Helium Leak Detection in the Supply Chain for Liquefied Natural Gas (LNG)

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Abstract. The energy demand of industrialised nations leads to an increasing consumption of natural gas. Natural gas is a natural product occurring in underground deposits. In terms of composition, it is more than 90 percent methane (CH_4). The most important gas resources are located in the Russian Federation, Arabia, the USA, and Algeria. Gas consumption in highly industrialised nations requires long-distance pipeline-bound transport. An alternative to pipeline transport is gas supply in liquid form via sea transport.

Natural gas retains its gaseous form down to a temperature of minus 162°C. Below this point it becomes a liquid and occupies a far smaller volume thus allowing for economic transport solutions. Main players in LNG export are Algeria, Indonesia, Malaysia, and Qatar. The technology is also emerging in Norway, Russia, and Australia.

Liquefaction requires modern gas production equipment and mature industrial cooling technology. The article describes the application of helium leak detection technologies to large industrial devices related to LNG technology. Starting from basic guidelines for good practice of helium Leak Detection we shall develop dedicated methods for demanding samples. Leak testing of plate-fin heat exchangers, coil-wound heat exchangers and fully assembled cold boxes will be discussed.

Introduction

The liquefaction plant represents ca. 50% of the investment cost of the entire LNG value chain [1]. For that reason there is a strong pressure from the LNG industry to reduce cost and construction times

Selection of Heat Exchangers

For the cryogenic process section plate-fin heat exchangers as well as spiral-wound heat exchangers can be applied. Plate-fin heat exchangers are well-suited for applications in LNG baseload plants. However, they are sensitive to large and rapid temperature changes and therefore regarded as less robust in comparison to spiral-wound heat exchangers. Large LNG plants require numerous plate-fin heat exchangers in parallel. Part of the cost advantage of the individual exchangers is reduced by the complexity of the piping needed to connect numerous plate-fin heat exchangers. Typical plate-fin heat exchangers for LNG plants are shown in Figure 1.

Figure 1: Typical plate-fin heat exchangers for LNG plants

Figure 2: Typical structure of the piping and equipment inside a cold box.

Figure 3: Typical spiral-wound heat exchanger for LNG plants

Spiral-wound heat exchangers [2] have been used in the cryogenic industry since the early days. When Carl von Linde liquefied air for the first time on an industrial scale in Munich in May 1895 he used two concentric tubes which were wound to form a coil [3]. A typical spiral-wound heat exchanger for LNG plants is shown in Figure 3.

Each heat exchanger type has specific merits at the proper place. Plate-fin heat exchangers are a good choice for the pre-cooling section of an LNG baseload plant. Spiral-wound heat exchangers are used for the liquefaction and for the sub-cooling section.

In some LNG plants the cryogenic heat exchangers have individual insulation. That is true of both the plate-fin and the spiral-wound heat exchangers. The insulation mainly consists of polyurethane foam or of foam glass [4]. The cold box concept represents an alternative insulation method. A so-called cold box is a box of normal carbon steel plates enclosing the cryogenic equipment and piping. The void space is filled with the insulation material perlite, a powdery mineral. Figure 2 shows the typical structure of the interior of a cold box.

Manufacturing of Heat Exchangers

The manufacturing of plate-fin heat exchangers is described elsewhere [5]. Briefly, raw materials for separator plates, fins, and side-bars are measured, cut and stamped. All parts are washed to remove oil, dried and stacked. They are brazed in a vacuum furnace under precise temperature control at approximately 600°C. Thereafter, headers and nozzles are welded to the block to complete the heat exchanger.

