# AVOIDING UNPLEASANT SURPRISES

Dual mixed refrigerant (DMR) and single mixed refrigerant (SMR) LNG processes require partial or total condensation of mixed refrigerants using an ambient air or water heat sink. To ensure optimal performance, it is essential that liquid and vapour phases remain intimately mixed as condensation occurs. Substantial performance impacts may result from improper design.[1] The ability to ensure optimal performance depends not only on the heat exchanger design used to condense the mixed refrigerant, but also on the liquefaction process employed.

## Effect of heat exchanger design

For some DMR and SMR processes, the mixed refrigerant that needs to be condensed enters the ambient cooled heat exchanger as a two-phase mixture. The refrigerant is divided among the multiple flow paths (tubes, passages, or channels) of the heat exchanger and cooled by the air or water on the other side of the exchanger. Non-uniform distribution of the refrigerant vapour and liquid phases will result in each path having a different condensation curve (temperature vs duty) which will cause internal pinching with the overall performance of the heat

**Mark Roberts, Katherine Wells, and Dr Annemarie Ott Weist, Air Products**, explore how to prevent unpleasant surprises during mixed refrigerant condensation.

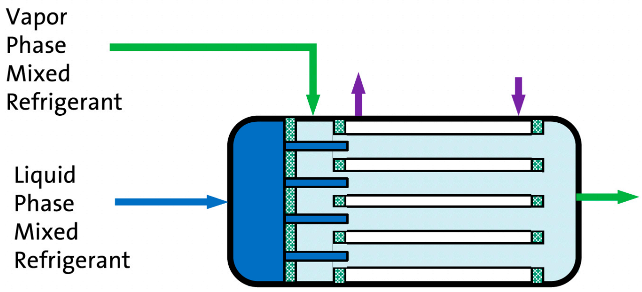


**Figure 1.** Shell-and-tube exchanger with injection tubes.

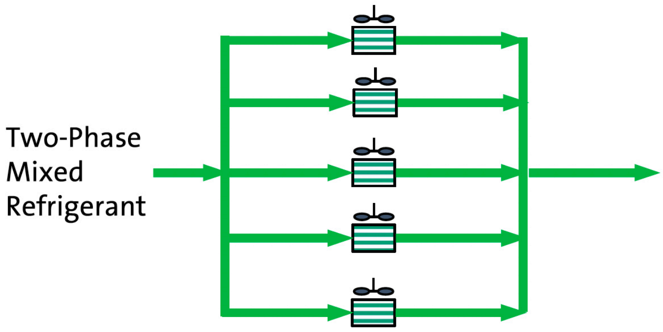


**Figure 2.** Air-cooled mixed refrigerant condenser bays in parallel.

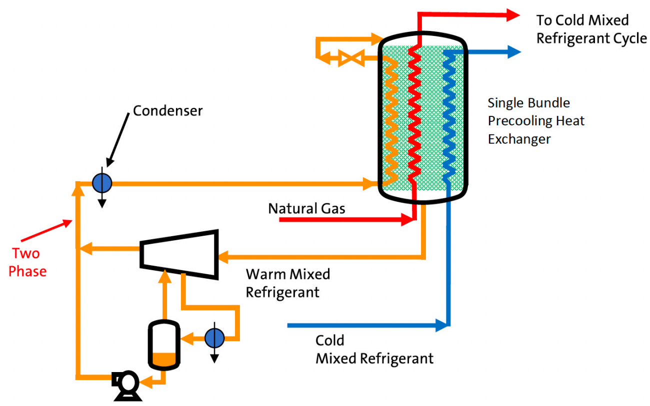


**Figure 3.** Pre-cooling section of the AP-DMR™ LNG Process with single bundle pre-cooler.

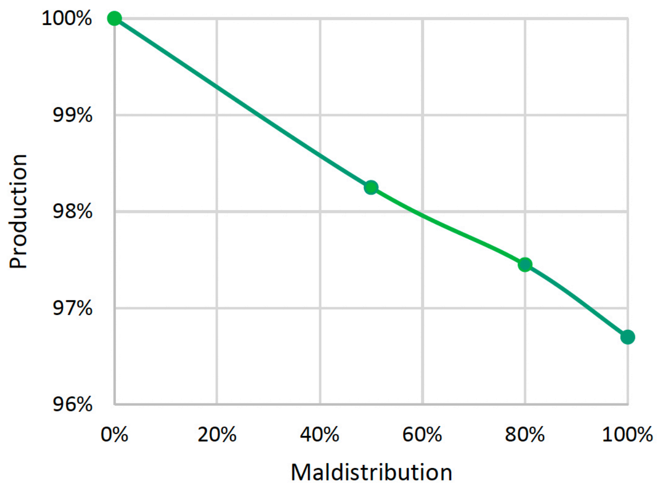


**Figure 4.** LNG production impact as a function of condenser maldistribution.

exchanger falling short of design. In addition, the type of heat exchanger used, and the cooling medium (air or water) can further impact the ability to achieve optimal performance.

