

## **WOBBE INDEX/CALORIFIC VALUE MEASUREMENTS HAND-OUT**

### **SIGNIFICANCE OF MEASUREMENT**

Tighter emission regulations and high-energy costs pose new challenges to control systems for fired heaters. Rapid changes in fuel gas heating value, air demand and composition are typical for applications in oil refineries, chemical plants and many other sites. Traditional feedback control based on temperature and stack oxygen and combustibles measurement is not quick enough to deal with fast changes effectively. This shortcoming is typically addressed by controlling the excess air set point with a certain safety margin. Unfortunately, whereas this approach prevents the emission of unburned components, it increases the CO<sub>2</sub> emission due to poorer fuel economy: air is heated unnecessarily and heat transfer efficiency is reduced. Moreover, NO<sub>x</sub> formation is promoted as a result of the higher oxygen level in the combustion process. For these reasons feed forward control of the air/fuel ratio is gaining more attention. Proper selection and installation of the fuel gas property analyzer and using the right control parameters is essential to get the best results.

### **Control Parameters**

Control system philosophy of fired heaters varies depending on the requirements and design of the heater or boiler. However, in all cases the thermal load of the furnace and the air/fuel ratio are two critical parameters that must be monitored and controlled. Depending on the control system design the Wobbe Index, the heating value and gas density may be required as input(s).

The heating value is the amount of heat produced when a unit volume or mass of fuel is burned stoichiometrically. The higher heating value includes the heat of condensation of the water formed in the combustion process, the lower heating value does not.

The Wobbe is a measure of the interchangeability of fuel gases when introduced into a heater via a burner with a fixed differential pressure. Two gases with the same Wobbe Index will deliver the same amount of heat into a combustion process per unit of time regardless of the composition.

$$\text{Wobbe index} = \frac{\text{Heating Value}}{\sqrt{\text{Specific Gravity}}}$$

To clarify the concept consider following fuel gas cases:

	MIX 1	MIX 2
CH <sub>4</sub>	40%	58%
H <sub>2</sub>	60%	-
N <sub>2</sub>	-	42%
Heating Value	20,82 MJ/Nm <sup>3</sup>	20,82 MJ/Nm <sup>3</sup>
Specific Gravity	0,26	0,73
Wobbe Index	40,55 MJ/Nm <sup>3</sup>	24,39 MJ/Nm <sup>3</sup>

The lower heating value by volume of these two gases is the same, i.e. 20.82 MJ/Nm<sup>3</sup>. The Wobbe Index however is 40.55 MJ/Nm<sup>3</sup> for mix number 1 and 24.39 MJ/Nm<sup>3</sup> for mix number 2! This means

that the amount of heat delivered per unit of time through the same burner will be 40% lower in the second case!

### **Control of air/fuel ratio**

The combustion airflow supplied to an industrial furnace is typically linked to the fuel gas flow. In smaller installations this may just be a mechanical link, in larger installations air and fuel gas temperature and pressure are taken into account. If large fluctuations in the fuel gas composition are expected, the signal from a Wobbe Index analyzer or calorimeter is used for correcting the air/fuel flow ratio. Typically the assumption is that there is a proportional relationship between heating value and air demand. Whereas this is correct for hydrocarbon bases fuel gases like natural gas, for fuel gases containing significant percentages of hydrogen, olefins, carbon monoxide and/or oxygen this approach fails. Take for example following fuel gas cases:

	MIX 1	MIX 2
Hydrogen	100%	-
Methane	-	88,5%
Nitrogen	-	11,5%
Wobbe Index	40,9 MJ/Nm <sup>3</sup>	40,9 MJ/Nm <sup>3</sup>
CARI	9,0	10,9

