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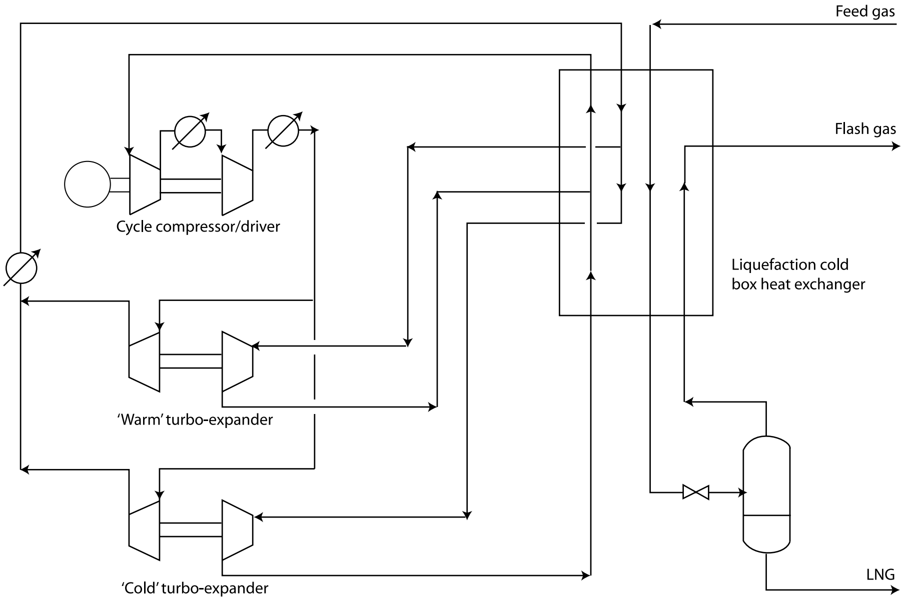
Taking to the high seas

Grant Johnson explains why floating liquefaction is a viable solution to LNG shortages

ALTHOUGH a number of onshore LNG plants are due to come on-line in 2009, few major LNG projects have been sanctioned recently. The cost of building these facilities has escalated and many of the plant locations under consideration have been deemed too technically- or politically- challenging, leading to deferment of final investment decisions.

Recent expansion in LNG import capacity, particularly in the US, Western Europe, India and China has therefore not been matched by additional LNG production capacity, and even given current economic conditions, experts expect a significant shortfall.

Figure 1: Dual turbo-expander flowsheet for gas liquefaction



potential for floating LNG

Offshore LNG production on a floating platform (FLNG) could overcome many of the difficulties with onshore LNG projects and has emerged as a competitive alternative. Key technological developments essential to the feasibility of FLNG were identified in studies made as far back as 30 years ago, but it is only in the last decade that concepts for LNG storage and transfer at sea have advanced to the point that FLNG projects are now viable - as illustrated by the Adriatic FLNG.

Storage tanks on a FLNG facility are filled over a number of days and must be robust to 'sloshing' loads when operating partially filled. As interest in FLNG has increased, the main LNG storage system licensors have established designs for partially-filled operation, increasing the number of yards capable of hull construction, and importantly including types of tank construction with much lesser impact on the available deck area for topside. In the same timeframe, a number of systems for ship-to-ship LNG transfer have undergone trials and are now commercially available.

There are several hundred 'stranded' natural gas fields with reserves of over 500b cubic feet, sufficient to support a FLNG facility with production capacity of 1–2m t/y for ten years or more. FLNG facilities may also be attractive for liquefaction of associated gas from oil production, which would otherwise be re-injected or flared. Unlike an onshore plant, there is potential for a FLNG facility to be redeployed to a new field as production declines.

The estimated investment cost for a FLNG facility is significantly lower than costs for the majority of onshore facilities constructed recently, and project schedule should be shorter. With current overcapacity in the LNG carrier fleet, shipyards are relatively quiet and in this competitive market, the cost of an LNG vessel is low relative to the major infrastructure costs for an onshore facility, which include gas pipelines, jetties, LNG storage tanks and requirements for site preparation and construction facilities.

liquefaction technology

For FLNG to be commercialised, investors and potential participants in the project have to be confident in its success. Fundamental to this is selecting the appropriate liquefaction process technology.

