White paper

Ammonia permeation in semi-welded plate heat exchangers

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Executive summary

Semi-welded plate heat exchangers are the perfect choice for a variety of refrigeration applications. Operators sometimes notice a weak smell of ammonia and worry that this may be due to a leak. In this paper we show that in most cases this smell is due to a natural process called permeation where a small amount of ammonia passes through the solid gaskets surrounding the portholes.

A human can smell ammonia at a level of about 5 ppm. The recommendation within the refrigeration industry is to always install ammonia detectors in the plant room with a pre-alarm set to a level of 50-300 ppm and a leakage alarm at 500-1000 ppm. In a normal system, the amount of ammonia that permeates into the surrounding air is far below recommended alarm levels and presents no risk to an operator's health or the operation of the equipment.

Comparing different heat exchanger models by measuring ammonia concentrations at the top of the plate pack is pointless because of differences in plate designs. The different geometries make direct comparisons impossible.

Such comparisons are also meaningless since the only factors that have any real impact on the permeation rate (under identical operating conditions) is the width of the gaskets and which material they are made of. The only way to minimize permeation is to be careful when selecting gaskets since different rubber materials have very different permeabilities.

Contact your local Alfa Laval representative if you have any questions or would like to discuss how to choose the best heat exchangers and gaskets for your specific application.

1. Introduction

Semi-welded heat exchangers are the perfect choice for a wide range of refrigeration systems and offer benefits such as excellent heat transfer efficiency, easy capacity expansion and high resistance to fatigue.

Ammonia is a common refrigerant and is used in many applications. In some cases operators notice a weak smell when they are very close to the heat exchanger and worry that gaskets may be leaking.

In this white paper we will demonstrate that the smell is due to a natural process called permeation and not a faulty gasket. We will also demonstrate that the amount of ammonia released to the surroundings is very low and that it does not cause any harm.

2. What is permeation?

Permeation is when a liquid, gas or vapour passes through a solid material. This is a natural process where molecules penetrate through the material, and should not be confused with leakage due to cracks, openings or cavities.

The force behind permeation is a difference in concentrations. It is a natural law that all substances strive to disperse evenly and level out differences in concentrations. Molecules in a region with high concentration will move towards regions of low concentration until the difference is levelled out. A more general term for this is diffusion, and an everyday example is when you put milk in your coffee. The milk eventually mixes completely with the coffee thanks to diffusion.

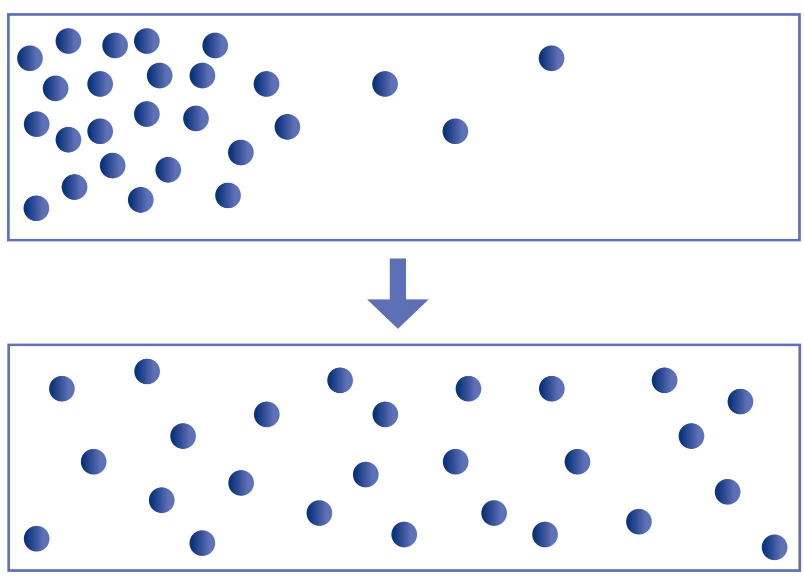


Figure 1 Any concentration differences caused by adding a substance in a closed vessel will eventually even out. The atoms or molecules will move randomly until the concentration is homogenous. An everyday example is when you pour milk in coffee.

If there is a solid barrier between areas with different concentrations, the diffusion process will still occur, but at a slower rate. This is called permeation.

