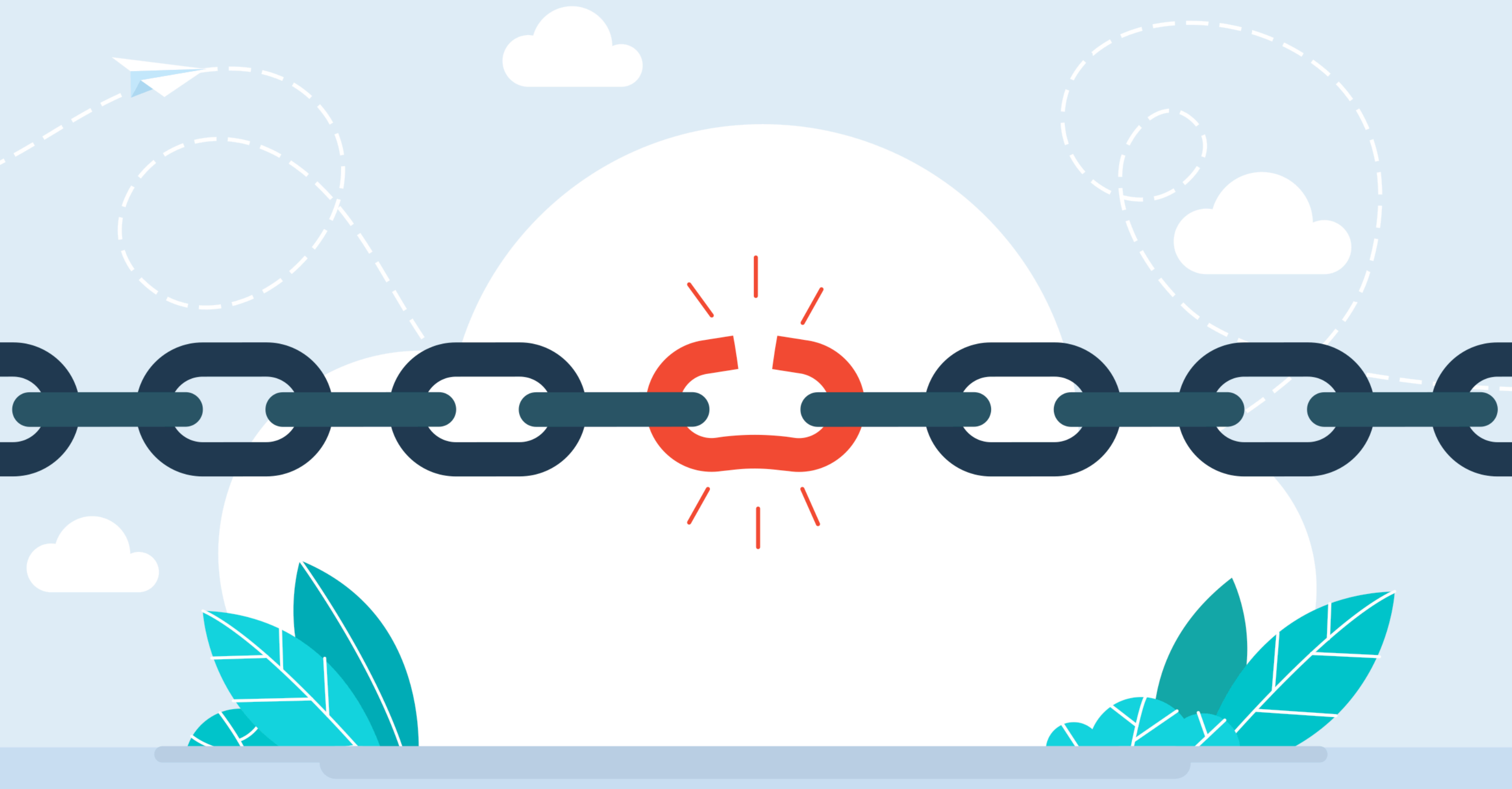
Breaking free from phase separation constraints: Part one

In the first part of a two-part article, **Wim Moyson and Tom Ralston, Kranji Solutions Pte Ltd**, outline phase separation issues in LNG pre-treatment and main liquefaction units.

Drawing upon over two decades of global experience, Kranji Solutions Pte Ltd has undertaken evaluations of proposed separator equipment designs for newbuild LNG plants and executed many projects to diagnose the causes of process issues on operating LNG facilities. The company has assisted established operators of the first wave of global LNG production and, over the last decade, the newly-emerging operators. Both long-established and recently emerged operators face persistent issues with phase separation equipment. Despite some advances in process configurations and operational practices, these recurring challenges continue to impact the efficiency and reliability of LNG production processes.

