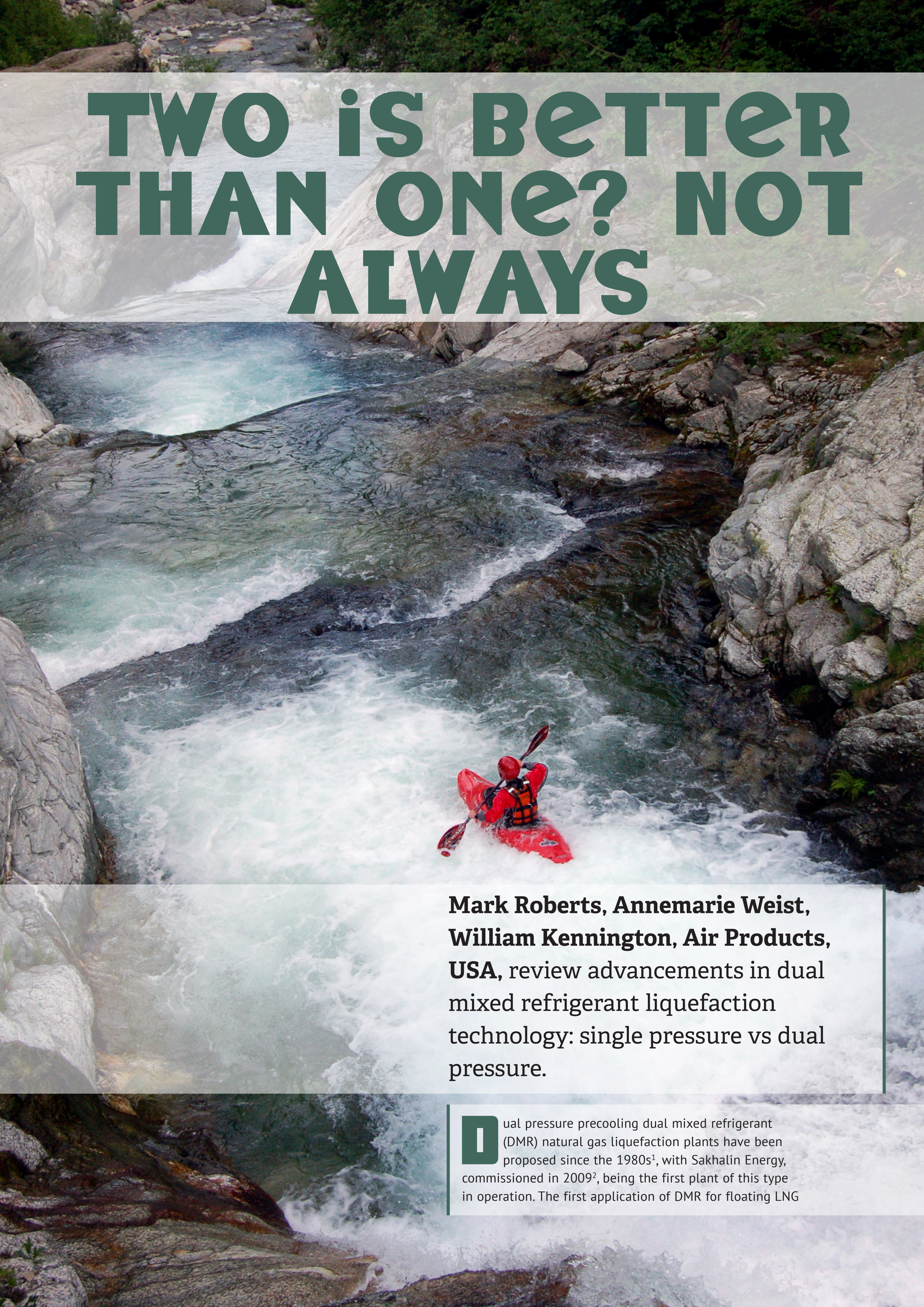

TWO IS BETTER THAN ONE? NOT ALWAYS

Mark Roberts, Annemarie Weist, William Kennington, Air Products, USA, review advancements in dual mixed refrigerant liquefaction technology: single pressure vs dual pressure.

