieve the necessary draft, in addition to that already incorporated into a biomass boiler or associated with a cyclone grit arrestor, is not recommended. However, health and safety requirements may dictate that an uninterruptable power supply (UPS) be installed to prevent the formation of an explosive atmosphere in the boiler's combustion chamber and flue if an additional fan is installed.

Particular care should be exercised in relation to the use of *Technical Guidance Note (Dispersion) D1* (NBS, 1993) which requires a flue gas efflux velocity of >10 m/s. This method must not be used for the majority of biomass installations which typically achieve efflux velocities <2 m/s.

10.2 Biomass flue systems

10.2.1 Components of a biomass flue system

A biomass flue is a connected system of pipes and fittings which takes exhaust gases from the boiler flue outlet and emits them to atmosphere. A biomass flue system will usually incorporate more components than an equivalent oil or gas boiler flue system, specifically:

— an explosion relief panel

— a draught stabiliser

— a condensate and rainwater drain

— one or more cleaning and inspection access panels

— one or more flue gas analyser test points

— a vertical flue stack.

For unsupported flues of 3 m or more in height a flue mast will usually be required. The maximum unsupported height will depend on local topography and weather conditions. In areas which experience high windspeeds the unsupported length may need to be shorter and the flue mast more substantial. A structural engineer will be required to determine the wind loading, and then to size

Figure 10.1 130 kW biomass boiler flue showing a lightning conductor

Figure 10.2 Combined draught stabiliser and explosion relief panel

the flue mast and concrete base. Figures 10.3 and 10.4 show typical layouts for biomass boilers with and without cyclone grit arrestors.

Cleaning and inspection access is required so that all sections can be visually inspected safely, quickly and easily without resorting to CCTV, although the use of a mirror may be necessary. Safe and ready access to the locations at which the inspections are carried out must be provided from floor level or a permanent access platform. As these will also be places from which cleaning will be carried out, access and space are required to convey, position and operate the cleaning equipment.

Flue gas analyser test points are required. These should be positioned upstream of a draught stabiliser and at least two clear diameters from an elbow or other fitting on either side of the test point. The test point must also be close enough to the boiler flue outlet that a reasonable temperature reading can be obtained – two diameters is an ideal distance.

10.2.2 Characteristics of a correctly designed and safe flue system

The following are characteristics of a correctly designed and safe flue system, including associated safety systems:

— The system protects the environment and human health.

— Dispersion from the terminal will not be influenced by wake vortices from any structure at any wind-speed from any direction.

— The flue is straight, vertical and has safe, practicable access for cleaning and inspection.

— The length of the primary flue between the boiler flue gas outlet and the flue is minimal – ideally ≤1.5 m for boiler up to 250 kW and proportionally longer for larger boilers.

— The flue will provide the required draft at the boiler flue outlet at all firing levels irrespective of weather conditions and without the use of a flue fan.

— All system flue components will be CE marked.

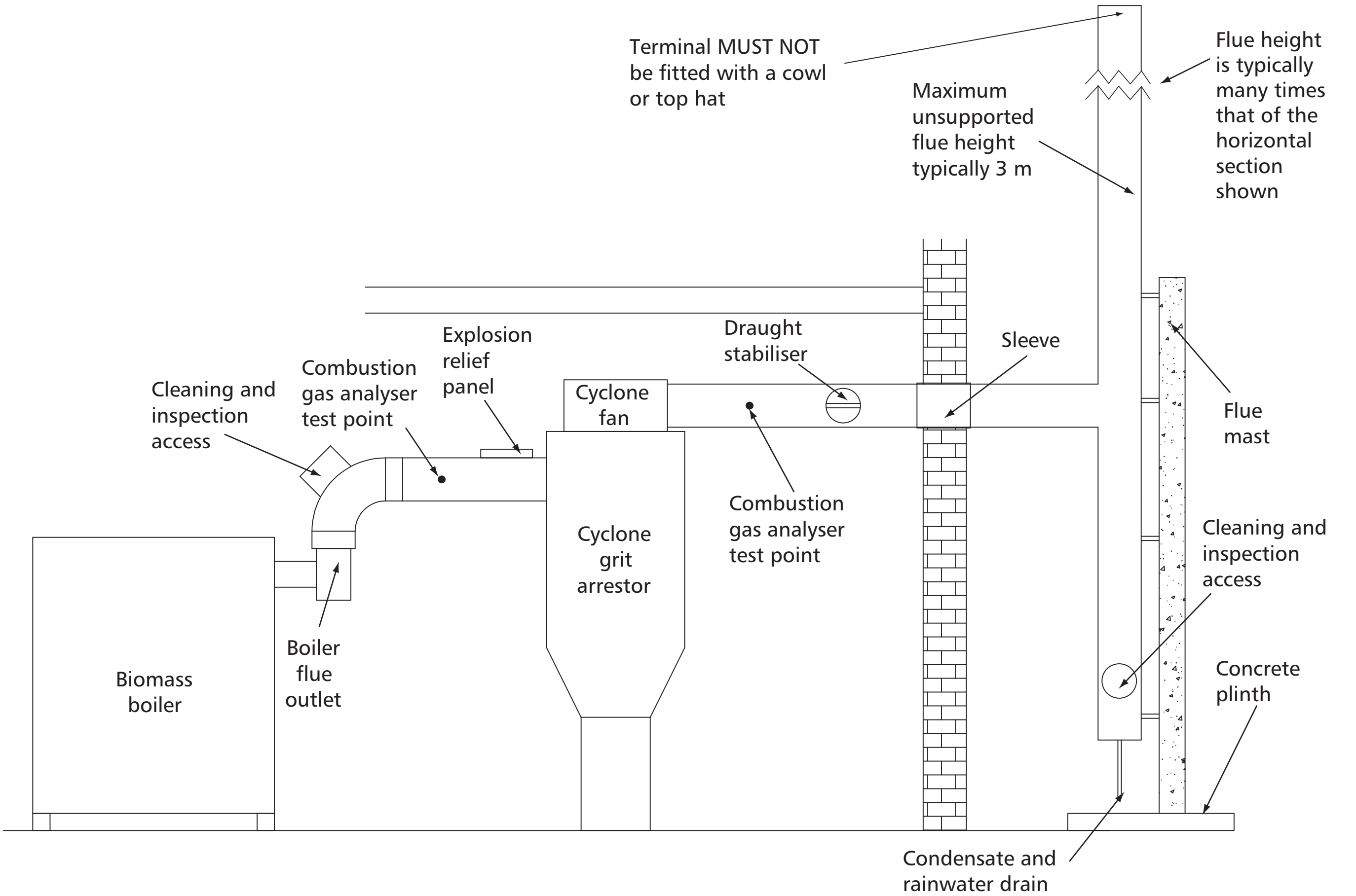


Figure 10.3 (above) Typical flue system for a biomass boiler with an external cyclone grit arrestor

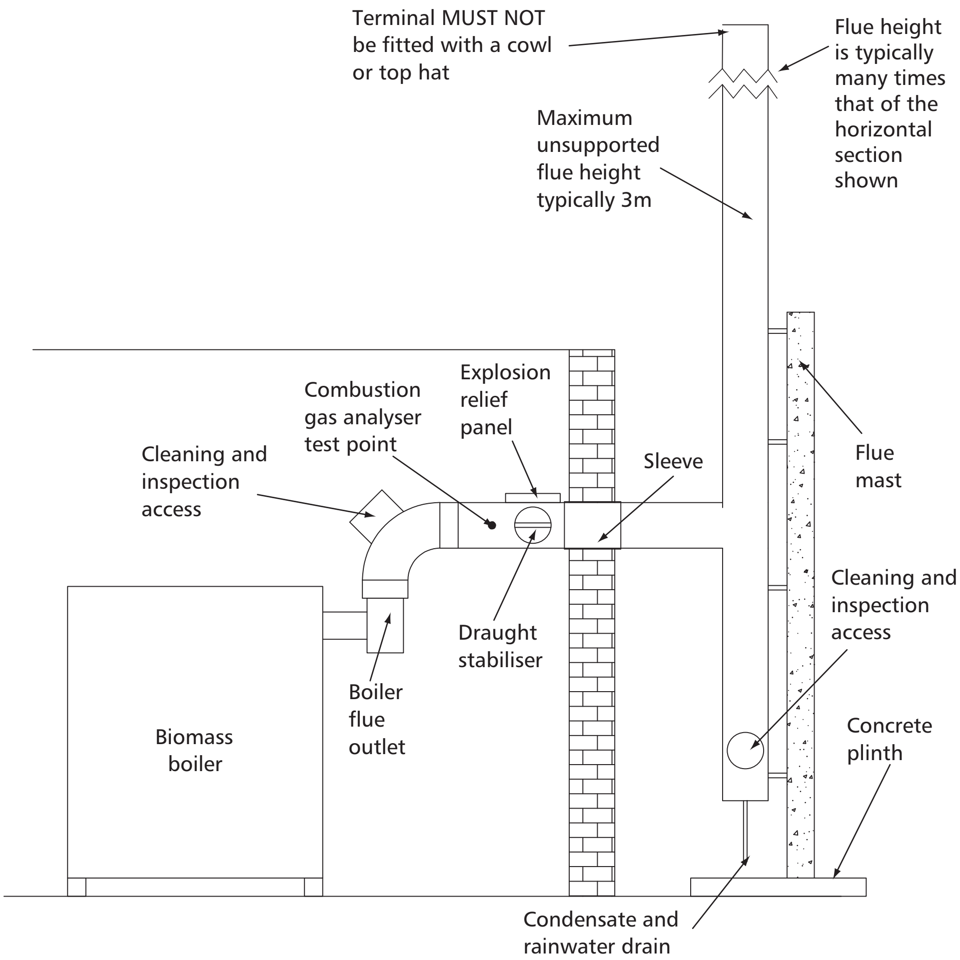


Figure 10.4 Typical flue system for a biomass boiler without an external cyclone grit arrestor

— A custom flue will be manufactured, designed, installed and tested in accordance with the requirements of BS EN 15287-1 (2007).

— Has gas-tight openings through which it is possible to clean and inspect the entire system without using a camera.

— Has unobstructed, horizontal access for testing with a combustion gas analyser.