The manufacturing procedure of the spiral-wound heat exchanger starts with the core cylinder, or mandrel, which can be rotated on a winding bench by means of two race rings in horizontal position. Support arms and liquid distribution trails are connected to what will be the upper side of the heat exchanger when it is erected to its final vertical position. Tube sheets are brought into their position at both ends of the heat exchanger. Spacer bars will keep the designed distance between the mandrel and the first layer of the tubes. Now the winding of the inner layers of the tubes can begin. Therefore, each layer is inserted into its tube sheet at one side, wound onto the mandrel and then inserted into the corresponding tube sheet at the other side. When the winding of the first layer is performed from left to right, the next layer is performed from right to left and so on. Proper distance between the individual layers is kept by spacer bars. To avoid a by-pass at the shell side the bundle is wrapped into a shroud. After the tubes have been welded to the tube sheets, bonnets are welded to the tube sheets. Parallel to the manufacturing of the bundle the lower and the upper part of the shell are being fabricated. During assembly the completed bundle is inserted into the lower part of the shell and the shroud is connected to the shell. The upper part is added, and the closing seams and nozzles are welded to the shell.

Figure 4 shows the location of plate-fin and spiral-wound heat exchangers in a cold box. The shown cold box is ca. 60 m high. The cold box offers a number of advantages insulating low-temperature processes:

- The cryogenic process equipment and piping are all welded together and laid pout as compactly as possible. This results in minimum material and thermal losses and maximum safety.
- The cold box can be constructed mechanically in workshops under optimised conditions.
- The cold box provides external mechanical protection during transportation and in the plant itself.
- The cold box allows for an “all welded” principle which is considered as the safest installation mode.
- The cold box enables detection of possible leakages both in production (e. g. before perlite filling) and during operation.
- Fire resistance requirements can be met with a cold box in an efficient way.