Dual pressure precooling dual mixed refrigerant (DMR) natural gas liquefaction plants have been proposed since the 1980s[1], with Sakhalin Energy, commissioned in 2009[2], being the first plant of this type in operation. The first application of DMR for floating LNG

(FLNG) production is Shell's *Prelude* FLNG vessel, which was commissioned in 2019 using a similar process.

In Figure 1, this dual pressure precooling DMR design is illustrated. The warm mixed refrigerant (WMR) is fully condensed and sent through a first precooling coil wound heat exchanger (CWHE). A fraction of the WMR is used to provide refrigeration at an intermediate pressure, while the balance is subcooled further in a second precooling CWHE, before being used to provide the final precooling

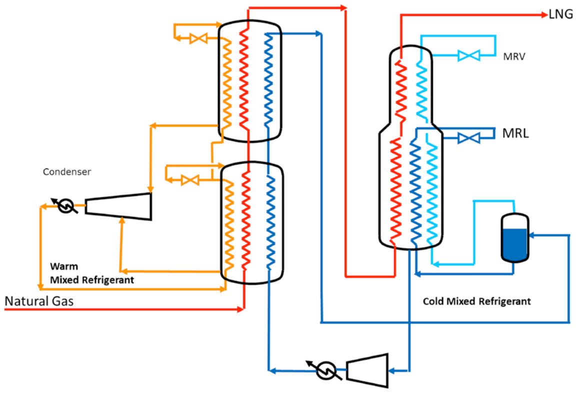

Figure 1. Dual pressure dual mixed refrigerant (DMR) process.

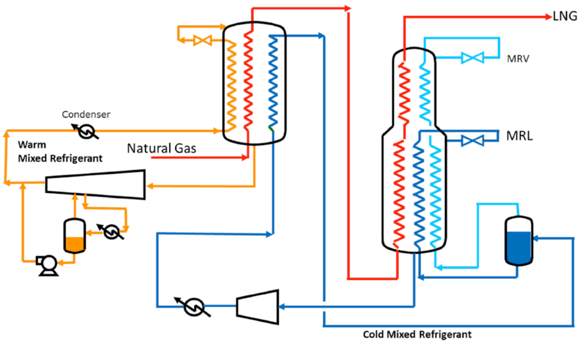

Figure 2. AP-DMR™ single pressure DMR process.

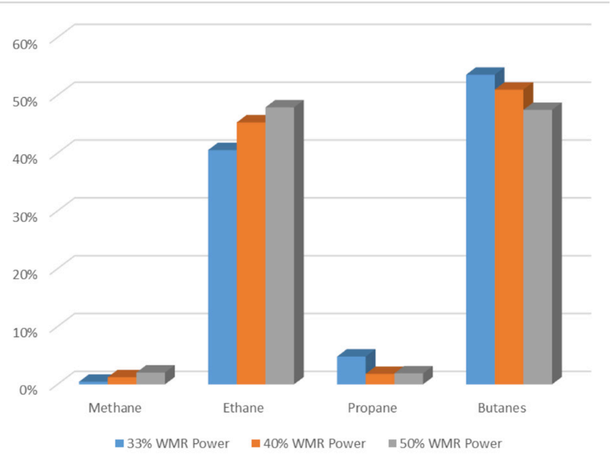

Figure 3. AP-DMR warm refrigerant composition as a function of power split.

refrigeration at a lower pressure. The lower pressure WMR is compressed in the first stage of the compressor and then mixed with the intermediate pressure WMR before the second stage of the compressor. For this process, the WMR is optimally a propane-ethane mixture.