— Has a draft stabiliser fitted, complete with seals, to ensure that the flue draft remains consistent with correct biomass boiler operation.

— Where required by the boiler manufacturer, has an explosion relief panel fitted.

— A condensate and rainwater drain is installed at the bottom of the vertical flue section.

— A CO alarm to BS EN 50291-1 (2010), BS EN 50292 (2002) is correctly installed in the boiler room.

— The surface temperature of any flue component should not exceed 43 °C.

— All required safety notices are correctly displayed.

— The flue system continues to provide sufficient draught under electrical mains failure conditions – normally satisfied without the use of an additional flue fan.

— The flue system is proven to be gas-tight at commissioning.

— A flue notice plate should be permanently marked and fixed in a prominent position close to the flue showing:

  — the address of the installation.

  — the product manufacturer.

  — the designer/supplier/installer.

  — their job number.

  — the date of completion.

  — the BS EN 1443 (2003) designation of the flue system.

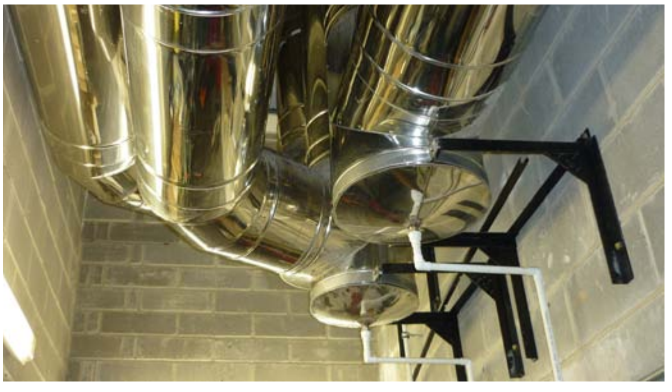


Figure 10.5 Condensate and rainwater drains

Table 10.1 Types of flue systems for biomass installations

Type of flue system	Standards	Life (years)	Features
Metal e.g. Twin-wall Insulated stainless steel	BS EN 1856-1	20–30	— Light and compact — Rapid assembly — Standard components — Flexible design possibilities — Many designations available — Custom components available from some manufacturers — May be supported by a mast or inside a windshield — Can enhance appearance of project
Ceramic: e.g. block systems with ceramic, refractory or pumice aggregate concrete (PAC) linings	BS EN 1857 BS EN 1858	30–60	— Can contain multiple flues — Relatively quick to build with modular casings — Easily clad to match building fabric — Can have good soot/tar-fire resistance — Available in smaller sizes up to 50,000 mm^2 cross section — Exceptional insulating and soot/tar fire resistance (PAC) — Some can be steel reinforced for <9 m high applications, making them entirely free standing
Ceramic custom-made: e.g. brick or concrete stacks with refractory brick, prefabricated ceramic or PAC liners	BS EN 13084	>30	— Concrete flues provide the largest sizes — Can be free standing
Composite thermosetting resin stacks and linings		>30	— High strength to weight ratio — <3000 mm diameter stack — Nil leakage rate — Linings up to 100 m without joints — Resistant to virtually any condensate — Clean installation of linings — Can be tailored to fit flues which vary in cross-section — Can sustain or reduce cross-section of existing flues — Re-lining of any flue type possible.

10.3 Flue system design

The materials from which a flue is constructed must be able to resist acid corrosion from the tars present in biomass combustion products. The flue must also be insulated to maintain heat in the flue gases and therefore their buoyancy.

10.3.1 Types of flue system for biomass installations

Table 10.1 details four types of flue structure.

10.3.2 Re-use of existing flues

When installing biomass in an existing boilerhouse, or replacing existing oil or gas boilers, it is possible to re-use an existing flueway subject to the following considerations:

— Observations of the condition and design of the structure and the flue must be made to establish suitability. Existing acidic condensate may have reduced the stability and utility of flues requiring remedial work.

— Can the requirements for a biomass flue be satisfied by re-using an existing flue?

— Can the existing flue be connected to the new plant without causing excessive resistance to the flow of flue gas resulting from changes of direction or length of run?

— If the flue is not suitable, can economic repair, modification or conversion by relining and/or other modification achieve the required performance?

Inspection of an existing flue requires that it be cleaned and then inspected and measured using a colour CCTV camera with pan and tilt to facilitate thorough inspection of the interior. The results of the survey must be analysed by an experienced flue specialist to assess whether the flue is suitable for conversion and the extent of any refurbishment work required. A calculation based on BS EN 13384-1 software will reveal whether the performance can be achieved.

10.3.3 Flue design process

The flowchart Figure 10.6 may be used to guide the biomass designer through the flue design process. The use of this flowchart to evaluate a single biomass boiler feeding a single flue in the UK requires:

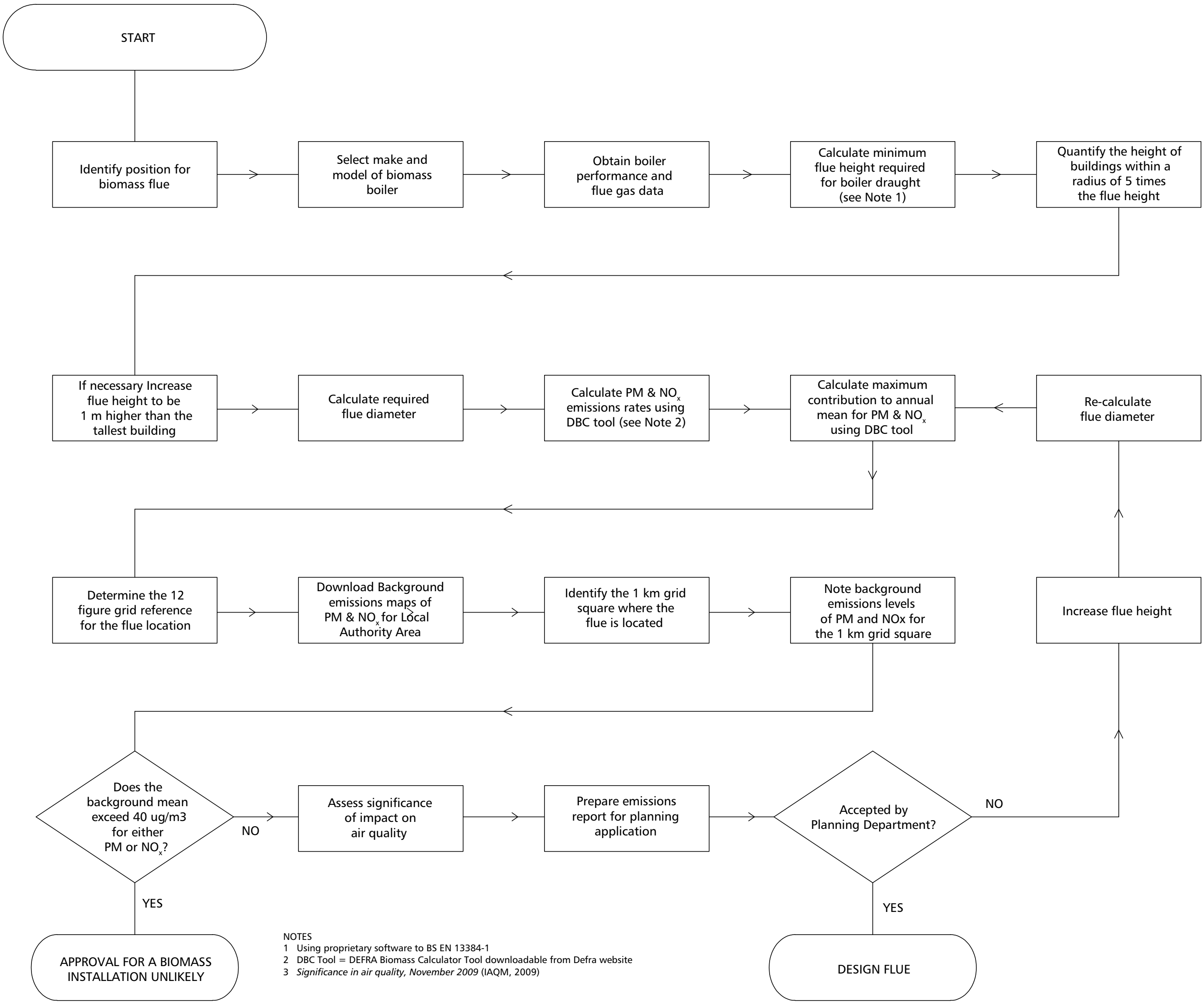


Figure 10.6 Flue design process flowchart

- The use of flue design software to BS EN 13384-1 (2008).
- The use of the DEFRA Biomass Calculator Tool (available from the Defra website).
- Reference to *Local Air Quality Management Technical Guidance LAQM.TG(09)* (Defra, 2009).
- Reference to *Significance in air quality* (IAQM, 2009).
- *Sustainable Design and Construction Supplementary Planning Guidance* (GLA, 2014).

For sites with complex topography or situations involving multiple boilers it may be necessary to sub-contract the technical assessment to a specialist flue dispersion modelling organisation.

10.4 Flue system component quality

To ensure that the flue will meet the demanding requirement for a biomass boiler installation its manufacturing parameters and material specifications must be controlled. Manufacturing must take place under an independently verified regime of testing and surveillance, and a currently valid EC Certificate of Conformity must be obtained. The flue and associated components must be CE marked in accordance with the Construction Products Regulation. It is not unknown for the EC Certificate of Conformity offered with a product to incorrectly refer to test procedures, to manufacture at sites where appropriate quality control procedures have not been validated, or even to different products. If any doubt exists, obtain proof of validity and applicability.

10.5 Flue system testing and commissioning

The purposes of flue testing and commissioning are to:

- Prove that the flue is gas-tight under all operating conditions by carrying out leakage testing to BS EN 1443.
- Prove that the flue provides the correct draught under both full and part load conditions by

Figure 10.7 Flue gas analyser

acceptance testing using a combustion test analyser to BS EN 50379-2 (2012). This test is NOT a gas-safe procedure.

— Set-up the draught stabiliser so that it opens when the draught exceeds the maximum permitted by the biomass boiler manufacturer.

