LIFETIME OPTIMISATION

Plate-fin heat exchangers (PFHEs) are key components in many processing plants. They have compact dimensions and offer a range of operating benefits. Yet using them incorrectly can result in significant failure and repair costs. The Linde Group's Engineering Division has established a team of specialists who can simulate the life expectancy of both existing and newly built PFHEs. They optimise the technical environment of PFHEs and provide plant operators with individual guidelines, which help to ensure that these essential components provide decades of trouble-free service.

Heat flow and heat exchange are fundamental for processing gas and liquids. On a small scale, perhaps you used this principle yourself if you boiled an egg for breakfast this morning. The key parameters to consider are temperature and pressure. For boiling an egg in a kitchen, where air pressure is around one bar, the water temperature has to reach 100°C – that is an easy equation. Because processes in a gas plant are far more complex, sophisticated equipment is essential for managing heat flow.

These heat management units are called heat exchangers, and their task is to transfer heat from a warm fluid to a cold fluid. There are three most commonly used types. Although shell and tube heat exchangers (STHE) and coil-wound heat exchangers (CWHE) are used to perform specific tasks, for example, managing high-pressure applications, allowance for mechanical cleaning or dealing with corrosive fluids, PFHEs have become the engineers' first choice for various operating scenarios.

Linde Engineering also employs PFHEs in most of its cryogenic processing plants. These include natural gas, synthesis gas, hydrogen, chemical and petrochemical plants, air separation plants, among others. As a manufacturer of

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demonstrate how to optimise plate-fin heat exchangers' lifetime.

PFHEs since 1981, Linde has adapted its units to suit the growing range of processes. Linde's PFHEs consist of flat and corrugated plates that are brazed in vacuum furnaces.

Delivery of 12 000 units since 1981

Vacuum-brazing is a complex technology that guarantees the production of exchangers that demonstrate a higher reliability compared to traditionally used salt-bath soldering. Linde has developed special vacuum furnaces, which are located in the production site in Germany. The vacuum brazing procedure forms part of Linde's own know-how and is the key to the unique quality of its PFHEs.

Furthermore, a second production site has been established in Dalian, a city of 6 million inhabitants in north-eastern China, near the Korean Peninsula. In total, Linde Engineering has supplied more than 12 000 PFHEs to plants all over the world.

Every PFHE is unique

Despite the high quantity of PFHE units produced, practically each and every PFHE is customised for its specific task. One reason is because the size of PFHEs has grown consistently since the 1980s. This means that the size of the vacuum furnaces continually adapted to fulfil the industry's standards. Today, Linde Engineering is able to deliver PFHEs with a length of up to 8.2 m. In recent decades, as LNG plants have increased in size – to capacities of millions of tpy – process streams have become stronger accordingly. A single process stream in a single PFHE block can carry up to 20 MW of heat duty or more.

The larger a heat exchanger is, the higher its heating area. In Linde's PFHE, the specific heating area can measure up to 2000 m^2 per m^3. From an economic perspective, it is more efficient to increase the size of individual heat exchangers rather than installing more units. This is an example of how Linde's steady investment in innovation in developing larger furnaces helps customers to reduce costs.

Another quality that makes each unit unique lies within the process requirements of individual plants. Each unit is designed individually for its specific requirements regarding heat exchange and boundary conditions like allowable pressure drop. Specialised engineers develop custom-made solutions for every plant. Even if many PFHE units look similar on the outside, their heat profile is typically one-of-a-kind.

Beside the unique structure, every PFHE offers the following advantages:

- High efficiency.
- Multi-stream (cooling and/or heating).
- Intermediate in/outlets.
- Low cost.
- Small volume resulting from high density in heat transfer area.
- Low weight due to aluminium material.
- Low design temperatures (to -269°C).
- High NTUs achievable (Number of Transfer Units).
- Pure counter-current flow.
- Allow minimal temperature differences between separate streams (less than 1 K possible).
- Usage as reboiler, condenser, heater, cooler, chiller, or a combination.

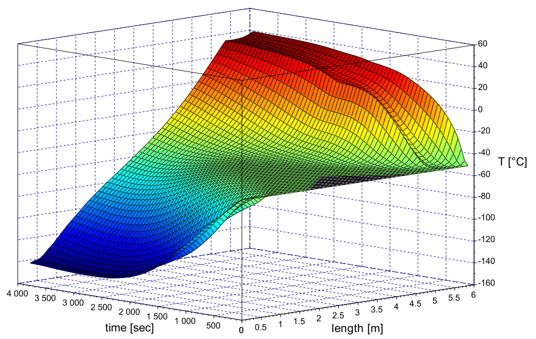

Figure 1. 3D surface plot of metal temperatures vs simulation time and heat exchanger length.

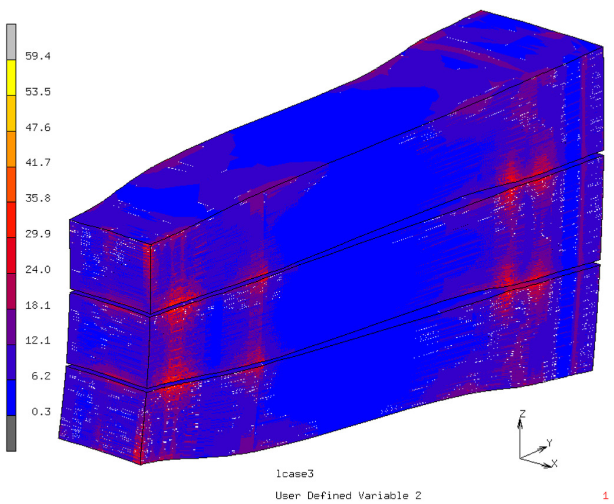

Figure 2. FEM simulations compile an evaluation of stresses.

