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Dual Methane Expander Cycle Liquefaction – Technology for a Low Energy Price Era

Authors: GW Howe, GF Skinner, AD Maunder – Gasconsult Limited, London, UK

Introduction

LNG producers have sought to enhance project returns through higher plant capacities to achieve economies of scale. Many complex multi-refrigerant plants were constructed to realise this objective. However the unprecedented capital costs and financial risks associated with these mega-scale plants may not be sustainable in an era of distressed energy prices. Some operators are looking for more flexible project development and commercial models that ameliorate risk. Some are seeking means to monetize smaller gas reserves with lower cost schemes.

Dual-methane (DM) expander liquefaction offers a differentiated solution for mid-scale and floating LNG (FLNG) applications. Unlike conventional processes it uses no external refrigerants, using instead the natural gas feed as the refrigerant medium in an optimised system of expanders. This eliminates refrigerant storage and transfer systems used in mixed refrigerant (MR) cycles, as well as the process equipment used to extract refrigerant components from the feed gas. Make-up refrigerant is low cost natural gas as opposed to nitrogen or a mixture of hydrocarbons thereby avoiding complex supply logistics and reducing operating cost. The absence of liquid hydrocarbon refrigerant also makes for safer operations. The methane process requires significantly less power than other 'safe' systems such as multiple expander nitrogen processes, allowing reduced capital cost through lower installed compressor power or increased LNG production from a selected compressor driver.

Single train capacities exceeding 2-metric-MMtpy are possible facilitating phased project development and lower initial capital requirements, yet still allowing progressive build out of significant LNG capacity. The avoidance of equipment to produce, handle, store and process external refrigerants not only reduces cost but also weight and footprint, making the technology particularly attractive for FLNG schemes. Where appropriate freed up deck space could be used to install additional productive liquefaction capacity which would enhance project returns.

A number of variants of the basic configuration have also been developed for low-pressure (LP) feeds, the removal of heavy hydrocarbons and to facilitate benefits from high-speed (HS) compression. These variants further differentiate the technology and are described in this work.

1 Process Configuration

A simplified schematic of a proprietary DM expander process is shown in Fig 1. Refrigeration is effected in two expander circuits, a warm circuit indicated in red and a low

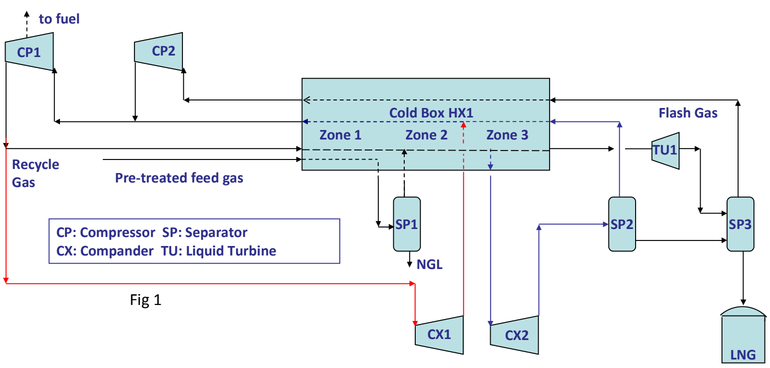

Fig 1

temperature circuit shown in blue. Chilled gases from expanders CX1 and CX2 are routed to the cold box for cooling duty and then returned to the expanders by the recycle compressor CP1. Flash gas is also routed through the cold box for cooling duty and recaptured to the system by a small compressor CP2 which feeds the suction of the recycle compressor. The expanders are configured as companders and operate in series with the recycle gas compressor (Fig 2), providing approximately 35% of the total compression power.