This article picks up on the closing paragraphs of Ralston and Hicks article in the March 2023 issue of *LNG Industry*,[1] where the general application of computational fluid dynamics (CFD) modelling,



to diagnose and resolve issues in LNG phase separation, was introduced. Whilst MySep's article was focused on the application of simulation digital twins to optimise the process, this article expands on the detailed modelling aspects and presents a selection of three industry cases that highlight some of the most prevalent issues Kranji Solutions has observed in LNG phase separation systems. Kranji Solutions' experience spans all key stages of LNG production processes, including:

- LNG process gas pre-treatment.
- Main liquefaction cycle.
- Natural gas liquids (NGL) processing and LNG downstream handling.

The examples shared relate to pre-processing and the main liquefaction stages of the process.

The company's structured diagnostic methodology includes detailed evaluations of client process data, physical surveys of vessel internals and associated pipework geometry, preliminary performance assessments using MySep software, and CFD simulations. Both single-phase and multi-phase flow modelling are undertaken as required. This integrated analytical framework, underpinned by decades of industry insight, enables the company to identify and address the root causes of separation malperformance. Coupling these analyses with the specialist experience of its process team provides the company's clients with practical recommendations that can be directly executed in house, or through appropriate service providers.

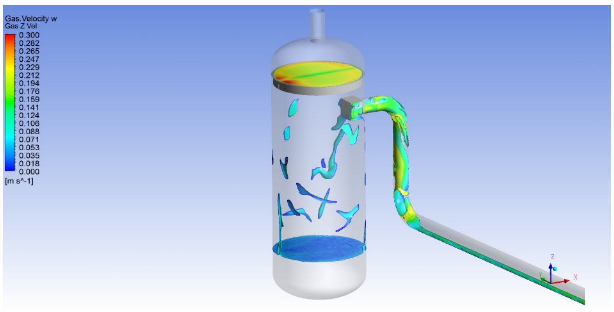


Figure 1. Slugging inlet flow in dehydration feed separator.

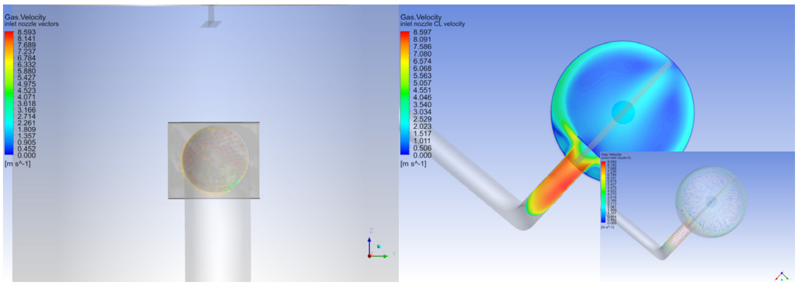


Figure 2. Swirling flow at inlet section (left) and counter-rotating flow vortices in the vessel at inlet plane (right).

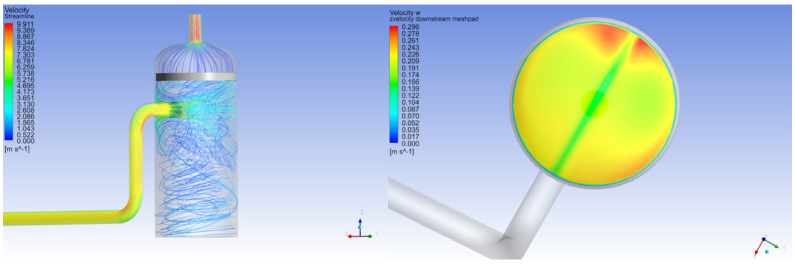


Figure 3. Gas flow maldistribution in gravity section and at demisting device.

Case 1: Separator in pre-conditioning – dehydration feed service

A leading international LNG operator experienced rapid degradation of molecular sieves within the dehydration system of their pre-conditioning unit. This issue led to excessive operational downtime and frequent replacement of costly bed materials. Kranji Solutions was engaged to perform an independent root-cause analysis and recommend effective mitigation measures.

A detailed investigation of the dehydration feed separator was undertaken using a combination of multi-phase, time-transient CFD simulations and analytical assessments performed with MySep Studio software. The CFD model incorporated the upstream piping geometry, including two out-of-plane bends and a vertical-riser section located immediately upstream of the separator inlet nozzle.

