A CWHE design for an evolving market

John Dally and William Schmidt, Air Products and Chemicals, take a look at the innovations in CWHE design meeting the demands of a changing LNG market.

The LNG market has witnessed significant evolution over the past several years, including the introduction of new process cycles, increased train production capacity, floating LNG (FLNG) facilities, more compact plant layouts and a move to modular construction methods. This article describes these changes and the innovations in coil wound heat exchanger (CWHE) design and fabrication to meet these new requirements and challenges, including:

- Process cycle developments.
- Increasing production capacity.
- Higher pressure designs.
- Materials of construction.
- Design for blast.
- Design for fatigue.
- Support design options.

Coil wound heat exchangers

A CWHE consists of one or more tube bundles inside of a pressure vessel shell. Each bundle can contain hundreds of kilometres of tubing, helically wound in multiple layers around a central mandrel. In typical LNG applications, the refrigerant fluid flows over the outside of the tubing on the shellside in the opposite direction of the natural gas feed contained in the tubes.

CWHEs are used in the majority of baseload LNG facilities to liquefy and subcool the natural gas, and account for over three quarters of global liquefaction capacity. They can currently be found in LNG trains with production capacities as small as 350 000 tpy and as large as 7.8 million tpy. Owing to their mechanically robust design and excellent heat transfer characteristics, CWHEs have a long track record of proven performance over this wide capacity range for a single liquefaction train.

Depending on the application, the CWHE can offer various benefits over other types of heat exchanger designs, including higher throughput in a single exchanger, a more compact footprint, increased reliability, higher thermal efficiency and better operational flexibility.

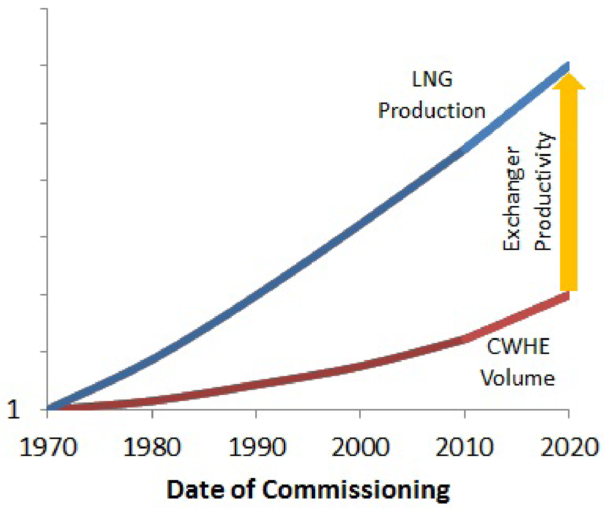

Figure 1. Exchanger productivity.

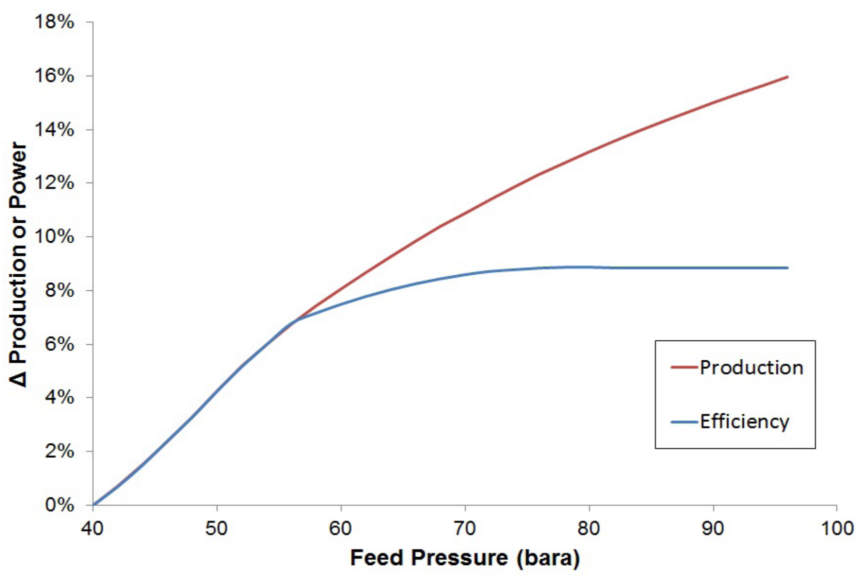

Figure 2. Productivity versus feed pressure.

Process cycle developments

Precooled mixed refrigerant (PCMR) liquefaction cycles account for over three quarters of global liquefaction capacity, primarily due to their best-in-class process efficiency. The high process efficiency of PCMR cycles makes them the preferred choice for most onshore baseload facilities. Desired train size, available plot space and other project requirements must be considered in selecting the best alternative. Non-PCMR cycles have reduced process efficiency, but require less CAPEX and are competitive at smaller train sizes. The dual mixed refrigerant (DMR) process, which replaces propane precooling with mixed refrigerant precooling, and several non-PCMR cycles reduce or eliminate propane storage, making them appropriate for floating LNG (FLNG), and all-vapour refrigerant processes, such as nitrogen cycles, are unaffected by ocean movement making them attractive for smaller FLNG applications.