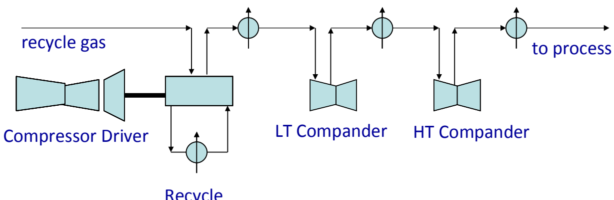

Fig 2

The methane cycle is similar in concept to nitrogen expander schemes. However it enjoys a fundamental advantage as methane has a higher specific heat than nitrogen. This significantly reduces circulating gas flows which in turn reduces power consumption and pipe sizes.

A patented feature of the described process is that partial liquefaction takes place in the low temperature expander CX2 – this efficiently converts latent heat directly into mechanical work and also permits a reduction in heat transfer area and cost of the main heat exchanger HX1. An optional liquid turbine TU1 in the LNG run down line also improves efficiency by providing a significant chilling effect.

These features, together with the optimised distribution of flows, temperatures and pressures in the expander circuits makes for a highly energy efficient system, around 300kWh/metric t of LNG in temperate climates. This performance is equivalent or better than single mixed refrigerant (SMR) processes, and 15-30% lower than the more sophisticated variants of dual and triple expander nitrogen schemes.

2 Alternative Configurations

A number of variants of the technology which have potential to further reduce capital cost and/or increase operating efficiency have been investigated. Open methane cycles lend themselves to advantageous configurations for LP feed gases, removal of heavy hydrocarbons and HS rotating equipment.

<u>Integrated Pressure Liquefaction (IPL) for Low Pressure Feed Gases</u>

All liquefaction technologies consume more power at lower feed gas pressures. The IPL variant (Fig 3) of the described process boosts LP feed gas by routing it after liquids separation in SP1 back to an inter-stage suction point of the recycle gas compressor, instead of to Zones 2 & 3 of the liquefaction section of the cold box as shown in Fig 1. This provides a higher inlet pressure to the cold box independent of the feed gas pressure, enhancing liquefaction efficiency without need for a separate feed gas compression plant. For 40°C ambient conditions on 25 bar pipeline gas (as might prevail for instance in the US

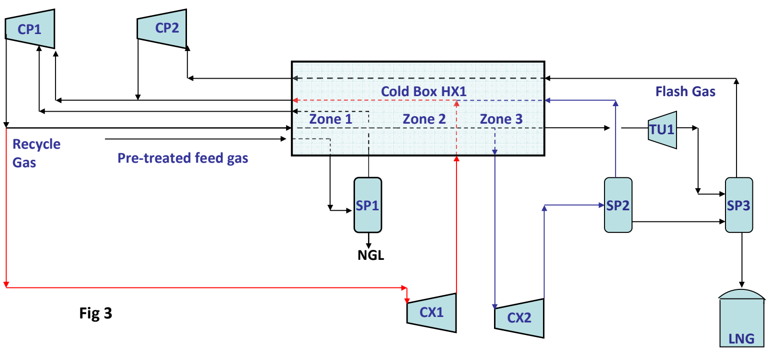

Fig 3

Gulf Coast region) IPL operation at 80 bar achieves a reduction in power demand exceeding 20% of that for the basic DM expander system (Fig 4). This capability is only available to open methane cycles. Nitrogen or SMR schemes need to build an additional compression facility to enhance liquefaction cycle efficiency; unlike open methane cycles, they do not have a methane compressor in their basic configuration.

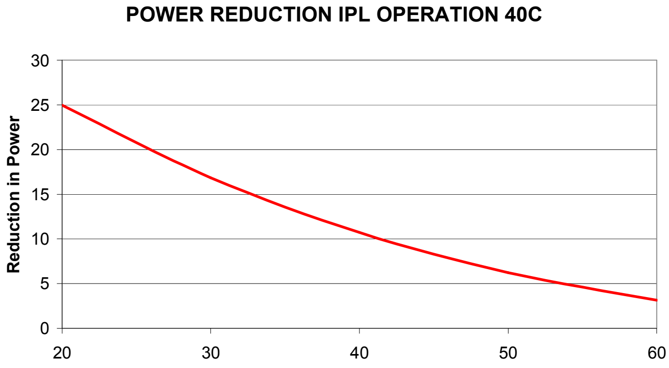

Fig 4

Fig 5 provides the authors' computations of the relative power demand measured in kWh/metric t of the DM (in 80 bar IPL mode), SMR and dual nitrogen processes over the pressure range 20 – 80 bar. This data is based on normalised machine efficiencies and provides an indication of the relative merits of the technologies in a warm climate and feedgas pre-cooled scenarios (40°C and -40°C 'cooled to' temperatures respectively). The dual methane process is advantaged over the full data range. The Fig 5 data assumes the design basis provided in Table 1.

