COMPRESSORS

Q&A

LNG Industry asked several companies to discuss some key topics regarding compressors in the LNG industry.

Joseph C. Fernandez, P.E., Manager, Application Engineering, Ariel Corporation

Joe Fernandez manages the Applications Engineering Department at Ariel Corporation. He has been with Ariel Corporation for over 26 years, and in the energy industry for over 38 years, responsible for engineering compression systems in the upstream, midstream, and downstream markets. This experience has included compressors used for feeding and offloading LNG terminals, as well for gathering, pipelines, storage, acid/sour gas carbon capture, utilisation, and storage, and vehicle fuelling.

Andrea Masi, Compression Product Platform Manager, Baker Hughes

Andrea Masi leads Baker Hughes' Compression Product Platform team, to define and execute the multi-generational product plan for centrifugal compressors, reciprocating compressors and turbo-expanders solutions. His career spans 21 years in strategic marketing product management and R&D advanced technology engineering across energy and industrial sectors. He graduated in Electronic Engineering at the University in Florence (IT).

Francesco Cangioli, Compression R&D Engineering Manager, Baker Hughes

Francesco Cangioli is New Product Development Manager, leading a team focused on compressors and expanders. Following a Masters Degree in Mechanical Engineering and a PhD in Reliability and Availability in Industrial Engineering at the University in Florence (IT), he has been part of Baker Hughes since 2012, covering multiple roles innovating on gas turbines, pumps, expanders, and compressors.

Serge Staroselsky, Chief Technology Officer, Compressor Controls Corporation

Serge Staroselsky has been with Compressor Controls Corporation (CCC) in various roles for over 25 years, assuming his current position in 2014. He works in product and technology development and has extensive experience in designing and implementing control systems for turbomachinery, specialising in antisurge control and protection and compressor capacity control, covering a variety of applications. He has a B.S. degree in Mechanical Engineering from the University of California at Berkeley and an M.S. in Mechanical Engineering from the University of Minnesota.

Jens Wulff, Managing Director, NEUMAN & ESSER Deutschland

Jens Wulff has extensive experience in compressor technology. He started as a Project Manager, became Area Sales Manager, and later Managing Director of the compressor production companies at NEUMAN & ESSER. Today, he is Managing Director of NEUMAN & ESSER Deutschland, the new machine company in Germany. Wulff has successfully managed several sales projects of LNG compressor systems over the years, including the first LNG boil-off gas compressor with innovative stepless reflux power control in 2016.

Arnd Viets, Managing Director, NEUMAN & ESSER South East Asia

Arnd Viets has held various positions at NEUMAN & ESSER. Among these, he supported the Asian branches in India and Thailand with technical support. Since 2014, he has been Managing Director for the first-class compression equipment at NEUMAN & ESSER South East Asia and is responsible for the Asia Pacific region. The high demand for LNG terminals worldwide and his strong technical background led him to develop highly efficient LNG terminal solutions.

Q1. How do compressors improve the efficiency of the LNG process?

Joseph C. Fernandez, Ariel Corporation

The flexibility provided by reciprocating compressors allows for the reduction in offloading pressures prior to being put into sales lines (inlets at storage facilities prior to the liquefaction), thereby improving the overall efficiency of the LNG plant. Another area where reciprocating compressors are used and help improve overall efficiency is as vapour recovery units, also due to the wide range of operating pressures under which they can run.

Andrea Masi and Francesco Cangioli, Baker Hughes

Compressors are the technological heart of the LNG process, playing a key role in performance and overall total cost of ownership (TCO). Improvements in compressor efficiency reduce power consumption, leading to a reduction in fuel or electricity consumption – depending on the driver adopted, and whether it is a gas turbine or electric motor. A compressor's higher efficiency is achieved through new technology injection, new impellers profile, and new seals: this is key for new LNG projects and also allows for upgrading existing assets to maximise output. Improving compressor efficiency (average +4% in the last three years through aerodynamic improvements) does not impact only consumption, but also directly abates emissions, providing a double benefit to the plant operator.

