Finding leaks in Main Cryogenic Heat Exchangers without shutdown

Liquefaction is the most fundamental step in the LNG production process. To achieve this there are several process solutions available, but the most commonly applied make use of Main Cryogenic Heat Exchangers. When internal leaks occur in these exchangers production losses can be as high as 5 percent of the total LNG output of a liquefaction train. DCI Meettechniek B.V. has a method which allows individual compartments in such an exchanger to be inspected for leaks while the LNG train remains in normal operation.

The MCHEs is where the liquefaction process typically takes place and where the process gas is transformed into the end-product LNG under the influence of high pressures and extremely low temperatures.
The MCHEs consist of vertical heat exchangers dozens of metres tall in which, depending on the design, a number of separate pipe bundles have been constructed (Figure 1).
These bundles (compartments) are cooled below -160 ºC by the refrigerant which flows through the shell side of the MCHE. This refrigerant consists of light hydrocarbons and is also referred to as Mixed Refrigerant, or MR.
The processed gas flows in a number of these compartments and will condense to its liquid form under the influence of the high pressure and the low temperatures.
The total length of the heat exchanger tubes in these MCHEs can be many kilometres. Considering the large total tube surface combined with extreme pressures and temperatures, it is not surprising that leaks occur in these heat exchanger tubes.
The process gas in the tubes has an over-pressure in relation to the shell, so that the process gas will leak into the shell side of the MCHE.
This results in a certain amount of production loss but, in addition, may also lead to a loss of efficiency due to pollution of the MR with process gas.

In addition to the financial losses which this implies, an unnecessary burden on the environment also occurs.
The MR recirculates in the system, therefore if a leak continues to exist, the gas will accumulate until the quality of the MR has deteriorated to such an extent that the gas present will have to be vented to the flare or (part of) the MR will have to be replaced.
The occurrence of leaks in these systems is not unusual in itself. Possible financial losses are taken into account up to a certain extent and are usually reckoned with in the design of the plant.
For this reason, the MCHEs are often slightly over-dimensioned to cope with any loss of return. However, unusually large leaks or leak sizes which are disproportionate to the period during which the MCHE is in operation are not anticipated.
Leaks may occur which are greater than 5 percent of the total LNG production of a processing

