LNG INDUSTRY

OPTIMISATION THROUGH DIGITALISATION

Tom Ralston, MySep Pte Ltd, and Philip Hicks, Pravo Consulting Ltd, UK, talk about turbo-charging LNG production in an uncertain world through the use of digital twins.

Just a few years ago, the LNG market was facing an unexciting future, with price depression and new sources and facilities coming on stream, including those feeding western Europe from Russia. To say that matters have moved on will seem a gross understatement – market turmoil, exacerbated by world politics and major European conflict, has brought great power brinkmanship at a level not seen since the Cuban missile crisis of the 1960s.

The global trade in LNG increased to 380 million t during 2021, as many countries rebounded from the economic impact of the COVID-19 pandemic, according to Shell's latest annual *LNG Outlook (2022)*.[1] This saw LNG prices hitting record levels; with total trade valued at over US$30 billion in 2020, and the expectation of reaching over US$66 billion by 2027, at a compound annual growth rate (CAGR) of 6.92% during 2022 – 2027.[2]

Today, the global consumption of natural gas is approximately 520 billion tpy, which is approximately 30% of total global energy consumption. The total consumption of natural gas in Europe is approximately 80 billion tpy, which includes approximately 30 billion tpy imported from Russia. Meanwhile, Russia's total production is approximately 90 billion tpy.

If Europe is to replace Russian sources, its remoteness from alternative sources of natural gas is a new spur to the global LNG market. The US promised to help the EU by providing 2 billion tpy of LNG in 2022 and 6 billion tpy by 2030. The mathematical imbalance makes stark reading and emphasises the strategic importance of LNG in the foreseeable future.

Gear shift in plant construction: fast-track modular processes

Against this background, strategies involving software solutions and digitalisation are helping producers optimise process designs in order to maximise output and energy efficiency. This has supported a gear shift in plant construction, with the development of modular trains providing fast-track construction cycles for reduced time to first export cargo. This has seen a huge increase in LNG liquefaction capacity in the south of the US, exploiting the US Permian reserves and other onshore gas and condensate resources. It sees the US poised to become the world's largest producer in 2022, displacing Qatar, according to Jamison Cocklin.[3]

Much of the new US capacity is following the approach of modular multi-train processes exemplified in the 3D conceptual layout of Figure 1.

It is arguable that the modular approach is key to enabling an increase in output to help address the sharp rise in market demand for LNG products.

The legacy model of creating mega LNG plants locks in a long cycle of finance, planning, design, and construction, before any revenue is generated, as opposed to the modular fast-track solution. Qatargas 2 and Rasgas 3, both in Qatar, are the largest liquefaction plants worldwide, based on capacity. Each of these plants have an annual natural gas liquefaction capacity of 15.6 million t. The next level of capacity, including Chevron's Gorgon in Australia, independent Freeport (US), and Cheniere's Sabine Pass (US), are approximately two-thirds the capacity of the largest plants. The 'mega plants,' built with two or three large liquefaction trains, are associated with project cycles which can span decades. Contrast this with Cheniere's Sabine Pass, which stepped up capacity incrementally from 2016 to 2019 by adding more modular mid scale trains and progressively increasing revenue. This plant has now achieved an operating capacity of approximately 10.6 million tpy from six trains.

Mindful of this requirement to both ramp up production and gain fast access to the market, the spotlight inevitably falls on efficiencies of process. A frequently neglected aspect of processes is phase-separation. For all the commercial LNG processes, separation is essential to each major processing stage, including:

- Oil/condensate/gas primary production.
- Gas pre-treatment – sweetening/dehydration.
- Refrigeration and pre-cooling.
- Natural gas liquids (NGL) fractionation.
- Main liquefaction process.

Poor separation performance can severely hinder overall production; not uncommon are shortfalls ranging from 10 – 30% of design capacity. It is also frequently associated with unplanned downtime and associated deferrals in production and revenue.

There are multiple ways that process designs and operations are optimised, and both operator and process licensor must consider how separation operations can be evaluated and modelled.

Steady state and dynamic digital twins to optimise process design and operation

Most, if not all, contemporary LNG processes have been developed using first principles process simulation. Usually, primarily steady state simulation is used, based on commercial software platforms such as: Aspen HYSYS®; Aspen Plus®; AVEVA PRO/II™; Honeywell UniSim®Design; KBC Petro-SIM®; Kongsberg K-Spice®, and Schlumberger (SLB) Symmetry. Most of the processes are developed conceptually using steady state simulation with some dynamic modelling, to refine specific aspects of the process or key equipment. The simulations are used to support the FEED, and detailed engineering phases of any new LNG plant project. In many cases, these simulation models will also be used in commissioning, trouble-shooting, and increasingly in optimisation of operations.

