A NOVEL APPROACH TO ETHANE REFRIGERANT EXTRACTION FOR GREENFIELD LNG PLANTS

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ABSTRACT

The first start of a Greenfield Propane-Mixed Refrigerant (C3-MR) LNG project can be challenging if the feed gas is very lean. The initial fill of refrigerant needs to be either produced or imported. High-purity propane is a commodity item available worldwide for importation, but this is not true for ethane, which typically represents approximately 50% of the mixed refrigerant volume.

Although ethylene is a commodity item which can and has been used as a replacement, it has quite different flammability and blast properties to ethane, and therefore requires greater separation distances in the layout as well as additional import facilities. This is inefficient and costly for a one-off use.

During normal operation the refrigerant ethane is sourced by fractionation of the scrub column bottoms. Hence operators can elect to make the first fill of ethane in a similar fashion by feeding gas at reduced rates to the scrub column and flaring the bulk of the feed gas from the overheads. The scrub column (cooled by Low Pressure (LP) propane) is typically only 5-10% efficient at recovering ethane at best, and so for lean feed flowing at reduced rates it can take many days to weeks of flaring to produce sufficient ethane to permit final cool-down of the Main Cryogenic Heat Exchanger (MCHE) and first production of LNG.

The paper describes a novel approach which uses the MR circuit itself to cryogenically extract ethane and heavier components from the feed gas with efficiencies in excess of 95%. Static and rotating equipment integrity constraints are of course honoured at all times. Ethane production time has been reduced 10-fold to 24-48 hours, with sufficient MR for start-up produced “in-situ”. Simultaneously the MCHE is cooled sufficiently to allow ramp-up to 80+% of full production immediately afterwards. This offers significant time and hence economic benefits over the traditional approach.

INTRODUCTION

A first start of a C3-MR LNG train at a Greenfield site always poses challenges, but particularly with lean feed gas. A key benefit of the C3-MR process is that it can extract the required refrigeration components from the feed gas. In a typical design, the scrub column serves two purposes, with cooling from the C3 refrigeration circuit removing the heavy tail of hydrocarbons to prevent freeze-out in the MCHE and also providing Natural Gas Liquids which are then fractionated to provide high purity ethane and propane for the MR and C3 circuits. Lean feed gas makes this task harder, but this can be addressed during normal running by adding additional cooling to the scrub column from the MR circuit, such as with a three-bundle MCHE or an additional heat exchanger.

For a first Greenfield start the high-purity propane required for the C3 refrigeration circuit must be imported and this is readily available commercially. However this is not true for ethane which typically makes up approximately 40-50% of the MR volume and so the traditional approach is to process feed gas at reduced rates through the scrub column to flare, extracting liquids using just the C3 circuit to make the required ethane. With lean feed gas this process can take weeks because there is less ethane in the gas and because the MR circuit is not available to assist with cooling the scrub column. The propane refrigerant circuit will also be operating at high turndown and recycle (for anti-surge) also compromises performance. As a consequence, the ethane extraction efficiency is only 5-6% at best. Lastly, the fractionation train will also be operating at reduced load, making production of high-purity product more difficult. All these challenges
align while a new plant is being commissioned, with its associated teething problems with instrumentation, analysers and other equipment. Ethylene is commercially available and can be used as a substitute, but it has significantly more severe explosion properties and may require a different plant layout, which is not cost-effective for a single use.

It is also technically possible to operate a C3-MR LNG train with a “dumb-bell” MR composition consisting of essentially nitrogen, methane and propane. This will result in a very flat temperature profile across the warm bundle resulting in difficult and unstable operation and will necessitate operation significantly below minimum turndown.

OBJECTIVE

This paper describes a different approach which was used to significantly accelerate the production of ethane at Woodside’s Pluto LNG plant by using existing hardware in a different way. Sufficient mixed refrigerant for a train start and ramp-up to 70% was made within two days, where the traditional approach had been expected to take in excess of two weeks. In addition to making sufficient mixed refrigerant, the approach also cooled the MCHE ready for a final ramp-up. For brevity of description, a basic familiarity with the normal start-up and operation of a C3-MR process is assumed.