Maximising production

There are three ways to increase production through the main cryogenic heat exchanger (MCHE) in an LNG train without sacrificing process efficiency: increasing exchanger size; increasing exchanger productivity; and shifting some of the refrigeration duty to other components in the LNG train.

Increasing exchanger size

MCHE sizes have grown to meet market demands over the years. Since the first CHWEs delivered in the late 1960s, diameters have increased by 40%, volumes have tripled, and weights have quadrupled. To keep up with projected market needs, continued growth in exchanger size is required. Air Products has constructed a new CWHE manufacturing facility located adjacent to a deepwater port in Manatee County, Florida, US, allowing the manufacture and shipment of larger and heavier heat exchangers than previously possible. The Port Manatee facility will allow fabrication and shipment of CWHEs up to 6 m in diameter and 60 m in length.

Increasing exchanger productivity

Figure 1 shows how LNG production per exchanger volume has increased over the years.

One means of increasing exchanger productivity is through higher feed pressures. Both process efficiency (as measured by specific power) and exchanger productivity increase with increasing feed pressures up to a point, typically in the 75 – 80 barg range depending upon feed composition, ambient conditions and other project specifics. Above this pressure, the exchanger productivity continues to increase; however, the process efficiency is essentially constant. Figure 2 shows how both process efficiency and exchanger productivity increase with feed pressure; Figure 3 shows how maximum feed design pressure has increased over the years.

To ensure the satisfactory design and fabrication of CWHEs with higher tubeside pressures, a significant amount of development has been completed, addressing the integrity and design of components such as the tubing, tubesheets, internal piping and associated process nozzles. Air Products has manufactured CWHEs with feed circuit design pressures over 100 barg.

Shifting refrigeration duty

Shifting refrigeration duty from the MCHE can debottleneck the exchanger, allowing increased production from the train while minimising specific power. Three proven methods for doing this are through nitrogen subcooling, end flash systems and mixed refrigerant precooling.

Air Products' AP-X® liquefaction process shifts the entire subcooling duty to a separate nitrogen refrigeration loop allowing for an approximate 50% increase in production from a given sized MCHE and MR compressor combination.[1] The first AP-X trains, commissioned over a decade ago, had design capacities of 7.8 million tpy.[2,3] Combining the AP-X cycle with currently available CWHE and compressor sizes enables LNG trains with production capacities over 10 million tpy.

End flash systems can reduce the amount of subcooling required in the MCHE, allowing for increased throughput.[4] CWHEs provide a robust option for end flash exchangers. The DMR process may be designed to shift heat duty from the MCHE to the precooler by reducing the precooler outlet temperature.

Materials of construction

Prior to the AP-X cycle development, Air Products' CWHEs employed aluminium tubing and internals within an aluminium shell. The first AP-X nitrogen subcoolers required a high-pressure shell, which was impractical to manufacture out of aluminium. The AP-X subcooler was the first CWHE to employ aluminium bundles and internals within a stainless steel (SS) shell, and the developments from their implementation are now being employed in other areas such as FLNG. They include solutions to key aluminium to SS transition challenges, such as sealing the annular space between the aluminium bundle and SS shell to prevent refrigerant bypass and providing access to the aluminium tubesheet chambers through the SS shell for inspection, testing and maintenance.

316/316L SS is used for the shells of Air Products' FLNG CWHEs, chosen for its strength, weldability and corrosion resistance. It is often worthwhile to take advantage of the higher strength SS shells and increase the shell design pressure further, increasing the allowable settle-out pressure during a shutdown and minimising refrigerant loss.

As diameter requirements for high pressure CWHEs increase, higher strength materials may warrant consideration.

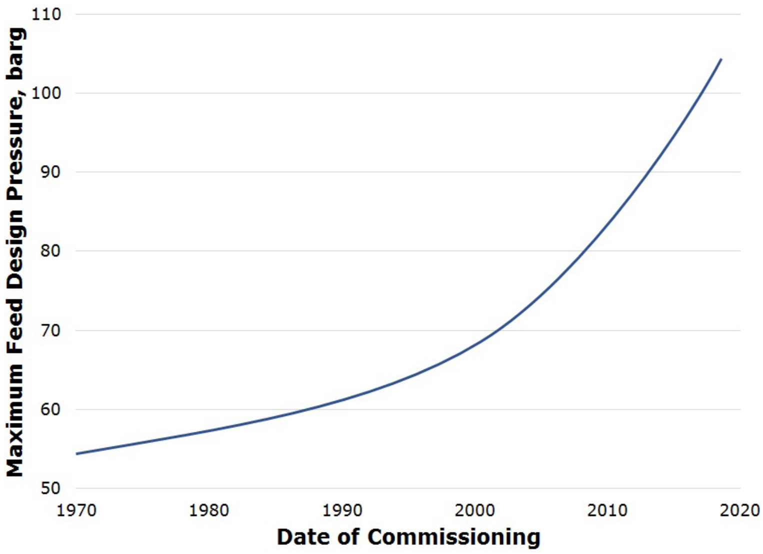

Figure 3. Feed pressure evolution.