Serge Staroselsky, Compressor Controls Corporation

From the point of view of a control system, first of all, capacity control of compressors should be a part of the overall LNG process control strategy; secondly, optimising loadsharing for parallel compressors; thirdly, minimising recycling with small antisurge margins; and, lastly, simplifying start-up and shutdown operations, reducing start-up time. For example, for some types of LNG processes, the control system typically maintains inlet header pressure for each refrigeration service, where the setpoints for the pressures can be derived by the overall plant optimiser. For other processes, different process parameters can be used as PVs for capacity control and integrated within overall optimisation scheme. Often, it is assumed that given the desire to produce maximum LNG rates, all refrigeration compressors operate far from the surge region. However, this is not always the case, particularly in climates where the design has to cover wide range of ambient temperatures. A compressor control system that is a part of the overall optimisation scheme must be able to operate in a stable manner while recycling and maintaining margins of <=10%, reliably preventing process upsets resulting in surging of the machines.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

By using efficient compressors, the LNG process can be improved significantly. For boil-off gas (BOG) management, efficient piston compressors are the best choice. NEUMAN & ESSER uses contact ring type machines with low internal leakage for these processes. As the BOG flow rate varies a lot, we also use efficient capacity control methods to save energy and reduce carbon dioxide (CO_2) emissions.

Q2. What factors are considered when deciding which compressor technology is needed for an application?

Joseph C. Fernandez, Ariel Corporation

The primary considerations in compressor selection are inlet and discharge pressures and required throughput. These will determine the best technology for the project, as well as the size and number of units required. Positive displacement compressors, such as reciprocating compressors, are good for high-discharge pressures and moderately high throughputs, and can accommodate a wide range of operating pressures; while rotary screws are well suited to low inlet pressures and very high throughputs, at lower discharge pressures. Dynamic compressors, such as centrifugals, are designed for very high throughputs and moderately high discharge pressures, with axial compressors providing the highest throughput capabilities and considerably lower pressure capabilities. Another consideration is the type of prime mover needed. Natural gas engines and electric motors are well suited for driving reciprocating and rotary screw compressors, whereas a turbine being used as a centrifugal compressor is a better solution.

Andrea Masi and Francesco Cangioli, Baker Hughes

Multiple factors are considered when selecting the most appropriate compression technology for the application, and usually include efficiency and availability. Indeed, the main drivers are flow and pressure that typically identify the most relevant technologies, such as compressor size and impeller types, then footprint, particularly for floating LNG (FLNG) applications. Typically, key decisions are driven by specific customer needs and by TCO, balancing CAPEX and OPEX of the solution. For example, the same service could be delivered with a larger compressor and higher efficiency to increase the diffusion ratio, or a smaller compressor with slightly lower efficiency (-2%) but with a weight benefit of about 20%.

Serge Staroselsky, Compressor Controls Corporation

From a control system vendor's perspective, it appears that the process design and capacity requirements play a dominant role in compressor technology selection. Up until recently, it seemed that improvements in process efficiency demanded larger capacity centrifugal compressors, up to 100 MW in a single casing, often driven by single-shaft gas turbines with limited rotating speed operating range. Today's trend seems to be toward smaller capacity centrifugal units, and with the plant having multiple trains to meet overall capacity requirements. It seems that the trend is also toward simplification of the control system and avoidance of compressors operating in parallel due to perceived complexity. However, in CCC's experience, compressors can be reliably operated in parallel, especially for units having an operating range of at least 85 – 105% of rotating speed, and the complexity of parallel operation should not influence the design toward reducing overall efficiency per train, that is, increasing process and compressor efficiency should take precedence over the complexity of controls.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

Determining factors include flow rate, flow and pressure fluctuations, and available space. Turbomachinery is best suited to high-flow scenarios under constant conditions, whereas reciprocating compressors are very well suited to variable flow rates and pressures from low to high. The available space influences the choice of whether a horizontal, vertical or V-type compressor is used.

Q3. How are compressors helping to reduce emissions (e.g. carbon dioxide) from the LNG process?