— Confirm the presence of a notice plate stating pressure class, identity, date, designation and supplier information, and that all components are CE marked.

10.5.1 Gas tightness testing

The flue system should be tested with a suitable instrument to ensure that its leakage rate does not exceed that designated according to EN 1443 (2003) for that flue type. Failure to achieve the degree of sealing for the pressure class and designated type will attenuate performance in use, may endanger personnel and may make obtaining clean, efficient combustion difficult or impossible. For an N1 Class negative pressure flue the maximum leakage rate at 40 Pa pressure differential is 2.0 $l/s \cdot m^2$.

During installation, testing is best carried out progressively as flue system assembly takes place so that failures are discovered prior to full assembly. This facilitates the immediate identification of a fault and its location saving expense and time in disassembling a completed system should a fault be discovered only on completion.

10.5.2 Commissioning and acceptance testing

The boiler/flue system is to be tested to ensure its performance is acceptable and within the design parameters for the project. Testing is to be carried out once the system can be operated at full fire for a sustained period as follows:

— Using an exhaust gas analyser compliant with EN 50379-2:2012.

— At full fire and at low fire; (but not in slumber mode).

— Measuring O_2/CO_2, CO, NO_2 concentrations – all in mg/m^3.

— Measuring the temperature of the incoming combustion air and of the exhaust gases.

— Measuring the pressure differential to verify the performance of the flue.

The analyser will then calculate the exhaust gas loss percentage, i.e. the percentage of energy loss up the flue from which instantaneous boiler efficiency can be determined.

Unless acceptable emission, temperature, draft and efficiency levels are recorded the biomass system should not be brought into service. 'Acceptable' means that the boiler performs according to the manufacturer's performance data and in accordance with the designed efficiency intentions for the project as a whole. It also means that the flue performs in accordance with its calculated performance. Allowance must be made for the fact that the BS EN 13384-1 (2008) calculations are always a 'snapshot' based on assumed ambient conditions and that conditions on the day of test will be different.

10.6 Typical wording for a specification for a metal flue system

The following may be used as a template for the wording of a specification for a twin-wall, insulated stainless steel flue suitable for a biomass boiler to EN 1443:

The flue/s is/are to be CE marked to BS EN 1856-1 to the following performance designation, BS EN 1856-1 T450 N1 D V2 L50050 G(50). The contractor is to provide the flue manufacturer's EC Declaration of Conformity for approval with respect to their preferred product.

The calculations for the sizing of the flue/flue system shall be in accordance with the full version of BS EN 13384-1. The contractor shall provide full calculations and data in accordance with BS EN 13384-1 together with installation drawings for approval prior to installation as required under the two standards.

Where the flue does not conform to BS EN 1856-1 and is considered a Custom Flue, the manufacture, design, installation and testing of the product must conform to the requirements of BS EN 15287-1 (2007).

Design

The primary flue may not have more than 180° aggregate change of direction between the axis of the boiler flue outlet and the axis of the main riser and changes of direction should be through maximum 45° segmented bends. The primary flue should preferably be no more than 2 m long with an absolute maximum length of 25% of the effective height of the main riser (effective height is the vertical distance between the boiler flue outlet and the terminal outlet of the main riser).

The main riser must be straight with no offsets. Where it penetrates any roof, steps must be taken to weather proof the aperture and to protect any insulation from water ingress.

A 12–14 mm diameter combustion gas analyser (CGA) port with a gas-tight cap must be provided in the primary flue at a horizontally accessible point twice the flue diameter from the boiler outlet and not close to a change of direction, draft stabiliser or cleaning access which may cause turbulence in the exhaust gases. Access to this port must allow space to insert and manoeuvre a CGA probe tip into the hottest part of the exhaust gas stream.

Execution

The flue is to be tested with a machine such as a Wöhler DP23 at each stage of assembly and on completion to ensure that it meets the design tightness requirement for its designation. The flue system and boiler shall be Acceptance Tested with a CGA at the commissioning stage to demonstrate that both are working as designed and a signed record of the results provided.

10.7 BS EN Standards referred to in the text

A list of relevant BS EN Standards, including all those applicable to flues, can be found in the References chapter of this document.

11 Summary of key considerations for biomass boilerhouse design

11.1 Design differences to oil and gas boilerhouses

This chapter contains information specific to biomass boilerhouse designed to use woodchips or wood pellets. The objective is to highlight the key differences between the design of oil and gas boilerhouses and biomass boilerhouses. Some key considerations which influence the design of biomass boilerhouses and fuel stores are:

Fuel delivery and storage

— Access for, potentially, large fuel delivery vehicles may be required.

— Biomass fuel has a lower calorific density than oil or gas requiring a physically larger storage volume.

— Significant health and safety considerations apply to biomass fuel handling, storage and extraction.

Biomass boiler and thermal storage sizing

— Biomass boilers should never be oversized otherwise both the physical space required and capital cost increase.

— A biomass boiler should never be sized at greater than the peak load.

— In combination with a thermal store most biomass boilers for non-continuous heat supply can be sized at between 30 and 60% of the peak load.

— The use of thermal storage allows a biomass boiler to operate continuously charging a thermal store. This strategy produces both high biomass boiler efficiency and high biomass boiler utilisation.

— Install adequately sized thermal storage.

Boilerhouse layout

— Greater clearances are required around biomass boilers for maintenance access, removal of ash bins, removal of augers, fire tube cleaning and the fuel extract and feed system from the fuel store.

— Space is also required for thermal storage, additional expansion vessel capacity and backup/auxiliary boiler(s).

Hydronic and controls arrangements

— Hydronic and control systems must be designed in an integrated manner.

— The integration of biomass boilers with oil and gas boilers requires the use of specific hydronic configurations to achieve high biomass utilisation and efficient biomass boiler operation.

Flues

— Flue design for biomass boilers is significantly more onerous than that for that for oil and gas boilers and may require the services of a specialist flue designer.

— Biomass flue systems require draught regulation, explosion relief, access for flue cleaning and rainwater drainage.

— Flue caps or top-hats must not be installed on a biomass flue.

— Flue fans, in addition to those forming part of the biomass system, must not be used.

— Every biomass boiler requires a separate flue – biomass boilers must not share a flue with any other biomass or oil or gas boiler.

— Biomass flue heights are determined by the need to produce sufficient draught to remove flue gases under all operating conditions and to disperse the products of combustion to meet local authority environmental and health requirements.

— Biomass flues must be of twin-wall construction incorporating insulation and of materials which resist attack by acidic tars.

11.2 Design flowchart

A feasibility study will have already established a prima facie case for technical, environmental and financial viability before proceeding to the design stage of the project. The document *Biomass heating: a guide to feasibility studies* (Palmer et al, 2011a), available from the Biomass Energy Centre, provides guidance on the feasibility study process so no further guidance on carry out feasibility studies is given in this manual.

Figure 11.1 provides a flow chart which gives an indication of the design steps required for a new boilerhouse installation before a project can proceed to the construction phase. If a biomass boiler is to be installed in an existing boilerhouse a subset of these design steps should be used relevant to the particular circumstances of the project. The process shown is a substantially linear one, i.e. the sequential steps which have to be taken to ensure that all aspects of the design are adequately covered. In reality iterations around some of these steps will be required, for example to examine fuel storage requirements and fuel stores sizes for different biomass fuels. The chart contains three key decision points concerning flue height, planning permission and client agreement to proceed. Iterations around these decisions may be required with the chart indicating the likely points to which the designer should return to reconsider aspects of the design to achieve a successful outcome.

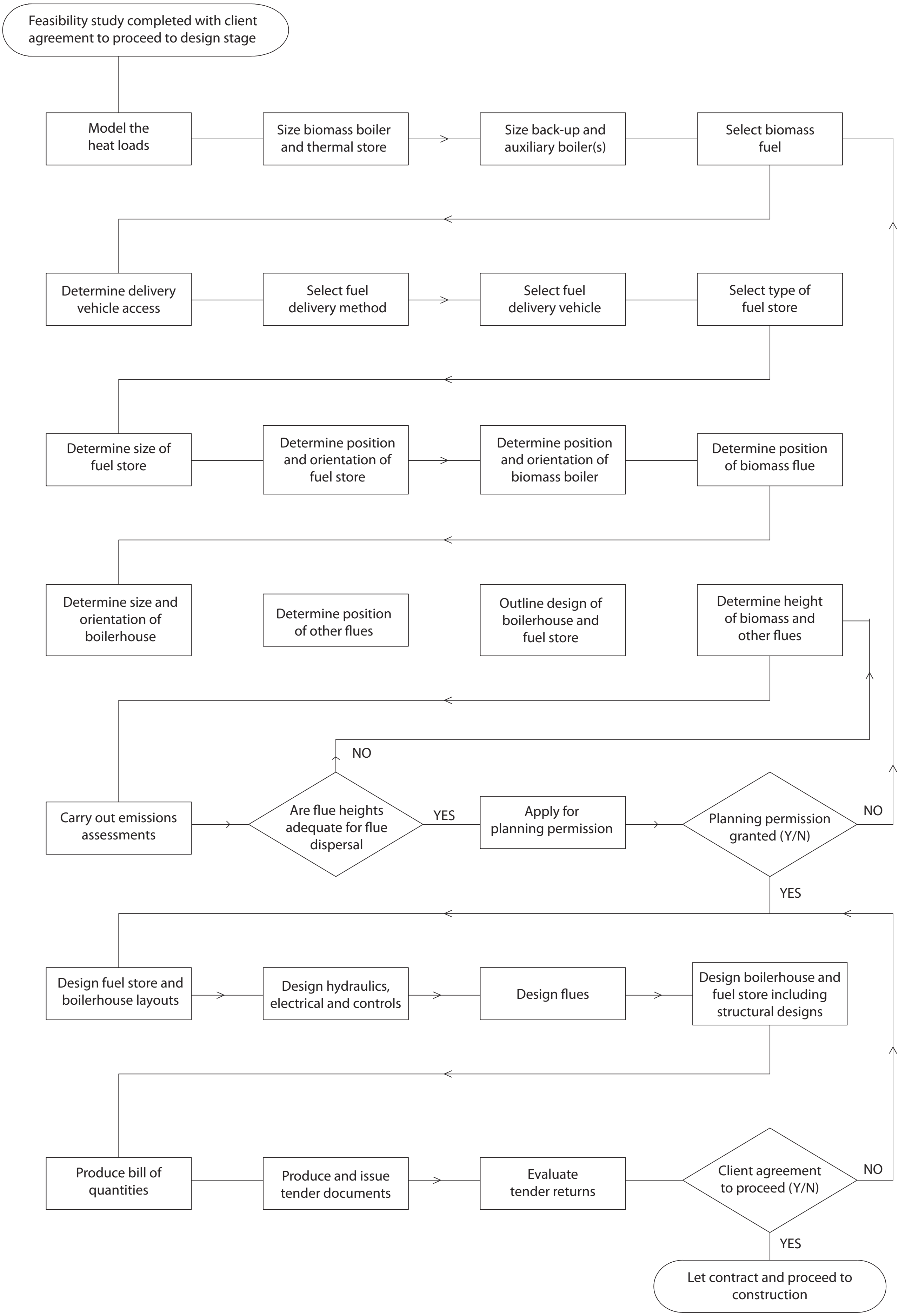


Figure 11.1 Flowchart showing indicative design steps for a biomass boilerhouse installation