METHOD

The Pluto LNG train design has some additional piping that is designed to allow continued operation without flaring in the event of an internal tube leak in the MCHE, in line with its environmental design requirements. These additions were used to advantage as part of this approach, justifying their incorporation many times over even before start-up. The first takes cold low pressure MR vapour normally vented from the top of the MCHE to flare and directs it through the cold recovery exchanger to the end-flash system. The other allows liquids from the HP MR receiver to merge with scrub column bottoms and be directed to the fractionation unit. These are shown in figure 1.
Woodside has many years experience as Operator of the North West Shelf Project’s Karratha Gas Plant adjacent to the Pluto LNG Plant. This includes experience with small internal tube leaks of natural gas into the MR circuit inside the MCHEs which was used to design the additional piping potentially required to purge components to maintain the required MR composition without flaring. It was also well understood that operation with a sustained small tube leak normally results in a slow build up of heavier hydrocarbon components in the MR, as the normal purges only remove the lightest hydrocarbons which make up the significant majority of leakage. This understanding underpinned the new concept, where feed gas would be deliberately passed “though” the MR circuit prior to start-up and the C2+ components concentrated and extracted.

As part of the development it was first necessary to confirm the technical feasibility and verify that all equipment and process constraints could be honoured. A key part of this was to simulate the proposed operation on Pluto’s Operator Training Simulator (OTS). This is a thermodynamically rigorous high-fidelity dynamic simulator of the entire LNG train which incorporates all the actual Distributed Control Systems (DCS) controls and graphics, process alarms and equipment safeguards including trips and shutdown systems. Because of the novel operation and the need to manage unsteady mass and energy balances, a number of scenarios were developed and evaluated to ensure the methodology was robust, and these were then used as the basis for detailed operating procedures. The OTS was able to verify that all expected flows, temperatures and pressures were within the required operating envelope, with the exception of the MCHE itself. In view of the unusual mode of operation of this key piece of equipment the vendor (Linde AG) was contacted and the expected Heat & Material Balance data from the OTS runs provided. They verified that the proposed operation would be acceptable and made some suggestions towards managing the temperature profiles within the MCHE, but given the novel approach also requested that they be present to monitor the conditions during the actual operation.
Prior to the development of the “once-through” process, the option of a “dumb-bell” MR mixture consisting of essentially methane (natural gas) and propane had also been evaluated (using the OTS) as an alternative to the extended ethane production period. Rates approaching 40% of design were achievable, but the temperature profile down the warm bundle was “flat” at approximately -60 °C. Even with the perfect radial distribution within the MCHE that the OTS assumed, the operation was still difficult to manage, as it was very difficult to avoid significant liquid drop-out in the MCHE vapour exit, and the liquid propane was much harder to vaporise in the compressor suction. Operation above 40% was infeasible due to excessive liquid drop-out and compressor operating envelope restrictions, and real operation in the range of 20-40% of design was expected to be quite unstable due to the inherent MCHE behaviour. For this reason this approach was discarded.

RESULTS

The procedure was first used as part of the Pluto start-up in early 2012. As per normal practice the MCHE and MR circuit were initially pre-cooled to approximately -30 °C using the MR/C3 kettles and Joule Thompson (JT) cooling from the feed gas (scrub column). This left the MR circuit containing low pressure lean feed gas from the scrub column overheads. At this point gas circulation through the Light Mixed Refrigerant (LMR) circuit was commenced. Forward flow was quite limited because of the low pressure ratio achieved across the MR compressors, since the gas was both light (molecular weight approximately 19 with significant nitrogen content) and warm because of compressor recycle. Flow was increased by continuing to pressure the circuit, but this was ultimately limited by suction pressure (density) constraints on the axial LP-MR compressor. The temperature at the top of the cold bundle in the MCHE stabilised at approximately -85 °C (against heat ingress through the insulation) with JT cooling limited by mass flow, as the LMR valve is designed for liquid but the flow was still mostly vapour.

