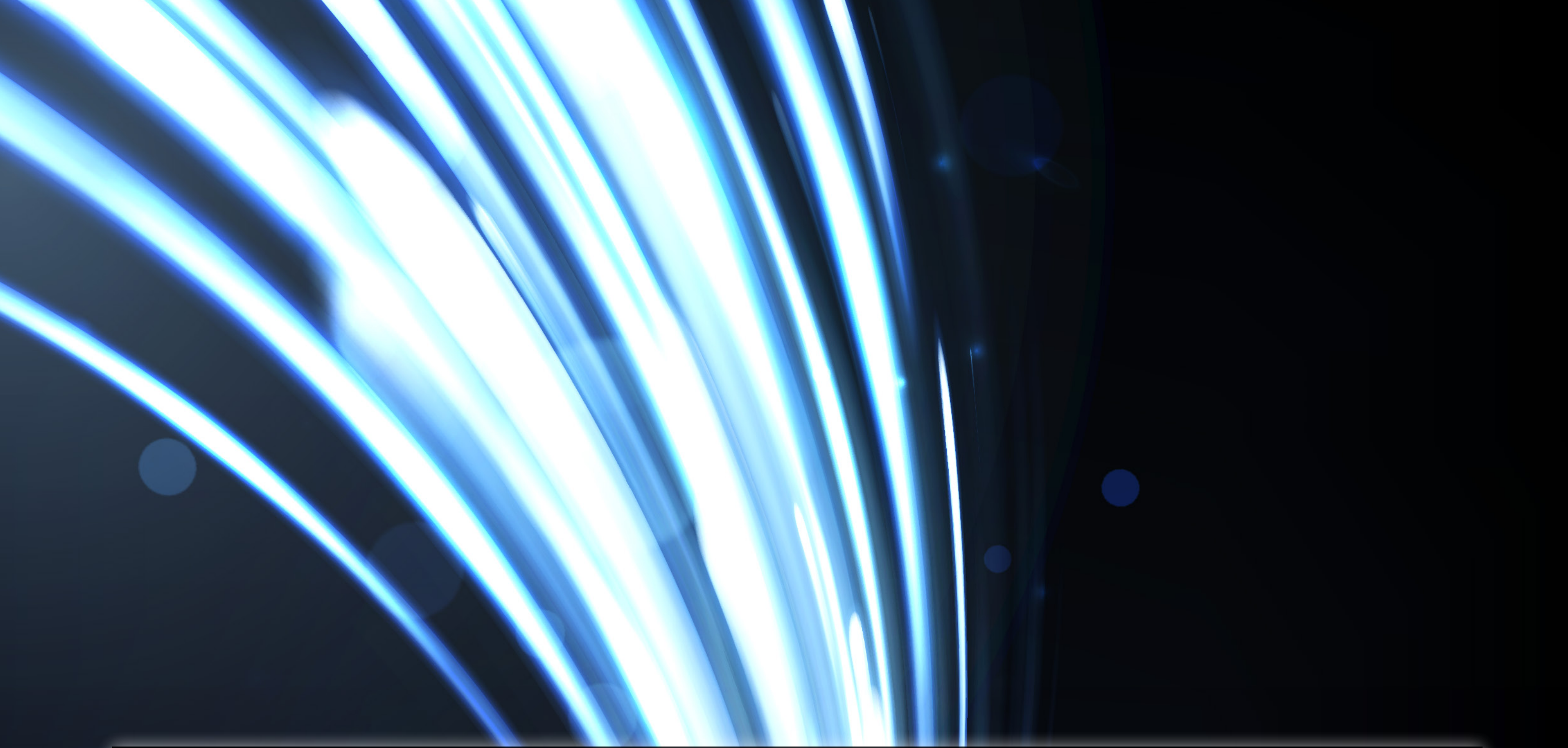

END-FLASH IS TOTALLY COOL

Robert P. Saunderson, Air Products, USA, explores how to find the right combination of LNG subcooling and end-flash.