The simulations can also be recognised as process digital twins as they are developed to undertake 'what-if' and sensitivity studies. They can be extended to form the basis for optimisation of operations, drawing on plant data from digital control systems and data historians, and they can form the foundation of an operator training system.

Such digital twins can also be used online to drive advanced process control, but with large complex models, limited convergence speed may somewhat inhibit these

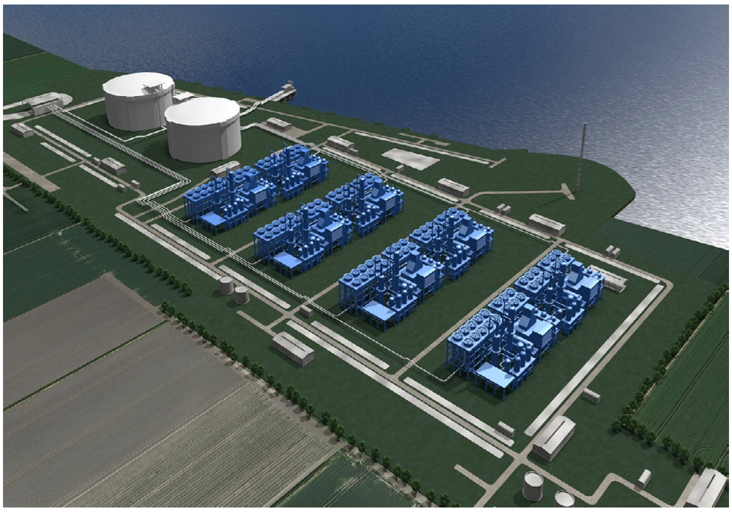

Figure 1. 3D representation of contemporary mid scale multi-train LNG production and export plant.

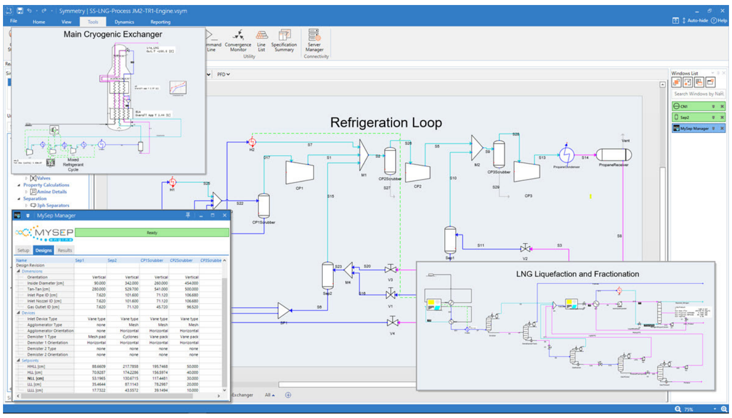

Figure 2. Simulation process flow diagrams of an LNG process in Schlumberger Symmetry.

applications. Recently, advanced process control for optimisation of complex processes has seen application of data analytics and artificial intelligence (AI) in combination with first principles simulation for improved speed in optimising operations.

In all of the above, for optimisation of design or operations, a major deficiency has been the absence of physically-representative modelling of the key phase-separation equipment behaviour within LNG processes. In this respect, the unique capabilities of the MySep Engine software module gives users of simulation-based digital twins access to separator modelling rigour within their dynamic or steady state models. This brings more accurate overall process modelling in the many LNG applications, where liquid carry-over has significant impact on heat and material balances. Analogous application of rigorous separation modelling in an operational digital twin for a refinery FCC application is demonstrated by Tellez-Schmill et al.[4]

Analysis to help avoid common pitfalls in process separation

Two- and three-phase separators are core elements of gas production, LNG, and midstream gas processing. Poor performance of separation equipment is associated with US$10 millions production losses daily across the industry. Some of the more common pitfalls in design include inappropriate performance requirements, reliance on hardware-vendor performance guarantee, potential for non-ideal flow conditions, impact of sizing, and layout of upstream piping.

Embedding rigorous separator modelling in process simulation is one of the latest areas of technical development. This permits operators to optimise overall process performance more effectively with a holistic approach. The same digital twin can be reused to serve process conceptual design, FEED, detailed engineering, and production optimisation.

