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Capital Cost and Efficiency Data for the ZR-LNG Dual Methane Expander Liquefaction Technology

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Introduction

LNG producers traditionally enhanced project returns through higher plant capacities, high energy efficiency and co-product recovery. Complex multi-refrigerant configurations have been deployed to achieve this objective for on-shore base load facilities. However high levels of LNG plant complexity and the associated high capital costs may not be sustainable in an era of lower energy prices which have the capability to jeopardise what have become, by any measure, enormous investments. These complex plants are also unsuited to smaller gas reserves which require innovative solutions if they are to be monetized, particularly off-shore.

Gasconsult's patented ZR-LNG process is a simple, low cost, energy efficient liquefaction scheme for application in the mid-scale capacity range. The process is highly differentiated. It requires no external refrigerants, no refrigerant import system or storage facilities and no ongoing refrigerant make-up. It achieves, without feed gas pre-cooling, an energy efficiency very close to base load dual refrigerant processes. The absence of liquid hydrocarbon refrigerants improves safety relative to mixed refrigerant schemes, particularly for floating applications; and the process requires significantly less power than other 'safe' systems such as the dual-expander nitrogen process. This lower power demand can be utilised to reduce capital cost through lower installed compressor kW or, more probably, to increase LNG production and project returns from a given compressor driver.

This paper provides energy efficiency data (kWh/tonne) for the ZR-LNG process for a broad range of process conditions to permit appraisal of the technology against competing liquefaction systems.

The paper also includes details of alternative configurations of ZR-LNG which facilitate heavy hydrocarbons removal and the handling of low pressure feed gases.

ZR-LNG Power Demand

In the ZR-LNG process the refrigerant is methane derived from the feed natural gas. A schematic of the process is shown in Figure 1. Liquefaction is achieved

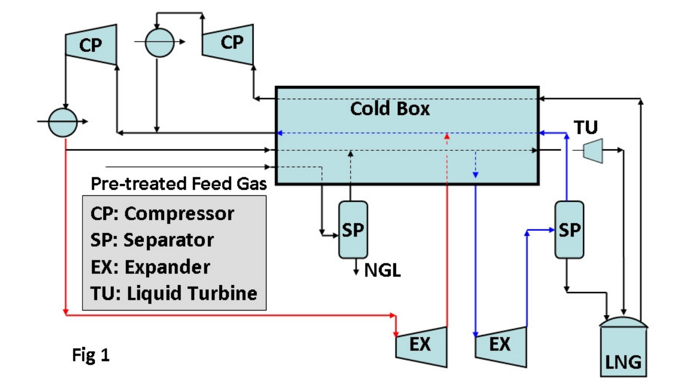

Fig 1

through the use of two expander refrigeration circuits indicated in red (high temperature) and blue (low temperature). Typically 35% of the gross compression power is recovered through the gas phase expanders. A low power demand is achieved by selection of optimised temperatures, pressures and flowrates within the expander circuits, together with partial liquefaction of the feed in the low temperature gas expander. Net power requirement is further reduced by a turbine on the liquid product run down to storage. A fundamental advantage arises from methane having a higher specific heat than nitrogen which reduces circulating gas flows, power consumption and pipe sizing relative to nitrogen schemes. The above features yield a net liquefaction unit drive power of circa 300 kWh/tonne of LNG with 60 bar feed gas and 20°C "cooled to" temperature. This specific power is equivalent or lower than typical SMR processes and some 30% less than dual expander nitrogen schemes.

Liquefaction efficiency is a key factor in evaluating LNG technologies and for mid-scale and larger plants its importance cannot be over-stated. Most plants are designed around a selected compressor driver and once this item is selected and its power output established the overwhelmingly dominant factor impacting a project's financial return is the energy efficiency of the liquefaction cycle. Higher efficiency processes will produce more LNG product per unit of power input, increasing project revenues[1].

