Fine-Tuning Filtration for FLNG

How Gas Turbine Air Intake Filtration Solutions Can
Help Maximize Floating LNG Production

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Fine-Tuning Filtration for FLNG

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Introduction

Floating LNG (FLNG) production offers operators the ability to process offshore gas resources at (or very close) to their source. FLNG production vessels (FLNGs) are able to tap into smaller and more remote fields and be employed alongside platforms used primarily for oil production to manage associated gas reserves, once considered uneconomical or 'stranded'. When a resource is exhausted, FLNGs have the potential to then be unmoored and reconfigured for a new feed gas composition range and/or consumer non methane component specification, and to be moved to another location to continue operations.

Although limited in size and smaller in total output than a typical land-based plant, FLNGs are attractive in terms of lower initial investment, potentially providing an easier and quicker route to Final Investment Decision (FID), with perhaps just a few partners and supply contracts needing to be in place to fund a project.

One innovative way to further reduce costs is to reconfigure/convert an existing LNG carrier vessel, which is what Golar LNG achieved with the *Hilli Episeyo*, the world 's first LNG carrier to FLNG conversion (Figure 1).

Fig. 1. The 4 x 0.6 million tpy train *Golar Hilli Episeyo* FLNG production vessel.

Benefits of FLNG

The financial and political benefits of operating and processing gas offshore, at source, using a non-permanent structure are clear. There is no costly subsea piping or compression stations required to move the gas to a shore-based facility for processing and there is no need to reclaim/develop a suitable coastal site for processing, storage, and transmission infrastructure, including harbour facilities. This second point can be very important and help to alleviate environmental concerns, avoid unwanted complexities with local community groups, speed up the permitting processes, and ultimately help reduce the time to first production.

Fig. 2. Golar Hilli Episeyo's gas turbine (GT) air intake/filtration system (4 x PGT25+G4 GTs).

Other benefits of FLNG include increased security for personnel on board and the fact that the FLNG facility can almost entirely be built and configured at a single shipyard in a dry dock, as opposed to having to continuously mobilise a diverse range of extremely skilled trades to and from site during the construction and commissioning phases. FLNGs treat and then process natural gas using marinised versions of the same technologies found on a land-based LNG plant, just on a much more compact scale - approximately ¼ the size for the same LNG output.

Compressors, condensers, and expanders are used to compress and cool refrigerants, such as methane, ethane, propane, and nitrogen. These refrigerants then provide the chilling duty in the heat exchangers, which transfer heat away from the pre-treated methane until it reaches its cryogenic liquid state as LNG. Mixed refrigerant heat exchangers are commonly used on board as they provide significant benefits in terms of compactness. The size of the LNG trains are typically around 0.5 million tpy and, as with land-based plants, there are commonly multiple trains running simultaneously.

In contrast to land-based sites where designs may perhaps be considered as field proven, layout optimisations, design experiences, and best engineering practices with regards to implementing FLNG production are still relatively new and are evolving. Indeed, to date only a handful of FLNG production vessels have been commissioned - *Petronas' FLNG Satu* and *Dua*, Golar's *Hilli Episeyo*, Exmar's *Tango FLNG*, and Shell's *Prelude*. Projects currently under construction include Golar's *Gimi* and ENI's *Coral South*.

Engineering Challenges with FLNG

Of course, one of the biggest engineering challenges with FLNG, as with the more common FPSO units, is the size of the vessel and where to physically locate everything on board. The liquefaction process adds a large quantity of specialised equipment, so the challenge is great. Within an extremely limited space, FLNGs need to include pre-treatment, filtration and separation activities of the feed gas. Then there is the liquefaction process itself with multiple mechanical drivers, compressors, expanders, heat exchangers, offshore specific offloading/transfer systems, and all the associated pipework. Gas turbines (GTs) are typically used to mechanically drive the refrigerant compressors, and GTs also require significant ancillary equipment to operate. One key piece of GT ancillary equipment is the GT combustion air intake system, which will be covered in greater detail later in this white paper.

Storage of LNG in its supercooled state, as well as storage of the valuable NGLs recovered during field separation, is required before these products can be transferred to carrier vessels and transported onwards to market.

In addition to all of this, the following features and equipment are also required: personnel facilities and accommodation; heating, ventilation, and air conditioning (HVAC); boil-off gas (BOG) management; ship and process management facilities; communications systems; electrical power generation systems; and the extensive safety/personnel escape equipment that is essential offshore. It is an incredibly tight squeeze to successfully engineer, locate, and configure all this equipment on board a floating, rolling, pitching, and yawing movable structure. Certification and health and safety requirements can therefore be quite arduous.