Simulation-based digital twin with rigorous separation

A simulation to represent an LNG process, augmented with MySep Engine rigorous separation modelling was developed using the SLB Symmetry process simulator. This is illustrated in Figure 2. The image combines a number of the linked process flow diagrams (PFDs) making up the full process model.

This digital twin can be used to explore operation over a range of conditions and to understand production capacity, taking account of the thermal, mass-transfer, and hydraulic behaviour of all key process unit operations such as:

- Main liquefaction exchanger.
- Process and refrigeration compressors.
- Process and refrigeration heat exchangers.
- Fractionation columns.
- Process and refrigeration separators.

Figure 3 presents selected results from this digital twin, as it was used to explore the impact of changing production capacity of the refrigeration process for LNG pre-cooling and partial liquefaction.

In the refrigeration loop PFD within Figure 3, the main refrigerant recycle separator (separator 2) is annotated with a number 2. This annotation also appears on the corresponding carry-over trend in the figure.

The LP compressor suction separator is designated 3 on the PFD, and its corresponding trend plot is identically annotated on the figure.

The intermediate pressure (IP) compressor suction separator is designated 4 on the PFD, and its corresponding trend plot is identically annotated on the figure.

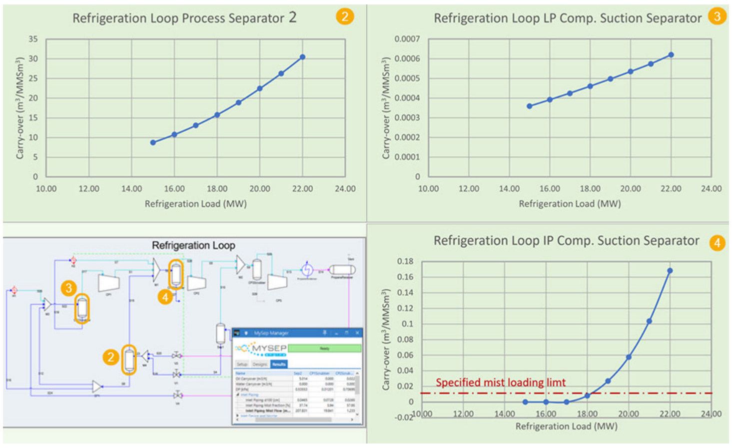

Figure 3. Digital twin of refrigeration loop process flow diagrams and carry-over trends.

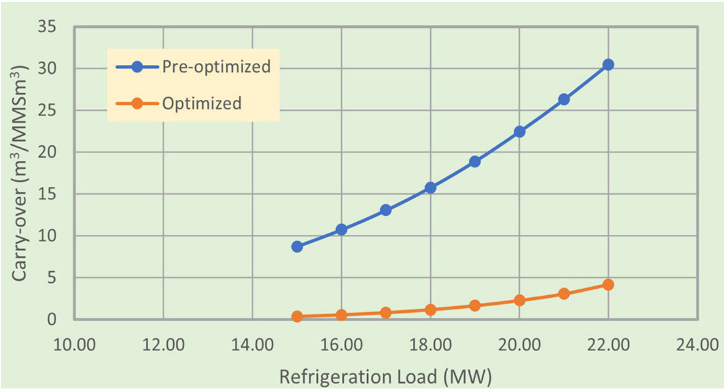

Figure 4. Performance of refrigeration loop process separator 2 comparing optimised and pre-optimised performance.

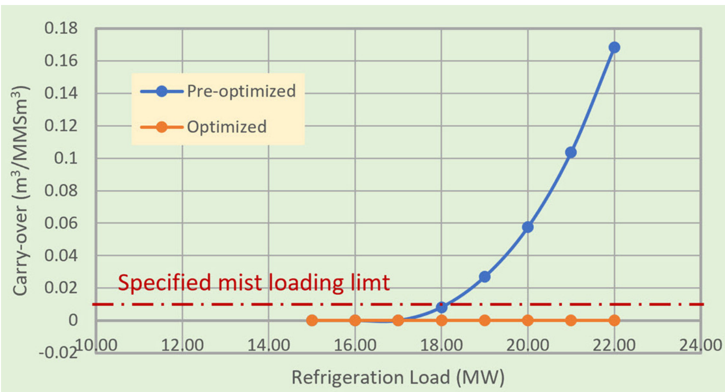

Figure 5. Performance of intermediate pressure compressor suction separator comparing optimised and pre-optimised performance.