The Wobbe Index for both gases is the same, i.e. 40,9 MJ/Nm<sup>3</sup>. The Combustion Air Requirement Index (CARI) however, which is defined as the stoichiometric air demand divided by the square root of the relative gas density, is 9.0 for Case1 and 10.9 for Case 2. This means that if the fuel gas composition changes from hydrogen poor to hydrogen rich composition the excess air may be controlled 20% too high! Please note that instead of Wobbe Index and CARI, a similar case can be construed for heating value and air demand, this follows from the definitions:

$$CARI = \frac{\text{Air Demand}}{\sqrt{\text{Specific Gravity}}}$$

### **COMPARED ARE TWO ON-LINE WI MEASUREMENT TECHNIQUES**

- Correlation between Specific Gravity and Wobbe Index
- Residual oxygen type Wobbe meter

### **Correlation between Specific Gravity (SG) and Wobbe Index**

The Wobbe Index can be correlated directly to the SG of fuel gas if the fuel gas is a mixture of hydrogen and hydrocarbons only. If components like nitrogen and carbon dioxide are present the correlation between SG and Wobbe Index becomes inaccurate. Both nitrogen and carbon dioxide are relative heavy but do not contribute to the Wobbe Index of the gas (WI=0 MJ/Nm<sup>3</sup> in both cases).

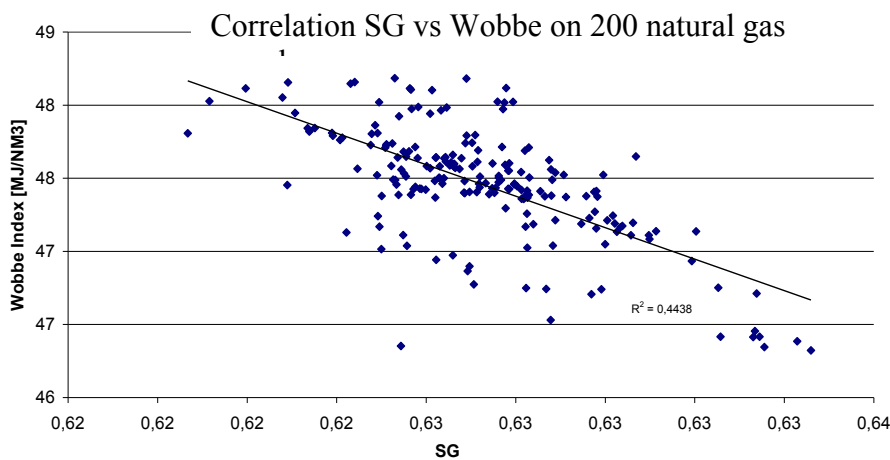
	SG	WI [MJ/Nm <sup>3</sup> ]
Nitrogen	0,967	0
Carbon Monoxide	0,967	12,85
Ethene	0,975	60,23

	SG	WI [MJ/Nm <sup>3</sup> ]
Carbon dioxide	1,53	0
Propane	1,55	74,75

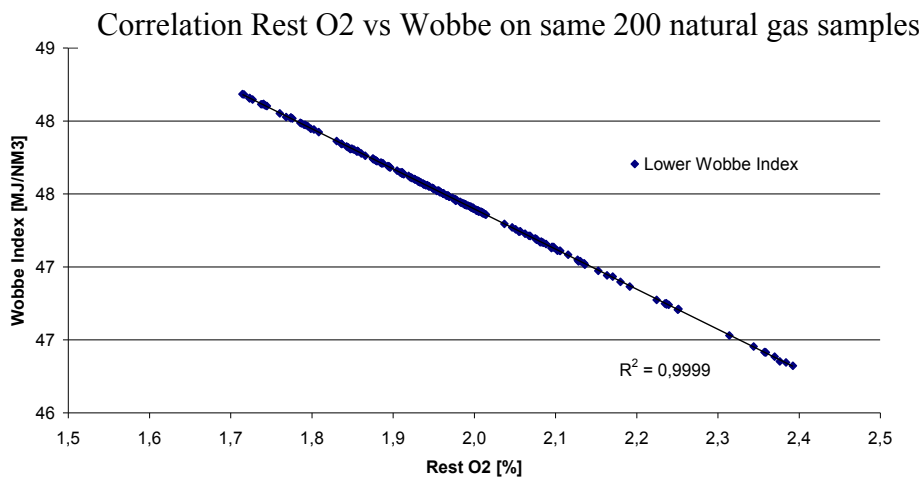
Example: Correlation SG to Wobbe for Natural gas.