The accepted wisdom that large-scale offshore LNG plants would use similar 'mixed refrigerant' liquefaction technology to those onshore was first challenged by Costain nearly 30 years ago, when an initial study for the UK's Department of Energy concluded that turbo-expander based technology, proven on small-scale 'peak-shave' LNG plants, had considerable merit for offshore LNG production even at base load capacities.

Turbo-expander refrigeration cycles operate by compressing and work-expanding a gaseous fluid, typically nitrogen, at high isentropic efficiency to generate refrigeration. The cycle gas is boosted in pressure by the brake-end of the turbo-expander. This technology is highly appropriate for FLNG, due to:

- inherent safety by avoiding liquid hydrocarbon refrigerants (and their storage) and potential fire and explosion hazards;
- insensitivity to vessel motion as the refrigerant is gaseous and refrigerant distribution in the liquefaction heat exchangers is constant;
- flexibility to changes in feed gas conditions and ease of operation due to the simplicity of the process;
- rapid start-up and shutdown in a safe and controlled manner;
- a small number of equipment items and consequently with a relatively small plant footprint and low topsides weight;
- modularisation being easier than for other liquefaction technologies enabling fabrication of the vessel and the topside modules to progress in parallel reducing delivery time; and
- use of conventional equipment, well proven in the cryogenic gas processing industry and ensuring competitive supply for all major components.

In evaluations in the late 1980s for a FLNG facility offshore Papua New Guinea, we advocated a dual turbo-expander process based on nitrogen refrigerant, as widely used for liquefaction of industrial gases (see Figure 1). The second turbo-expander operates over a lower temperature range, well matched with the LNG sub-cooling duty, giving improved efficiency (see Figure 2).

Today, there is wide consensus that the double turbo-expander cycle is the technology of choice for FLNG at capacities of 1–2m t/y. In this range, some equipment will require multiple trains so it makes sense to configure the equipment in two liquefaction trains, which has the added benefit of increasing overall availability.

It is feasible to construct two liquefaction trains with a total capacity of 1.5m t/y, and industry has already gained experience at fitting these with a cycle compressor, turbo-expander and liquefaction cold box. Engineering studies show that a plant of this capacity can be accommodated within the available deck space of a conventional hull, with LNG storage volume based on off-take carrier capacity. For higher production capacities, the process topside modules rather than LNG storage volume will start to dictate the hull size.

A dual expander plant with efficient cycle compressors and turbo-expanders will have a specific power consumption of less than 0.50 kWh/kg of LNG. For high pressure feed gas, this can drop to less than 0.40 kWh/kg, but the need for pressure let-down to remove heavy hydrocarbons from the feed gas means this figure is realistic only for very lean feed gas, for example where these components are extracted upstream.

gas reception, pre-treatment and fuel gas

Conventional process technologies and equipment can be used for gas reception (including slug catcher, liquids separation, filtration and condensate stabilisation) and pre-treatment (including acid gas removal, molecular sieve dehydration and mercury removal).

Offshore, there is a greater incentive to minimise gas processing due to space and weight constraints. Heavy hydrocarbons will need to be removed as condensate, both to meet LNG specifications, and to remove high freezing point aromatics such as benzene which could otherwise solidify in the liquefaction plant. It may be tempting to try and recover LPG as a separate product, but this needs to be considered carefully as this introduces additional equipment for recovery and fractionation, storage and offloading and increases inventories of flammable hydrocarbon liquids in the topside modules.