In a natural gas liquefaction (LNG) facility, the amount of subcooling performed on the LNG and the quantity of end-flash vapour produced affects the investment in liquefaction equipment and refrigeration power. Since there is limited flexibility in some instances and a wider array of possibilities in others, it is important to understand each of the available options. This will allow the right combination of LNG subcooling and end-flash to be selected based on all factors influencing the decision when using an AP-C3MR^{TM} or AP-DMR^{TM} LNG process.

Fully-subcooled liquefaction process

While liquefaction of natural gas is performed at high pressure (55 – 75 bara), the LNG storage tank is operated just above atmospheric pressure. To prevent flash in the LNG storage tank due to adiabatic pressure reduction from liquefaction pressure to tank pressure, LNG must be subcooled to approximately -161.5°C to -163°C in the main cryogenic heat exchanger (MCHE). This is known as a 'fully-subcooled' liquefaction process.

The feed gas to liquefaction in a fully-subcooled process must have ≤ 1 mole% nitrogen content to meet the standard LNG product specification in the storage tank. Although this process produces no adiabatic end-flash or tank-flash, vapour is formed in the LNG storage tank due to heat leak and pump work in the LNG piping to storage and heat leak into the storage tank itself. This vapour is known as storage tank boil-off gas (BOG). The BOG, which is displaced by rising liquid level in the tank from incoming product, must be withdrawn from the storage tank to avoid an overpressure. Although nitrogen will preferentially migrate to the vapour phase, there is not enough BOG formed to appreciably lower the nitrogen content of the LNG. Since BOG is mostly methane (usually 84 – 97% methane, 3 – 16% nitrogen, and ≤ 125 ppm ethane), it is often compressed and used as fuel. In a fully-subcooled process, the nitrogen concentration in the BOG and the MCHE exit temperature strongly correlate with the nitrogen content of the natural gas feed as shown in Figure 1. Since the fully-subcooled process generates a relatively small amount of BOG that can be used as fuel, this process is a good fit when the refrigerant compressors in the liquefaction unit are driven by motors drawing power from the local electric grid. In facilities where the

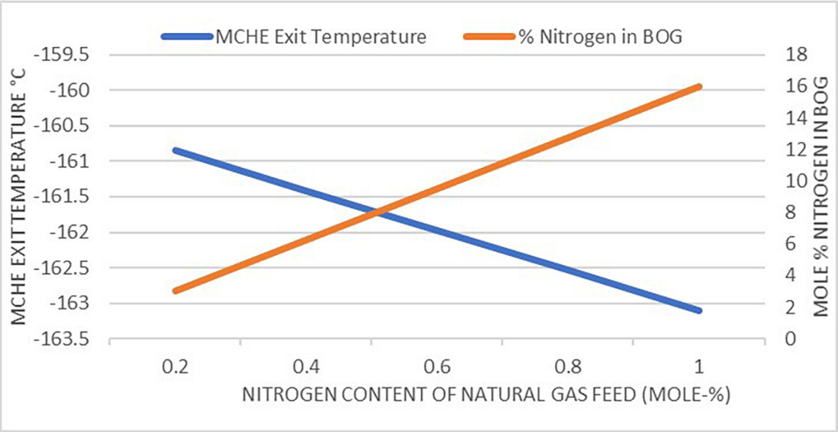

Figure 1. MCHE exit temperature and BOG nitrogen content as a function of nitrogen content in the natural gas feed.