## Water-cooled LNG plant

Water cooling is commonly employed for floating LNG plants. Typically, either shell-and-tube or diffusion bonded exchangers are used.

For diffusion bonded exchangers (also known as printed circuit heat exchangers), the dominant concern is uniform distribution of mixed refrigerant liquid and vapour phases into each passage. There have been several studies focusing on even distribution of phases into these exchangers.[2,3] Vendors have developed methods to achieve good distribution, often by performing phase separation before the heat exchanger and separately introducing the vapour and liquid into a special mixing zone at the entrance to the heat transfer passages.

For shell-and-tube exchangers it is critical that the condensing mixed refrigerant is in the tubes with cooling water in the shell. Otherwise, it is difficult (if not impossible) for the designer to ensure that the phases remain in equilibrium as mixed refrigerant is incrementally condensed, resulting in negative performance impacts.[1] Introduction of mixed refrigerant liquid and vapour phases into each tube can be accommodated using injection tubes, as shown in Figure 1.

## Air-cooled LNG plant

Many more tubes are required for an air-cooled mixed refrigerant condenser than for a water cooled one due to the lower heat transfer coefficient. For a mid scale or large scale DMR or SMR plant, multiple air-cooled exchanger bays in parallel with finned tubes and fans are required to accommodate the high tube count (Figure 2). For an air-cooled plant, distribution of equal proportions of mixed refrigerant liquid and vapour phases into each tube among several parallel air-cooler bays is challenging and cost-effective solutions have not been identified.

## Example: Single bundle pre-cooler option

Figure 3 shows the pre-cooling section of the AP-DMR™ LNG Process employing a single bundle coil-wound heat exchanger for pre-cooling.

In this process, low pressure warm (pre-cooling) mixed refrigerant (WMR) is compressed in the first compressor stage, partly condensed in the WMR intercooler and phase separated. The vapour is compressed in the second stage and combined with the liquid before being totally condensed. This cycle has been successfully employed in the Coral Sul floating LNG plant.[4]

Due to a small footprint and easily modularisable pre-cooling section, there has been increasing interest in the AP-DMR LNG Process for air-cooled land-based LNG plants. To assess the potential performance impact of introducing two phase WMR into multiple parallel air-cooler bays, Air Products performed a parametric study evaluating the effect of varying levels of liquid-vapour maldistribution.

Figure 4 shows the results of this study. LNG production assuming fixed compressor driver power is plotted as a function of condenser inlet maldistribution. The maldistribution varies from 0% to 100%, with 0% representing perfect distribution of equal proportions of mixed refrigerant liquid and vapour phases into each tube among several parallel air-cooler bays, and 100% representing complete separation of the phases with liquid and vapour in separate tubes.

If maldistribution is small the resulting small production penalty would be acceptable; however, predicting the maldistribution is problematic. The two-phase flow through header piping between exchanger bays and between tubes within each exchanger bay is complex, making it difficult, if not impossible, to predict maldistribution and the resulting performance impact. One could design the plant with the assumption of 100% maldistribution, requiring 3.5% additional power to overcome the lower performance, but this is a significant impact to OPEX.