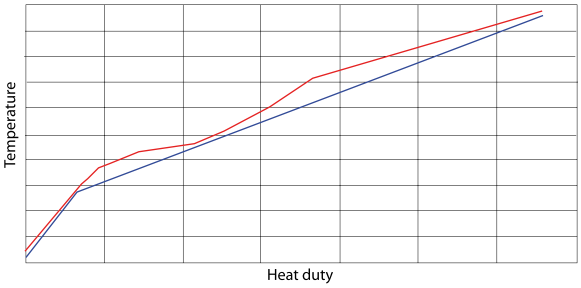


Figure 2: Typical cooling curves for dual turbo-expander liquefaction

Fuel gas can be sourced from recompressed LNG flash- and boil-off gas, with the balance from feed gas. Where the feed gas contains more than 1% of nitrogen, this has to be removed in a separate step at the cold end of the liquefaction process to meet LNG specifications. Nitrogen will concentrate in the LNG flash gas and the impact on fuel gas quality, so anyone considering feed gases with high nitrogen content will have to address this.

Designers have to analyse the effect of ship motion to make sure their designs are robust, particularly for the columns in the acid gas removal system, mal-operation of which could lead to carbon dioxide breakthrough and freezing in the liquefaction plant. Pieces of equipment influenced by vessel motion will ideally be located on the centreline of the FLNG vessel, which will be designed to 'weathervane' to the wind, minimising tendency to roll.

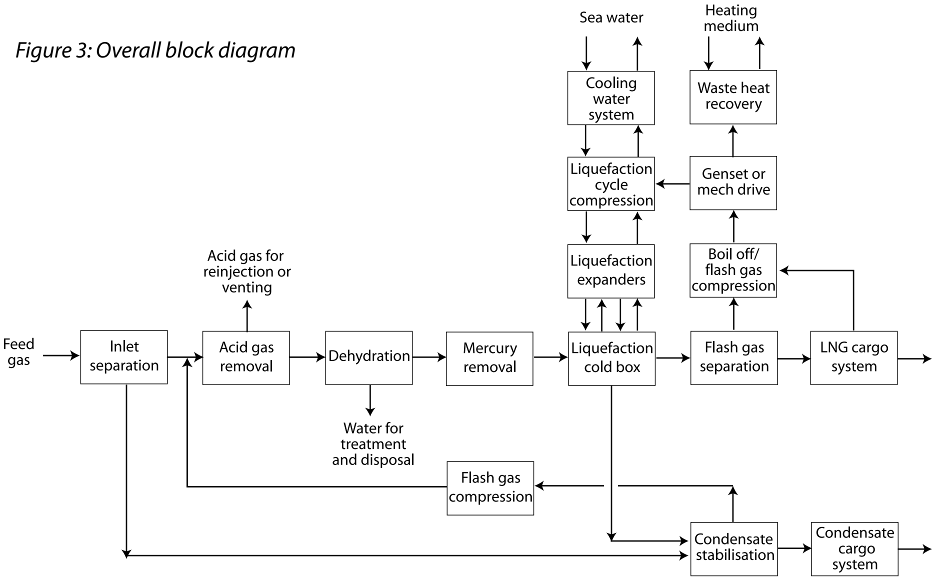
cycle machinery

From the very earliest evaluations, designers have proposed using aero-derivative gas turbines for FLNG as they reduce footprint and weight; provide higher thermal efficiency; and give high reliability and reduced maintenance downtime compared with their industrial counterparts.

These evaluations initially considered the aero-derivative gas turbine generator sets with motor-driven cycle compressors. Electric motors of 40–50 MW are outside the experience of the LNG industry and most suppliers, but there is also lack of industry experience in the use of direct aero-derivative gas turbine drives.

There are considerable advantages in driving the cycle compressors directly, eliminating the generators, variable speed drives and electric motors which add to footprint and weight and therefore to cost and introduce losses in efficiency and therefore reduced

Figure 3: Overall block diagram



LNG production. Given how complex the electrical system for a motor drive is, the direct mechanical drive solution is expected of similar availability, even when accounting for the need to include spare power generation capacity.

As the refrigeration cycle machinery is a major contributor to footprint, weight and cost, it is normal to fully utilise available power from the selected gas turbine to maximise LNG production. Having to refrigerate the gas turbine inlet air can increase power output in hot, tropical climates by up to 30%.