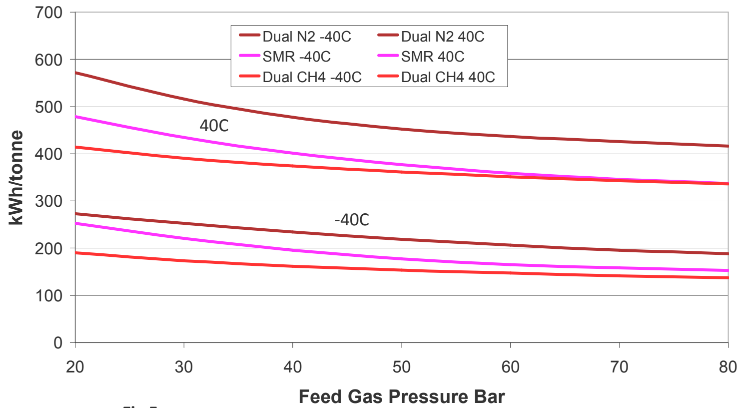

Fig 5

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%

Integrated Heavies Removal (IHR)

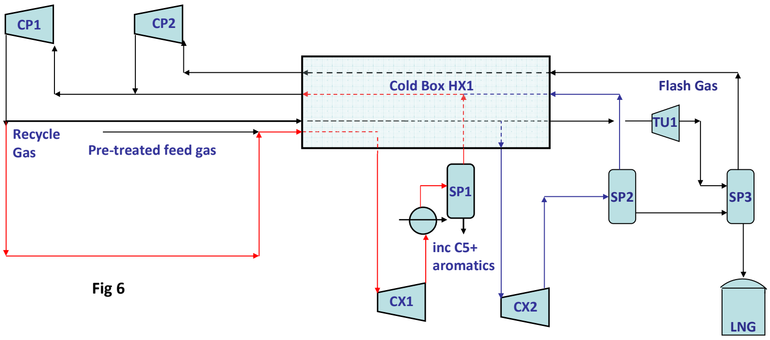

Fig 6

With heavier feed gases above or close to their critical pressure adequate removal of C5+ and aromatics may require an upstream NGL unit. Typically this expands the feed gas to a sub-critical pressure, condenses the heavy material and then recompresses the depleted gas for liquefaction. In its IHR variant the described DM cycle process removes heavy components by passing the feed gas plus recycle gas through the warm circuit gas expander CX1 (Fig 6) and separates the condensed heavy material from the expander outlet at sub-critical pressure, around 10-15 bar. This solution de-couples the vapor/liquid separation and feed gas pressures and saves a large part of the equipment and cost of a separate expander-based NGL removal unit. Specifically the compander (CX1), re-compression facilities (CP1) and associated bulk materials already exist in the basic DM configuration, avoiding additional capital cost. Weight and footprint are also reduced which is particularly relevant to FLNG schemes.