Refrigeration for the liquefaction and subcooling of the natural gas is provided by a second cold mixed refrigerant (CMR). Multi-pressure precooling processes such as this one, can offer high efficiency and flexibility for varying ambient conditions and refrigeration driver selection. Air Products has developed a new single pressure precooling DMR technology that has significant advantages over the dual pressure design, especially for floating applications.[3]

Single pressure precooling: the process

Figure 2 shows an AP-DMR™ configuration with a single CWHE for precooling, and therefore a single WMR shellside refrigerant pressure. The WMR is first compressed, then fully condensed by ambient cooling, subcooled in the precooling CWHE, and let down in pressure through a Joule-Thompson (J-T) valve in order to provide refrigeration to precool the feed and CMR. The compression is performed in two stages, with partial condensation in the intercooler and pumping of the liquid and mixing with the vapour exiting the second stage. The WMR has a constant composition through the process, except for the second compression stage and pump-around. By allowing for interstage condensation of a heavy fraction from warm refrigerant, this single pressure process offers a high efficiency similar to the dual pressure DMR process.

The single pressure precooling design enables the use of a single CWHE for precooling, reduces the amount of large-bore low pressure piping, and eliminates a low pressure WMR compressor suction drum, significantly reducing the required plot plan and the vessel topside weight. This makes it particularly attractive for FLNG applications, as well as land-based applications with tight real estate constraints.

As with most dual refrigerant systems, there are options for arranging the drivers and refrigerant compression. Aeroderivative drivers are often considered for FLNG because of their high efficiency and lighter weight. The number of these drivers depends on the specific driver chosen and the desired production rate.

If two drivers are used, a DMR process may be configured with one driver dedicated to the WMR compression and the other to the CMR compression. This results in a 50:50 power split, meaning that the total power for the system is divided evenly between the WMR and the CMR. When there are four drivers, one common arrangement is to have two drivers in parallel for the WMR and two in parallel for the CMR, also resulting in a 50:50 power split. The parallel drivers improve plant availability.

When three drivers are used, one driver may be used for the WMR with the remaining two being used for the CMR compression, resulting in a 33:67 power split. The three drivers may be configured such that the two CMR drivers are each compressing 50% of the CMR in parallel.

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If the power from five drivers is preferred to meet production goals, then they may be arranged with two parallel drivers for the WMR and three drivers for the CMR, resulting in a 40:60 power split. The three CMR drivers may be arranged with two in parallel for the low pressure stage and one for the middle and high pressure stages, or alternately all three CMR drivers in parallel.

There are configurations that would be analogous to the AP-SplitMR® machinery configuration, in which some drivers can have stages for both MR systems. While this arrangement is often used in land-based plants, it is not preferred for FLNG operations because of the additional piping required.

For FLNG, some owners have a preference to minimise the flammable inventory in the refrigeration circuits. Propane is the greatest concern because of its high volatility combined with its dense vapour, which can accumulate at low elevations, such as in hull spaces, etc. A key advantage of the AP-DMR process for FLNG applications is that propane may be eliminated from the WMR without penalising efficiency. While the WMR for the dual pressure DMR process typically comprises propane and ethane, the WMR for the AP-DMR process comprises primarily butane and ethane. Figure 3 shows optimised WMR compositions for various WMR to CMR power splits, for three different power split designs. It is worth noting that the optimal composition for the WMR, when precooling accounts for 40% or more of the total power, has no additional propane other than the propane included as an impurity in the ethane and butane components. By contrast, the WMR for a dual pressure DMR design contains approximately 50% propane.

For cases where the driver configuration allows deeper precooling with 40% or more of the power on precooling, propane can also be eliminated from the CMR with only a small (approximately 2%) power penalty.

The AP-DMR process, as shown in Figure 2, has been selected for the 3.4 million tpy Coral South FLNG project to be stationed in the Rovuma Basin, off Mozambique's coast. The vessel is currently under construction and is depicted in Figure 5. Commissioning is expected in 2022.

Single pressure precooling: process with dual-bundle precooler

Figure 4 shows a modification of the single pressure configuration in the AP-DMR process. This option features a dual-bundle precooler for even better efficiency. The second bundle allows for the interstage liquid to be sent directly through the precooling CWHE in a separate tube circuit. This design has advantages over the AP-DMR option in Figure 2, as it eliminates a piece of rotating machinery (the pump), while retaining topside space advantages over the dual pressure precooling cycle option in Figure 1. This option also eliminates the need to have a dual-phase inlet stream to the WMR condenser. This is particularly beneficial for the air-cooled condensers which are utilised by most land-based plants. One LNG facility utilising the AP-DMR with dual-bundle configuration precooler is currently under construction and another is in feed.