References

Barbrauskas, V (2003) *Ignition Handbook: Principles and Applications to Fire Safety Engineering, Fire Investigation, Risk Management and Forensic Science* (Issaquah, WA: Fire Science Publishers)

Brites (2009) *Pre-delivery and design checklist* [Online] Available from http://www.biomassenergycentre.org.uk/pls/portal/docs/page/bec_technical/best%20practice/balcas%20commercial%20pre-delivery%20checklist%20v9.pdf [Accessed: 30 June 2014]

BSI (2012) PAS 111:2012 *Specification for the requirements and test methods for processing waste wood* (London: British Standards Institution)

Carbon Trust (2009a) CGT012: *Biomass heating: A practical guide for potential users* [Online] Available from: http://www.carbontrust.com/resources/reports/technology/biomass-heating [Accessed 30 June 2014]

Carbon Trust (2009b) *Biomass Monitoring Report* [Unpublished report]

Carbon Trust (2012) CTG074: *Biomass Fuel Procurement Guide* (London: Carbon Trust)

Carbon Trust (2013) *Biomass Decision Support Tool* [Online] Available from: http://www.carbontrust.com/resources/tools/biomass-decision-support-tool [Accessed 30 June 2014]

Carlsson K. (2008) *Gas cleaning in flue gas from combustion of biomass* [Report of EU Project ThermalNet]

CEA (2011) *Health and safety in biomass systems, Design and operation guide* (London: Combustion Engineering Association and Carbon Trust)

CIBSE (2006) Guide A: *Environmental Design* (London: Chartered Institution of Building Services Engineers)

DECC (2014a) *New biomass sustainability requirements for the renewable heat incentive* (London: Department for Energy and Climate Change)

DECC (2014b) *Timber standard for heat and electricity* (London: Department for Energy and Climate Change)

Defra (2009) *Local Air Quality Management: Technical Guidance LAQM. TG(09)* (London: Department for Environment, Food and Rural Affairs)

Defra (2012) AEA/R/ED46626/AEA/R/3296, Issue 1: *Conversion of biomass boiler missions concentration data for comparison with the Renewable Heat Incentive emission criteria* (London: Department for Environment, Food and Rural Affairs)

DGS, Ecofys (2005) *Planning and Installing Bioenergy Systems: a guide for installers, architects and engineers* (London: German Solar Energy Society (DGS) and Ecofys)

EC (2010) *Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling* (Brussels: European Commission)

EEA (2013) Report No 9/2013: *Air Quality in Europe – 2013 Report*. [Online] Available from http://www.eea.europa.eu/publications/air-quality-in-europe-2013 [Accessed 30 June 2014]

GLA (2014) *Sustainable Design and Construction: Supplementary Planning Guidance* (London: Greater London Authority)

HSE (2011) EH40 /2005: *Workplace Exposure Limits*. 2nd Edition. (London: Health and Safety Executive)

HSE (2012) Bulletin number OPSTD 3-2012: *Risk of carbon monoxide release during storage of wood pellets* [Online] Available from: http://www.hse.gov.uk/safetybulletins/co-wood-pellets.htm [Accessed 30 June 2014]

IAQM (2009) *Significance in air quality: November 2009* (London: Institute of Air Quality Management)

INP (1993) *Guidelines on discharge stack heights for polluting emissions* (London: Inspectorate of Pollution)

International Energy Agency (IEA) (2008) *Particulate Emissions from Biomass Consbustion in IEA Countries: Survey on Measurements and Emission Factors* (Nussbaumer, T., Czasch C., Klippel N., Johansson L., Tullin C. on behalf of IEA Bioenergy Task 32) (Zurich: Swiss Federal Office of Energy)

Jansson C., Alderling M., Hogstedt C., Gustavsson P. (2011) Mortality among Swedish flue sweeps (1952 - 2006): an extended cohort study. *Occup Environ Med* 2012;69:1 41-47 [Online] Available from: http://oem.bmj.com/content/69/1/41.full.pdf+html. [Accessed: 30th July 2014]

Kasimir, D.I., Nemestothy P. (eds.) (2008) *EVA Fuel Cost Calculator* (Wien: Austrian Energy Agency)

Keller, R. (1994) *Primärmassnahmen zur NOx Minderung* (Ph.D. Thesis: Laboratorium für Energiesysteme, ETH, Zürich)

Lave, L.B.; Seskin E.P. (1973) An Analysis of the Association Between U.S. Mortality and Air Pollution. *J. Amer. Statistical Association* 68: 342.

Mokdad, A.H.; et al. (2004) Actual Causes of Death in the United States, 2000. *J. Amer. Med. Assoc.* 291 (10): 1238–45.

Nussbaumer, T. (1997) Primary and secondary measures for NOX reduction in Biomass combustion. In: Bridgwater A.V. and Boocock D.G.B. (eds.) *Developments in Thermochemical Biomass Conversion* (London: Blackie Academic and Professional)

Nussbaumer, T. (2011) *Characterisation of particles from wood combustion with respect to health relevance and electrostatic precipitation* (Lucerne: University of Applied Sciences)

Ofgem (2012) *UK Solid and Gaseous Biomass Carbon Calculator* [Online] Available from: https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator [Accessed 30 June 2014]

Ofgem (2013a) *Renewable Heat Incentive Guidance Volume One: Eligibility and How to Apply* [Online] Available from: https://www.ofgem.gov.uk/ofgem-publications/83036/rhiguidancevolone1.pdf [Accessed: 30 June 2014]

Ofgem (2013b) *Renewable Heat Incentive guidance: Non-domestic scheme Metering Placement Examples* [Online] Available from: https://www.ofgem.gov.uk/publications-and-updates/renewable-heat-incentive-guidance-non-domestic-scheme-metering-placement-examples [Accessed: 30 June 2014]

Palmer, D., Tubby, I., Hogan, G. and Rolls, W. (2011a). *Biomass heating: a guide to feasibility studies* (Farnham: Biomass Energy Centre)

Palmer, D., Tubby, I., Hogan, G. and Rolls, W. (2011b). *Biomass heating: a guide to medium scale wood chip and wood pellet systems* (Farnham: Biomass Energy Centre)

Palmer, D., Tubby, I., Hogan, G. and Rolls, W. (2011c) *Biomass heating: a guide to small log and wood pellet systems* (Farnham: Biomass Energy Centre)

Salzmann R. (2001) Fuel staging for NOX Reduction in Biomass Combustion: Experiments and Modelling. *Energy & Fuels* 01/2001; 15(3). DOI:10.1021/ef0001383

Téllez J, Rodríguez A, Fajardo A (2006) Carbon monoxide contamination: an environmental health problem. *Rev Salud Publica* (Bogota). 2006 Jan-Apr;8(1):108-17. [Online] Available from: http://www.ncbi.nlm.nih.gov/pubmed/16703967 [Accessed: 30 June 2014].

Van Loo S. and Koppejan J. (eds.) (2008) *The handbook of biomass combustion and co-firing* (London: Earthscan)

WHO (2010) *Guidelines for Indoor Air Quality: Selected Pollutants* (Copenhagen: World Health Organisation)

Standards

BS EN 1443:2003 *Flues. General Requirements.*

BS EN 1856-1:2009 *Flues. Requirements for metal flues. System flue products.*

BS EN 1857:2010 *Flues, Components. Concrete flue liners.*

BS EN 1858:2003 *Flues. Components. Concrete flue blocks.*

BS EN 50379-2:2012 *Specification for portable electrical apparatus designed to measure combustion flue gas parameters of heating appliances. Performance requirements for apparatus used in statutory inspections and assessment.*

BS EN 13384-1:2002 + A2:2008 *Flues. Thermal and fluid dynamic calculation methods. Flues serving one appliance.*

BS EN 15287-1:2007 *Flues. Design, installation and commissioning of flues.*

BS EN 15287-1 AMD1. *Flues. Design, installation and commissioning of flues. Part 1. Flues for non-room-sealed heating appliances.*

BS EN 50291-1:2010 *Electrical apparatus for the detection of carbon monoxide in domestic premises. Test methods and performance requirements.*

BS EN 50292:2002 *Electrical apparatus for the detection of carbon monoxide in domestic premises. Guide on the selection, installation, use and maintenance.*

BS 3572:1986 *Specification for access fittings for flues and other high structures in concrete or brick work.*

BS 3678:1986 *Specification for access hooks for flues and other high structures in steel.*

BS 4207:1989 *Code of practice for the installation of monolithic linings for steel flues and chimneys.*

BS 4211:2005 + A1:2008 *Specification for permanently fixed ladders.*

BS 5854:1980 (1996) *Code of practice for flues and flue structures in buildings.*

BS EN 1856-2:2009 *Flues. Requirements for metal flues. Metal flexible flue liners and connecting flue pipes.*

BS EN 1857:2003 + A1:2008 *Flues. Components. Concrete flue liners.*

BS EN 1858:2008 *Flues. Components. Concrete flue blocks.*

BS EN 1991-1-4:2005+A1:2010 *Eurocode 1. Actions on structures. General actions. Wind actions.*