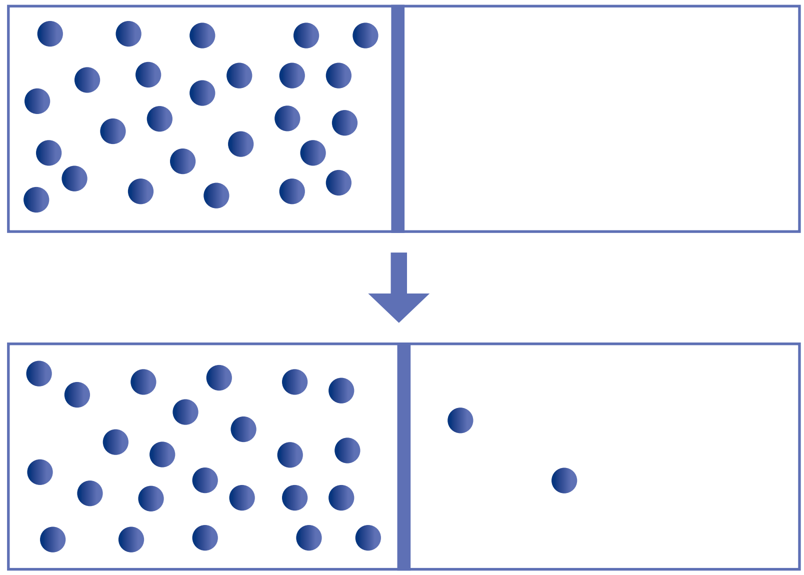


Figure 2 Permeation is diffusion through a solid barrier.

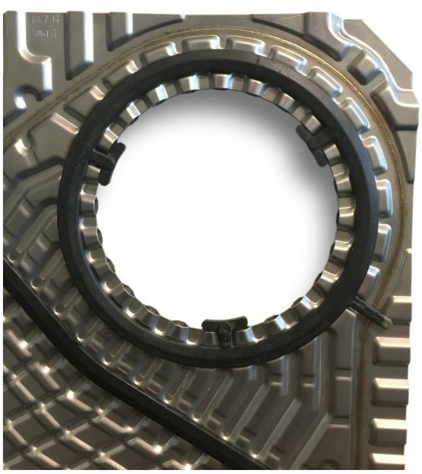


Figure 3 Ammonia will permeate through the gasket rings in a semi-welded heat exchanger. Permeation is minimized by selecting the optimum polymer for the gasket, taking permeability, operating temperature and pressure into consideration.

Some parameters that affect permeation rate are concentration difference, temperature and the permeability of the solid material. Different materials have different permeability; for example are polymers much more permeable than metals.

Among polymer-based materials, rubbers generally have higher permeability than plastics, but there are large differences depending on polymer type, structure, morphology, amount of fillers, types of fillers, etc.

In a semi-welded plate heat exchanger (SWPHE) where one channel is filled with ammonia, there is a high concentration of ammonia on the inside and a negligible concentration on the outside. This will inevitably cause permeation to some degree. The permeation through metal is zero in all practical senses. But the ring gasket, made of a polymer-based material, will inevitably allow some ammonia to permeate.

The concentration of ammonia inside the heat exchanger will remain at 100% and on the outside it will be approximately 0%. The temperature will also stay constant during operation, resulting in a constant permeation rate.

Inside the gasket material, ammonia molecules will move towards the outside. The ammonia concentration is highest at the inside surface of the gasket and decreases gradually towards the outside. This concentration gradient is the driving force for permeation inside the gasket.

2.1 Diffusion in the surrounding air

After permeating the gasket, ammonia molecules will enter the air surrounding the SWPHE. The concentration of ammonia will be highest close to the gasket and decrease by the distance from the heat exchanger.

This concentration difference drives molecules away from the SWPHE and into the room due to diffusion. But this time it occurs in air and not in a solid material.

The distribution of ammonia molecules in the room is aided by air movements. Air circulation is lower closest to the gasket due to the honeycomb pattern, which creates a partly confined space. The result is that the ammonia concentration is higher at the edge of the heat exchanger.

The ammonia concentration in the room drops rapidly by the distance to the SWPHE and is negligible after a few centimetres.

3. How much ammonia permeates?

Alfa Laval has developed a method for calculating the amount of ammonia that can be expected to escape from a semi-welded heat exchanger under normal operating conditions.