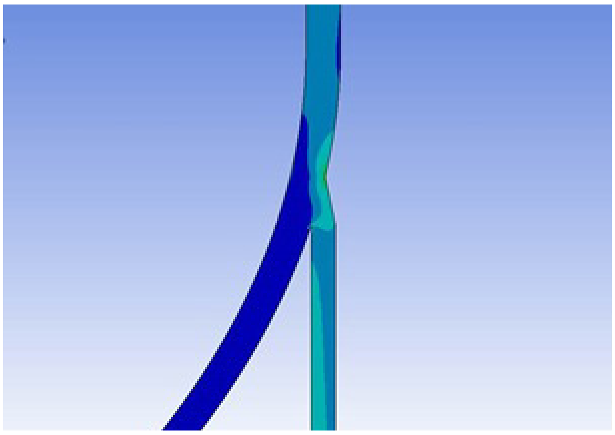

Figure 4. Skirt to bottom head joint finite element analysis (FEA).

FLNG design

Design loads

FLNG service requires numerous loading scenarios to be evaluated, including transit, operating, cyclonic, damage, blast and fatigue loads. Checking each of these scenarios individually is iterative and time-consuming and makes it difficult to optimise the exchanger design or evaluate the design sensitivity to the various mechanical parameters under the designer's control. Software has been developed to evaluate all the above scenarios at once and make quick sensitivity checks on multiple design parameters.

Blast

Due to the concentrated equipment layout on an FLNG vessel, the CWHEs typically require blast-capable designs. Ductility level blast loads are typically specified, requiring the CWHEs to maintain structural integrity and pressure containment but allowing localised deformation. An upper lateral guide is usually required for blast scenarios, to transfer some of the blast load to the surrounding module frame and reduce the loads at the exchanger base. The surrounding module stiffness is a critical factor in determining the load sharing between the CWHE and the surrounding structure. The module stiffness also affects the dynamic response of the exchanger and thus the effective loading. Again, software is available that automatically calculates the dynamic response and effective loading based on the blast profile and the combined module/CWHE system parameters.

Fatigue

Utilising SS instead of aluminium for the CWHE shell increases fatigue life by a factor of approximately 50. Optimisation of the upper guide location and design can increase it further. Assessment software can calculate cyclic stresses from wave induced accelerations and perform a fatigue assessment of the pressure envelope. The structural stresses at most circumferential shell seams are calculated by formulae based on thickness difference, permissible misalignment and cone angles where applicable. For geometries not amenable to design by rule, such as the skirt to bottom head joint shown in Figure 4, finite element analysis (FEA) is used to calculate the appropriate stress concentration factor to apply to the fatigue analysis.

Internal components are analysed with similar methods where appropriate. Components not amenable to design by rule or analysis have been qualified by physical fatigue testing.[5]

Support design

The design of a CWHE base support for a steel module frame differs significantly from one on a concrete foundation, and it is important to understand and break from existing land-based paradigms. There is no requirement for large base plates to spread the load or large anchor bolts spaced relatively far apart. Smaller diameter anchors at closer spacing can reduce the local moment into the skirt and eliminate the need for gussets, producing a more uniform stress field with fewer stress risers for improved fatigue resistance. Anchor bolts do not have to be pre-installed, so bolting can be added inside the skirt after erection, eliminating local moments into the skirt and further reducing cyclic stress. Or the bolted base plate can be eliminated, and the SS skirt welded directly to the carbon steel frame or deck. Air Products has employed all three options (outer bolts only, inner and outer bolts, and welded connection) for FLNG applications.

Modularisation and pre-dressing

There has been much written recently about modularisation strategies for small and mid scale LNG plants, and modularisation is an integral part of all FLNG designs. There is also more interest in pre-dressing and modularisation for onshore baseload applications. Air Products' standard CWHE design incorporates a high degree of modularisation and pre-dressing capability. Multi-bundle CWHEs are multiple exchangers in one package, with MR separation, liquid distribution and internal headering included, and can be designed for full pre-dressing with insulation, platforms and external piping installed prior to erection.

Conclusion

The advances in CWHE design and manufacturing achieved over the past several years have kept pace with market demands and set the stage for the next wave of LNG supply expansion and diversification. **LNG**

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