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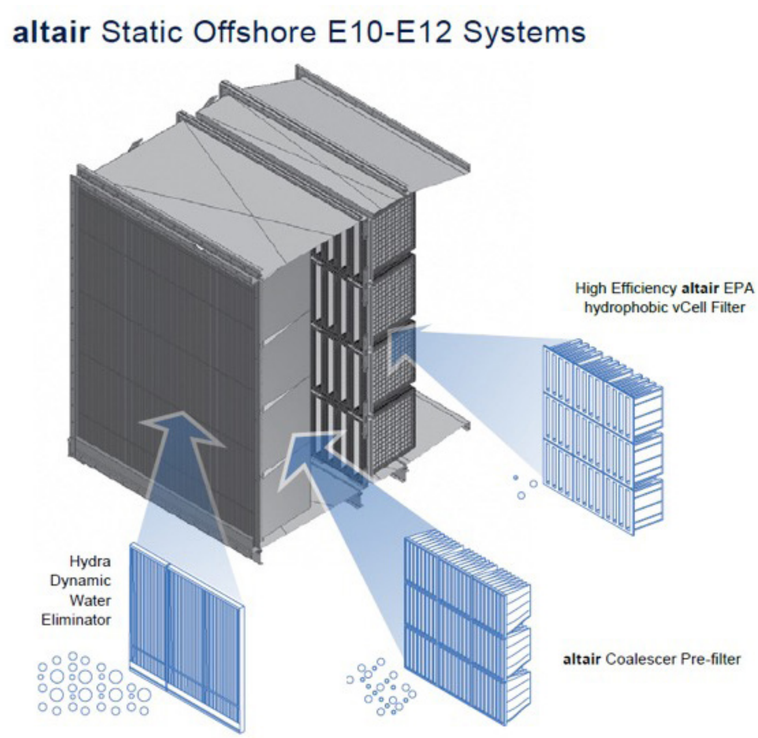

Fig. 3. Typical offshore compact/high velocity gas turbine (GT) air intake system configuration.

Maintaining Equipment

Fig. 4. View inside a high velocity GT filterhouse on the Golar *Hilli Episeyo* FLNG vessel. Left: The M6 rated prefilter. Centre and right: The E12 rated hydrophobic final filter.

Refrigerant compressors

While everything previously noted in this article is essential for operations and for personnel safety, the refrigerant compressors hold the key to maximising production. The loss of a refrigerant compressor can ultimately lead to an operational shutdown (planned or otherwise), which can cost millions of dollars per day in lost production. Maintaining the reliability of this equipment for extended intervals is essential. This has never been more true than when operating offshore, where limited personnel and spare parts on board may mean that specialised crew and equipment (if available) need to be mobilised from ashore.

Refrigerant compressors are mechanically driven (rotated) by, in most cases, GTs. Steam turbines and electric motors are also used, but the GT dominates this space both offshore and onshore. Availability and reliability of the GT then becomes equally critical to production. As everything needs to be compact and as light as possible, aeroderivative GTs are preferred as refrigerant compressor drivers over frame engines because they are smaller and lighter, and have components that are quick and easy to interchange, making maintenance simpler. They are also designed to offer high reliability, and can be quickly ramped up and down, allowing for any forced interruptions caused by adverse weather conditions to not have a prolonged effect on production.

GT internals

GTs ingest enormous amounts of air as part of their combustion process, air that left untreated will contain all manner of nasty contaminants, which can cause serious damage, erosion, corrosion, and fouling of the highly optimised GT internals. Harsh weather conditions; high levels of small airborne particulate in the form of sand, dust, airborne hydrocarbons, and salt aerosols; added to the concentration seasonality of these contaminants, are just some of the challenges faced by a GT air intake filtration system offshore. The offshore environment is brutal for any piece of equipment, let alone one that needs to continuously run in the face of harsh storms, sea spray, mist, fog, and almost every other type of water challenge.

Filtration Requirements

Filters may need to handle sand blown from the desert as well as salt from the ocean. In the intense heat of the desert, seasonal winds can lift dust particles as high as 6 km into the air and carry them for thousands of kilometres, settling on offshore structures and vessels.