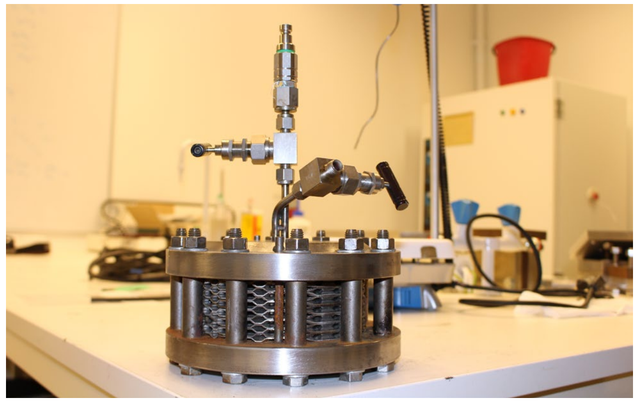
We have built a test rig where we can measure permeation for a set number of gasket rings, and then we can use the measured data to calculate the permeation rates for different heat exchanger configurations.

3.1 Empirical tests

The standard procedure we use for measuring permeation is as follows:

1. Six cut-outs with portholes from M10-BW plates are stacked together as if they were mounted in a heat exchanger. Ring gaskets of the material type being examined are placed between the plate cut-outs.

Figure 4 Alfa Laval has developed a method for testing the permeability of heat exchanger gaskets. The gaskets are placed in a test rig and the rig is filled with ammonia under pressure. By measuring the weight loss over time, the annual permeation rate can be calculated.



2. The plate stack is placed in a test rig and compressed to apply the correct pressure on the gaskets.
3. The stack with test specimens is filled with ammonia. At room temperature the ammonia pressure is 8.5 bar.
4. The weight of the rig is measured over time to monitor the weight loss due to the permeation of ammonia.

This test gives us the ammonia loss due to permeation through six gaskets over a certain time frame. By repeating the test with different gasket types we can compile a table presenting ammonia loss due to permeation in grams per year and gasket for different gasket types, see table 1.

Table 1 Permeation in g/year per welded plate cassette for different types of gaskets.

Permeation through gaskets used with ammonia and standard mineral oil in refrigeration applications Plate type: M10-BW		
Ring gasket quality	**Permeation in g/year per cassette at 8.5 bar pressure and room temperature**	**Temperature range for gaskets in operation (°C)**
CR (Chloroprene)	6	-30 to +110
NBR-LT	50	-45 to +20
HNBR	22	-10 to +160
EPDM for NH3 + PAG oil	5	-25 to +135
FEPM-AL	6	+10 to +160

Permeation in semi-welded heat exchangers with other plate types and port sizes can be calculated by multiplying by a factor that corresponds to the difference in gasket circumferences. These factors are presented in table 2.

Table 2 Permeation from other plate types is easily calculated by multiplying by a factor that accounts for the different gasket circumferences.

Permeation factors for other plate types than M10-BW	
Unit	**Conversion factor**
MK15-BW	1.4
TK20-BW	1.9
T20-BW	1.9

3.2 Calculation example

How much ammonia permeates in a typical heat pump installation? In this example we show how you calculate the total amount of ammonia that permeates during one year.

In this example one Alfa Laval SWPHE is used as an evaporator and another one is used as a condenser.

Evaporator specification

- Model: Alfa Laval MK15-BWFDR
- Number of cassettes: 57
- Gasket material: CR

Condenser specification

- Model: Alfa Laval M10BW-FT
- Number of cassettes: 68
- Gasket material: HNBR

Tables 1 and 2 provide all the necessary data to make the calculations.

Permeation from the evaporator =
6 g/year (value for CR per cassette) x 1.4 (factor for MK15-BW) x 57 (total amount of cassettes) = 479 g/year

Permeation from the condenser = 22 g/year (value for HNBR) x 68 (total amount of cassettes) = 1,496 g/year

Total permeation = 1,496 + 479 = 1,975 g/year.

This equals a daily permeation of 5.4 g/day.

This can be compared to the ammonia emission from a human being, which is approximately 17 g/day.

In other words, the expected permeation is very low and well under all safety limits.

3.3 How different plate designs affect detection

Different producers of heat exchangers design their plates differently, which can affect the perceived smell and ammonia concentration right next to the heat exchanger.

If you compare two semi-welded heat exchangers with the same operating conditions and port sizes, the main factor affecting permeation is the gasket material. To minimize permeation it is therefore important to carefully select the optimum gasket material, taking permeation and operating conditions into consideration.