At this point a make-up and purge (“once-through”) operation commenced. Light gas from the scrub column was fed into the LP MR compressor suction at a significant rate (> 500 TPD), limited by the valve capacity. Simultaneously cold vapour was purged from the top of the cold bundle to flare via the endflash cold recovery heat exchanger to maintain the system pressure. The significant make-up flow cooled the LP-MR compressor suction in two ways – it was cold gas at -70 °C plus it backed out warm recycle. This increased the overall compression ratio at the same suction pressure, increasing the overall circulation rate and the cooling of the MCHE. A small LMR flow was initiated through the tube side of the endflash cold recovery heat exchanger, providing another cooling stream to the top of the MCHE. As the MCHE temperature dropped, the main tube-side LMR flow continued to increase as its vapour fraction upstream of the JT valve reduced, and within a short time stable flow control was achieved with fully condensed LMR and valves at less than saturation. The temperature was stabilised at -135 °C, with the energy balance being adjusted by the LMR rate through the endflash cold recovery heat exchanger.
The cold liquid LMR flashing into the MCHE only yielded a few percent vapour from the initial flash, but to satisfy the material balance (maintain a stable pressure in the loop), it was necessary to vent more than twice this quantity. The additional vapour was generated by vaporising a portion of the cold liquid as it flowed down the shell-side of the MCHE cold bundle and exchanged heat with the upward-flowing tube-side LMR stream, as shown in figure 2. We believe this created a distillation effect in the upper portion of the MCHE where upward flowing vapour (boiled off by the warmer tube-side LMR flow) contacted downward flowing liquid and meant that the C2/C1 separation achieved was excellent. It was not possible to model this behaviour directly as the MCHE unit operations we used (Unisim) could not cope with this partial flow reversal, but an estimate was made using discrete flash operations.

By design, this process was not initially at steady-state. The feed gas contained ~5.6 mol % C2+, but the gas purged from the MCHE shell at low pressure and -135 °C contained nitrogen and methane with only traces of C2+. The C2+ components continued to build in the circulating MR, and eventually began to condense in the High Pressure (HP) MR receiver. There was no Heavy Mixed Refrigerant (HMR) flow, making the lower part of the receiver and this piping section a dead-leg. At this point equilibrium was achieved, with the nitrogen and the bulk of the methane in the make-up stream rejected to flare, and the remaining methane and heavier components accumulating as liquid in the HMR piping system. After approximately 12 hours, the piping and then eventually the receiver were filled with a raw C2+ mixture that was a good approximation to typical HMR. The natural ratio of C2 to C3 in the scrub column overheads approximates the typical MR composition, and the one-stage flash with the kettles and HP-MR receiver resulted in a significant methane component as well.

Throughout this process, the flow rate of the circulating LMR approached the normal design rate, and both the natural gas and HMR flows through the MCHE were zero. The temperature at the top of the MCHE was only slightly warmer than the normal operating temperature and the overall temperature profile of the MCHE was also typical of normal operation. Since the MCHE had vastly more area than required for this operation, it was necessary to decide where the profile would be physically. The initial thought had been to take the entire temperature profile across the cold bundle, leaving the entire warm bundle at warm approach temperature but in consultation with the vendor, it had been decided to set the mid-point temperature close to design (approximately -125 °C). This was readily managed operationally as there were existing measurements and provided several benefits – it allowed the temperature profile across the cold bundle to approximate the design conditions, it increased the thermal mass of “cold” MCHE metal thus providing better stability and also progressively cooled the HMR liquid distribution system to its normal temperature. The entrance and exit temperatures of the warm bundle were therefore also typical, although obviously a significant section of the heat exchange area was at warm approach. This operating point protected the MCHE mechanical integrity during the process and also left the MCHE with an ideal temperature profile for a straight-forward ramp-up of LNG production. The MCHE temperature profile was monitored by the vendor during the ethane production process as shown in figure 3 and during the first LNG production and no issues were encountered.
The original plan based on the OTS results was to fill the HP-MR receiver and then commission the HMR and natural gas flow to commence making LNG and ramp-up the train to ~70% of design. The make-up and purge operation had already cooled the MCHE to the necessary temperature profile to allow a normal ramp-up, with the top of the warm bundle stabilised at about -125 °C. As the train is ramped up, there is always an associated hold-up of MR on the shell-side of the MCHE (especially the warm bundle) and this would need to be provided from the HP-MR receiver as there was no additional liquid ethane available. In practice it was found there was insufficient MR in the receiver when full to achieve >50% rate and still maintain the necessary liquid seal at the bottom of the receiver. This was not unexpected as it was recognised that the OTS model of the MCHE worked “perfectly” even at deep turndown whereas real coil-wound exchangers would not. Although it may have been possible to continue the “make-up and purge” operation to generate more C2+ in the MR circuit while also increasing the LNG production rate, it was felt this would be too difficult to manage. The decision was taken to stop LNG production and utilise one of the additional prepared procedures, where the basic “once-through” operation was maintained and the HP-MR receiver level maintained by withdrawing the raw HMR liquid from the receiver and directing it to the fractionation unit along with the scrub column bottoms.

