ABSTRACT

Liquefied Natural Gas (LNG) supply is projected to grow 4.5% per year to 2030, over twice the rate of gas production (2.1%) and faster than inter-regional pipeline trade (3.0%) (BP, 2012). Since the Millennium, challenges in LNG design drove machine manufacturers to design larger machines primarily utilizing gas turbines. Plant capacities in the past decade grew from 3.5 to 5.5 million tons per annum (MTPA) primarily due to the availability of large gas fields. Today, smaller remote gas fields combined with market drivers such as limited pipeline availability, dropping spot prices, increased reserves, and reduced capital budgets, have forced end users to rethink design. Although higher train capacities drive economies of scale, the challenge arises when building smaller plants and lowering costs. Stranded natural gas, such as US and Chinese shale gas, makes LNG the most feasible means to transport and deliver energy to market. Through plant design standardization and increased equipment efficiencies, producers can achieve the best balance of economics, speed to market, and process flexibility. Recent projects have shown integrally geared compressors (IGC) to be advantageous for small scale liquefaction. Design considerations such as zero refrigerant loss, high plant operational efficiency, use of electric drivers, and appropriate specifications will be addressed.

OBJECTIVE

This paper is intended to highlight the growing market demand for small scale LNG plants and review the requirements for the mixed refrigerant compressor. The market sectors and key driving factors for LNG operations will also be discussed. The results section identifies the important features and evaluation factors for the main piece of rotating equipment in the liquefaction system, the mixed refrigerant compressor.

MARKET DRIVERS

Historically, the LNG industry leaders have been driving economies of scale through increased plant sizes. Since the 1970s, LNG train sizes have been growing from approximately 1.0 MTPA up to 7.5 MTPA. The compressor drivers have also evolved from steam turbines to more economical large frame gas turbines and electric motors. This progression has proven valuable, but relies upon large gas fields to feed these world scale plants.

When reviewing the global gas field outlook BP has stated that shale gas and coal bed methane (CBM) will account for 63% of North American production by 2030. They have also projected that 46% of China’s gas production growth will come from CBM and shale gas (BP, 2012). Many of these fields are stranded applications with no infrastructure to monetize the product.

Moreover, reduced gas spot prices and condensed capital budgets have lead more companies to pursue small scale LNG. While large scale projects can take years to design, permit, construct and commission; small scale LNG plants can deliver speed to market and greatly reduced capital expenditures.

Besides gas supply and spot pricing, other factors determining optimal plant size include market demand, operational flexibility, and optimization of storage and delivery methodology. Operational flexibility can be achieved through multiple small trains, while still retaining high levels of efficiency. Delivery methods can range from tractor trailers to railcars. Normalized loading frequency can also eliminate the need for large storage tanks. Liquefied natural gas is filling the gap in many markets including remote gas delivery networks, peak shaving applications and transportation fuel markets.
Focusing on the transportation market, there is an ever-present demand for clean abundant energy source. With the recent surge in natural gas supply in North America, LNG fuel can be approximately $1 cheaper per diesel gallon equivalent (van Loon & Gismatullin, 2012). The cost to convert a commercial long haul truck is less than $100,000 before tax incentives. With current gas prices, companies can expect payback in less than five years (van Loon & Gismatullin, 2012). Beyond trucking, Marine environmental regulations may also indirectly promote the usage of LNG as an alternative propulsion fuel. These regulations will limit harmful emissions such as sulphur oxides (SOx) and nitrogen oxides (NOx). Switching to LNG will greatly reduce these emissions while remaining a cost-competitive fuel. Other benefits of LNG for transportation are storage capacity and range. LNG occupies 1/600th the original volume of gas and can be stored at near atmospheric pressure. When compared with CNG, an LNG tank of the same volume will provide more than twice the overall range.

In conclusion, a review of the market drivers for natural gas supply and LNG demand indicate a positive outlook for the small scale LNG Industry. The next section contains a brief review of the plant designs, which will lead into the compressors technology selection process.

RESULT – THE INTEGRALLY GEARED MIXED REFRIGERANT COMPRESSOR

A number of factors go into process technology and plant design selection; these include plant scale, energy cost, capital investment and operating plan. Several commonly utilized designs include Expander, Nitrogen Refrigeration and Single Mixed Refrigerant (SMR). The SMR process offers more efficiency than a simple expander cycle and requires fewer pieces of machinery.

Once the optimal process is selected, Front End Engineering Design (FEED) can begin for the main components such as the cold box, coolers, and mixed refrigerant (MR) compressor. The typical SMR process requires about 260–370 kilowatts (kW) per MMcf/d of LNG capacity. The exact value depends on the system design parameters, such as feed gas pressure, ambient conditions, and process specifications (Hoffart, 2010). The MR compressor is the main power consumer and is critical to plant operation.

We know the importance of the MR compressors, but what about the prime movers for this small scale application. World scale LNG plants have seen a shift from steam turbine drivers to gas turbines for cost, equipment count, and efficiency reasons. Now electric motor drives are becoming more prevalent at this large scale. One of the first examples is an LNG facility in Hammerfest, Norway, where compressors are driven by electric motors (Chellini, 2012). Moreover, gas turbine orders for mechanical drives have continued to decline. A five year trend shows a 46% drop in GT orders from 2007 to 2011 (Haight, 2012). Further studies have shown electric motors can increase plant availability by 3-4% over a gas turbine drive due to reduced maintenance and downtime requirements. When scaling a large plant down to 1/20th the size, 6 MPTA to 0.3 MTPA the driver evaluation criteria remains the same, but the scales tip heavily in favor of electric motor drives.