Joseph C. Fernandez, Ariel Corporation

Reciprocating compressors within the LNG process rely on a pressure packing case which seals around the reciprocating piston rod. Ariel employs solid ring technology in the packing cases which contains processed gas by eliminating the leak paths of conventional segmented ring sets. The company's packing cases typically reduce fugitive emissions to meet or exceed Environmental Protection Agency (EPA) regulations. This packing design is also very reliable, providing improved time between maintenance cycles. Reciprocating compressors are also being considered to collect flare gasses, reducing carbon dioxide emissions. Reciprocating compressors are also proving to be the solution of choice for carbon sequestration trains associated with LNG export facilities.

Andrea Masi and Francesco Cangioli, Baker Hughes

The main driver to decarbonise the LNG process is compressor efficiency. With a history of 30 years in LNG installations, Baker Hughes brings a track record of continuous efficiency improvement, with plants that have seen an efficiency increase of up to 5 – 6% when duplicating trains over a 5 – 10-year timeframe. At the same time, the company has seen a trend in power density, around maximising throughput while reducing the compressor size – up to the recently developed high pressure ratio compressor (HPRC) that unlocks a dramatic reduction in the number of casings (allowing to compact up to three casings in one). The impact is a reduction in emissions from dry gas seals, along with overall lifecycle impact.

In some cases of a smaller size, hermetically sealed electric technology, such as the Baker Hughes' integrated compressor line (ICL) is an effective solution. ICL is a zero-emissions compressor during operation and pressurised standby. Being an electrical driven compressor, emissions are proportional to electrical grid power generation emissions. In case of green electrical power, ICL is removing up to 99% of emissions compared to gas-fired solutions.

Serge Staroselsky, Compressor Controls Corporation

Again, from the perspective of a control system for compressors, the main factors in reducing emissions are avoidance of trips and large pressure fluctuations, which can lead to flaring and result from the inability of the control system to handle disturbances. In addition, optimal loadsharing between units and reduced recycling can lead to reduced power consumption and thus reduced emissions. Loadsharing and well responding control system are very important for BOG compressors where inlet conditions can rapidly change due to various modes of operation, with incoming gas of widely different temperatures. Observing operations at a large plant with multiple trains, it appears that disturbances occur fairly often, due to maintenance activities on various trains, so the response of a control system plays an important role in maintaining stable operation. Technological advancements may further reduce emissions, however, there is still a lot that can be done today to reduce emissions through better controls.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

Compressors can be used to re-liquify the BOG or make use of it as a fuel. This avoids flaring the BOG without a use and saves a lot of CO_2. As the compressors are mostly electrically driven, a higher compressor efficiency saves electrical power which also has a specific CO_2 footprint.

Q4. What component of a compressor is most prone to failure and thus requires the most maintenance?

Joseph C. Fernandez, Ariel Corporation

Valves. Valves consist of a sealing element, often with damping plates and damping from the gas. As a spring mass damped system, the valve motion is optimal at one condition, with fair motion across a small range. The factors defining the range include operating pressure, both suction and discharge, operating speed, gas composition, temperature, and valve design. Gas cleanliness also plays a role in valve reliability.

Valve reliability can be optimised through upfront design and monitoring for changes in conditions.

Andrea Masi and Francesco Cangioli, Baker Hughes

Unlike other applications such as those in upstream, the LNG mission profile is usually characterised by stable operations and clean gas. Compressor failures are quite rare and tend to be due to the wear on components, such as dry-gas seals. These components require dedicated preventive maintenance and advanced prognostic services to monitor their operating performance and identify potential failures in advance. Through advancements in the 24/7 remote monitoring of LNG compression trains worldwide, Baker Hughes has reached 99+%

average availability, enabling LNG players to maximise their production and reduce operating costs.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

For reciprocating compressors, the valves at the cylinder inlet and outlet are the most failure prone component. Monitoring their behaviour, e.g. via temperature, vibration, and sound measurement, is key for avoiding unplanned shutdowns.

Q5. With new LNG markets arriving and others expanding, how is compressor technology changing/adapting? Are there any limitations?