Natural gas contains both nitrogen and carbon dioxide. The amount (and allowed fluctuations) of N<sub>2</sub> and CO<sub>2</sub> in the natural depends geographic location. Using a SG measurement to correlate to Wobbe Index (or heating value) can lead to relative large inaccuracies. Below graph indicates the relation between the SG and the heating value of a (well controlled) natural gas grid over a period of 8 months. The inaccuracy in this correlation is +/-2..3% while the CO<sub>2</sub> fluctuation is only 1% and the N<sub>2</sub> fluctuation is less than 4%.

In order to provide a reliable measurement on natural gas (for blending, peak shaving, combustion control, custody transfer) dedicated Wobbe Index analysers are used.



	min	max
CO <sub>2</sub>	1,15%	1,66%
N <sub>2</sub>	0,92%	3,58%
C <sub>2</sub> H <sub>4</sub>	0,00%	0,00%
C <sub>2</sub> H <sub>6</sub>	4,52%	5,58%
C <sub>3</sub> H <sub>6</sub>	0,00%	0,00%
C <sub>3</sub> H <sub>8</sub>	1,09%	1,50%
C <sub>4</sub> H <sub>10</sub>	0,38%	0,56%
C <sub>5</sub> H <sub>12</sub>	0,11%	0,18%
C <sub>6</sub> H <sub>14</sub>	0,07%	0,10%
CH <sub>4</sub>	87,78%	90,74%

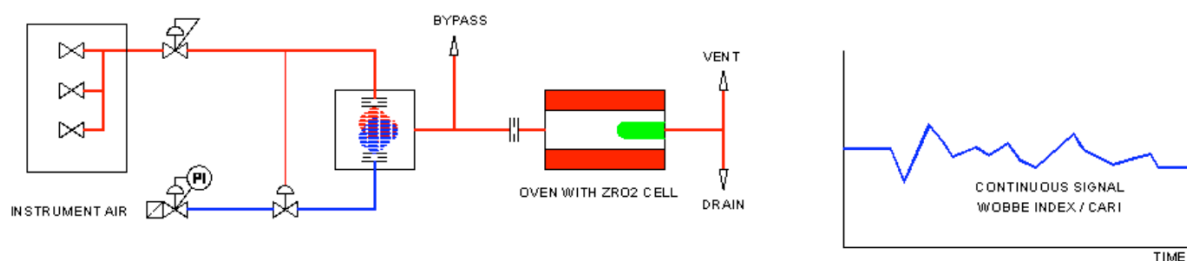


### **Residual oxygen type Wobbe meter**

Hobre Instruments model WIM Compas (successor of the 9600 and 9900 series) outputs the Calorific Value or the Wobbe Index.

Principle of operation;

The measurement principle of the Hobré Instruments Wobbe Index analyzer is based on the measurement of residual oxygen after catalytic combustion of the flare or fuel gas. A small sample flow is mixed continuously with dry air in a constant fixed ratio. This ratio depends on the gas composition and is determined on a case-by-case basis. Using an electrical heated catalytic oven the air fuel mixture is fully burned at a temperature of approximate 812°C. The residual oxygen is measured with a highly accurate and reliable oxygen sensor. The oxygen sensor used is a Zirconium oxide (ZrO<sub>2</sub>) cell. The measured residual oxygen content provides a measurement of the Combustion Air Requirement Index (CARI) and good correlation to the Wobbe Index of the gas.