The analysis confirmed that excessive liquid carryover from the dehydration inlet separators was the principal cause of the molecular sieve degradation. The observed malperformance was attributed to a combination of interacting factors arising

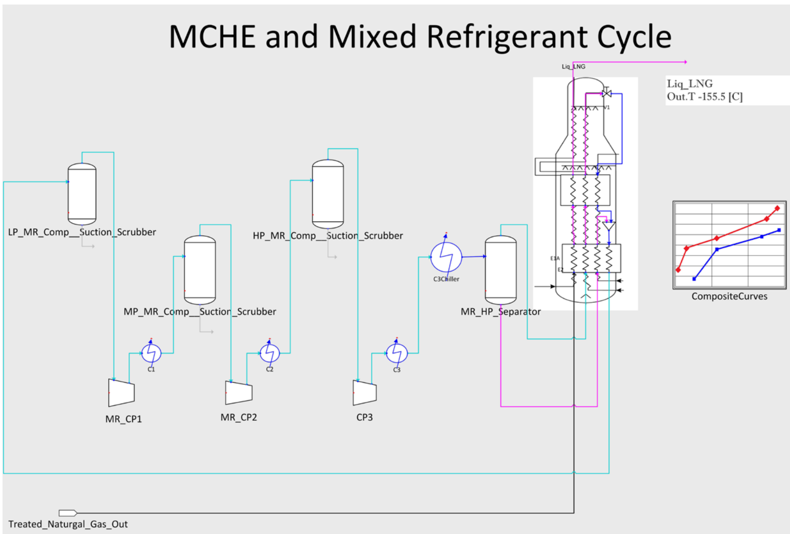


Figure 4. Refrigeration loop process flow diagram from a C3 MR process simulation.

from inlet piping flow behaviour and separator internal characteristics.

The MySep Studio analysis identified a stratified wavy flow regime would be prevalent were the horizontal section of the inlet piping of sufficient length. This would be relatively favourable for liquid-gas separation. However, the CFD simulation demonstrated that the upstream piping configuration caused liquid accumulation at the bottom of the vertical-riser segment, leading to intermittent slug flow at separator inlet (Figure 1).

CFD analysis also revealed significant gas and liquid swirl at the separator inlet, caused by the combination of asymmetric out-of-plane bends and an undesirable configuration of inlet device. The diverter plate device directed incoming fluids to the vessel inner shell, establishing strong counter-rotating flow vortices within the separator (Figure 2).

Upon impingement with the inlet deflector, the entering fluids will experience an abrupt change in flow direction, generating intense shear forces and associated turbulence. Using the droplet breakup correlation of Hinze 1995, it is possible to evaluate the impact of small scale turbulent eddies, as manifest by the turbulent energy dissipation rate, and their interaction with liquid droplets.[2] High energy dissipation rates promote droplet breakup which can be directly predicted by the correlation. This analysis demonstrated that the shear generated by the inlet deflector produced an increase in the concentration of smaller droplets than that present at the equilibrium conditions within the upstream piping. This elevated population of smaller droplets increased the liquid load approaching the demisting device.

In addition, the CFD simulation revealed severe gas and liquid maldistribution within both the gravity separation and demisting sections, leading to localised overloading of the wire mesh demisting device and further diminishing its separation efficiency. This is observed as the red areas on velocity contour at the plane immediately upstream of the demisting device, as shown on the right of Figure 3.

Based on these findings, Kranji Solutions proposed a series of modifications to address the identified causes of malperformance. A vane type inlet device, combined with an upstream anti-swirl element, was recommended to minimise shear generation and promote uniform gas flow distribution within the vessel and towards the demisting section. In addition, the existing mesh pad was replaced with a thicker, higher-efficiency knitted wire mesh to further enhance separation performance. Follow-up CFD simulations verified that the proposed modifications improved internal flow distribution and reduced liquid shearing and droplet break-up – thereby mitigating the root causes of the molecular sieve degradation.

Case 2: Main liquefaction cycle compressor suction knock out drum

An LNG operator constructing a natural gas liquefaction facility in Australia using the C3-MR process engaged Kranji Solutions to conduct an independent design verification of a key separator. This focused on the LP MR Compressor Suction KO Drum (LP_MR_Suction_Scrubber