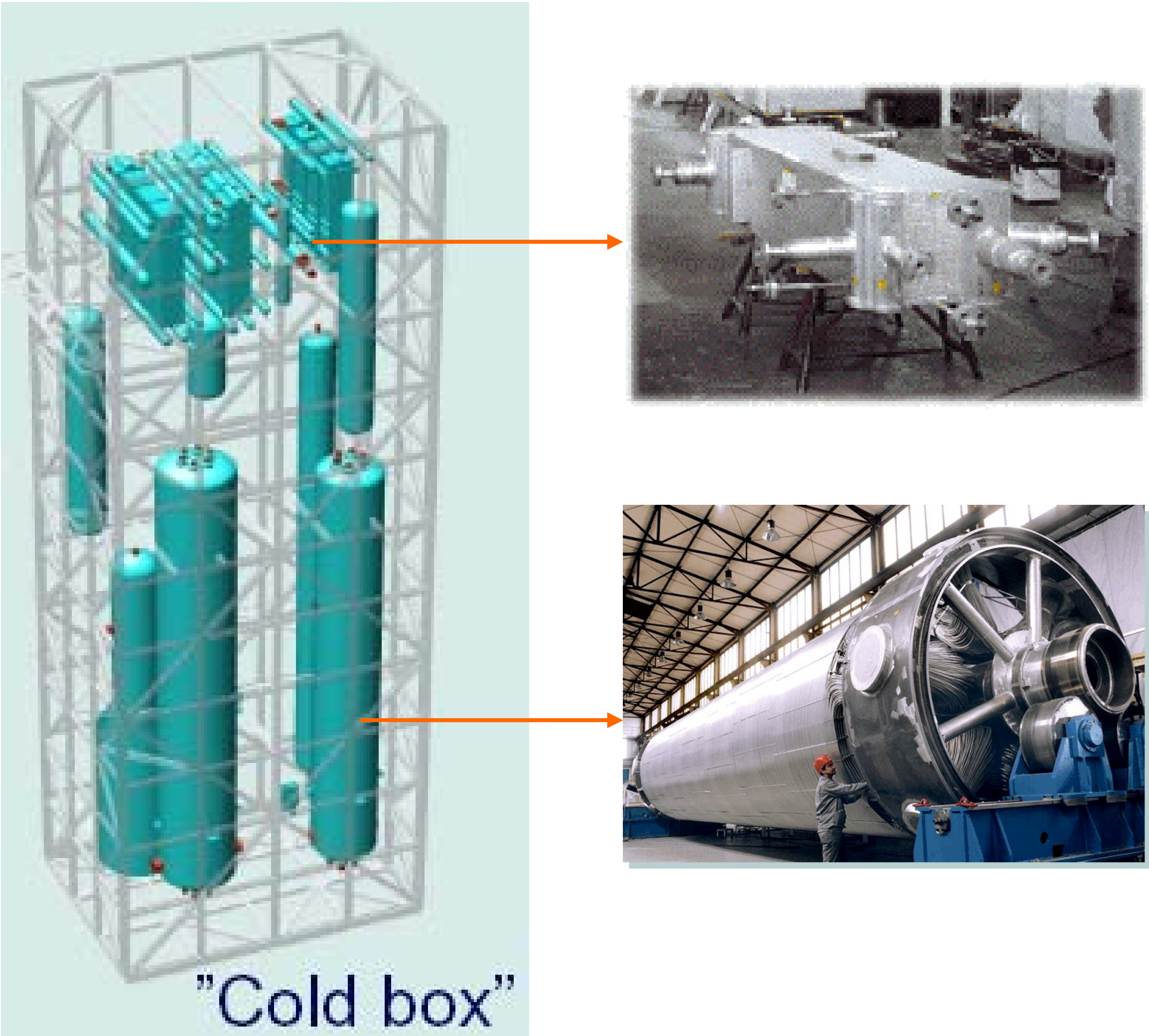

Figure 4: Location of plate-fin and spiral-wound heat exchangers in a cold box

Helium Leak Detection of Heat Exchangers

LNG plants are transferring various liquids, gases and mixed phases through the processing plant. These fluids can range from water to flammable methane to toxic hydrogen sulphide. A certain amount of natural gas leaking from a system has been, in the past, acceptable and in some cases unavoidable. Natural gas has been flared from remote oil and gas production facilities. However, as we become more aware of the need to protect environment and personnel helium leak testing is applied to ascertain and maintain the integrity of the system. This applies both for processing plants in operation and subsystems during production.

Helium leak testing uses helium as a tracer gas either undiluted or in a mixture with nitrogen. Helium is used as a test gas for the following reasons:

- Low background signal (5 ppm natural abundance)
- Chemically inert
- Safe
- Comparatively cheap
- High selectivity

The test gas mixture is used to pressurise vessels and process systems to their operating pressure which simulates live conditions. In some cases a pressure burst test is performed prior to the helium leakage test for safety reasons. The test gas that escapes from a flange, fitting, valve, or leaky welding is transferred to a helium sensitive mass spectrometer. This device ionises the gas and measures the amount of helium present, which is used to determine the amount of gas emanating from the leak.

The method offers a very high sensitivity and a wide dynamic range [6]. It can easily be calibrated with commercially available test leaks. With these test leaks both quantification and measurement of response time can be determined.

Helium leak test is applied to numerous applications including leakage test of

- vacuum systems (e. g. for semiconductor production)
- automotive components (compressors, condensers, airbag components)
- medical components (pacemakers)
- and many others

Plate fin heat exchangers are tested before shipment and during various steps during production. The product is subjected to X-ray, helium leakage, flow and pressure testing. The helium leak test of a plate fin heat exchanger is performed as hard vacuum test. In a global test the various sections are pressurised consecutively and tested against each other. During this operation one section is pressurised with test gas and the other section is evacuated and connected to the helium leak tester. This procedure yields a quantitative global information about the leakage rate. In case of a detected leak the respective section can be de-pressurised and potential leaking areas can be sprayed with helium to allow for leakage location.

In this paper we shall focus on the test of spiral-wound heat exchangers. In a first step an acceptance test is performed on the incoming coils. The tubes used for production of spiral-wound heat exchanger vary in external diameter from 10 to 25 mm. The length of the tubes can reach up to 3,000 meters. The coils are pressurised and the pressure in the coils is monitored. In case of mechanical disintegration the leakage is detected by a massive, instantaneous pressure decay. The leakage is of macroscopic size and can easily be detected visually.