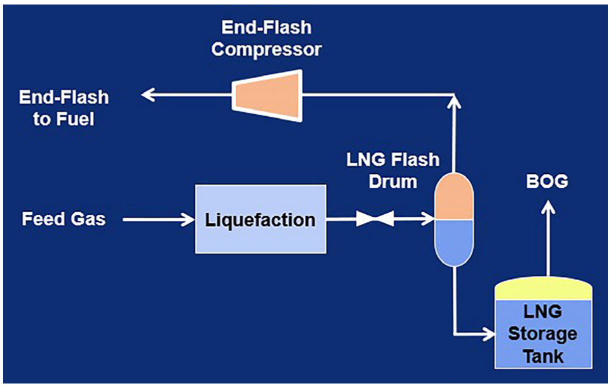

Figure 2. Schematic of the 'end-flash' liquefaction process.

refrigerant compressors are driven by gas turbines, the BOG provides only a small fraction of their fuel requirement, so typically the remaining fuel is drawn from feed gas upstream of liquefaction. Generally, the feed pressure is greater than the fuel header pressure, so no additional compression is needed. Fuel drawn upstream of the liquefaction unit will contain any LPGs that were not removed in an upstream NGL extraction unit.

Flash-in-tank liquefaction process

Since most LNG storage tanks can accommodate additional vapour, some facilities elect to operate with adiabatic tank-flash gas. When adiabatic flash gas in the storage tank becomes part of the BOG, the LNG temperature at the MCHE exit is typically -155°C to -156°C. This is known as a 'flash-in-tank' liquefaction process. Although a lower percentage of the feed gas becomes net LNG compared to the fully-subcooled process, the refrigeration power required per an identical amount of LNG in storage (specific refrigeration power) can be 6 – 7% lower for the flash-in-tank liquefaction process. Generally, the adiabatic flash portion of the BOG is 65 – 75 mass% of the total vapour generated in the storage tank. This process removes a larger amount of nitrogen from the LNG. Typical tank designs can accommodate the increased vapour flow when the feed gas has ≤ 1 mole% nitrogen.

End-flash liquefaction process

When the feed gas to liquefaction has > 1% nitrogen content, the fully-subcooled and flash-in-tank processes are not acceptable options, since nitrogen must be expelled from the LNG prior to entering the storage tank. Instead, an LNG flash drum is included downstream of the MCHE allowing the MCHE exit temperature to be warmer, typically between -145°C and -151°C depending on plant fuel requirements, since a warmer exit temperature creates more flash vapour. This is known as an 'end-flash' liquefaction process and is depicted in Figure 2.

The LNG flash drum usually operates at 1.25 bara. The vapour generated in the LNG flash drum, which has a higher nitrogen content than BOG, is typically compressed and sent to the fuel header. The MCHE exit temperature is influenced mainly by fuel demand and feed gas nitrogen content, with a higher fuel demand or greater feed gas nitrogen content leading to a warmer MCHE exit temperature.

When using an LNG flash drum, 90 – 95% of the fuel requirement for the gas turbines driving the refrigerant compressors and other power generators can be drawn from the end-flash and BOG while a buffer of about 5 – 10% of the fuel is typically drawn upstream of liquefaction.

End-flash liquefaction process with nitrogen rejection

At higher feed gas nitrogen content an LNG flash drum may not be sufficient to expel enough nitrogen to meet the ≤ 1 mole% nitrogen specification in the LNG product. Since nitrogen removal is a broad topic with too many options to cover here, please consult the reference listed at the end of this article for more information.

End-flash liquefaction process with recycle

To further reduce the specific refrigeration power, the MCHE exit temperature can be warmed to -140°C to -146°C if a portion of the end-flash is compressed and recycled to rejoin the natural gas feed at the liquefaction unit inlet. This is known as an 'end-flash with recycle' liquefaction process and is depicted in Figure 3.

Recycling end-flash vapour creates a higher nitrogen content in the LNG exiting the MCHE, meaning that it is important to be aware of the threshold where a nitrogen removal scheme becomes necessary instead of an LNG flash drum due to the additional cost of this unit.