The efficiency improvement achieved from using the AP-DMR configuration with a dual-bundle precooler results from using different refrigerant compositions in the warm and cold sections of the precooling exchanger. The heavier liquid condensed in the intercooler is subcooled and used to provide refrigeration to the warm bundle of the exchanger,

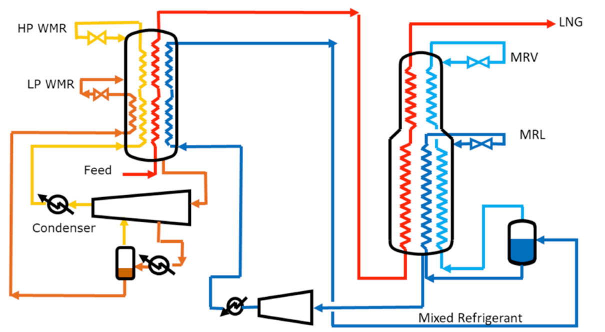

Figure 4. AP-DMR process with dual-bundle precooling exchanger.

Figure 5. Coral South FLNG vessel. Image courtesy of ENI.

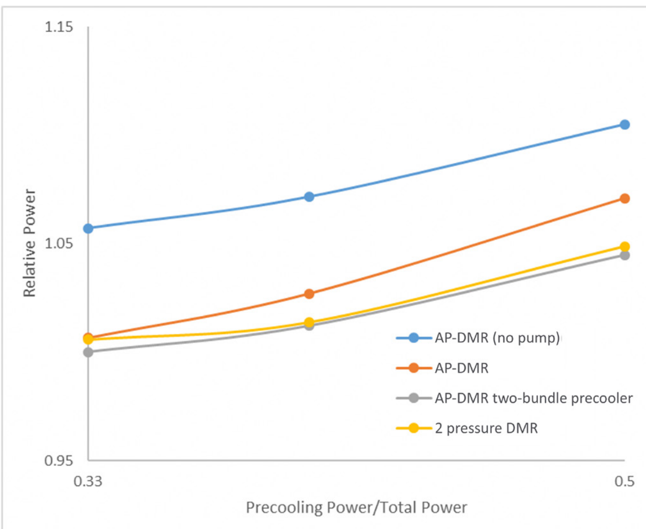

Figure 6. Relative power for AP-DMR options as a function of power split.

Figure 7. NewWave™ FLNG concept. Image courtesy of TechnipFMC.

while the lighter liquid exiting the discharge condenser is used to provide refrigeration to the cold bundle of the precooler. This is particularly true for cases where the driver configuration allows deeper precooling with 40% or more of the power on precooling. Figure 6 shows the relative power requirement for the AP-DMR and AP-DMR with dual-bundle precooler configurations as a function of refrigeration power split, from 33% of total refrigeration power on WMR precooling to a 50:50 WMR to CMR power split.

A modified version of the AP-DMR with dual-bundle precooler configuration was used for the NewWave™ FLNG, a joint concept development between Air Products, TechnipFMC, and Baker Hughes (Figure 7).[4] For this concept, LNG output from a referenced hull design was increased above 7 million tpy, and an intensified version of the AP-DMR with dual-bundle precooler configuration using proven large CWHEs with a reduced equipment count was employed. In the cold section of the liquefier, process intensification was achieved by eliminating the CMR separator of Figure 4, as well as the cold bundle of the main liquefaction CWHE. The result was more revenue per unit of platform deck area and a reduction in the total MR inventory, thus improving the safety profile.

Summary

Single pressure precooling DMR cycles offer clear advantages for both land-based LNG and FLNG applications. Providing the precooling refrigeration with a WMR vaporising at a single pressure can reduce vessel topside area and weight and greatly decrease or eliminate C3 refrigerant inventory, while retaining the high efficiency and flexibility characteristics of DMR technology. **LNG**

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