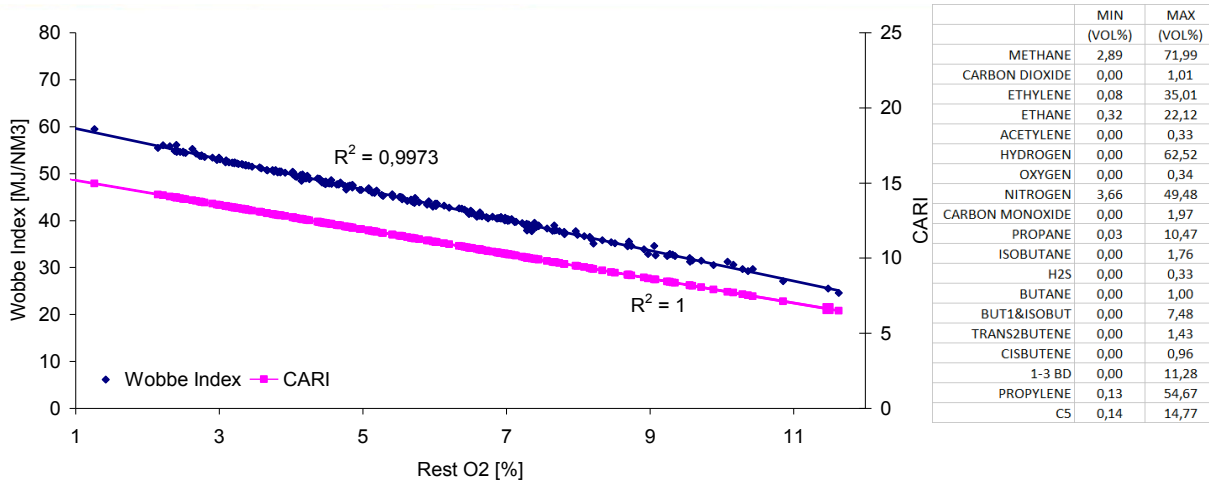


To convert the residual Oxygen percentage to a Wobbe Index value the analyzer is calibrated with two gases with known Wobbe Index values: a low calibration gas with a low Wobbe Index and a high calibration gas with a high Wobbe Index. Prior to calibration, the known Wobbe and CARI values are entered into the instruments software. When starting a calibration, the analyzer subsequently switches from sample to low cal. gas, high cal. gas and back to sample.

During calibration, the residual oxygen percentage, for the corresponding Wobbe Index and CARI value is determined and stored. By using these values, determined during calibration, the slope and offset (linear regression) of the calibration line can be calculated.

The ratio between CARI and Wobbe Index is not the same across alkanes, alkenes, carbon monoxide and hydrogen. For this reason an application review should be performed by the vendor, in order to recommend the calibration gases. By using the correct calibration gases the correct line (with correct CARI – Wobbe Index ratio) is programmed. The example below shows the correlation including 2% CO and 60% H<sub>2</sub> fluctuations.

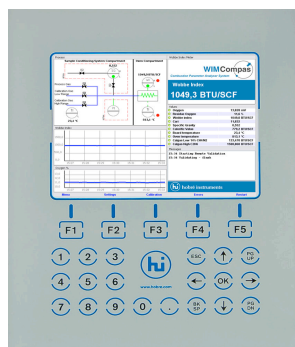
Typically accuracy of the analyzer on a refinery fuel gas is +/-1% of full scale on Wobbe and +/-0,4% of full Scale on CARI.



The graph above is based on 220 samples from a flare application.