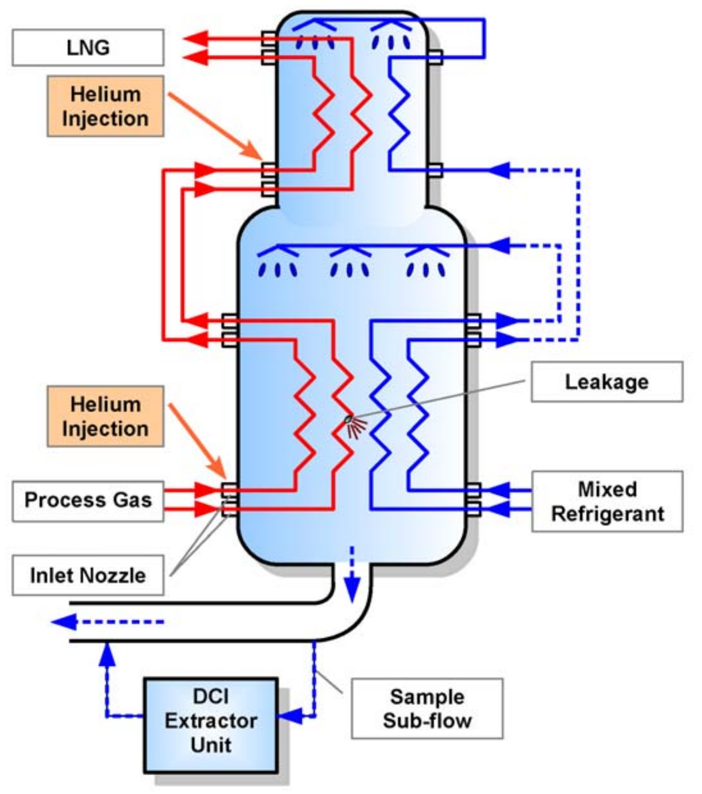

Figure 1: Schematic representation of a MCHE

train. The financial losses suffered because of such leaks may be as high as $100,000 per day. When these losses become unacceptable, it may be necessary to take action in the form of repairs.
The decision to proceed with repairs and the associated shutdown is not one taken lightly. In addition to the costs of the work, the lost revenues because of loss of production may amount to many hundred thousands of dollars per day.
In reality there is often just a suspicion of a leak, which makes the decision even more difficult on whether or not to shut down, since it is possible the leak does not exist.
DCI Meettechniek, the Dutch technical services provider to the process industry, has an inspection procedure that has been implemented on various LNG liquefaction plants. Its system allows individual compartments in a MCHE to be inspected for leaks while the LNG train remains in normal operation.
Therefore the production of LNG is not interfered with at all by this inspection. If potential leaks are to be traced with the usual methods, it is necessary to decommission the LNG train and to make the tube sheets of all individual compartments accessible.
When all individual compartments are to be tested while out of operation, this not only takes much longer, but unnecessary interventions may be performed with all the associated consequences.
If DCI tests the individual compartments for leaks while the plant is in operation, specific action can be taken on the compartments which have been found to be leaking. This may substantially reduce the duration of a shutdown, which in turn results in significantly lower levels of lost production.
In the cases where DCI implemented its system at LNG plants, several MCHEs were tested and multiple leaks were demonstrated.
In one instance, the first measurement was followed by a second measurement during which, in addition to the process gas compartments, the MR compartments were also inspected for leaks.

Onstream extraction measurement

One of the methods used by DCI is the "extraction method" and is used to show up internal leaks in heat exchangers during operation.
Leaks are detected by means of helium as a tracer gas. Most leaks exist due to a pressure gradient, where a leak flow exists from the high-pressure side to the low-pressure side.
The helium is therefore injected into the high pressure side of the heat exchanger to be tested. If there is a leak, the helium will flow towards the low-pressure side together with the high-pressure matrix.

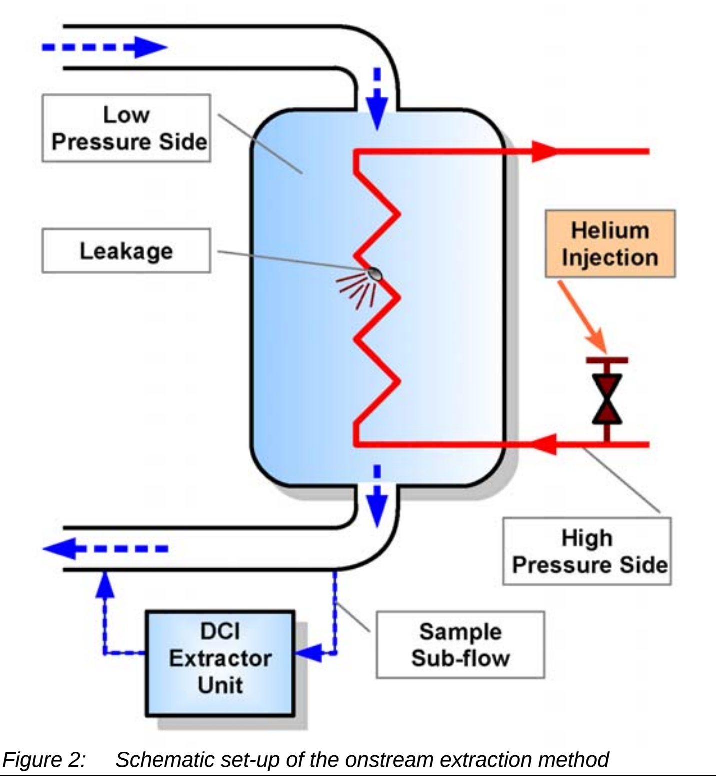

Figure 2: Schematic set-up of the onstream extraction method

The concentration of helium in the outgoing line of the low-pressure side is monitored continuously and in real-time by means of the Extractor Unit developed by DCI.
The Extractor Unit is capable of extracting helium from almost any matrix, at a very wide range of pressures and temperatures. For the purpose of the measurement a small sub-flow (by-pass) is created from the outgoing flow on the low-pressure side (see Figure 2).
The unit extracts any helium present from the sub-flow and submits it then for analysis to a mass spectrometer which is set exclusively for the detection of helium.
Because of natural influences a certain concentration of helium is often already present in the matrices to be analysed (air, for example, contains 5ppm of helium).
Therefore the level of and the variations in the background signal are analysed for a certain period of time

prior to the injection of the helium.
Next a pre-calculated quantity of helium is injected into the matrix of the high-pressure side within a certain period of time. If a leak is present, part of the helium will flow with the high-pressure matrix through the leak into the low-pressure side.
The increased helium concentration will then be demonstrated by means of the Extractor Unit and the mass spectrometer. The results are shown in real-time in a diagram in which the leak is visible as a clearly discernible peak.
The choice of helium as a tracer gas is based on a number of favourable properties of this gas. First of all, helium is a gas which is chemically completely inert. Therefore it is possible to inject helium safely into almost any matrix without having any effect on the products and chemicals present.
Besides, helium is the only stable molecule with atomic mass 4. This allows it to be distinguished perfectly from other molecules and to be detected very specifically by a mass spectrometer.