High Speed Compression

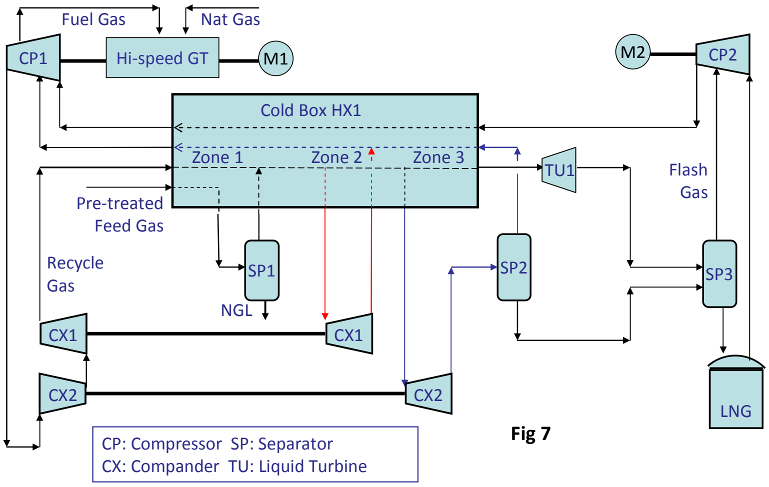

Fig 7

Methane can be compressed at significantly higher rotational speed than the higher molecular weight hydrocarbons found in mixed refrigerant cycles. This permits use of HS driver/compressor combinations significantly lower in cost and weight than those used in conventional processes. In a recent study conducted around a HS 46MW output gas turbine (Fig 7) the main recycle compressor is direct driven and runs at a much higher speed (6600 rpm) than conventional MR compressors. Because the turbine is a single shaft machine, a small starter/helper electric motor M1 is provided. The study, developed with support from the OEM, demonstrated an ability to achieve a capacity of 1.5 metric-MMtpy per train with a power demand of circa 310 kWh/metric t of LNG, based on a feedgas pressure of 60 bar, ambient air temperature of 30°C and seawater 23°C. Significant weight savings (>70 metric t) for the gas turbine + recycle compressor were demonstrated compared to a typical aero-derivative based solution; with cost savings for this equipment in the order of 20-30%. Although the gas turbine subject of the study was an industrial machine the change out capability at 48 hours is comparable to aero-derivative machines and it also has longer Equivalent Operating Hours (60,000 hrs) between major overhauls than aero-derivatives. The energy efficiency at >38% was respectable with DLE < 15ppm NOx.

3 Technology Advantages

In addition to its low power demand, reduced equipment count and low footprint a further set of advantages accrue to methane cycles from the absence of external refrigerants. Many of these have particular relevance for FLNG schemes; where weight, deck space, operational simplicity and safety are important factors.

- No refrigerant logistics issues are present in remote or offshore locations. Neither shipments of light and heavy hydrocarbons, nor segregated storage to facilitate blending a mixed refrigerant are required.
- Absolute security of refrigerant supply is assured.
- No propane or other liquid hydrocarbon refrigerants are present which offers a major safety advantage relative to MR schemes
- Single phase refrigerant (always a gas) makes the system motion tolerant
- Operational benefits relative to MR schemes are present. These benefits include no refrigerant make-up cost, no refrigerant composition adjustments to maintain cycle efficiency, shorter start-up time from warm condition and reduced flaring

4 Project Returns

Most liquefaction schemes are built around a pre-selected compressor driver. An economically matched set of ancillary process equipment is assembled around this driver. Once the compressor driver is selected the power available for liquefaction is set. Then the overwhelmingly dominant factor determining LNG production is the liquefaction cycle efficiency. For mid-scale projects the differential can run to some hundreds of millions of dollars as measured by NPV. Fig 8, developed by the authors from a case study, plots cumulative NPV versus time for the DM cycle, a dual-nitrogen cycle and a basic SMR scheme for a nominal 4-metric-MMtpy 5 train FLNG project monetizing a 2 TCF gas field. The DM cycle earns higher returns over a shorter period of time because its superior efficiency supports a higher production capacity.