Power Demand relative to Feed Gas Pressure

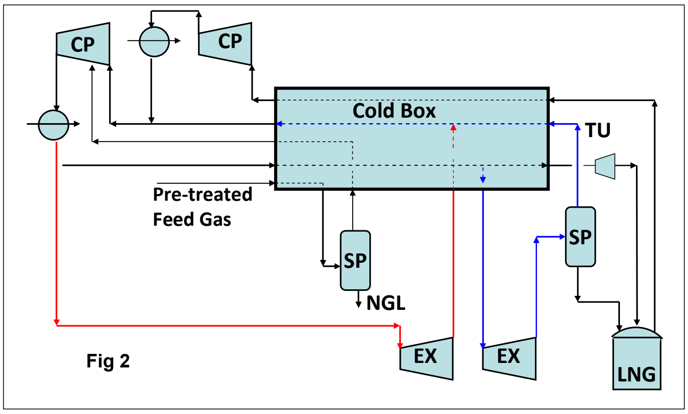

Fig 2

All liquefaction processes exhibit an increase in power demand at lower operating pressures. Fig 2 shows modifications to the basic ZR-LNG process which Gasconsult has developed to address the requirement for high liquefaction efficiency and to ameliorate the phenomenon of falling efficiency at lower feed gas pressures. This configuration termed Integrated Pressure Liquefaction sees the feed natural gas, after liquids removal, introduced at an appropriate inter-stage point in the recycle gas compressor. This enables the liquefaction pressure to be set at a higher pressure than the feed gas without installation of additional compression plant with its associated capital and operating costs.

Fig 3 quantifies the reduction in power demand achieved with Integrated Pressure Liquefaction. It plots absolute power demand versus pressure for ZR-LNG operating in conventional mode at feed gas pressure and 80 bar Integrated Pressure Liquefaction mode at "cooled to" temperatures of -40˚C and +40˚C. The ability to operate in Integrated Pressure Liquefaction mode and derive these benefits is unique to open methane cycles as nitrogen or SMR schemes do not have a refrigerant system comprising methane compression equipment.

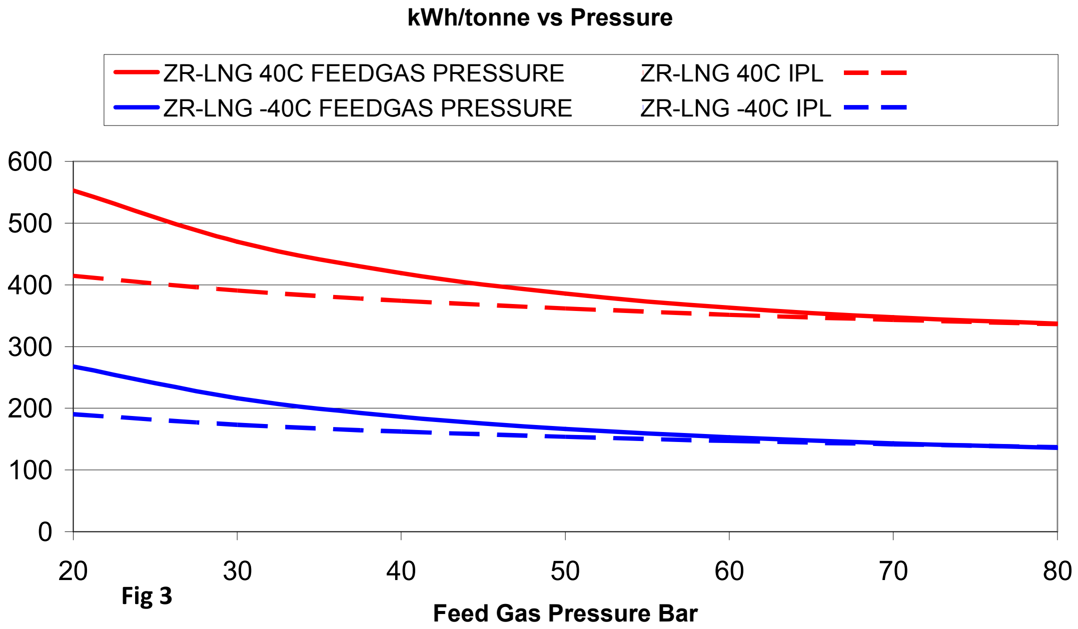

Fig 3

<u>Power Demand Relative to other Technologies</u>

Figs 4 and 5 plot ZR-LNG power demand operating in Integrated Pressure Liquefaction mode against the SMR and dual nitrogen processes for 40C and -40C respectively. These temperatures represent a hot ambient environment and pre-cooled liquefaction scenarios respectively. Data for this has been secured from internal Gasconsult simulations checked against data provided by other technology licensors[2]. The data uses a normalised design basis in respect of machine efficiencies and arrangement. It shows ZR-LNG advantaged over the full operating envelope under consideration.