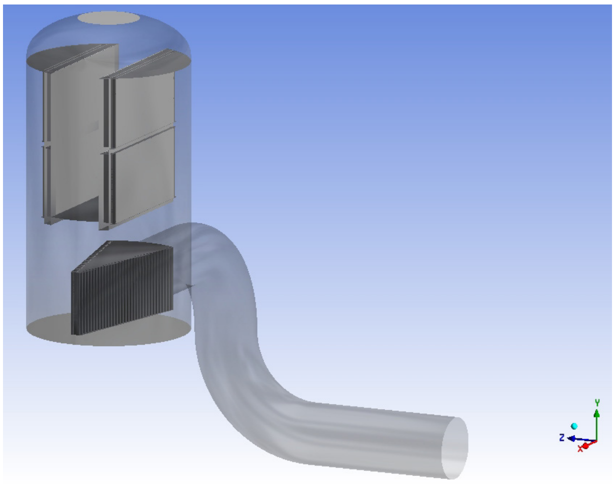


Figure 5. 3D geometric representation of computational fluid dynamics model of KO Drum.

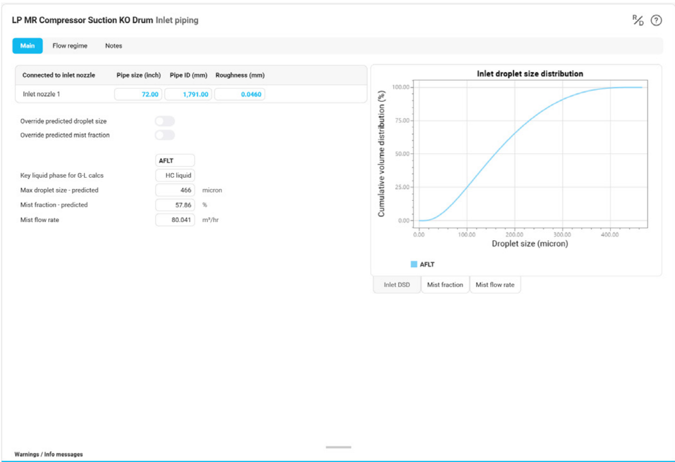


Figure 6. MySep Studio software analysis of inlet piping behaviour.

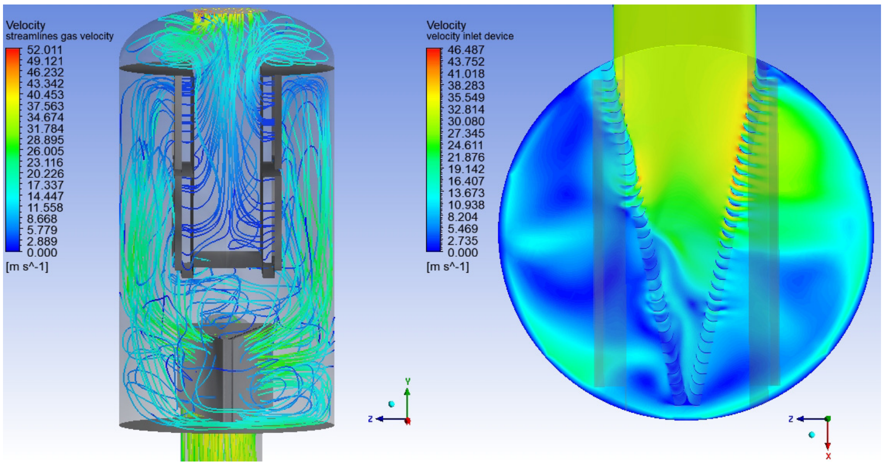


Figure 7. Gas velocity streamlines (left) and gas velocity contours at mid plane of inlet device (right).

in Figure 4) within the main mixed refrigerant loop of the process. The three stages of compression here are essential to provide refrigeration to the main process liquefaction exchanger. The objective of the study was to assess the adequacy of the separator and its internals design for specified process conditions.

The evaluated KO Drum configuration comprised a vane type inlet device followed by a two-bank gas-box arrangement, combining mesh and vane demisting elements. The drum was modelled using MySep Studio to conduct an analytical review of its performance, whilst a 3D CFD model (Figure 5) was prepared to review detailed flow behaviour within the vessel. To ensure realistic simulation of the flow distribution within the vessel, the model included the upstream pipework geometry. The rigorous assessment focused on mechanisms known to influence separator performance and liquid carryover.

The MySep Studio analysis indicated challenging inlet conditions with a high mist fraction and small maximum droplet size (Figure 6).

CFD simulations confirmed that the asymmetric inlet pipe geometry induced non-uniform flow leaving the vane-type inlet device, resulting in preferential gas flow paths across the vessel.