Onstream measurements on MCHEs

For the inspection of MCHEs, a modified version of the onstream extraction method was used. After intensive consultations with the clients, DCI has worked out a theoretical model and used this as a basis for developing a method for performing these onstream measurements.
In the case of MCHEs, the low-pressure side is the shell side through which the MR flows. The helium concentration in the MR is analysed continuously by looking at a sub-flow from the outgoing line on the bottom of the MCHE.
Once there is a clear picture of the background, the helium injection is performed into the process gas compartment that is to be inspected. A pre-calculated amount of helium is injected by means of special equipment under a pressure which is about 10 percent higher than the process gas pressure present.
The injection lasts for some tens of seconds and takes place into the inlet nozzle of the compartment to be examined (see Figure 1). Here the helium mixes with the process gas and is thus carried along with the process gas flow through all the heat exchanger tubes of the compartment.
The helium-enriched process gas will flow through the system as a concentration band. The width of this band depends on the duration of the injection.
The helium concentration depends on the injection rate and the process gas flow in the compartment. When this helium-enriched process gas flows through a leaking heat exchanger tube, the leakage will cause this gas mixture to flow to the shell side of the MCHE.
In this way the helium is absorbed in the MR flow and is carried along to the outgoing pipe at the bottom side of MCHE. Here the increased helium concentration is observed by means of the DCI Extractor Unit and the leakage in the MCHE can be determined on the basis of these measured values.
When the helium concentration in the MR system has returned to the background level, the next compartment can be tested for the presence of leaks.
In this way the presence of leaks can be determined in every single compartment while the plant is in operation. The LNG circuits in MCHEs usually consist of two compartments connected in series. These are referred to as the so-called warm bundle (bottom compartment) and the cold bundle (top compartment, see Figure 1).
These two compartments can be inspected independently from one another for the presence of leaks by injecting helium in the inlet nozzle of either the warm bundle or the cold bundle.

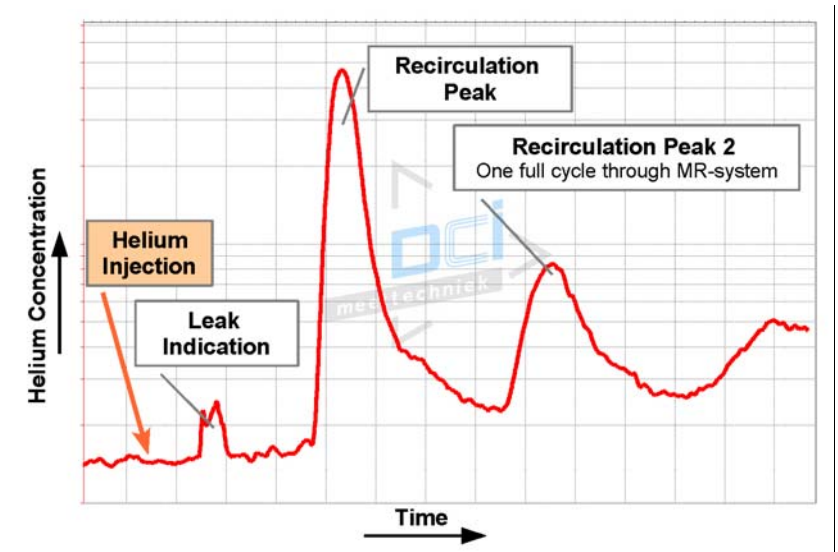

Figure 3: Example of a result diagram concerning a MR compartment inspection with leak indication and recirculation

Quantifying leaks

In addition to the helium injections into the process gas compartments to be inspected, a so-called *Reference Injection* is performed.
A relatively small amount of helium is injected directly into the shell of the MCHE to simulate a leak. This reference measurement serves a number of purposes.
Firstly, it serves to verify the correct functioning of the measuring system. If the DCI Extractor Unit functions correctly and the sampling from the outgoing MR pipe has been realised correctly, an increase of the helium concentration must be observed as a result of the Reference Injection.
The Reference Injection is also used to determine the retention time of the measuring system. When helium-enriched process gas flows through a leak in the shell side, it will take the helium some tens of seconds to reach the measuring equipment.
As estimations concerning the location of the leaks are sometimes made on the basis of reaction times of leak indications, it is necessary to know the retention time of the measuring system.
However, the principal information which the Reference Injection provides is the sensitivity of the measurement. The sensitivity can be determined by means of the size of the indication and the injected volume of helium.
The most interesting aspect of this information is that it enables DCI approximately to quantify the leaks found, if any.
In this way the scope of the size of any leaks becomes clearer and it is possible to set priorities for repairs.
It is also possible in this way to compare successive measurements of the same compartment with one another, so that information is obtained about the evolution of leaks.