NA to BS EN 1991-1-4:2005+A1:2010 *UK National Annex to Eurocode 1. Actions on structures. General actions. Wind actions.*

PD 6688-1-4:2009 *Background information to the National Annex to BS EN 1991-1-4 and additional guidance.*

BS EN 1991-1-5:2003 *Eurocode 1. Actions on structures. General actions. Thermal actions.*

NA to BS EN 1991-1-5:2003 *UK National Annex to Eurocode 1. Actions on structures. General actions. Thermal actions.*

BS EN 1993-3-1:2006 *Eurocode 3. Design of steel structures. Towers, masts and flues. Towers and masts.*

BS EN 1993-3-2:2006 *Eurocode 3. Design of steel structures. Towers, masts and flues. Flues.*

NA to BS EN 1993-3-1:2006 UK National Annex to Eurocode 3. Design of steel structures. Towers, masts and flues. Towers and masts

BS EN 1998-6:2005 *Eurocode 8. Design of structures for earthquake resistance. Towers, masts and flues.*

NA to BS EN 1998-6:2005 *UK National Annex to Eurocode 8. Design of structures for earthquake resistance. Towers, masts and flues.*

PD 6698:2009 *Recommendations for the design of structures for earthquake resistance to BS EN 1998.*

BS EN 13084-1:2007 *Free-standing flues. General requirements.*

BS EN 13084-2:2007 *Free-standing flues. Concrete flues.*

BS EN 13084-4:2005 *Free-standing flues. Brick liners. Design and execution.*

BS EN 13084-5:2005 *Free-standing flues. Material for brick liners. Product specifications.*

BS EN 13084-6:2004 *Free-standing flues. Steel liners. Design and execution.*

BS EN 13084-7:2005 *Free-standing flues. Product specifications of cylindrical steel fabrications for use in single wall steel flues and steel liners.*

BS EN 13084-8:2005 *Free-standing industrial flues. Design and execution of mast construction with satellite components.*

BS EN 13384-2:2003+A1:2009 *Flues. Thermal and fluid dynamic calculation methods. Flues serving more than one heating appliance.*

BS EN 13384-3:2005 *Flues. Thermal and fluid dynamic calculation methods. Methods for the development of diagrams and tables for flues serving one heating appliance.*

BS EN 15036-2:2006 *Heating boilers. Test regulations for airborne noise emissions from heat generators. Flue gas noise emissions at the outlet of the heat generator.*

BS EN 14961-1:2010 *Solid biofuels. Fuel specifications and classes. General requirements.*

BS EN ISO 17225-2:2014 *Solid biofuels. Fuel specifications and classes. Graded wood pellets.*

BS EN 15234-1:2011 *Solid biofuels. Fuel quality assurance. General requirements.*

ISO 13790:2008 *Energy performance of buildings -- Calculation of energy use for space heating and cooling.*

ÖNORM M 7133:2013 W*oodchips for energy generation: quality and testing requirements* [from the Austrian Standards Institute]

ÖNORM M 7135:2000 *Compressed wood or compressed bark in natural state - Pellets and briquettes - Requirements and test specifications* [from the Austrian Standards Institute]

ÖNORM M 7137: 2012 *Compressed wood in natural state – Woodpellets. Requirements for storage of pellets at the ultimate consumer* [from the Austrian Standards Institute]

Glossary

This list concentrates on terminology commonly used in biomass heating installations.

Ash

Comprises bottom ash and fly ash.

Ash bin

Receptacle for ash from combusted biomass. Smaller boilers have a bin on wheels. Larger boilers have a bin receiving ash via an auger.

Auger

An Archimedean screw (a rod with a helical projection) used to transport biomass fuel (pellets or chips) from a fuel store into the combustion chamber, or to remove ash from the combustion chamber.

Automatic feed boiler

A boiler that has a woodchip or biomass pellet feed mechanism from a fuel store, and where the amount of fuel fed into the combustion chamber is under automatic control.

Automatic ignition system

Typically uses an electrical hot-air heater unit to ignite the fire-bed in smaller boilers. In larger boilers, this can be via a gas flame gun, or by a small oil burner.

Bag filter

A filter in the flue gas stream fine enough to catch small particulate matter. Made of a high temperature fabric such as Nomex or Kapton.

Batch fed boiler

Boiler fuelled by logs and joinery off-cuts. Labour is required to manually load the fuel.

Biofuels

A generic term for fuels derived from wood. Includes solid fuel such as chips and pellets, plus gaseous and liquid fuel derived from fermentation and high temperature gasification of ligneous material.

Biomass

Most commonly derived from solid wood, e.g. trees. Also from short rotation coppice, miscanthus, grain husks, olive kernels, sawdust and straw.

Biomass decision support tool

An Excel spreadsheet based tool to assess the most cost-effective biomass heating system sizing and integration. Developed by the Carbon Trust in collaboration with Strathclyde University and the Campbell Palmer Partnership. Available as a free download from http://www.carbontrust.com/resources/tools/biomass-decision-support-tool. A comprehensive user manual can be downloaded.

Biomass boiler

A boiler designed to burn solid fuels such as biomass. Any one boiler design will only able to burn a limited range of materials. Boiler thermal mass is normally much heavier than fossil fuel boilers dues to far greater refractory brick mass in the combustion chamber. The biomass boiler, if correctly configured with thermal storage and system control, can achieve >90% of the annual heat demand from biomass when sized at 25% to 40% of peak load.

Biomass designer

Tasks, duties and experience are defined in Chapter 1. They are far wider than needed for fossil-fuelled boiler installations (oil and gas) and require professional level engineering knowledge.

Biomass fuel storage sizing

Typical figures for a 100 kW biomass boiler operating 10 hours/day for 7 days:

— wood pellets: 1.7 tonnes requires 2.6 m^3 of storage

— wood chips (30% moisture content): 2.4 tonnes requires 11.2 m^3 of storage

— wood chips (50% moisture content): 3.7 tonnes requires 12.2 m^3 of storage.

Buffer vessel

Used to improve system efficiency and to protect the boiler by capturing residual heat on boiler shut-down. Size is much smaller than a thermal store. Must always have sufficient thermal capacity to absorb residual heat on boiler shut-down.

Bulk density

The density of fuel as delivered. Typical values are:

— wood pellets: 650kg/m^3

— woodchips (30% moisture content): 215 kg/m^3

— woodchips (50% moisture content): 300 kg/m^3.

Burn-back device

Prevents biomass fuel burning back from the flame-bed to the fuel store. In operation this is often achieved with a rotary valve that feeds a finite mass of fuel each time it rotates, there always being a metal barrier between fire and fuel, or a spring-return flap valve. Emergency provision includes: a bi-metal strip detector to disable the fuel feed auger; drenching the fuel feed path with water from a fire bottle activated by an over-temperature thermostat or wax plug; and/or a direct acting water drench valve connected to the water mains

Camlock connector

A proprietary and widely used connector for connecting biomass pellet delivery hoses to pellet stores.

Ceramic filter

Used to reduce particulate emissions from combustion gases from biomass boilers down to $PM_{2.5}$.

Chain grate

Consists of an endless moving chain in the combustion chamber onto which solid fuel is deposited for combustion. Fuel dries as the grate progress along the combustion chamber with ash falling off the end.

Combustion chamber pressure

Biomass boilers must operate under a negative combustion chamber pressure to ensure unburned and dangerous gases cannot escape. Typically, a flue gas fan is modulated to maintain the required negative pressure.

Chimney

A chimney is a structure which may or may not be an integral part of a building and will contain a flue or flues.

Chimney fan

The majority of biomass boilers have an integral flue gas fan or an external cyclone incorporating a fan.

External chimney fans must be capable of operating at flue temperatures up to 200 °C. Unless electricity supply backup is available from a battery power supply, and the fan modulates to maintain the required pressure at the boiler flue outlet, the use of a chimney fan must be considered as bad practice, and it may contravene health and safety requirements to install such a fan. This is because failure to operate under power failure or fan failure can lead to build-up of explosive gases in the combustion chamber and flue resulting in many reports of explosions – ignition is by the hot fire-bed.

Clinker

Clinker is glassified ash. It is produced when silica present in the fuel melts on the grate because of excessive grate temperature.

CO (carbon monoxide)

Carbon monoxide is a toxic product of the incomplete combustion of fuels when there is insufficient combustion air. It is also produced by the off-gassing of recently manufacture wood pellets. It is colourless and odourless. Humans are very sensitive to the toxic effects of CO – 35 ppm can cause headache and dizziness within six to eight hours. 3 200 ppm gives headache, dizziness and nausea within five to ten minutes, and death within 30 minutes. Biomass boilers operating in slumber mode have high levels of CO in the flue gases – a good reason for flues to be tested to be airtight.

CO alarm

Biomass boiler-houses should have a CO alarm installed and maintained to ensure proper function.

CO_2 (carbon dioxide)

A normal product of combustion.

Compressed air pulse cleaning system

Usually found in a horizontal tube biomass boiler, the fire-tubes that transfer heat from combustion into the boiler water, collect ash and dust from combustion. A way of keeping the tubes clean is to send pulses of compressed air along each combustion tube at regular intervals.

Contaminants

Fuel contaminants can lead to unsatisfactory combustion, and flue gas emissions containing toxic contaminants. Recycled wood, if used, must be proven to be free from paint products, adhesives, worktop and cabinet finishes, and from wood treatments. Silica in fuels can result in the formation of glassy slag.

Controllability

Overall, there must be a controllable hydraulic system where water circulating in boilers and heat stores has temperature and flow defined at all times, plus controls that define heat production and distribution. Biomass boiler systems are often combined with other heat sources such as fossil fuel (oil or gas) boilers that have a faster response to calls for heat. The control system must ensure that the slower response boilers are given the opportunity to satisfy the heat load without the unnecessary consumption of fossil fuel in other heat sources.

Cyclone grit arrestor

A cleaning device that removes grit from flue gases post combustion. This may be incorporated into a boiler or supplied as a separate piece of equipment. It always incorporates a fan to overcome pressure losses through the cyclone, the fan being controlled to maintain the correct negative combustion chamber pressure. It can remove only larger particulates from flue gas.