In a second step the coils are helium leak tested. The pressurised coils are placed in a vacuum test chamber that is connected to the helium mass spectrometer. The schematic set-up is shown in **Figure 5** [7].

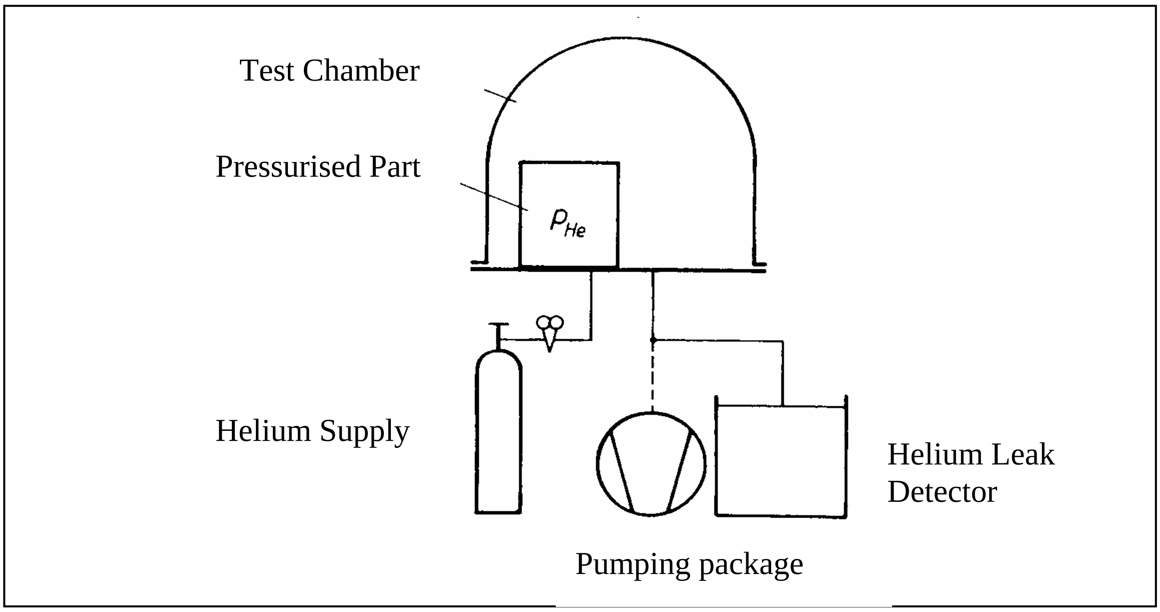

Figure 5: Schematic set-up of a Global Hard Vacuum Test

The equipment consists of a customised chamber (volume ca. 5 m^3), a parallel pumping group (Adixen 200 m^3/h roughing pump with 350 m^3/h roots blower) and a commercially available helium leak detector (adixen ASM142). The main advantages of the global vacuum test are high throughput and high sensitivity. The sensitivity of the test is mainly determined by the ratio of pumping speeds of the parallel pumping package and the helium leak detector. The throughput is determined by handling time and by the pumping speed of the parallel pumping package.

After passing the acceptance test the coils are processed as described above. The heating area of a large spiral-wound heat exchanger can reach up to 25,000 square meters. In order to reach this large area more than 10,000 individual tubes must be welded. The length of each tube can reach up to 350 m.

Individual layers of the spiral-wound heat exchangers can be measured during production. The schematic set-up for test of individual tubes during production is shown in **Figure 6**.