### Specifications Hobré Instruments WIM Compas F

Range	Wobbe	0-100 MJ/Nm3 (0-2500 BTU/SCF)
	Heating Value	0-120MJ/Nm3 (0-3000 BTU/SCF)
	CARI	0-25
Accuracy	Natural gas	+/- 0,4% FS
	Fuel gas	+/- 1% FS on fuel gas (with H2 and CO fluctuations)
	CARI	+/-0,4% FS for both natural gas and fuel
Repeatability		+/-0,05% FS or +/-30kj (which ever is higher)
Response time	Natural gas	< 5 seconds to T90
	Fuel gas	Typically 5 seconds to T90 (depending composition / SG)
Ambient temp		Ambient temp : +10 – 40 deg C optionally -20-55deg C
Haz. Area	General purpose, ATEX zone 1 or 2, IECEx Zone 1, Class 1 Div 2.	



### **Zero HC emission version**

The continuous version of the WIM Compas F has an internal bypass, containing a gas/air mixture. The gas/air ratio is depending on the application but is typically 1:10. This bypass vent is installed to speed up the response of the analyzer and has to be routed to atmosphere (no back pressure allowed).

As an increasing amount of customers does not allow venting hydrocarbons in the atmosphere anymore, a zero HC emission version of the WIM Compas F is available. The bypass vent on this unit only contains hydrocarbons (no air) and can handle backpressures. For this reason the bypass on the zero HC emission version of the WIM Compas F can be routed to flare.

### **Specifications Hobre Instruments WIM Compas F (Zero HC Emission)**

Range	Wobbe	0-100 MJ/Nm <sup>3</sup> (0-2500 BTU/SCF)
	Heating Value	0-120MJ/Nm <sup>3</sup> (0-3000 BTU/SCF)
	CARI	0-25
Accuracy	Natural gas	+/- 0,4% FS
	Fuel gas	+/- 1% FS on fuel gas (with H <sub>2</sub> and CO fluctuations)
	CARI	+/-0,4% FS for both natural gas and fuel
Repeatability		+/-0,1% FS or +/-50kj (which ever is higher)
Response time	Natural gas	5- 10 seconds to T90
	Fuel gas	5- 10 seconds to T90 (depending composition / SG)
Ambient temp		Ambient temp : +10 – 40 deg C optionally -20-55deg C
Haz. Area	General purpose, ATEX zone 1 or 2, IECEx Zone 1, Class 1 Div 2.	

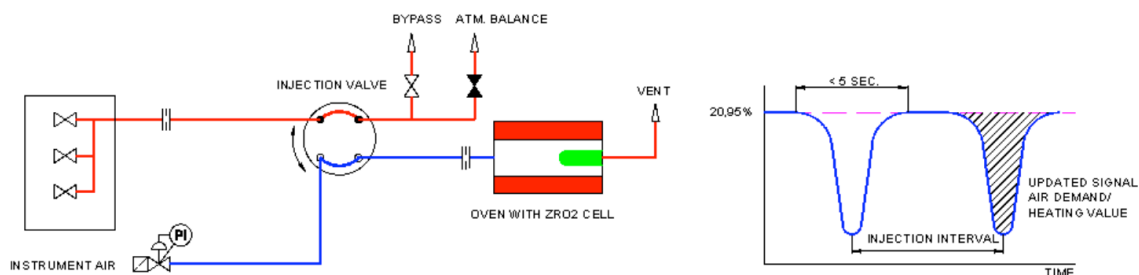
### **Corrosive gas applications**

Flares are used to eliminate waste gas, which is not feasible to use or transport. Legislation around flaring is increasingly intensified, as flaring is an undesirable process both environmentally and economically. Moreover, it results in health and safety issues and in waste of energy, which can be utilized for future generations. For this reason users are forced to minimize their flaring activities to a minimum. Flare gases are increasingly blended into the fuel gas systems to be combusted in for instance industrial boilers (see application note fuel gas systems). Besides the elimination of waste gas, flares are an important part of a plants safety system. Non-waste gas released during an upset condition is typically combusted in a flare system. By flaring gas during an upset condition gas processing equipment is protected against over pressure.