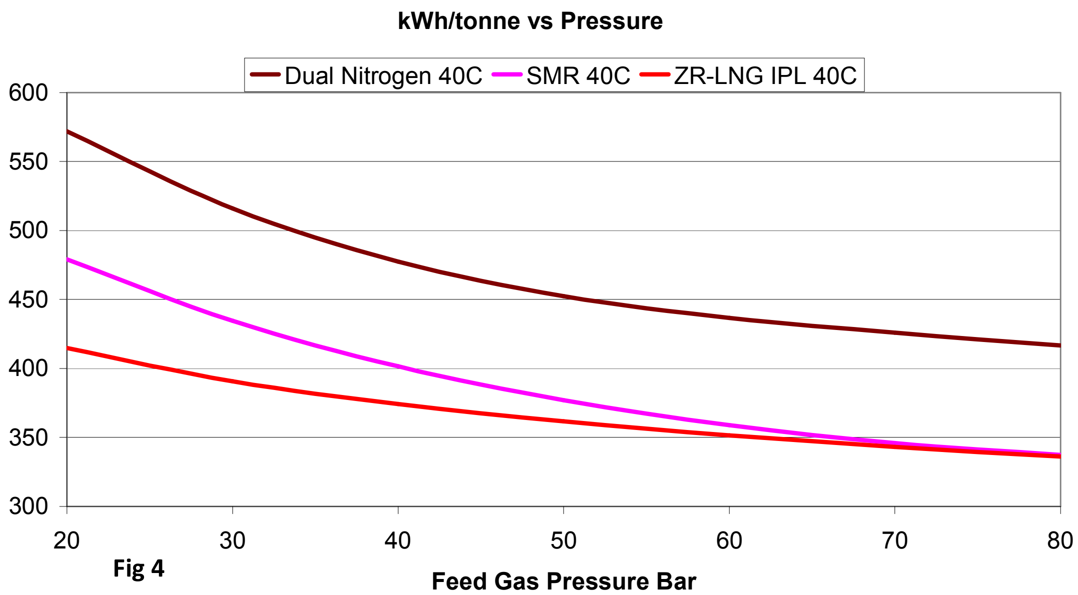

Fig 4

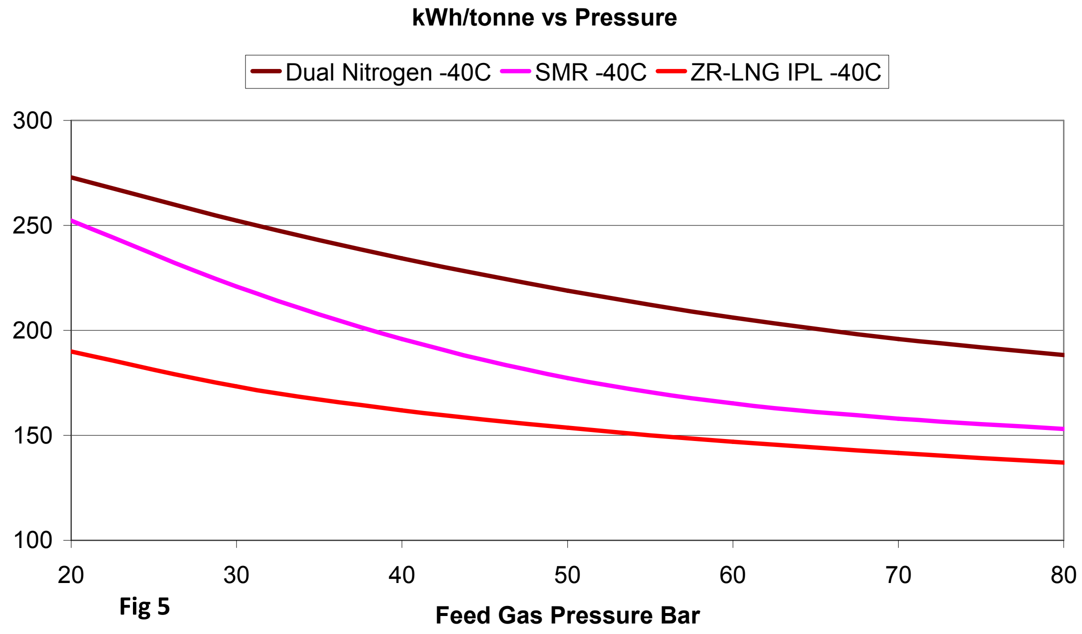

Fig 5

The Basis of Design for the assessment data provided above is shown in Table 1.