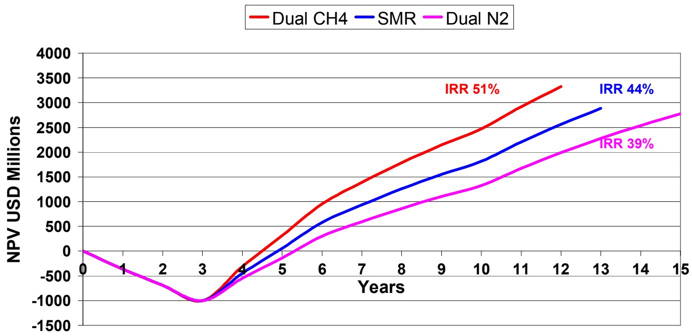

Fig 8

5 Technical Validation

All equipment in the methane cycle process is fully proven in operation and the process steps are well established in dozens of cryogenic gas processing plants. BP and 3 engineering companies (under non disclosure agreements) have reviewed the described design, from Hysys simulations through key process and detail design parameters. All of the companies confirmed the energy efficiency and key performance parameters. Leading equipment vendors have confirmed the mechanical design/configuration viability and that all equipment operates within a window of proven operating experience. Work performed in conjunction with a leading OEM established economically matched rotating equipment configurations around various gas turbine drivers for single train capacities in the range 0.9-metric-MMtpy to 2.2-metric-MMtpy. An important outcome from this work was confirming an achievable train capacity of >2-metric-MMtpy. For the particular compressor driver this is significantly higher than achievable by nitrogen or the simpler SMR processes, providing economy of scale advantage for the methane cycle.

6 Takeaway

For mid-scale operation the DM expander process combines high energy efficiency with a fundamental simplicity, low equipment count and low investment cost. Elimination of external refrigerants provides opex, capex and logistics advantages and simplifies operations. The open methane cycle allows advantageous variants to the basic process which provide further cost and efficiency advantages. Single train capacities exceeding 2-metric-MMtpy of LNG allow substantial production capacity build out on a phased basis, reducing upfront costs and reducing project risk. No equipment supply is tied to the technology licence and all equipment is available from multiple vendors; allowing fully competitive procurement with cost and schedule benefits.

Note

The dual methane expander process described in this article is the ZR-LNG system (Zero Refrigerant LNG) owned, patented and licensed by Gasconsult Limited.

The Gas Turbine cited in the High Speed Compression variant is a Siemens SGT-800.

The various economically matched equipment configurations in the capacity range 0.9-metric-MMtpy – 2.2-metric-MMtpy were worked up with GE Oil and Gas and are as shown in Table 2 below with a Basis of Design as per Table 1 (but with process streams cooled to 20°C)

TABLE 2				
LNG Prodn metric-MMtpy	0.9	1.1	1.5	2.2
Gas Turbine	PGT25+G4	LM6000PF	LM6000+MD	Frame 7
Compressor/Absorbed MW	2BCL800/29.8	2BCL1007/34.8	2BCL1400/46.7	2BCL1400/81.5
LT Expander/Power MW	EC50-1/5.4	EC50-1/6.7	EC50-1/9.5	EG50-1/13.4
HT Expander/Power MW	EC60-1/11.1	EC50-1/13.8	EC50-1/8.6	EC60-1/13.8
HT Expander/Power MW			EC50-1/8.6	EC60-1/13.8

Bill Howe is the Chief Executive of Gasconsult. He graduated as a chemical engineer from Birmingham University and has spent 30 years in the E&C industry mainly with Foster Wheeler where he was Managing Director of their South African affiliate and subsequently Director of Sales and Marketing at Foster Wheeler Reading, UK.

Geoff Skinner is a Director of Gasconsult. He graduated from Oxford University and joined Foster Wheeler in the UK in 1965. From 1981 to 1986 he was Technical Director of Foster Wheeler Synfuels Corporation in Livingston, New Jersey. On his return to the UK, Geoff acted as a consultant to several multinational companies and has registered a number of patents including LNG liquefaction processes.

Tony Maunder is a Director of Gasconsult. He has degrees in Mechanical Sciences and Chemical Engineering from Cambridge University. After working with ICI General Chemicals, he spent 16 years in the E&C industry, finally with Foster Wheeler. From 1980 to 1993 he worked for BP Research and BP Engineering on natural gas conversion to liquids, synthesis gas and fuels. He has registered a number of LNG liquefaction process patents.