Dispersion modelling

Undertaken using specialist programs, this is used to predict the path of flue gases as they mix with external air with turbulence created by hills, valleys and local buildings. The toxicity of biomass flue gases is such that at no time should building occupants or persons in the neighbourhood be able to smell biomass fumes.

Draught stabiliser

Part of the flue system that when correctly commissioned and maintained, prevents external wind blowing across the flue from creating an excessive draught in the flue with the potential to upset combustion conditions in the boiler. It normally consists of a metal flap with adjustable counterweight, positioned close to the base of the chimney. May be combined with an explosion relief damper.

Drench bottle

A drench bottle is used in smaller biomass boiler fuel feeds to prevent fire burn-back into the fuel store should the primary methods such as gate valves or flap valves fail. If the temperature in the fuel feed rises above the melting point of a wax plug, the drench water in the bottle is released, wets the fuel and stops the spread of fire.

Drench valve

A direct-acting mechanical device normally used in the fuel feed mechanism in larger biomass boilers to prevent fire burn-back into the fuel store should the primary methods such as gate valves or flap valves fail. Normally uses a temperature sensitive phial that opens a water valve so that the fuel feed is doused with water. The water source is either a cold-water storage tank or mains water. This valve normally needs a manual reset after operation. The maintenance regime must prove operation, and the building management system should monitor availability of water.

Effective height

The vertical distance between the axis of the boiler flue outlet and the chimney terminal. With the exception of underground plant rooms, this will be less than the height at ground level.

Efflux velocity

The velocity of exhaust gases at the exit from a chimney stack. Note that efflux velocities from biomass boiler chimneys will normally be in the range of 1.0 to 3.0 m/s.

Emergency heat exchanger

Biomass boilers are thermally heavyweight and could seriously overheat should water circulation through the boiler stop for any reason including power failure. Many biomass boilers therefore have an emergency heat exchanger as a means of removing the excess heat should the water temperature rise to a dangerous level. (Such heat exchangers are a legal requirement on all biomass boilers in Austria.) Operation must not be dependent on availability of electrical power. It often uses mains water running through the head of the boiler, discharging to waste.

Electrostatic filter

A filter for removal of fine dust in flue gases that uses high voltage to attract the dust onto surfaces that can then be cleaned.

Emissions

See *Exhaust gases*

Energy density (of biomass fuel)

Typical values (kW·h/m^3) are:

— wood chips (30% moisture content): 694–868

— wood pellets: 2 833–3 306.

For comparison, other typical values are:

— coal: c. 7 000

— oil: c. 10 000

— LPG:c. 6 500.

Exhaust gases

Otherwise known as flue gases. If from a biomass boiler, these will have a composition very heavily dependent on the quality of combustion. Carbon dioxide is a major constituent. Other gases are carbon monoxide, nitrous oxides, and non-combusted volatiles / tars – particulate matter (PM_{10} / $PM_{2.5}$) Typical temperature at boiler outlet with normal combustion is 120 °C to a maximum 200 °C.

Explosion relief damper

A device installed on the flue outlet from the boiler which opens in the event of a gas explosion within the boiler to relieve the pressure of the explosion and prevent damage to the boiler. May be supplied combined with a draught stabiliser in a single unit.

Farmers' lung

A serious chronic disease induced by the inhalation of biologic dusts such as from stored biomass. Damp wood chips (such as those with moisture content above 30%) stored for more than 2 to 3 weeks can develop a spidery white fungal web that emits spores associated with farmers' lung. These spores can develop in the human lung and seriously compromise the functions of the lung. Reputed to be as dangerous as asbestosis requiring immediate treatment with antibiotics.

Fill pipe

A pipe of typically 100–120 mm diameter used to deliver wood pellet fuel by blowing from tanker to fuel store, and normally fitted with a Camlock connector. Pellet fuel stores normally have two or three fill pipes one of which is opened to a dust bag to capture pellet dust that would otherwise escape to the vicinity of the fuel store.

Filter – bag

Bag filters made of materials resistant to flue gas temperatures (e.g. ceramic fibre and Nomex / Kapton) used to reduce particulate and dust emissions from biomass boilers.

Filter – ceramic

Used to reduce particulate emissions down to $PM_{2.5}$ from combustion gases from biomass boilers.

Fire tube

The metal tube that acts as the heat transfer interface between the hot combustion gases and the water being heated in the boiler. Normally, the hot gases pass through the tube. Can be either vertical or horizontal.

Fire tube cleaning

The hot gases passing through the fire tube contain dust and grit which coats the tube surface and acts as a thermal insulating layer. Cleaning can be manual by brushing or scraping the tube surfaces, or by compressed air pulses that blow the dust away. Larger biomass boilers have built-in powered scrapers that are regularly operated to keep the tube surfaces clean.

Firebed

The area in the boiler where biomass fuel is combusted. Can be considered to have several zones starting with fuel drying, then heating to 200 to 350 °C to release fuel gas volatiles, then the higher temperature combustion of carboniferous fuel components. The firebed can be formed on be a chain grate, fixed grate, rotary grate or stepped grate. The biomass combustion temperature on the firebed should be limited to 700 °C to prevent slag formation.

Flame temperature

The temperature of the combusted gases above the firebed. The flame temperature needs to be high enough to combust the wood gas but kept to a maximum of 1 150 °C to prevent atmospheric NO_X formation.

(Not to be confused with flue gas temperature where the combustion gases have already given-up heat to the boiler water.)

Flap valve

A self-closing valve in the fuel feed mechanism used to meter fuel into the boiler and to prevent burn-back into the fuel store.

Flow meter

A meter that measures the flow of water in hydronic circuits. This can be mechanical (e.g. a vane or propeller in the water), ultrasonic (where the velocity of sound is modified by the speed of the water), or magnetic (where the flowing water generates a voltage in a magnetic field proportion to the water velocity). Costs and accuracy vary widely. Installation must ensure laminar (non-turbulent) water flow through the meter. This can be achieved with straight pipes 10 to 20 pipe diameters before the meter, and at least 5 pipe diameters afterwards.

Flue

A flue is a passageway between a combustion device and the terminal of a chimney. It must be smooth, insulated, fire-proof and predominantly vertical. It must be capable of long-term resistance to heat and acidic corrosion. It must have a low, known leakage rate which will not change in operation. It acts as a duct for combusted gases to take them to a position and height where they will not cause annoyance or a health hazard.

Flue fans

The flue for biomass boilers must provide a draught sufficient to remove combustion products from the boiler under all operating conditions. Because of the nature of flue gases under some operating conditions (there can be an explosive mix from some boiler/flue combinations in slumber mode), including under power failure, this must be achieved without the use of flue fans if health and safety is not to be compromised. Note that efflux velocities from biomass boiler chimneys will normally be in the range of 1.0 to 3.0 m/s. Accordingly, it is inappropriate for calculations on flue sizing to be made using Memorandum D1 of the Clean Air Act, which requires a minimum efflux velocities >10 m/s.

Flue gas

Otherwise known as exhaust gases. If from a biomass boiler, has a mixture very much dependent on the quality of combustion. Carbon dioxide is a major constituent. Other gases are carbon monoxide, nitrous oxides, and non-combusted volatiles / tars. Typical temperature at boiler outlet with normal combustion is 120 °C to 200 °C.

Flue gas dispersion

Flue gases from biomass boilers contain toxic gases with no known lower safety limit – defined by the World health Organisation. Flue gas dispersion / dilution must therefore take place in such a way that no building occupants or persons in the neighbourhood breathe in flue gases under any boiler operating or weather conditions. This is achieved by adequate chimney height and positioning the chimney to avoid turbulence and down-draughts from nearby buildings.

Fly ash

Fine particles of ash from the combustion process that are carried by the flue gases. Any heavy metals present in the fuel, e.g. lead, cadmium, zinc, will condense out in the fly ash.

Forward flame boiler

A boiler in which the flame from the grate propagates forward along the grate to a combustion gas zone located above the far end of the grate. Found on boilers designed to burn dry fuels up to 20% moisture content.

Fossil fuelled boiler

Fossil fuelled boilers are fired with oil and gas.

Fuel level

In a biomass fuel store, fuel level / amount of stored fuel is based on a measurement of fuel level in the store. A common measurement method is ultrasonic measurement of fuel height in the store. Problems can occur when the ultrasonic sensor head is coated in dust, or during delivery when atmospheric dust from the fuel can prevent valid measurements.

Fuel quality

The key parameters are moisture content, dimensions (pellets can be 6 mm or 8 mm diameter, wood chips vary in size), origin (where was the source) and ash content.

Fuel Standards

The main standards are CEN based. The core reference is BS EN 14961-1: 2010 *Fuel specifications and classes – Part 1: General requirements*. New Standards are ISO based such as ISO/TC 238. Measurement methods are in related standards.

Fuel store

There are two main types – those with sloping sides where the fuel naturally falls down to an exit point (for wood pellets) with onward movement using gravity or an Archimedean screw or a chain, or with a flat bottom with 'sweepers' moving the fuel to an exit point, or using a walking floor. Fuel stores must be ventilated (new pellets produce carbon monoxide for up to six weeks after manufacture), and any electrical fittings must be fireproof.

Fugitive dust

If from leaky flues, must be regarded as a carcinogenic compound that must not be breathed in or allowed to come into contact with bare skin. Flues must be appropriately air-tight. For more information see Chapter 10.

Glazed crown

Formed from melted ash from the combustion process in an underfed stoker boiler. Caused by excessive combustion temperatures and/or contaminated fuel. The crown has to be removed before normal combustion is possible.

Grate

Formed from metal resistant to combustion temperatures, this supports the fuel during the combustion process, then allows the ash to pass through/over into a collection area.

Grit arrestor

Usually a cyclone which provides a low velocity area where grit falls down into a collection container.

Header

A pipe connecting two or more boilers in parallel, and then to other parts of the boiler-house. Can be a flow header connecting the outputs from the boilers, a return header connecting boiler inputs, and can be a low-loss header.

Heat exchanger

This exchanges heat between two water systems – e.g. a boiler system and the heating pipework. Care needs to be taken that the size is large enough to keep pumping costs to an acceptable minimum. Can be a plate-type heat exchanger, or a calorifier.