Joseph C. Fernandez, Ariel Corporation

A major area of advancement in reciprocating compressors is the incorporation of smart technologies, such as machine monitoring, and predictive maintenance. These enhancements allow for better planning of shutdowns, and ensuring that critical parts are on hand when needed, thereby minimising downtime. Another area is automation in particular where measured process data is used with a programmable logic controller (PLC) to control compressor performance based on plant needs. Examples of automation include electric motor-driven units utilising variable frequency drives to control speed, and automated compressor unloading devices, such as Ariel's eVCP, providing efficient and effective methods to control throughput and fuel usage.

Andrea Masi and Francesco Cangioli, Baker Hughes

LNG demand is growing, and additional projects FIDs are needed shortly. Analysing the technical requirements, the company can see an increase of electric motor and high-efficient aeroderivative gas turbines (such as the Baker Hughes' LM6000PF+ or the LM9000) driving compressors instead of traditional heavy-duty gas turbine – mainly in operation in mature projects. Looking at the entire refrigerant train size, the preferred choice is a multiple number of mid-size trains modularised vs traditional large trains stick built.

Baker Hughes' mid scale solution is the perfect fit for those projects where time-to-LNG, lower production costs and project de-risks are key priorities. Combining electric motor compressors with more efficient power generation island, operators are able also to reduce plant carbon footprint. The company's compression technology can be tailored to different approaches, traditional and modularised, providing the best compromise between performance optimisation and standardisation.

Serge Staroselsky, Compressor Controls Corporation

There seems to be a trend for new plants toward electric-driven packages, and generally, toward pre-packaged modular solutions, with trains of approximately 0.5 –1.5 million tpy capacity. Whether this trend will stay and expand depends on the performance of some of the newly commissioned plants using the modular approach with multiple trains. For control systems the general trend is toward more autonomous operation, which is particularly important for remote locations, where experts can access the system, or at least information from the system, without having to be on site. Building a safe communication infrastructure remains a challenge at some locations and places limitations on the availability of remote access.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

There are currently no real limitations. Progress is made on controllability and online-monitoring for predictive maintenance. With the digital NEA|XPLORE system, NEUMAN & ESSER has its own platform for data collection and analysis for machine health, maintenance planning, and corrective measures.

Q6. Detail the process and design behind one of your most popular compressors.

Joseph C. Fernandez, Ariel Corporation

Ariel Corporation continuously improves designs and uprates the capabilities of our compressors. New designs and improvements start with input from its customers. The design engineers develop the concepts taking into account the company's vast field experience and what it has learned in its state-of-the-art R&D facility. Multi-department teams work together to make sure the new products meet the demands of the markets, and provide good value to the customer and exceed equipment uptime expectations.

Andrea Masi and Francesco Cangioli, Baker Hughes

Baker Hughes is always active in technology development, investigating frontier technologies and developing solutions that can meet the market's requirements. It is continuously working on improving and enhancing thermodynamic stages, materials, and internal sealing and bearings, as well as on digital solutions.

Each development goes through a structured design process that is rigorous in terms of quality, allowing some flexibility in the required steps to be followed based on its complexity.

For a stage family release (continuous envelope of phi, mach, and diameter), the average time is usually four years, from the preliminary design, going through the complete experimental validation in a fully instrumented in-house test rigs and to releasing the geometry and performances database to be offered.

Baker Hughes introduced advanced artificial neural network and early validation tests (simplified model test fed with rapid prototyped impellers), which has drastically reduced the development time to two years, and is ready to meet new market demands, including carbon dioxide and hydrogen.

For hydrogen compression, the company is delivering the first units of the HPRC. This is a strong fit for this application due to its capability to run 40% faster than conventional compressors, while allowing an improved rotodynamic. This solution has been widely tested internally from the mechanical and thermodynamic perspective in the past few years, making it ready to be adopted today.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

Using its unique design tool 'KO3', NEUMAN & ESSER can carry out all technical tests from an installation and performance point of view for the most critical operating cases and special/offset operating cases with one mouse click. This allows the company to provide comprehensive support in the design and optimisation of the compressor system and the entire process. Specifically for BOG compressors, the company can detail various scenarios during commissioning and operation.