Figure 3 shows that as the required refrigeration capacity increases, higher circulation of the system refrigerant is necessary. The increased vapour and liquid flows result in variation of the liquid carry-over from certain of the key process separators. The entrained liquid influences other unit operations. Of particular concern in this part of the process is the possibility of excessive entrained liquid in the suction side of each stage of compression. In the figure, a prescribed carry-over limit is shown for the IP compressor suction separator. This limit effectively constrains the system to a maximum refrigeration capacity of 18.3 MW.

Optimising bottlenecked operations with a process digital twin

The digital twin described above can also be adapted to analyse an operating LNG process. Here, key operational parameters can be used to define current process flows, temperatures, and pressures, with data derived from the plant distributed control system or data historian. It would not be unusual to find the process bottlenecked as seen here.

The digital twin reflects overall production constrained by excess carry-over of liquids in the IP compressor suction separator of the system refrigeration loop. How can that be optimised to increase production?

The separator design capabilities of MySep Studio software can be used to explore options for retrofit of the existing vessels in any part of the process. Exploring the critical vessels for the refrigeration loop, the digital twin helped to establish an optimum. It was only necessary to upgrade separator 2 to achieve satisfactory performance with no carry-over issues.

Using the digital twin with MySep Engine embedded, it is possible to compare the pre-optimised operation with that featuring an upgraded process separator 2. Figure 4 compares the pre-optimised performance with an 'optimised' arrangement, benefiting from alternative selection of separator internals. There is a very significant reduction in carry-over across the range of refrigeration loads.

Turning attention to the IP Suction Separator, the digital twin demonstrates improved performance without any modification, as illustrated in Figure 5. Its performance is improved because of reduced carry-over from the main refrigerant recycle separator (separator 2), which is upstream of the compression system.

The figure clearly shows that with the system optimised, the refrigeration capacity is no longer constrained by carry-over in the IP compressor suction scrubber and there are no other significant issues with other separators in the refrigeration loop.

To illustrate what kind of retrofit upgrade was required on the main refrigerant recycle separator, separator 2, Figure 6 can be considered. This compares the configuration of internals in the 'as-built' arrangement vs the optimised 'retrofit' for separator 2.

The retrofit arrangement on the right of Figure 6 illustrates how the vessel can be provided with an 'agglomerator' and demisting cyclones replacing the original vane pack demisting device. Typically, such retrofits could be carried out during a plant turnaround with very modest installed costs in the order of US$500 000 – US$700 000.

In this process, the increased refrigeration capacity to approximately 21 MW could support a potential 15% increase in LNG production, with corresponding production revenue benefit.

As a result of the system optimisation, the digital twin demonstrates overall LNG production capacity can be increased significantly until other process constraints come into play. Performance constraints in other equipment, such as close approach temperatures in multi-stream heat exchangers or compression capacity limits, cannot easily be addressed without major capital outlay and significant overall process modifications.

Computational fluid dynamics troubleshooting non-ideal separation installations

Michel van Vorselen of Kranji Solutions Pte Ltd can cite almost 20 years company experience supporting LNG international licensors, operators, and engineering companies. This has often included detailed computational fluid dynamics (CFD) simulation of key equipment for onshore LNG and floating production (FLNG). Client's challenge of assuring equipment performance on facilities subject to ocean movement has involved Kranji experimental as well as CFD studies.

He describes how separation equipment malperformance troubleshooting is a regular business stream for Kranji, where projects range from issues with gas treatment, dehydration, or gas sweetening to refrigeration processes, liquefaction, and NGL fractionation processes.

Often, misguided emphasis on minor capital cost saving results in selection of undesirable separator internal equipment configuration. This frequently gives rise to performance issues that result in unplanned downtime or production bottlenecked below