The additional liquid from the MR circuit was quite different in composition to the normal scrub column bottoms, being effectively a “mirror image” of the C2-C5 component distribution. Although the natural gas flow “through” the MR circuit was only 15-20% of the flow through the scrub column (with the remainder flared directly from the scrub column) the extraction efficiency was so much better at 100% versus 5% that the “once-through” flow actually had to be reduced to stay within the limits of the de-ethaniser rundown capacity. The de-ethaniser was rapidly brought to a high purity operation and over the next 48 hours the C2 sphere was filled with sufficient ethane for a normal train start.
The MCHE temperature profile was already suitable for LNG operation - effectively the final cool-down was complete - and the HP-MR receiver was full. The natural gas and HMR flows were commenced, with forward flow of HMR initially backing out the “once through” natural gas flow through the MR circuit. Within one shift the train was ramped up to stable operation at 70% of design rate as intended.

ISSUES IDENTIFIED

As with any novel operation, there were some issues identified in use which needed to be addressed. The OTS runs had identified correctly that the ‘once-through’ process could not in itself achieve sufficient pressure in the HP-MR receiver to enable forward flow to the Fractionation unit. Effectively the molecular weight of the steady-state composition was too low at ~21 to provide the required pressure rise. Although it would have been possible to operate the de-methaniser at a somewhat lower pressure, this was instead addressed by circulating the raw HMR liquid from the HP-MR receiver through the HMR exchanger on the scrub column overheads and back to the compressor suction. This effectively enriched the MR circulating through the compressor, increasing the discharge pressure and at the same time dropped the scrub column overheads temperature by 8 °C and improved its C2 recovery. This had been predicted, but what also happened was that the circulating MR loop also became progressively richer in C4 components which are undesirable in normal mixed refrigerant. This resulted in a heavier than planned MR composition for the ramp to 70% and some care needed to be taken to avoid dewpoint issues at the MCHE warm exit. However the C4 fraction in the MR was rapidly reduced by normal procedures over the next 24 hours with minimal inconvenience. This could have been avoided by starting the ramp-up with a lower level in the HP-MR receiver and adding more ethane.

Although the forward flow of natural gas through the MCHE during the ethane production process was zero, some recirculation within the MCHE was noted, driven by the temperature profile. Again, this was not unexpected and was addressed by partially depressuring the natural gas circuit within the MCHE during this period.

CONCLUSIONS

The use of the new approach confirmed that using the MR cycle to rapidly extract ethane from a lean feed gas was practical and efficient. The combined approach of initially filling the HMR piping and receiver and then diverting incremental production to the fractionation unit was successful. The alternative approach of filling the receiver, commencing production and simultaneously ramping to design rates while continuing to extract ethane is still considered practical but the trade-off of time saved (~24-36 hours) versus increased complexity of operation would require consideration. Compared to the traditional alternative of only using the scrub column to generate ethane, the novel process is estimated to have saved between two and three weeks of commissioning time, with commensurate increase in LNG production and associated economic benefits. The required amount of flaring prior to first rundown was also significantly reduced.

Although a first start of a land-based LNG site is assumed to be a one-off event, it is possible that this approach could also be used for a floating LNG operation. It could be reasonably anticipated that an FLNG vessel could move between fields during its operating life. Depending on how refrigerant inventories are handled, such a vessel might have a number of “Greenfield” start-ups with varying gas compositions and this approach may assist with these.

The value of using an OTS for a complex engineering study was also clearly highlighted. This approach had been used several times previously by Woodside and given excellent results. Because it was a high-fidelity simulation, there was high confidence in the validity of the result, and this was confirmed by the final results. Where unavoidable simplifications were present, multiple scenarios were identified and tested to ensure a robust overall methodology was developed. Having these options fully developed as approved procedures well prior to commissioning also meant that they could be rapidly utilised without requiring complex Management of Change processes. This was seen as particularly important for a novel process.