Q7. Detail a short case study of a compressor installation at a stage of the LNG process.

Joseph C. Fernandez, Ariel Corporation

Ariel compressors are utilised throughout the entire process of production, processing, and transportation of natural gas globally. With over 67 000 compressors shipped since 1965, most of the gas produced in the US has been compressed within an Ariel on its way to becoming feedgas for LNG terminals.

Andrea Masi and Francesco Cangioli, Baker Hughes

Baker Hughes' projects with Qatargas (QG)[1] are a good representation of the evolution of its compression technology over the years. Following up on the three compression trains installed at Qatargas 1, Baker Hughes was asked a few years later to support a series of major expansion projects for Qatargas and Ras Laffan LNG Company. In 2009, Qatargas 2 started production, and this is the best example of how the evolution in compression technology improves the value that the company delivers to the customer. The project objective was to double plant production, starting from an already large production plant.

Increasing the driver size, QG adopted a Frame 9E gas turbine; consequentially, larger compressors were needed to handle higher capacity with a lower speed than before. This required unprecedented casing and impeller sizes up to 1800 mm. This was within the capabilities of Baker Hughes' manufacturing facility in Florence, Italy (centre of excellence for compression technology), that can machine compressor casings with internal diameters up to 12.4 ft (3800 mm), and 3D shrouded impellers with diameters exceeding 6.5 ft (2000 mm) from a single forging. Dry gas seals with internal diameters of 1.14 ft (350 mm) were also qualified.

Since then, Baker Hughes' compression technology has further evolved in a number of ways. An improved casing design reduced the rotor length, allowing the adoption of the power density concept for the compressor design. This evolved design led to a smaller impeller diameter with a larger flow coefficient that, together with the development of new high mach stages with mixed flow design, led to a casing diameter reduction between 10% and 20% depending on the compressor, and a weight reduction between 5% and 10% handling the same flow.

Today, an improved stage efficiency (about 3%) drives a heavy impact on emissions and fuel consumption.

Serge Staroselsky, Compressor Controls Corporation

For a control system installation for a Conoco-Phillips cascade process, a plant has multiple LNG trains, with each train including parallel propane, ethylene, and methane compressors. The compressors are driven by aero-derivative gas turbines with 20% speed variation. Control system maintains the process variable of each refrigeration service and loadshares between parallel units. Operations can adjust the control setpoints from plant distributed control systems, either manually or via plant optimiser, and thus simultaneously change performance of parallel units, without the need to manually adjust individual machines. The units may operate with some recycle on hot ambient days and surge margins are on the order of 10% or even less, yet the system operates in a stable manner and can handle most disturbances. There are also multiple centrifugal boil-off gas (BOG) units driven by a constant speed electric motors and equipped with IGVs and operating in parallel. During a transient condition, it is very important for all BOG parallel units to respond simultaneously with their inlet guide vanes – essentially, all BOG units must respond as one, otherwise the BOG header pressure fluctuations may cause flaring. In the near future, high speed data capture from the control system will be made available to a plant historian, so that plant engineers will have familiar and easy interface to high resolution data for analysis.

Jens Wulff, NEUMAN & ESSER Deutschland, and Arnd Viets, NEUMAN & ESSER South East Asia

The different compressor installations are depending mainly on the size of the equipment and the installation location.

For LNG ship applications, mainly skid designs are built with a fixed connection point for process gas and for supply systems. Most often, such complete systems are designed as a lift to reduce additional installation time. Very often, such compression systems have already undergone a verified test run prior to delivery to ensure and confirm performance.

Complete skid designs in a range from 1.5 – 2 MW drive power are possible for LNG terminal applications. Above this rating and depending on the configuration, foundation mounted equipment is installed with a combination of utility skids and direct foundation mounted equipment. **LNG**

References

1. 'From massive to mega: the Qatargas LNG trains that changed the industry', *Baker Hughes*, (28 September 2020), www.bakerhughes.com/case-study/massive-mega-qatargas-lng-trains-changed-industry