Advantages of end-flash liquefaction processes

Although a larger fraction of feed gas is diverted to end-flash gas in the end-flash processes, the refrigeration required per unit of net LNG in the storage tank decreases as the MCHE exit temperature becomes warmer. Reducing MCHE duty by warming the MCHE cold-end exit temperature decreases the amount of refrigeration required at the coldest temperatures. A colder MCHE exit temperature is achieved mainly by increasing the nitrogen content of the mixed refrigerant (MR). The rest of the MR is hydrocarbon based: methane, ethane, and propane. Since nitrogen is the MR component with the highest heat capacity ratio, it is the most power intensive to compress. End-flash processes redistribute duty from the coldest section of the process to the less energy intensive warmer parts, thereby reducing refrigeration compressor power consumption for the same net LNG production.

Provided there is a use for the end-flash and BOG, typically as fuel, it is favourable from a refrigeration perspective to make the MCHE exit temperature as warm as possible. This is most advantageous when trying to keep the power requirement for the refrigeration compressors within the power available from the installed gas turbines that drive these compressors. As the MCHE exit temperature is warmed, power is diverted from the refrigerant compressors to end-flash compression. The diversion of power from refrigerant compression to end-flash compression is approximately power neutral from an overall liquefaction unit perspective. The end-flash compressor and end-flash recycle compressor are typically driven by electric motors.

The end-flash exchanger

The cold temperature vapour from the LNG flash drum is approximately -161°C to -162°C and can be used to provide refrigeration to a portion of the feed gas drawn at high pressure from just upstream of the MCHE warm-end inlet at about -30°C. The heat exchanger used for this refrigeration recovery is called an end-flash exchanger and is depicted in Figure 4.

An end-flash exchanger covers a similar temperature range to the MCHE and has a duty that is about 2% of the total MCHE duty. The benefit of end-flash processes and the end-flash exchanger is most apparent when it can be used to increase LNG production by diverting power out of the refrigerant compressors and duty out of the MCHE and other liquefaction unit heat exchangers. Although it is possible to route the cold -161°C vapour from the LNG flash drum directly to compression instead of recovering its refrigeration, using this vapour as refrigerant in an end-flash exchanger and warming it to approximately -30°C prior to compression can increase LNG production by 1.5 – 2%.

Typically, the end-flash system consists of the end-flash exchanger and a separate LNG flash drum. There are several types of heat exchangers that have been used in end-flash service. The most common involve an array of parallel brazed or printed-circuit aluminium heat exchangers mounted inside in an insulated steel-framed structure. The other type is a coil wound exchanger (CWHE). The end-flash exchanger can experience significant thermal stress due to the very wide temperature range it covers (-30°C to -160°C). The MCHE, which covers a similar temperature range, has mostly been a CWHE due to its mechanical tolerance for high thermal stress. The LNG flash drum can be incorporated into the sump of the CWHE shell as shown in Figure 5, thereby reducing overall equipment count and plot space requirements.

Externally connected piping and platforms are supported from the vessel without the requirement for an additional structure. This design also eliminates low pressure cryogenic piping between the LNG flash drum and end-flash exchanger, which decreases pressure drop to the end-flash compressor suction.

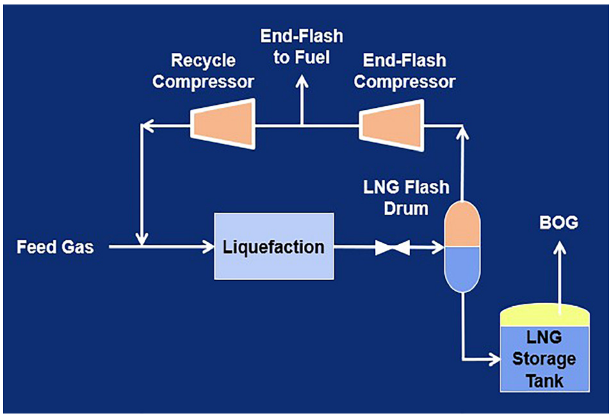

Figure 3. Schematic of the 'end-flash with recycle' liquefaction process.