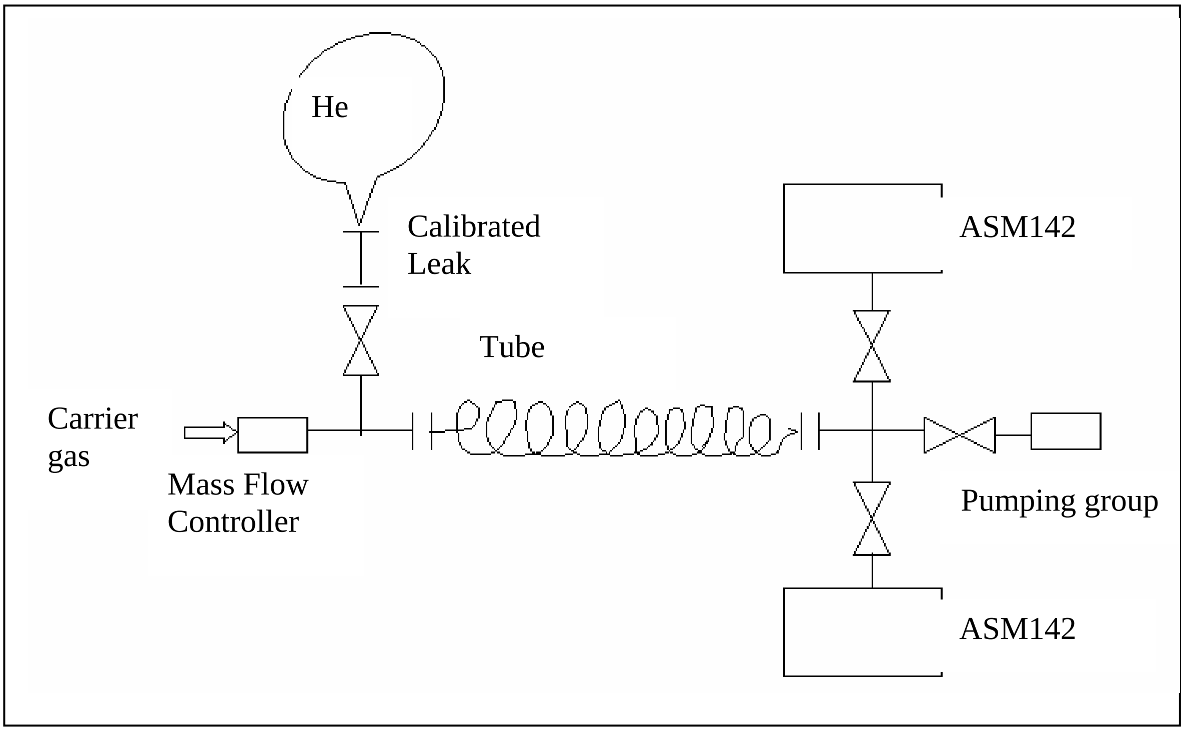

Figure 6: Schematic set-up of carrier gas test (“bullet test”)

Carrier gas is used to perform the test at laminar flow regime. Pump down of the tubes to the ultimate pressure of the leak detector would result in molecular flow regime. In this flow regime the conductance of the tube is much smaller than in laminar flow regime which results in extended measuring times [8]. If we consider a typical tube with a length of up to 350 m the theoretical response time would be more than four days in molecular flow. In laminar flow regime a test can be performed in ca. 3 minutes.

In practice a gas distribution system is connected to a group of tubes. The carrier gas flow is precisely regulated with a mass flow controller. A collector system is connected on the other side of the tubes. The gas flow is pumped by an auxiliary pumping group (Adixen rotary vane pump 60 m^3/h plus Pfeiffer roots pump 250 m^3/h). In parallel a helium leak detector (adixen ASM142) is connected. The maximum response time can precisely be measured with the calibrated leak at the inlet side. After calibrating the system helium is sprayed over the length of the tubes. Within few minutes a result is obtained.

After assembly of the various heat exchangers in the cold box a final leak test can be performed prior to perlite filling. The schematic set-up for integral test of the cold box is shown in **Figure 7**.