A preferential flow path was observed in Figure 7 with a substantial portion of the gas flow concentrated on the left-hand side when looking from the inlet nozzle into the separator, and clearly jetting over the surface of collected liquid. Under such conditions, excessive gas velocity at the gas-liquid interface can create unstable waves, from which liquid droplets can ultimately be torn off and re-entrained into the gas flow. The onset of this phenomenon was evaluated using the Kelvin-Helmholtz interfacial wave instability criterion.[3]

The critical gas velocity was calculated and compared with the actual velocities observed at the liquid surface in the CFD simulation (Figure 8). For the simulated case, the critical gas velocity was exceeded by a factor of around 15, confirming a strong likelihood of severe re-entrainment from the liquid surface.

Further analysis of the demisting section showed that the two-bank mesh/vane combination resulted in non-optimal gravity separation and significant flow maldistribution across the face of the demisting devices. As commonly observed for such configurations, gas preferentially flowed through the upper region of the demisting device, creating a vertical velocity gradient from top to bottom. Despite the combined flow resistance of the mesh agglomerator, vane-pack demisting device and a downstream flow distribution baffle, local K-values reached up to 0.39 m/sec., exceeding the mean by 54% (Figure 9).

The CFD results showed acceptable left-right flow balance between the two mesh/vane pack banks (+3% and -3% deviation from the mean). However, within each bank, the upper sections carried approximately 56% of the total flow, confirming significant maldistribution, the degree of which was further analysed.

Under the evaluated operating conditions, both liquid re-entrainment from the liquid surface and localised high K-values at the demisting section were identified as major contributors to potential liquid carryover. Accordingly, recommendations were issued to the operator to implement mitigation measures aimed at minimising re-entrainment risk (anti re-entrainment device) and to reduce throughput to maintain efficient separation performance. These findings emphasise the importance of symmetrical inlet piping, uniform internal flow distribution, and optimised demisting device design to achieve reliable and effective gas–liquid separation performance in compressor suction KO drums.

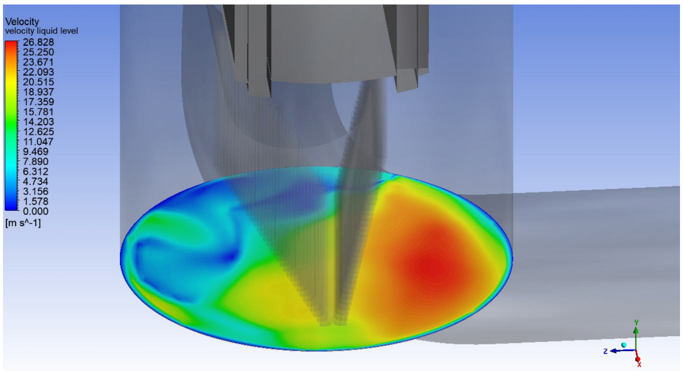


Figure 8. Gas velocity contours over liquid surface.

Conclusions

This first part of a two-part article which outlines of separation issues which constrain LNG production introduces the general methodology applied by Kranji Solutions Pte Ltd. It details examples on LNG pre-treatment processing and main liquefaction processes, discussing malperformance issues found in the first case, and the careful exploration of potential issues reported to the operator, in the second case.

The second part of this two-part article will discuss remedial measures more fully, and will also summarise other issues frequently encountered in LNG processes. In addition, part two includes Kranji Solutions' recommendations on assuring performance through good design practice. **LNG**

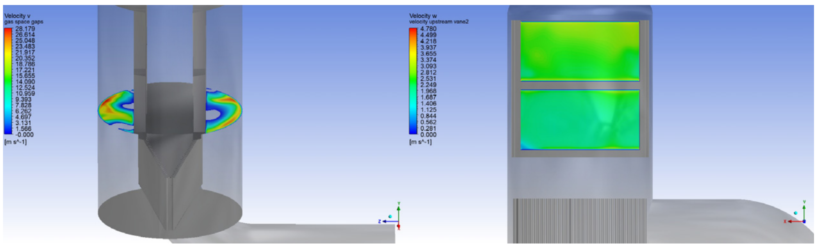


Figure 9. Gas velocity contours of gas flow in the cylinder segment (left) and entering the vane pack (right).

References

1. RALSTON, T. and HICKS, P., 'Optimisation through digitalisation', *LNG Industry*, (March 2023), pp.35 – 40.
2. HINZE, J., 'Fundamentals of the hydrodynamic mechanism of splitting in dispersion processes', *AIChE Journal*, (September 1995), Vol. 1, Issue 3.
3. MATA, C., PEREYRA, E., TRALLERO, J., and JOSEPH, D., 'Stability of stratified gas-liquid flows', *International Journal of Multiphase Flow*, (August 2002), Vol. 28, Issue 8.