Lowering cooling water temperature, increasing feed pressure or reducing the degree of LNG sub-cooling (thereby increasing flash gas rate to the fuel gas system) can potentially reduce specific power consumption for LNG production. Even if liquefaction cycle power is constrained by the selected gas turbine, there is considerable flexibility to increase production capacity at the expense of additional power consumption outside the refrigeration cycle in feed gas compression, flash gas compression or mechanical refrigeration. The footprint, weight and cost of additional equipment must be justified against additional revenue from LNG production and power requirements assessed with due consideration of the power generation system configuration.

The high thermal efficiency of aero-derivative gas turbines compared with the industrial heavy-duty gas turbines conventionally used in onshore plants means that although the liquefaction cycle is less efficient, fuel consumption and total exhaust emissions can be similar to many onshore plants.

Radial inflow turbo-expanders are very reliable with minimal need for maintenance. FLNG uses conventional operating parameters and as frame sizes are at the higher end of the manufacturer's range, they are very efficient. Turbo-expanders typically use active magnetic bearings to minimise footprint and weight.

liquefaction heat exchangers and cold boxes

Aluminium plate-fin heat exchangers, conventional in cryogenic natural gas processing onshore, are ideal for floating liquefaction, being light, compact and highly efficient for multi-stream duties.

Multiple plate-fin heat exchanger cores can be accommodated in cold box modules providing insulation and weatherproofing, with a two-train 1.5m t/y liquefaction plant requiring one cold box per train.

process heating and cooling

Process heating is needed for the molecular sieve dehydration system, acid gas removal system and for condensate stabilisation. The gas turbines produce more than enough heat for the process and waste heat recovery is the most cost-effective and thermally efficient solution for process heating.

A FLNG facility needs much more cooling water than an oil-processing FPSO, with a 1.5m t/y facility requiring around 15,000 m^3/h of cooling water.

Direct cooling against seawater in an open loop requires all cooling system components, including heat exchangers, to be constructed in corrosion resistant materials, typically titanium. It would appear that an open loop system has potential to achieve lower process temperatures, and therefore enable increased LNG production for a given driver power.

However, open loop systems need expensive shell-and-tube heat exchangers, which also add to the module's footprint and weight.

A viable alternative is a closed-loop cooling water circuit that rejects heat to seawater in heat exchangers which are installed below deck, reducing pumping requirements and use of corrosion-resistant materials. A closed-loop system used in conjunction with compact heat exchangers enables temperature approaches similar to an open-loop system; importantly, they require a fraction of the space and weight that would be needed for heat exchangers on the topside module.

plant layout and safety

Onshore LNG plants and the LNG carrier fleet have both enjoyed an excellent safety record. FLNG introduces more stringent requirements due to the congested nature of the plant, storage and personnel areas. This makes safety considerations paramount in plant layout, and designers have to think carefully about the need for personnel refuge and escape routes.

The primary safety concern is the inventory of hazardous, flammable gas and LNG and the consequence of any loss of containment. Hazard mitigation and blast overpressure are critical elements for layout and the benefits of nitrogen refrigerant become apparent in setting safety distances and minimum spacing for equipment.

Several classification societies have developed requirements for FLNG facilities and will act as a 'design authority' in developing the formal safety assessment with the engineering team to determine fundamental safety criteria, philosophies and procedures.

It is clear in work to date that there are no obstacles to the safe design of a FLNG facility using nitrogen refrigerant, with quantitative risk assessment showing lower risk than many onshore LNG plants.

Weight control and minimisation is also of primary importance in FLNG design. It is evident that layout optimisation can have considerable impact on the length and weight of piping and associated supporting steel, particularly considering the large bore pipework in the nitrogen refrigerant and cooling water systems.

conclusion

Offshore LNG production provides a competitive alternative to onshore production at a time of LNG shortage. With uncertain gas prices and funding for major projects becoming more difficult, the commercial case for floating LNG may be even better as FLNG projects can be economical at smaller capacities, giving lower cost and reduced time to first production. **tce**

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