Heat meter

Measures rate at which heat is flowing in a pipe by multiplying the rate at which water is flowing by the temperature difference between the flow and return pipes. Needs to include corrections for the density of water that varies as its temperature varies. Can include an integrator that outputs total heat flow over a period of time.

Hook lift bin

Fuel can be delivered in a container that can be lifted by a hook-lift attachment to the delivery lorry. Has the advantage that a large quantity of fuel can be delivered in minutes to a site. The empty fuel container is picked-up by the same delivery lorry.

Horizontal (or primary) flue

Flues take combustion gases from the boiler to the outside air. Most of the pipe must be vertical, but it is acceptable to have short horizontal lengths of flue to connect the boiler to the bottom of the vertical section. Horizontal flues should be as short as possible – certainly less than 2 m for boilers up to 5 MW.

Horizontal tube boiler

A boiler where the fire tubes (through which flow the hot gases from combustion) are horizontal.

Hydronic system

Hydronics is the use of water as the heat transfer medium in heating and cooling systems. This also includes water in combination with corrosion inhibitors or antifreeze chemicals. This is different from a hydraulic system which can be filled with any working fluid.

Ignition

The wood fuel in the biomass boiler needs to be heated above a very minimum of 230 °C for ignition to occur, and normally to 450 °C or more In smaller boilers this is achieved using a fixed hot air heater, in larger boilers by a small oil or gas burner firing into the biomass fuel fire bed.

Impact mat

When biomass pellets are delivered, they exit from the delivery pipe at high velocity. An impact mat, normally of a rubber type material, is placed so that the pellets impact on a soft surface and thus minimise pellet break-up and dust production.

Initial ignition boiler

Two main types of biomass boilers exist. Automatic ignition boilers are lit when heat is required (automatic ignition) and allow the fire bed to burn out when heat is no longer required. Initial ignition boilers keep a lit fire-bed even when no heat is required, with fuel being fed into the fire-bed at c. 0.5% of the full-fire rate (often referred to as slumber mode or kindling mode boilers).

Inspection access

A flue needs to have a door or panel to provide access for inspection and cleaning. This door / panel must have safe access, and allow for flue cleaning tools to be used.

Kindling mode boiler

See *Initial ignition boiler*

Lambda sensor

The lambda sensor in a biomass boiler measures the amount of oxygen in the flue gas. The combustion control system takes this as one of its inputs, and adjusts combustion air and rate of fuel input to ensure efficient combustion and to keep emissions such as nitrous oxides and carbon monoxide within specification.

Lignin

The woody component of biomass fuel.

Log boiler

A boiler manually fed with logs.

Manual feed boiler

A boiler that has its fuel manually loaded.

Manual ignition boiler

A manual ignition boiler is lit at the beginning of a heating season and has sufficient fuel fed into the fire bed to keep it continuously alight when the is no demand for heat. This is also called slumber mode operation and requires provision for removal of heat from the slumber fire bed. Also referred to in this document as initial ignition.

Metering

In biomass boiler installations this normally refers to measurement of the amount of heat produced by a boiler. A heat meter consists of a device to measure the flow rate of the heating fluid (normally water, but can be a water glycol mix) and the temperature difference between heating flow and heating return pipes. An integrator sums the heat flowing to give the total amount of heat produced. Overall accuracy is approximately ±2%.

Mixed flame boiler

A boiler in which the flame from the grate rises vertically above the grate to the combustion gas zone. This is most commonly found on underfed stoker and vertical firetube boilers.

Moisture content (MC)

The moisture content of wood fuels varies between 8–10% for biomass pellets (always supplied 'dry'), to >50% for wood chips from wood that has just been harvested. The combustion process has to dry out the wood before combustion can start and this takes a considerable amount of heat. Several measurement methods exist. One commonly used method is to check for weight loss when heated in an oven at 105 °C. Biomass boiler specifications define the permissible range of MC for satisfactory operation. Deliveries of biomass fuel should be checked for MC being compliant with the fuel purchase specification.

Mould

Biomass chips with a moisture content above 33% stored for more than 2 to 3 weeks can develop a white spidery mould whose spores are associated with farmer's lung disease.

Moving grate boiler

Can be a chain grate, stepped grate or rotary grate. See *Chain grate*, *Stepped grate* and *Rotary grate*.

Negative pressure flue

Flues should operate under negative pressure under all operating conditions. This is achieved by the 'stack effect' – hot flue gases are less dense than outside air and thus will rise of their own accord in the flue.

ÖNORM

Is an Austrian standards specification body. For biomass fuel Standard M7 133 applies to wood chips and M7 135 applies to biomass fuels. Often used as the fuel specification for biomass boilers of Austrian manufacture. Being superseded by the CEN/TC 335 standards. Standards for detailed aspects of biomass fuel include BS EN 14774-1:2009, BS EN 14775 / 14918 / 14961 etc. Also CEN/TS 14588 etc.

Overfeed stoker

Fuel is fed to one end of a continuous chain grate from above. At the fuel feed end, the fist (drying) stages of combustion take place. As the chain moves into the combustion chamber the later stages of combustion occur. Just before the chain grate returns, it tips combustion ash into a collection box.

Packaged boiler-house

Smaller biomass boiler-houses, up to around 400 kW can be supplied pre-assembled. Standard shipping containers are sometimes used, with the fuel store at one end and the boiler pumps, valves and controls at the other end. The thermal store can be internal or located externally, dependent on size.

Particle control

The combustion process of biomass (and other) fuels can produce grit and dusts. Environmental specifications limit such emissions. Control is achieved using cyclones for larger particles, and fabric and electrostatic filters

Pellet

Pellet fuels for biomass boilers are made by extruding dry wood chips (moisture content typically <10%) into 6 mm or 8 mm diameter pellets (can be larger). These provide the best energy density per unit of storage volume and are very easy to deliver as they can be blown using flexible pipes up to 30 m from the delivery tanker. They are more expensive than wood chips. It is very important to be aware that, especially for the first six weeks after manufacture, pellets exude carbon monoxide at a level sufficient to cause death to humans entering fuel stores. Pellet fuel stores must be adequately ventilated as carbon monoxide is also a flammable gas.

Pellet delivery

Pellet delivery in small quantities up to 5 m^3 is often by blowing along a 125 mm flexible hose up to 30 m long from a tanker. Can also be delivered by tipping, or by hook-lift containers. Delivery rates faster than 12 tonnes per hour can damage pellets leading to failures in fuel transport augers feeding fuel to the biomass boilers.

Plant sizing strategy

Options on relative sizes of biomass boiler, auxiliary boiler (often fossil fuelled such as by oil or gas) and thermal store vs. heating and hot water load characteristics need to be formally explored to optimise biomass utilisation – eg a good performance-in-use target is 95% of annual heat requirement is to be from biomass fuel. Calculations are easier if a sizing tool such as the Carbon Trust Biomass Decision Support Tool is used.

PM_{10}

Flue gases from biomass (and other fuels) boilers can contain particulate patter of 10 micro-meters (μm) and smaller in size, thus known as PM_{10}. (For comparison, an average human hair is roughly 100 μm thick).

Polycyclic aromatic hydrocarbons (PAH)

These are components of flue gases from biomass combustion which according to the World Health Organisation (WHO) have no known safe minimum level of acceptable exposure.

Pre-heat (of hot water service)

Biomass boilers are typically sized in the range of 30% to 50% of maximum heat load. Fossil fuel boilers in comparison are sized at 110% of maximum heat load, and in premises such as offices and schools, heat both the heating and hot water services simultaneously when turned on two to three hours before the beginning of a work day. In contrast, the biomass boiler can be used to heat the hot water, but this would be done in the two to three hours before the boiler is asked to put heat into the building heating. The hot water would stay hot in the insulated hot-water cylinder, and be available for the start of the work day. Note that the first few hours of the heating load require a far higher heat output. Subsequent calls to heat more hot water normally occur after the early morning high heating load, and can, dependent on weather, be handled within the maximum heat output of the biomass boiler.

PressSet

An abbreviation for a 'pressurisation set'. Until the availability of PressSets, boiler and heating systems were pressurised using a feed and expansion tank at roof level. If a PressSet is installed, typically in the boiler-house, there is no need for feed and expansion tanks and all their pipework and maintenance.

Primary air

Primary air in a biomass boiler provides oxygen to facilitate the early stages of the combustion process, while secondary air is used to burn the volatile compounds in another (and hotter) part of the combustion chamber.

Ram stoker

A ram stoker pushes fuel for the biomass boiler. An alternative to a fuel feed auger.

Recirculation

In a biomass boiler (and some fossil-fuel boilers) is where partially combusted fuel vapours from mid / end stage of the combustion process are recirculated back beneath the grate. Used to maintain a low combustion temperature on the grate while ensuring adequate dwell-time for complete combustion of flue gases.

Refractory (and refractory lining)

Otherwise known as a fire-brick, this is highly resistant to the heat of the flames in the combustion chamber of a boiler. When hot, it provides radiant heat within the boiler that (dependent on boiler type) dries out water in the fuel and then initiates the combustion process. Biomass boilers generally have a heavy weight of fire bricks that have significant thermal inertia. The refractory lining must be sized to match the boiler's designed mid-point fuel moisture content.

This means that heat is available from the boiler for some time (5 to 20 minutes) after the call for heat ceases. This heat must be dissipated safely, either into the boiler water, or in the case of power failure, by an emergency heat exchanger that uses cold mains or storage water dumper to waste.

Renewable Heat Incentive (RHI)

A financial support programme by the UK government for renewable heat. For more information related to biomass boiler installations, see https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi

Reverse flame boiler

A boiler in which the flame from the grate rises from the end of the grate then propagates backwards through the gas combustion zone to exit the combustion chamber above the entrance to the grate. Found on boilers designed to burn wet fuels (40%–55% moisture content) where the hot gases heat a refractory lining running above full length of the grate is heated to assist in drying fuel as it enters the grate.

RHI

See *Renewable Heat Incentive*

Rising gate

Used with a ram stoker fuel feed system. As fuel is pushed towards the boiler a gate rises to allow fuel to enter the combustion chamber and closes again once fuel has been delivered onto the grate.