TABLE 1	**BASIS OF DESIGN**
Gas Composition Mol %:	CH_4 95%; C_2H_6 4%; C_3H_8 1%
Gas Pressure at liquefaction inlet	As indicated
Feed Gas Pressure	As indicated
Process Streams cooled to	-40C and 40C
Heat Leak to Cold Box	0.50%
Minimum cryogenic approach temp	3 deg C
Recycle gas compressor polytropic η	85%
Expander adiabatic η	87%

<u>Operability, Flexibility and Heavies Removal</u>

LNG output is controlled by adjusting the speed of the recycle gas compressor, in conjunction with expander inlet guide vane control. Experience with broadly similar cold boxes in the fertilizer industry indicates that cool-down from ambient temperature will be faster than with mixed refrigerant processes, due to the simplicity of the gas-phase refrigeration cycle. At start-up from “warm” the cold box would be cooled down, typically at a maximum of 50^0 C/h by starting the gas turbine and circulating feed gas through the expanders. An alternative for initial cool-down is to utilize the flash gas compressor to circulate gas through a JT valve at the cold end of the process, allowing a delay in start-up of the gas turbine. No significant flaring of natural gas is expected during cool-down. Flare load on machine trip is also expected to be less than with the SMR process.

The process has been extensively evaluated over a wide range of feed gas compositions, pressures and ambient temperatures. Compressor and expander efficiencies and heat exchange design factors have been based on manufacturer's predictions. These evaluations show ZR-LNG to be well suited for the vast majority of mid-scale applications. Power demand is in general little affected by feed gas composition after NGL removal. Nitrogen in the feed gas tends to accumulate in the recycle gas flows, increasing power demand. However as most natural gases contain less than 2% nitrogen this is generally not a limiting factor for the technology. Simulations indicate that at 5% feed nitrogen power demand increases by approximately 12%, still leaving the technology considerably advantaged on efficiency over nitrogen expander processes.

An interesting feature of the ZR-LNG process is its ability to remove heavy hydrocarbons including aromatics. Project specifications typically require < 0.1 mol% C5+ and aromatics to be < 1 mol ppm. Among other factors, this reduces the risk of freezing and blockages in the liquefaction equipment. However gas liquid separation deteriorates as pressures approach the critical pressure of methane, typically around 50 bar. This may in some circumstances rule out use of a conventional scrub column, as it would not reliably achieve the required removal efficiencies. The high mol-wt components are then usually removed by expanding the feed gas to a lower pressure, condensing the heavy material and recompressing the depleted gas to the inlet pressure of the liquefaction process. With the ZR-LNG process it is possible to achieve the required removal of heavy components by passing the feed gas plus recycle gas through the high temperature gas expander (Fig 6) and separating the condensed heavy material from the expander outlet at around 10-15 bar. This solution de-couples the gas/liquid separation pressure from the feed gas pressure and saves a large part of the equipment and cost of a separate expander based NGL removal unit. For FLNG application there would also be a substantial saving in deck space.

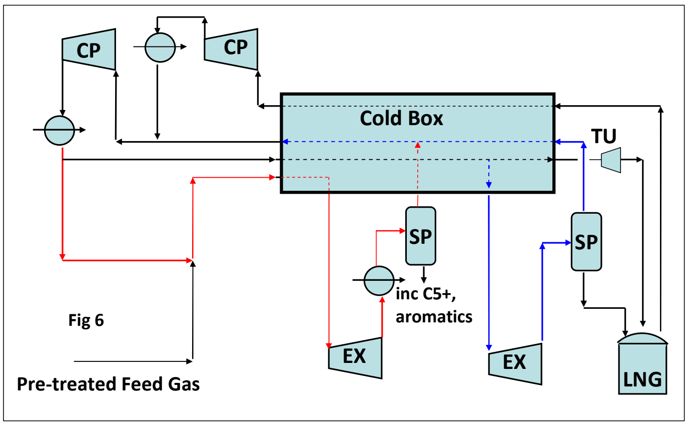

Fig 6

Process Integrity and Validation

All equipment used in the ZR-LNG process is proven in service in comparable duty. All processing steps in the flowsheet are well established in numerous cryogenic gas processing plants. The technology has been positively evaluated by BP and under NDA by two leading E&C companies and a specialist gas processing consultancy. These evaluations have confirmed the integrity of the ZR-LNG process concept, established the validity of the key design/operating parameters and verified the power demand data.