Thermal stress leads to failure

To ensure optimal performance, some technical usage restrictions for PFHEs exist. The use of corrosive fluids is not allowed, as these could damage the aluminium alloy construction. PFHEs also face some limits in applications concerning high pressure and high temperature. Compared to other heat exchanger types, for example, CWHEs or STHEs, PFHEs are more sensitive to rapid changes in load. These can lead to thermal stress that can cause leakage of the heat exchanger unit in the long term by thermal fatigue.[1]

In countless studies, Linde's engineers have evaluated PFHEs under realistic operating conditions. Their main conclusion gained from the analysis of failure cases: fatigue resulting from thermal stress under off-design conditions[2] is a major cause of failures, and is responsible for significant lifetime consumption.[3]

But what is thermal stress and why can it be harmful?

In short, thermal stress refers to mechanical strain arising from local and/or temporal changes in temperature. When exposed to heat, metal expands. Because the temperature profile throughout the PFHE is uneven – hot streams become cold, cold ones become hot – expansion is uneven as well.

This causes an effect that is common in bi-metals. The physical cause is different, but geometrically they behave likewise: one side expands further than the other, which results in bending or warping.

Of course, a PFHE will not bend like a banana because of temperature differences or rapid temperature changes. Linde's PFHEs are built with a higher stress resistance than is needed under normal operating conditions. Improper operation does not damage the heat exchanger immediately. But continuous excessive stress leads to fatigue and to changes in the material's microstructure. Grain boundaries within the aluminium alloy lose alignment and the crystal lattice becomes weaker. Ultimately, leakages occur, resulting in high costs for repair and an unplanned interruption in operations.

How to extend a heat exchanger's lifetime

To fully understand the connection between stress and how this shortens a product's lifetime requires taking a short excursion into materials science. As German railway engineer August Wöhler discovered in the second half of the 19th century, cyclic stress is a bigger threat to a material's stability than single stress episodes, even those producing a higher peak stress. Wöhler created a model to put the stress in relation to the number of cycles a specimen can run through before damage occurs because of fatigue. Today, this is known as the Wöhler curve. It shows that even small differences in stress levels can have a massive impact on the material's lifetime.

So, reducing thermal stress changes is the key to guaranteeing a long lifetime of a heat exchanger. Unfortunately, units will typically experience temperature swings as part of normal operations. Since every plant and its PFHEs are custom-made, they face individual thermal stress loads. An individual analysis is needed to calculate thermal stress, and this will be used to estimate the lifetime of a single PFHE.[4]

Step forward in understanding plant dynamics

This is exactly what Linde's interdisciplinary team of specialists does. They have been investigating thermal stress and its effect on plant components for more than a decade. Based on this experience the Linde team has been able to develop simulation tools that allow insights into temperature distributions and the resulting thermal stress.[4] These tools provide operators with both qualitative and quantitative information on unstable operation situations, such as plant start-up, trip scenarios and transitions between various modes of operation.

One example of a simulation tool is a dynamic thermo-hydraulic heat exchanger modelling framework. It is based on Linde Engineering's in-house process simulator called Optisim®.[5] A further modelling system has been patented: the dynamic 3D finite-elements analysis modelling system LIBAS® (Linde Brazed Plate-fin Analysis of Stress) for PFHEs is based on theoretical investigations and practical experiments.[6]

Both are combined und utilised in the Hazard Analysis (HAZAN), for lifetime estimation studies and for root-cause studies of PFHE failures. During the plant-engineering phase, analysis is carried out with these tools. The results help the design engineers to optimise their concept.[7] Thanks to detailed studies performed in advance, plant design has become more precise and sustainable. Additionally, the use of dynamic models has been a big step forward in understanding the dynamics of plant equipment.

Life prolonging measures for heat exchangers

The expertise gained through simulation and analysis helps Linde's engineers to prolong the lifetime of heat exchangers already in operation as well. The basis for their work is the lifetime analysis of running heat exchangers. As many of Linde's PFHEs were installed more than 20, sometimes even 30 years ago, the focus at that time was not on measuring all possible data streams. Therefore, reliable data is rarely available from this period. In those cases, specialists of structural mechanics, process engineering and other departments contact the plant operators to define typical scenarios that heat exchangers face during operation. After performing thermo-hydraulic simulations and finite-element methods (FEM) simulations, they compile an evaluation of stresses. Based on this, they suggest measures to improve (e.g. operation procedures) and by doing so prolong the lifetime of a PFHE.

For plant operators, this evaluation of stress variables can be extremely useful – and cost-saving. In some cases, a PFHE failure forces operators to shut down the entire plant. Even in mid-scale plants, loss of profits can rise to millions of euros per day, not including the costs of repair. If the damaged PFHE has been installed in a cold box, repair becomes even more complex due to the limited accessibility of the box due to their compactness.

As an experienced manufacturer of PFHEs and a pioneer in customised plant design, Linde Engineering offers a unique combination of manufacturing and service. Customers and plant operators from all over the world have benefitted from Linde's lifetime estimation. While detailed analysis is executed within Linde plants only, lifetime screening is possible for all kinds of PFHEs. **LNG**

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