Typically, gas turbine issues relating to the ingestion of ambient air particulate, salts, and hydrocarbons account for 60 - 80% of overall gas turbine losses. If this aspect can be controlled correctly, this is a positive step towards establishing reliable plant operations and maximising LNG output for extended intervals.

GT filtration systems need to be designed for the site conditions they will face for the majority of the time, but they also need to be flexible and adapt easily to the environmental and seasonal changes which will occur. On an FLNG vessel, for the reasons already described, they also need to be super-compact or 'high velocity'.

Handling salt

Salt is particularly perilous to the GTs on FLNGs because there is such a large quantity of it churned up from the sea. While the filterhouse and internals will typically be manufactured from 304 or 316 grade stainless steel, sodium from sea salt (NaCl), if allowed to get downstream of the filters, will still combine with sulfur in the fuel to create sodium sulfate (Na_2SO_4). This chemical reacts with the base metal of the turbine blades in the high temperatures of the hot gas path, causing rapid corrosion and component failures. This very common effect is known as hot corrosion or sulfidation. Chlorine in the salt also very commonly acts as a pitting corrosion initiator in colder parts of the turbine, potentially leading to catastrophic damage.

Salt can be difficult to handle because of its hygroscopic nature i.e. it has an affinity for water. Indeed, it absorbs moisture readily and can move easily from solid to liquid form with changes in ambient relative humidity. A filtration system, therefore, needs to efficiently defend the turbine from both liquid and solid phase contaminants. When salt is wet, it easily sticks to turbine blades and attracts other contaminants, quickly affecting the aerodynamic performance of the turbine. Unlike contaminants that cause fouling, one of the major problems with salt, however, is that the corrosion it causes is often not perceived in monitored turbine performance data until something physically breaks. FLNGs by their very nature will always be exposed to a great deal of salt laden sea spray. To handle this salt effectively, a filtration solution needs to allow for input concentration, aerosol size distribution, and aerosol physical state - whether droplet or particle. The right solution must also consider the impacts of increased pressure drop introduced by adding multiple filtration stages with salt protection. In order to stop salt getting downstream to the GT on an FLNG production vessel, the use of hydrophobic filtration is essential.

Fig. 5. Inadequate GT air intake filtration - corrosion pitting in this case led to crack propagation and ultimately compressor blade liberation.