Rotary grate

Found on underfed stoker boilers where fuel is pushed up into the centre of the grate from below and works its way outwards as it combusts. Ash falls off the outer circumference of the grate.

Secondary air

Secondary air is used to burn the volatile compounds in the hotter part of the combustion chamber that is a short distance above the fire-bed.

Silo

A fuel store for holding biomass chips or pellets can be in the form of a silo – a pit or large above-ground container for storing bulk materials.

Slag

Combustion temperatures and/or contaminated fuel can cause ash from the combustion process to melt or glassify. This is known as slag.

Slumber mode boiler

See *Initial ignition mode boiler*

Sparge pipe

A pipe containing a series of holes along its length, used for flow and return inlets in thermal stores to minimise turbulent mixing in the store.

SpillPress

A pressurisation set where water is pumped under pressure into expansion vessels.

SpillSet

A pressurisation set where expansion water is allowed to spill into a spill vessel external to the hydronic system.

Stack effect

Caused when hot flue gases, which are more buoyant than outside air, rises in a flue.

Stepped grate

Combustion grate slopes down from fuel feed to ash bed where a reciprocating movement transports fuel from drying zone to main fire zone and then the burn-out zone. Has wide tolerance of fuel type and particle size, fuel moisture content can be up to 55%. Stepped grates largely avoid clinkering and blockages. Overall this is a very good design, but has higher initial cost. Grate bars often contain a high proportion of chromium to provide abrasion resistance.

Stoichiometric

This refers to an ideal combustion process where the fuel is burned completely. In practice, a small amount of excess air is required to realise complete combustion of available fuel, and to ensure that products of incomplete combustion, e.g. carbon monoxide, are minimised.

Stoker burner

Fuel is fed horizontally from one side onto a flat and short grate. This is simple technology and therefore much less expensive than other boiler types. It offers a fast response to load variations and a turndown ratio 4:1 or better. Very little heat is generated in 'slumber mode' and it produces black smoke if fuel is to too wet (must be >35% moisture content). Usually has poor separation between primary and secondary air and is very prone to slag formation. Water cooling of the grate is usually required.

Stool pieces

Stub lengths of pipe, normally with flanges, that can be easily adjusted should valves and heat meters have different dimensions between flanges, or different flange sizes.

Stratification

This occurs in storage vessels containing hot water provided there is minimal turbulence from water flowing in to the vessel. Hot water has a lower density that cold water and thus the hot water will tend to the top of the vessel (tank or cylinder), and the cold water will tend to the bottom. In practice, with hot water at 60 °C and cold water at 20 °C, then with minimal turbulence, a transition between hot and cold water occurs in a band approximately 150 mm high. The amount of stored hot water can thus be determined by finding the position of this transition layer.

Stratified store

A hot water store, often a cylinder, functioning better when vertical, with inlet pipes terminating in sparge pipes (longer pipes with many water outlet points), will behave as a stratified hot-water store.

Sub-clinical exposure

Flue gases from biomass boilers can be breathed-in in a much diluted form. Though there is no acute respiratory effect, over a period of time a cumulative dose can exist that does have impacts on health. There are many chemicals existing in flue gases, some of which the World Health Organisation (WHO) has deemed as having no minimum level of acceptable exposure. The corollary is that flue terminals must be properly positioned so that nearby building occupants and persons in the neighbourhood cannot smell or breathe-in fumes from combustion of biomass materials.

Summer load

The minimal load found in buildings in summer, usually from hot water alone.

Sweeping arm extractor

A fuel extract mechanism for woodchips whereby rotating arms sweep fuel onto an open fuel extract auger.

Sweeping auger

An auger which rotates in a fuel store collecting fuel in a similar manner to sweeping arms and feeding it into the same auger mechanism.

System pump

The pump between a thermal store and the headers.

Tar

The heavier component of flue gases which can condense out at normal atmospheric temperatures.

Terminal height

The height of the flue outlet above ground level.

Test point

A point close to the boiler where a flue gas combustion analyses can be attached.

Thermal store

Used to enable a relatively small boiler to provide the majority of the annual energy demand from biomass. Allows boilers to operate continuously for long periods and thus improve operating efficiency. This can also function as a buffer vessel if control sensors are correctly positioned. The size of the thermal store is boiler type and load type dependent. The Biomass Decision Support Tool enables easy optimisation of thermal store size, operating efficiency and capital cost.

Tipping grate

Usually found in association with a stoker burner boiler. The grate tips at regular intervals to remove ash from the grate.

Transfer auger

An auger used to transfer fuel from a fuel extract auger in a silo to a rotary valve or flap valve on the boiler.

Turbulators

Found in vertical tube boilers, spiral inserts in fire tubes which spin flue gases to deposit fly ash onto the firetube walls. They are mechanically agitated at frequent intervals to cause fly ash to drop into an ash bin below.

Turndown ratio

The ratio of maximum to minimum output of a boiler.

Underfed auger

A fuel feed auger which transports fuel beneath a boiler and pushes it into an underfed grate.

Underfed stoker boiler

Fuel is fed into the combustion chamber from below using an auger feed. Fuel moisture content can be up to 50%. Found on a wide variety of vertical and horizontal tube boilers. Slag formation can occur on the 'dome' of fuel, causing the boiler to flame-out.

Uninterrupted power supply (UPS)

Uninterrupted power supply. Used to provide a battery-backed mains power supply to critical components such as control systems and flue fans.

Utilisation factor

Hours per year full load equivalent operation divided by 8 760 hours.

Vertical tube boiler

A boiler in which the fire tubes are mounted vertically.

VOC

Volatile organic compound.

Walking floor

A fuel extract system where metal bars operated by hydraulic rams push fuel towards one end of a fuel silo to be deposited onto a fuel extract auger or ram stoker feeder.

Wood gas

The gases produced during pyrolysis. Consists of CO, CO_2, H_2 and other complex organic compounds.

Woodchip

Produced by either a disk or drum chipper, chips of wood which are small enough to be to be handled by automatic fuel feed systems.

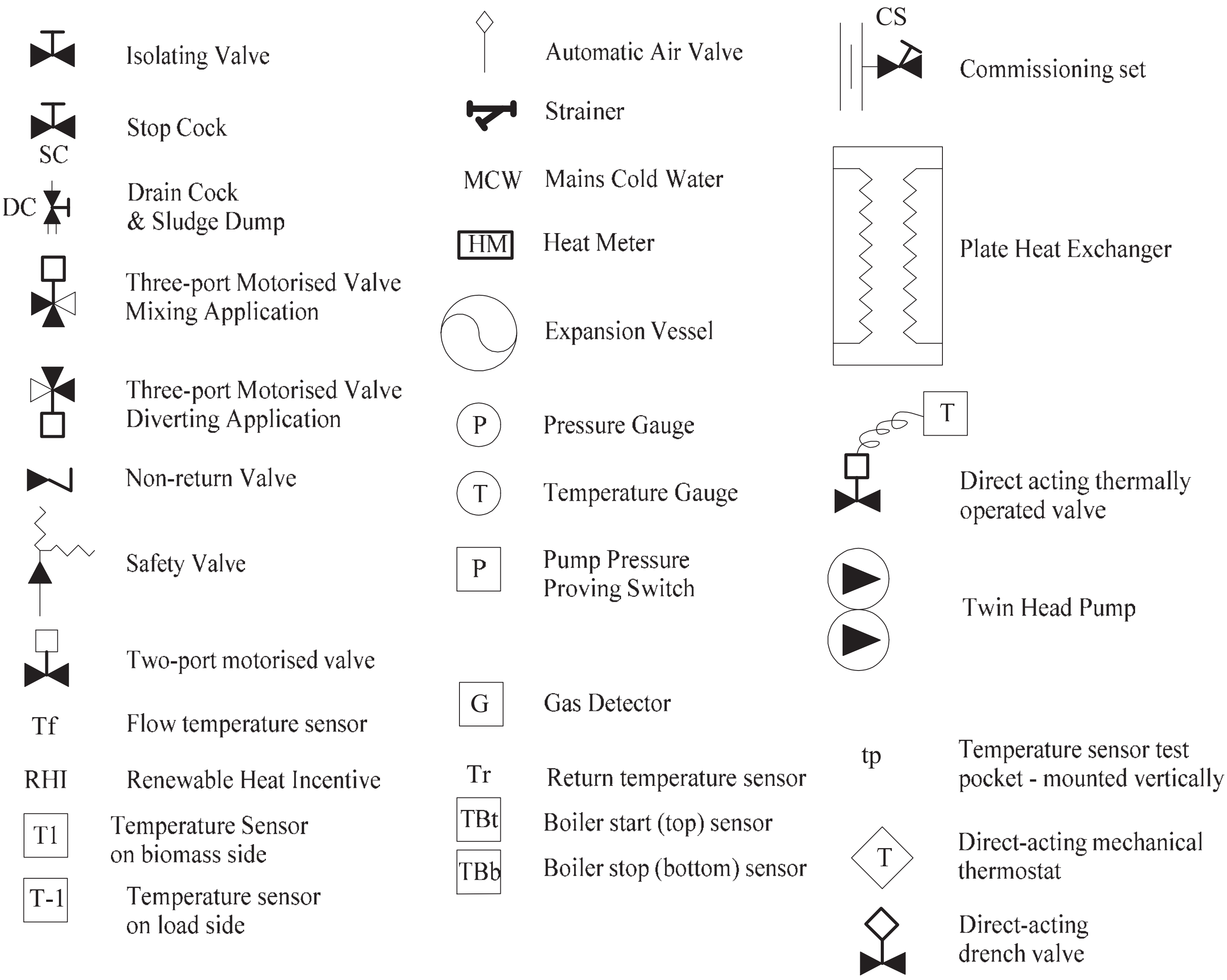
Woodfuel

Comprises all types of fuel from wood including, woodchips, wood pellets, short rotation coppice, industry offcuts and by-products.

Woodsure

A woodfuel assurance and certification scheme.

Key to symbols used in hydraulic diagrams



Index

Note: page numbers in italics refer to figures; page numbers in bold refer to tables; footnotes are shown thus: 34n

The Chartered Institution of Building Services Engineers
222 Balham High Road, London, SW12 9BS
+44 (0) 20 8675 5211
www.cibse.org

ISBN 9781906846510