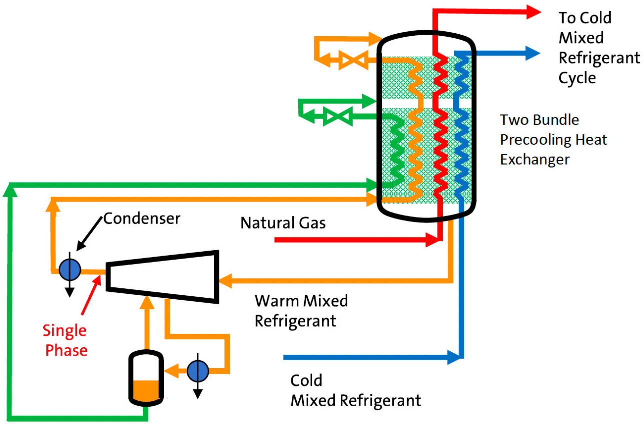


**Figure 5.** Pre-cooling section of the AP-DMR LNG Process with two bundle precooler.

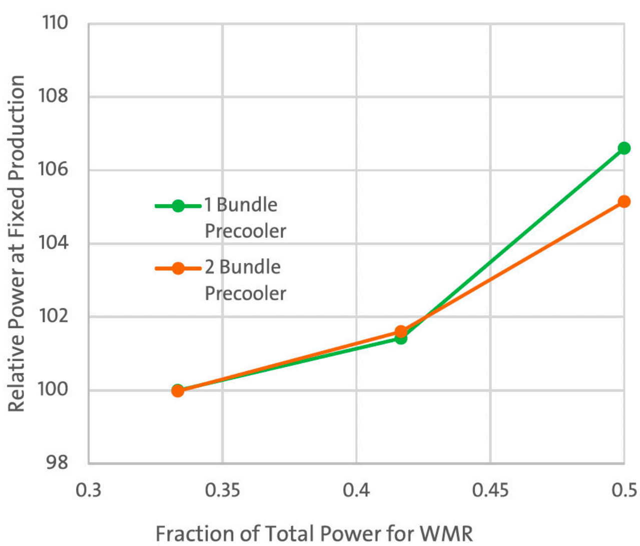


**Figure 6.** Relative power as a function of power split.

## Example: Two bundle pre-cooler option

Figure 5 shows the pre-cooling section of the AP-DMR LNG Process employing a two-bundle coil-wound heat exchanger for pre-cooling. Air Products has developed this process in part to address concerns regarding the WMR condenser in a land based air-cooled plant.

In this process, WMR is partly condensed in the WMR intercooler then phase separated, with the resulting liquid sent directly to a dedicated circuit in the precooling heat exchanger rather than to the WMR condenser, thereby eliminating the pump used in the single bundle option. In this process, single phase fluid enters both the WMR compressor intercooler and aftercooler, eliminating the concerns about maldistribution in air-cooled condensers.

The liquid mixed refrigerant produced from the WMR intercooler is used to provide refrigeration to the warm (lower) bundle of the precooling exchanger, while the lighter liquid mixed refrigerant produced from the condenser is used to provide refrigeration to the cold (upper) bundle of the pre-cooling exchanger. Use of two different WMR compositions in the two zones of the pre-cooling exchanger provides an efficiency benefit, particularly at a 50:50 warm mixed refrigerant to cold mixed refrigerant (CMR) compression power split.

Figure 6 shows the relative power consumption of both AP-DMR LNG Processes as a function of power split, defined as WMR Power/(WMR+CMR) power. At a 0.33 power split, for example with one gas turbine driver for WMR and two gas turbine drivers for CMR, the relative power is the same. At a 0.5 power split, for example with one gas turbine driver for WMR and one gas turbine driver for CMR, the two-bundle precooler version has an efficiency advantage of around 1.5%. For both cycles, optimal efficiency occurs at around a 0.33 power split.

## Summary

Air Products has developed efficient dual and single mixed refrigerant LNG processes that are suitable for both floating LNG production using water cooling, and land-based LNG production using air cooling. Unlike pure refrigerants, condensation of mixed refrigerants against an ambient heat sink presents unique challenges. Care must be taken in both the condensing heat exchanger design and liquefaction process selection to ensure that both liquid and vapour phases remain in equilibrium as the mixed refrigerant condenses. **LNG**

## References


1. PETTERSEN, J., and FREDHEIM, A. O., 'Experience with water cooled mixed refrigerant condensation' *IGT International Liquefied Gas Conference Proceedings*, (2010).
2. KE. H. et. al., 'Analysis Exploring the Uniformity of Flow Distribution in Multi-Channels for the Application of Printed Circuit Heat Exchangers', *Symmetry*, Vol. 12, No. 314, (2020).
3. BAEK, S. et. al., 'Microchannel heat exchanger for two-phase Mixed Refrigerant Joule Thomson process', *AIP Conference Proceedings* 1573, pp.612 – 617, (2014).
4. 'Mozambique's first LNG cargo departs from Coral Sul FLNG, offshore the Rovuma basin', *Eni*, (13 November 2022), www.eni.com/en-IT/media/press-release/2022/11/eni-coral-first-cargo.html