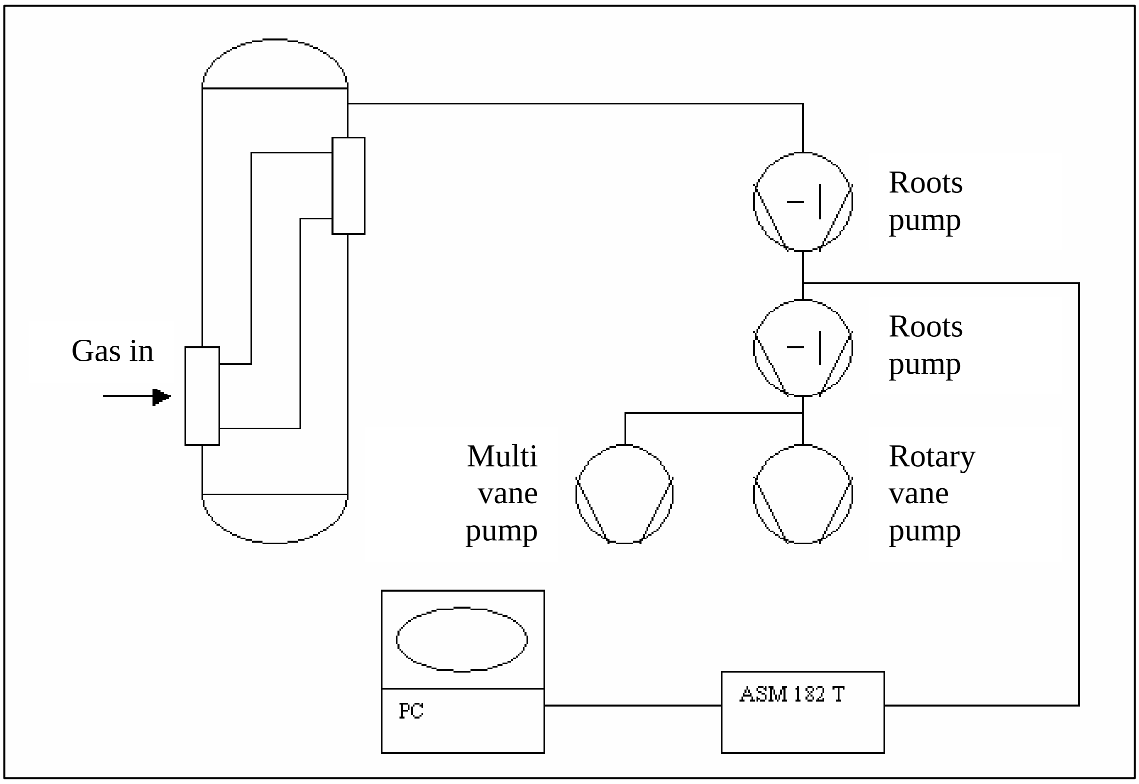

Figure 7: Schematic set-up for integral test of the cold box.

The exterior casing of the cold box has a volume of ca. 200 m^3. Individual sections of the casing can be evacuated. After pressurisation of the heat exchangers an integral leak test can be performed. The design of the pumping group allows for high flexibility in leak test equipment used and on various test ports optimum test conditions can be achieved regarding helium background signal and pressure limits of various leak detector models [9].

A system that has been helium leak tested is left virtually inert and dry [10]. Instrumentation can be calibrated and system equipment and operations can be tested prior to the introduction of the process gas. This applies as well for surface-bound liquefaction equipment as well as for LNG carriers [11].

Conclusion

Helium leakage testing is a valuable tool during production of plate-fin heat exchangers, spiral-wound heat exchangers and fully assembled cold boxes for the LNG industry.

Consequent application of the method over the whole production process significantly reduces time needed for testing. Helium leak testing will provide manufacturers with the comfort that production personnel is capable of doing the job and that time-critical components without any back-up can be delivered in time.

Evidence is proofed to operators that their systems have been tested under live conditions and that hook-up will be achieved on schedule.

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