With the increasing amount of flare gas being blended in fuel gas networks, a wider range of fluctuation can be expected in the combustion process. Due to the increasing amount of corrosive elements in the fuel gas (for instance Sulfur components), different approach might be required. When combusted Sulfur components form SO<sub>2</sub>/SO<sub>3</sub>, which, in the presence of water, forms Sulfuric acid. Water is always available as it is formed by the combustion of hydrocarbons. Depending on the concentration of the corrosive elements, corrosion / clogging is a matter of time with both the type of analyzers described earlier.



Especially for the applications where high concentrations of corrosive elements are expected, Hobré Instruments developed a version of the WIM Compas for measuring heating value. Within this version of the WIM the very small volumes of gas are injected into a carrier of instrument air on a time based interval. The air (with injected gas) is again combusted in the electrical heated catalytic oven. The amount of air required for the combustion of the fixed volume is determined using a zirconium oxide sensor. This air demand correlates directly to heating value without the need of a specific gravity cell (per ASTM-D4891-89). Optionally hot application units (upto 150degC) are available.



### Specifications Hobré Instruments WIM Compas F (injection version)

Range	Wobbe Heating Value	0-100 MJ/Nm3 (0-2500 BTU/SCF) 0-120MJ/Nm3 (0-3000 BTU/SCF)
Accuracy	Natural gas Fuel gas	+/- 0,4% FS +/- 1% FS on fuel gas (with H2 and CO fluctuations)
Repeatability		+/-0,5% FS or +/-50kj (which ever is higher)
Response time		Depending on injection interval. Typical update time: 30 seconds
Ambient temp		Ambient temp: +10 - 40 deg C optionally -20-55deg C
Haz. Area	General purpose, ATEX zone 1 or 2, IECEx Zone 1, Class 1 Div 2.	

### Instrument installation and selection

When it is decided to install an analyzer for measuring the heating value and/or Wobbe Index for feed forward fuel and air/fuel ratio control, following requirements should be fulfilled:

1. The analyzer should be as fast as possible.

It makes no sense to install a slow responding measurement if changes occur within seconds.

2. Repeatability should be as low as possible.

High repeatability levels will require smoothing of the signal, typically by averaging. As a consequence the response from the control system to a step change will be slower.

3. Local installation close to sample tap point.

Ideally the fuel gas heat value and air demand signal should be available before the fuel gas leaves the burner tip. This means that the travelling time of the fuel gas from sample tap point to the burner should be longer than the travelling time from sample tap point to the analyzer plus the analyzer response time.

4. The sample handling system should have minimal internal volume.

Although a fast loop theoretically can compensate for any dead volume in the system this will result in excessive venting and/or flaring of fuel gas. Smart solutions are available on the market. Please consult the analyzer manufacturer for the optimum solution.

5. A combustion air requirement signal should be available.

As outlined the heating value or Wobbe Index can be poor indicators for the air demand in fuel gas applications and feed back control using stack analyzers is typically a slow process. An accurate feed forward signal to control the air/fuel ratio can optimize your process and the stack analyzer can be used for fine-tuning.

6. Rangeability of the analyzer should match all possible cases

Typically the analyzer should be able to handle large fluctuations in the fuel gas composition. The extreme cases are important, as these are the cases where the measurement is most important!

7. Thorough application review; each application is different and proper review is essential. Issues that should be considered include:

- Calibration gas selection
- Parameters measured
- Fuel gas hydrocarbon and/or water dew point - It is not uncommon that fuel gas is taken from a knock-out vessel. Care must be taken that no condensation takes place in sample lines or inside the analyzer
- Sulfur content and presence of other corrosive components - Wrong material selection can rapidly corrode and clog an analyzer
- Overall response time - A lag time analysis from sample probe tip to analyzer signal output should be provided to ensure compliance with the requirements. This is especially important when high-pressure gas lines must be analyzed
- Ambient temperature range and fluctuations
- Hazardous area certification