Other Features

Other advantages of ZR-LNG when compared to competing mid-scale schemes are:

- procurement flexibility; all major equipment items may be competitively sourced from multiple vendors, reducing project costs and schedule
- security of refrigerant supply (the process uses the feed gas itself)
- no make-up costs and complex transportation logistics for refrigerants
- no refrigerant extraction, storage and transfer facilities, reducing cost and footprint
- no heavy liquid hydrocarbon refrigerant, reducing blast and fire risk
- no requirement for ongoing mixed refrigerant composition adjustments to optimise cycle efficiency – simpler operation
- motion tolerant – single phase refrigerant with all passages in the heat exchange cores having vapour phase feeds
- shorter cool down time and lower flare duty relative to mixed refrigerant processes

Some of these advantages assume even more relevance for remote locations where refrigerant availability may be precarious or costly and for the emerging FLNG market, where deck space constraints and safety issues bring additional dimensions to plant design.

Plant Configurations and Cost Estimates

Expander based processes were traditionally only considered for smaller liquefaction plants because of limitations in expander capacity and the poor efficiency of the nitrogen processes. However modern design and manufacturing techniques have improved rotating equipment efficiencies and this coupled with the low energy consumption of the ZR-LNG process mitigates this limitation and stretches the envelope of expander based competitiveness.

Work jointly undertaken by Gasconsult with GE Oil & Gas demonstrates that the ZR-LNG configuration is suitable, using industrial gas turbines, for on-shore application up to a capacity of ~2 million tonnes/y per train and using aero-derivative turbines for FLNG application up to ~1.5 million tonnes/y per train. A typical configuration for an aero-derivative based scheme is outlined below, based on the conditions in Table 1 but with a "cooled to" temperature of 20 deg C.

FLNG Train: PGT25+G4 Aero-derivative Turbine Driven

The configuration for this 900,000 tonnes/y system is provided in Fig 7. Power recovery is effected by operating the expanders in compander mode in series with the recycle gas compressor; performing part of the recycle gas compression duty.

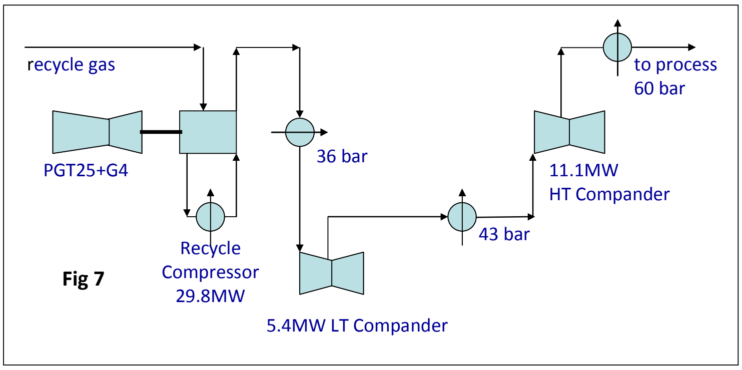

Fig 7

Table 2 provides a range of plant capacities developed by Gasconsult together with GE Oil & Gas around various similarly configured gas turbine/compressor/expander arrangements.

TABLE 2				
LNG Prodn Mil TPA	0.9	1.1	1.5	2.2
Gas Turbine	PGT25+G4	LM6000PF	LM6000+MD	Frame 7
Compressor	2BCL800	2BCL1007	2BCL1400	2BCL1400
LT Expander	EC50-1	EC50-1	EC50-1	EG50-1
HT Expander	EC60-1	EC50-1	EC50-1	EC60-1
HT Expander			EC50-1	EC60-1
Estimate of Cost $ Mil	210	250	290	390

The cost estimates in Table 2 are for the liquefaction system only and exclude feed gas treating and utilities. They were compiled on a factored basis based on quotations for all major equipment and assume a 2015 instant execution basis. The aero-derivative options assume modularised construction for FLNG application.

<u>Summary</u>

The ZR-LNG process provides a simple energy efficient and low cost scheme. It increases the capacity envelope for expander based processes for mid-scale liquefaction plants permitting capacities up to ~2 million tonnes/year per train. Absence of liquid hydrocarbon refrigerants has cost, safety and operational benefits, particularly for FLNG.

Two new variants further enhance the competitive advantage of the ZR-LNG technology:

- the ability to operate a methane cycle in Integrated Pressure Liquefaction mode improves liquefaction cycle efficiency with low pressure feeds.
- the ability to remove heavy hydrocarbons and aromatics to a low concentration using the high temperature expander is expected to be of significant benefit for FLNG and for smaller land-based applications.

Gasconsult provides ZR-LNG technology licences directly to LNG producers who may arrange design and construction by their preferred engineering company. Licences are also available to E&Cs and liquefaction system licensors who wish to offer the technology on a project by project basis or secure a specific geography for exclusive marketing.

References

1 Howe, Skinner, Maunder LNG Industry July/August 2014

2 Bauer, Linde Engineering, Private Communication Dec 2012