Figure 4: Extraction measurement set-up

The sensitivity of the measurement is affected by the physical and dimensional properties of a leak and the locally prevailing pressures, temperatures and flows.
Therefore, it is difficult to quantify leaks on the basis of the size and form of the observed leak indications.
However, based on various research projects and collected data, DCI has developed a calculation model which is used for determining a reliable indicative value for the size of the observed leaks.

Additional information

In addition to finding leaks and indications of their size, it is also possible to distil additional information from the measuring results.
One possibility is to determine the flows in the system, such as the flow of the process gas in the MCHE. It is also possible to determine the circulation times of recirculating systems, such as the recirculation time of the MR (Figure 3).
At the request of one DCI's LNG-producing clients, the company performed measurements on MR compartments.
Initially the MR flows through the MCHE on the tube side, after which it returns via some detours to the shell of the MCHE, where it is flashed and performs its refrigerating function.
This means, however, the total amount of the injected helium eventually ends up in the shell, whereas the amount of helium which enters into the shell side via the leak may be less than a one hundredth part of the total.
The background increase as a result of this large amount of helium can therefore be higher by a factor 100 than a leak indication, if any, and therefore the risk exists that the leak indication fades into the background and is no longer discernible.
This makes the realisation of a leak tightness test on these compartments substantially more complex than a measurement on a process gas compartment.
However, it is not impossible, since part of the helium will initially flow through the potential leak, towards the shell. Only after some time will the complete volume of the injected helium find its way into the shell via the long route, which results in a large indication and in an increase of the background concentration of helium.
The time in between is sufficiently long so that the leak indication and the so-called recirculation peak are well separated (Figure 3).

Since the MR system is in principal a closed system, the increased helium concentration can remain present for a long time.
For this reason it may take some time before the background signal is sufficiently low and stable again to perform a next measurement. In this way various leaks have been demonstrated in the MR compartments of several MCHEs.

Flexibility, possibilities and benefits

The great strength of the onstream extraction method resides mainly in its flexibility. The method can be used to demonstrate leaks between all separated systems where a pressure gradient exists.
Helium injections into the high-pressure side are possible without any problem up to system pressures of about 10MPa (100 bar). Injections at higher pressures are also possible in principle, however, the practical implementation has to be examined. The temperatures present at the high-pressure side are hardly of any relevance.
The Extractor Unit is capable of extracting helium from gases as well as from liquids, therefore it is possible to offer both phases as a sample matrix from the low-pressure side.
The sample flow can be offered in a temperature range from about -20 to 100 ºC and at pressures up to a maximum of 1MPa (10 bar).
If the temperature and/or the pressure of the low-pressure side exceeds these limits, it is possible to bring the pressure and the temperature of the sample flow within the limits specified before it reaches the Extractor Unit.
Thus, it is possible even under these circumstances to determine the helium concentration of the sample matrix.
This makes this method widely applicable in a wide range of matrices provided that the sample matrix does not solidify or crystallise at these adjusted pressures and temperatures.
Measurements can be performed on liquids as well as gases or mixtures of these and in very large pressure and temperature ranges, as long as a controlled sample flow can be realised through the Extractor Unit.
Because of this flexibility, the method is used in widely varying systems in, for example, the food industry and the petrochemical industry, where leaking heat exchangers are identified in heat exchanger trains of Hydrotreater units (desulphurization).
Within the LNG production process an application has now been found in the form of measurements on MCHEs, but other applications are possible as well.
Onstream measurements can be performed on nearly all heat exchangers, an example being thermal oil leaks in Waste Heat Recovery Units.
It may also offer benefits for the LNG producer and for the MCHE supplier to carry out measurements during the "Performance Tests" which precede the hand-over of MCHEs.
The principal benefit in all these measurements is obviously the possibility of obtaining detailed information about the presence of leaks while the plant can continue normal operation.
When measurements are performed on MCHEs using this method, leaks can be demonstrated per compartment and an indication can be provided concerning the size and the evolution of the leaks.
This data will give the LNG producer a clear view of the extent of the leaks and thus of the necessity and the duration of a shutdown.
With this information the LNG producer has an instrument with which a motivated decision can be made on whether a shutdown and the associated costs are justified.

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disclaimer
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