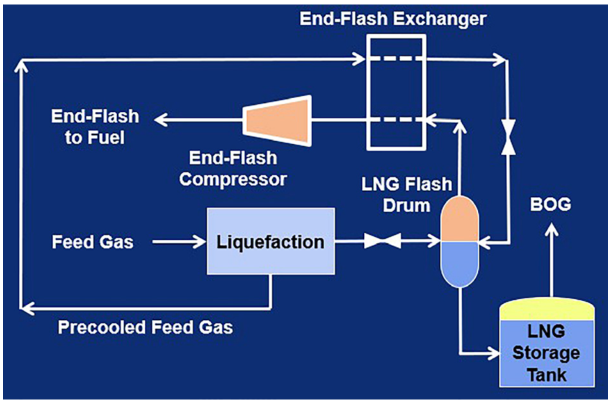

Figure 4. Schematic of the 'end-flash' liquefaction process including end flash exchanger.

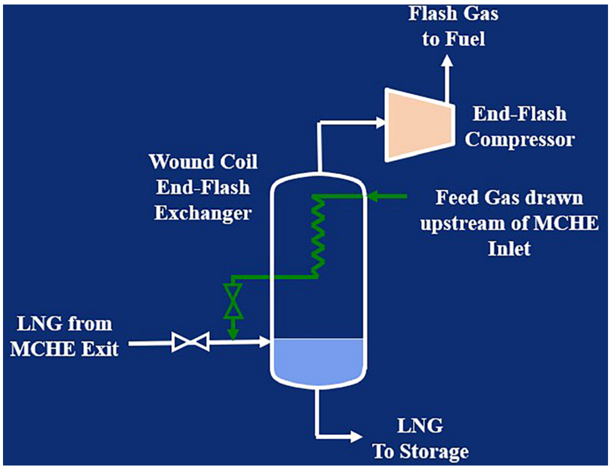

Figure 5. Schematic of the wound coil end-flash exchanger.

Table 1. Debottlenecking by converting to end-flash processes

Liquefaction process	MCHE exit temperature (°C)	Net LNG in storage tank (% of base case)	Refrigeration compressor gas power (% of base case)	End-flash compressor (+ recycle compressor) gas power (% of refrigeration compressor gas power)
Flash-in-tank (base case)	-156	100% (base case)	100% (base case)	0%
End-flash, no recycle	-151	103.5%	100%	3.5%
End-flash, with recycle	-146	107.5%	100%	7.5%

Case study: using end-flash liquefaction processes for debottlenecking

When the feed gas to liquefaction has ≤ 1 mole% nitrogen, the prevailing tendency is to design the liquefaction unit using a fully-subcooled or flash-in-tank liquefaction process to avoid the capital cost of the end-flash equipment – separator, exchanger, and compressor(s). However, adding this equipment and converting to an end-flash process (with or without end-flash recycle) can represent a debottlenecking opportunity to increase LNG production. Table 1 shows an example of how conversion from a flash-in-tank process to an end-flash or end-flash with recycle process can increase net LNG in storage (after BOG is deducted) by adding power for end-flash and recycle compression without increasing refrigeration power consumption. This example is applicable when gas turbines are used to drive the refrigerant compressors. All the end-flash vapour is used as fuel unless it is recycled to join the feed gas at the liquefaction inlet.

Case study recommendations

For an LNG facility with ≤ 1 mole% nitrogen in the feed gas, it is best to evaluate liquefaction processes with and without end-flash during the design phase. Since gas turbines have mostly discrete power generating capability, the desired LNG production capacity may not fit well with any reasonable combination of gas turbines selected to drive the refrigerant compressors. The power of certain gas turbine drivers can be augmented by electric starter/helper motors, but in some instances the addition of an end-flash system may be the best option to maximise LNG production capacity.

Reference

1. OTT, C. M., ROBERTS, M. J., TRAUTMANN S. R., and KRISHNAMURTHY, G., 'State-Of-The-Art Nitrogen Removal for Natural Gas Liquefaction: New Solutions to Meet Market Needs', Gastech (2014).

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