Filtration Requirements Continued

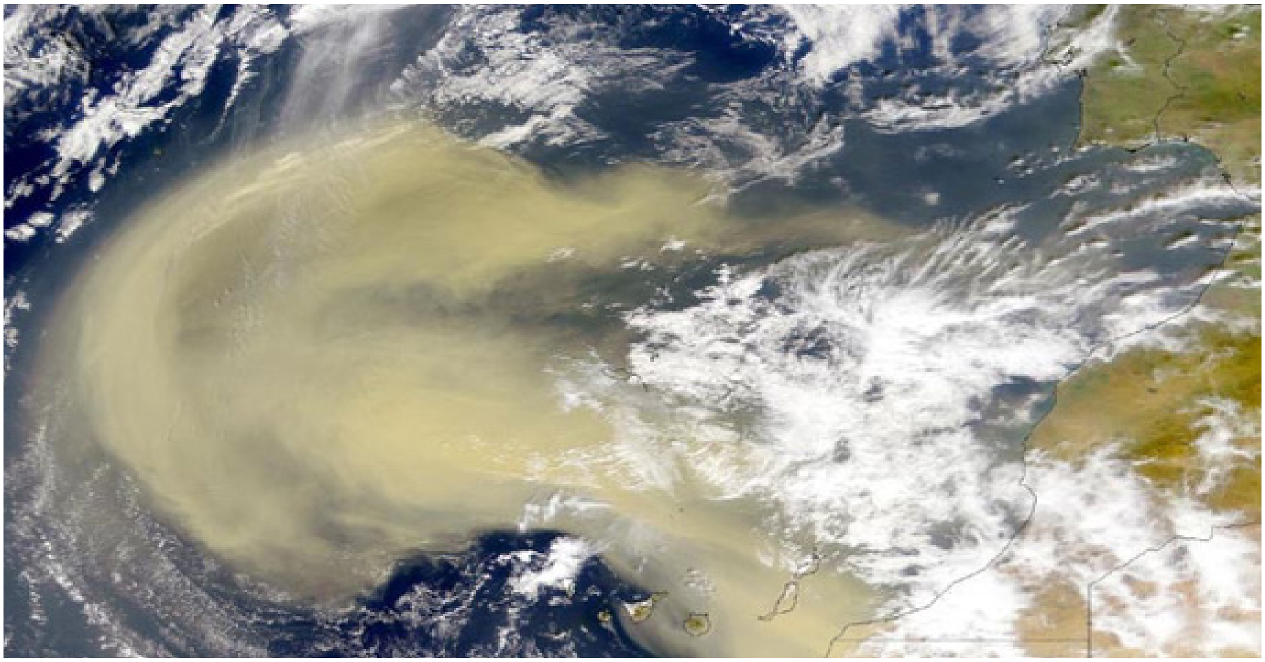

Fig. 6. Extreme dust events on land can travel thousands of kilometres offshore. Satellite image of a dust storm moving offshore from the coast of West Africa.

Sand and dust

Sand and dust can cause numerous issues for an installation in terms of both damage to machinery and degradation of turbine performance. Large dust particles of sizes greater than approximately 2μm can cause erosion, affect turbine efficiency, and, if the erosion causes parts in the front end of the equipment to break, these may travel through and cause severe machine damage. Finer dust can stick to parts of the machine and change the operating aerodynamics. This, in turn, reduces turbine efficiency, requires online and eventually offline water washing, reduces availability, and increases operational costs. Efficient particulate arrestance (EPA) rated filters are designed to stop the very finest of particulate passing downstream to the GT.

Moisture in the inlet air stream will combine with dust to form mud which can then also block a filter. Filter media selection is therefore a critical choice for reliable operations. Glass fibre media is the preferred choice for high efficiency hydrophobic filtration. It is thick in comparison with some other technologies, and this greater pore volume makes it naturally less prone to sudden blockages. This means that very high efficiency filtration can be achieved without the risk of alarm/shutdown triggers from sudden pressure spikes, and it provides the capability of much longer and more predictable running between maintenance intervals.

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Designing Filtration for FLNG

There are a number of additional factors that need to be considered in the design of an FLNG turbine air inlet system. Size and weight are paramount, but the system also needs to enable online changing of prefilters to maximise GT availability and uptime. The increased air velocity and compactness of the filter systems (compared with land based systems where space is much more readily available) means the aerodynamics and air turbulence created as the air flows through the filtration and acoustic systems need to be carefully modelled and optimised to create smooth, laminar air flows and to meet the GT air inlet distortion limits as defined by the GT OEM. Operators also need to select a filtration solution that can accommodate numerous options of filter without mechanical changes - one which easily adapts to new filtration requirements depending on the location of the vessel and/or seasonal variations in concentration and size distribution of the airborne challenge.

Conclusion

As the cleanest burning hydrocarbon, the demand for natural gas continues to grow. The relatively recent development of FLNG production makes remote and smaller gas resources much more accessible and financially viable. It also potentially provides project developers with a shorter timeline to first production.

To ensure profitable ventures, the reliability of the systems used to liquefy gas onboard an FLNG vessel is critical and, although GT filtration systems may seem like a smaller part of the overall puzzle, they are vital to ensuring ongoing smooth operations. GT air intake systems need to be designed for the real-world environment in which they will be used, while also able to effectively and efficiently handle a diverse range of seasonally varying contaminants including salt, dust, oily hydrocarbons, and moisture. For FLNG vessels it is essential that these systems are physically compact and flexible enough to allow operators to easily change filter types depending on location.

Designing GT air intake solutions for the offshore environment requires a thorough understanding of the very specific challenges such systems will face, but when undertaken correctly offers operators a lightning quick return on investment.

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About Parker Gas Turbine Filtration

With more than 50 years of experience delivering innovative solutions for gas turbine inlet filtration and monitoring fleet-wide performance data, our industry and applications experts will select the appropriate filter for your site designed to meet your specific operating goals.

Parker Gas Turbine Filtration supplies a full range of inlet systems and filters engineered to meet your operating goals, including:

- Higher power output
- Lower operating costs
- Proven performance utilizing advanced filter technology
- Extended gas turbine availability
- Maximum protection against corrosion and fouling.
- Easy maintenance and change out.

Through our brands, altair® and clearcurrent®, we are the choice for advanced filtration for new units and replacement filters. Our inlet system designs include self-cleaning (pulse) and static inlet systems for all gas turbine OEMs. We supply a full range of filter types at all efficiency levels. The predictable and reliable performance of our air filters significantly reduces compressor contamination and the need for unplanned maintenance.

For more information on Parker's gas turbine inlet filtration systems, please visit our website or call **1-800-821-2222**.

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