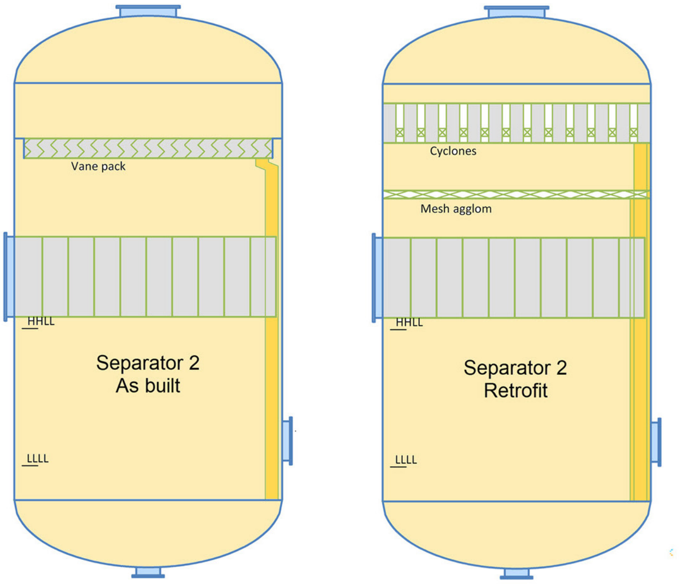

Figure 6. Comparison of 'as-built' and optimised retrofit configuration for separator 2.

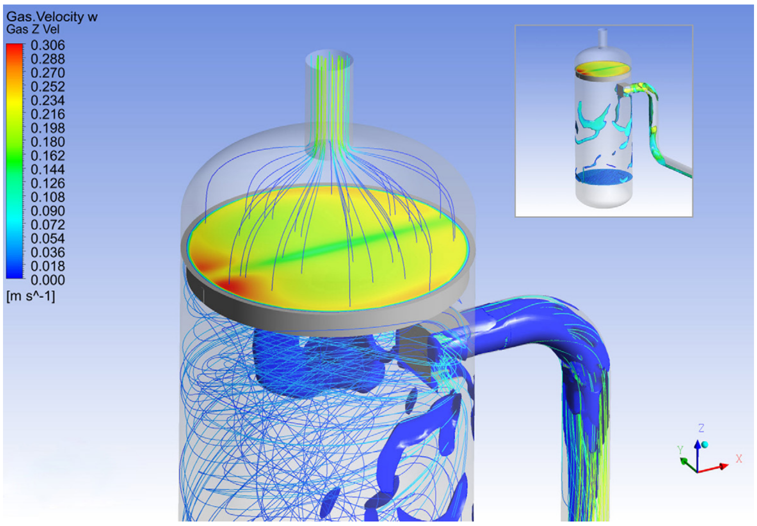

Figure 7. Dehydration inlet separator computational fluid dynamic. Source: Kranji.

design capacity. The consequent costs of US$10 millions for the process operator are often not anticipated by the EPC charged with plant design, in pursuit of minor CAPEX saving in the order of US$10 000s.

Another source of operational issues can be poorly configured inlet pipework arrangements, promoting undesirable gas and liquid flow distributions within separators. Ultimately, this may also manifest itself in excessive carry-over of liquids to sensitive downstream equipment.

Figure 7 derives from a Kranji study on a large Middle-Eastern LNG plant, where the process gas dehydration molecular sieves required frequent bed replacement. This resulted in excessive plant downtime and undue expense from the need to frequently replace the costly bed material.

The cause of dehydration issues was demonstrated to result from excessive liquid carry-over from inlet separators.

Kranji's studies revealed a malperformance derived from a combination of cause factors:

- Liquid slugging in inlet pipes.
- Gas and liquid swirl at inlet due to combination of upstream bends.
- Excessive bulk liquid and droplet shearing from undesirable inlet device type.
- Severe gas and liquid maldistribution in gravity section and demisting section.

Kranji Solutions was able to recommend a number of modifications to mitigate the causes of malperformance. Further CFD simulations verified the performance improvements.

The above is a typical example of many such successful projects Kranji Solutions has delivered to LNG operators and licensors across the globe.

It should be noted that suitable remediation of non-ideal separator installations often results in a configuration which can be effectively modelled and incorporated in a predictive digital twin.

For LNG plant sulfur recovery unit (SRU) processes, in addition to separation-related corrosion failure issues, Kranji has also been involved in troubleshooting sulfur condenser failures. Complex two-phase buoyancy-driven circulation showcases very challenging multi-phase CFD.[5]

Conclusions

In conclusion, digital twins are now regarded as essential to optimise LNG process conceptual designs, FEED, and detailed designs.

In LNG operations, digital twins are proving equally essential for optimisation to meet production business targets, maintain asset integrity, and avoid unplanned shut down.

Rigorous separation modelling is a key component for optimisation and maximised revenue for the LNG sector. It is vital for fully functional simulation-based digital twins.

For operational troubleshooting, expert multi-phase CFD studies can diagnose the root causes of separation and other equipment malperformance in LNG processes. Suitable revamping can provide a basis to represent performance within a digital twin. **LNG**

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