Integrally geared compressors are well suited for electric prime movers as there is no need for an external gearbox. The main motor speed of 1,000 – 3,600 rpm is increased by the larger diameter bullgear which drives smaller diameter rotors. Rotors are positioned surrounding the bullgear in an arrangement which
allows for up to four pinions per gearbox. Each pinion has the capacity to drive two impellers which are mounted in an overhung configuration. This allows each pinion speed to be optimally designed for a given aerodynamic requirement. When compared to inline compressors, where all impellers are driven at the same speed, machine and stage efficiencies can be higher. Overall, the combination of electric driver and integrally geared compressor lead to a robust compressor solution for refrigerant services.

Most refrigeration systems rely on a closed loop circuits. It is critical for environmental and economic reasons that no refrigerant is released to atmosphere. One downside to integrally geared centrifugals compared to inline compressors is their need for additional sealing interfaces. This challenge is overcome by utilizing dry face seal technology on all stages of compression. For lower pressure stages tandem seals with intermediate labyrinths are employed. Tandem seals with carbon ring separations seals are very effective for higher pressure stages. Moreover, the secondary seals featured a recovery port which captures the majority of seal leakage which is ducted to the compressor inlet.

IGC’s also easy accommodate interstage cooling for even greater efficiency. Small scale LNG plants tend to be air cooled as seawater and closed loop cooling systems are not typically available. Larger interstage pressure drops of 0.5 bar can be included in the design to accommodate the air coolers and associated piping runs. Moreover, when designing a refrigeration process, intermediate side streams can also be extracted or inserted easily as each stage of compression is located in a separate casing.

Integrally geared compressors also offer easier installation, smaller footprint, and faster commissioning than other compression technologies. This is attributed to several key design criteria from an IGC. First, IGCs do not emit harsh vibrations or pulsations and therefore do not require special foundations. The civil plan only needs to support the static weight of the compressor package saving engineering costs and material. Second, IGCs are designed to be packaged as a complete skid with minimal field work. The package can incorporate the compressor, interstage piping, control valves, lubrication system, dry face seal support system, and in most cases the main driver base plate. This minimizes customer connections and ensures quality control from manufacture. Overall footprint can also be reduced by 50% when compared to traditional inline compressors external gearbox and driver arrangement. Some small LNG plant concepts have been designed as a modular system and can be efficiently mobilized and erected for even greater speed to market than traditional layouts. In conclusion, single skid integrally geared compressors are very effectively integrated into these small scale plant designs.

IGC’s are inherently oil-free and several unique features ensure no lubricant can enter the process gas stream. The main gearbox bearings utilize oil seals with grooved rings to eliminate oil migration along the pinion shaft to the process seals. Some manufactures also include an atmospheric gap between the process seal and the oil seal to further separate the mix refrigerant from any contaminants. Moreover, when compared to oil flooded screw compressors no separation equipment is required to remove the entrained lubricant from the gas stream. Separation equipment adds additional maintenance requirements and can also fail, sending oil containments into the mixed refrigerant loop. Overall, centrifugal oil-free solutions are specified by many process licensors as the preferred compression solution.

<table>
<thead>
<tr>
<th>Compressor Type</th>
<th>Availability %</th>
<th>Reliability %</th>
<th>Proactive Maintenance DT hr/per 5 years</th>
<th>MTBF years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best</td>
<td>Average</td>
<td>Best</td>
<td>Average</td>
</tr>
<tr>
<td>Reciprocating</td>
<td>99.5</td>
<td>97.3</td>
<td>99.8</td>
<td>97.8</td>
</tr>
<tr>
<td>Lubricated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screw oil flooded</td>
<td>99.2</td>
<td>97.7</td>
<td>99.8</td>
<td>98.8</td>
</tr>
<tr>
<td>Screw oil free</td>
<td>99.6</td>
<td>99.0</td>
<td>99.9</td>
<td>99.7</td>
</tr>
<tr>
<td>Centrifugal</td>
<td>99.9</td>
<td>99.7</td>
<td>1.000</td>
<td>99.8</td>
</tr>
<tr>
<td>Clean Service</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MTBF = Mean Time Between Failure; DT = Down Time
Reliability of the MR compressor is paramount to a successfully operating liquefaction system. Centrifugal Compressors have proven to have the longest Mean Time Between Failure and also show strong availability of 99.7%. This highly reliable solution is achieved due to a five year continuous operation design philosophy with several manufactures reporting eight years of uninterrupted service (Almasi, 2012). In contrast, screw and reciprocating solutions require far more maintenance, but offer lower initial capital expenditures.

SUMMARY/CONCLUSIONS

In conclusion, small scale LNG will play a predominate role in shaping the energy landscape of the future. With major players, such as Shell, investing hundreds of millions in infrastructure and no sign of oil prices dropping dramatically, LNG is the economical, clean, portable energy of the future. The sun is just rising on the small scale LNG plant horizon. Through standardize scope of supply and process and compressor design integration, the future looks bright for integrally geared compressor technology.

ACKNOWLEDGMENTS

The author would like to thank Cameron Compression Systems for their permission to present this paper. The author would also like to thank Nauman Islam, Chuck Impastato and Trevor Grabau for their assistance with the content of this paper.

REFERENCES