The geometry of the plates around the portholes affects the ammonia concentration at the edge of the plate pack. Even if the total permeation is the same, the local concentration can vary. A shorter distance from the ring gasket to the surrounding air results in a higher local concentration at the edge of the heat exchanger compared to a plate design where the distance is longer.

Alfa Laval plates are designed for maximum mechanical strength, low weight and minimal materials use, resulting in a shorter distance between the ring gasket and the plate edge compared to many other producers' plates. Figure 5 shows the difference between an Alfa Laval plate and a traditional plate.

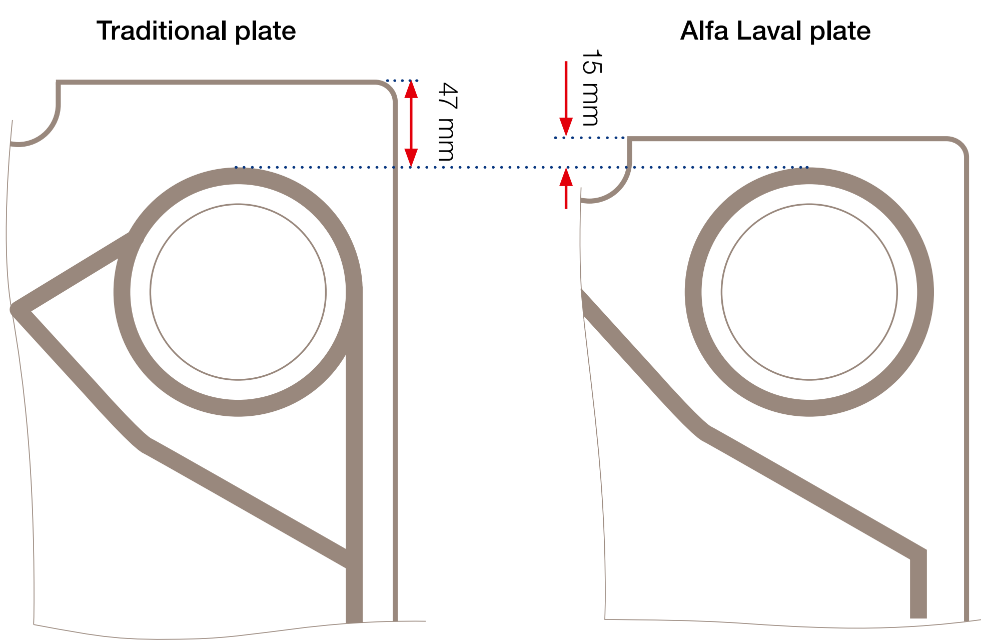


Figure 5 Differences in plate design mean the distance from the ring gasket to the edge of the plate pack can vary significantly. This means measurements made at the top edge of the plate pack will not be directly comparable.

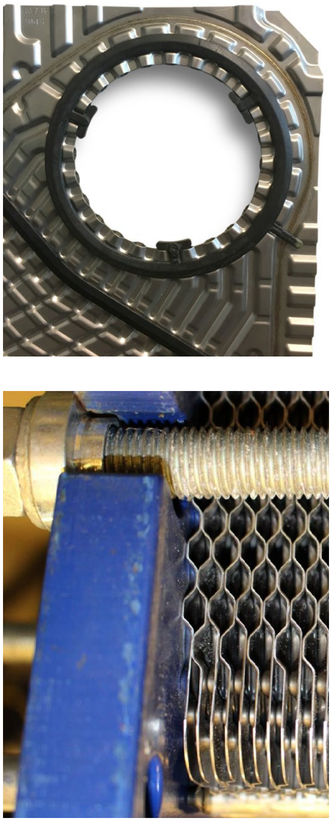


Figure 6 Alfa Laval's unique honeycomb pattern strengthens the plate and makes it possible to minimize the distance between the porthole and the plate edge.

In the case in Figure 5, the Alfa Laval plate is 32 mm shorter, resulting in a higher ammonia concentration at the edge of the plate pack since the ammonia has a shorter distance to diffuse into the surrounding air.

The strength in Alfa Laval plates comes from the honeycomb pattern that extends all the way to the edge of the plate. When putting the plates together, this pattern creates small air pockets that prevent the surrounding air from moving freely around the ring gaskets. This further increases the local ammonia concentration compared to plate designs without a honeycomb pattern.

These differences make any comparisons between different heat exchangers inaccurate. The only thing you can compare that makes a real difference is the gasket material. Any measurements will be misleading since both the distance between the ring gaskets and the plate edge, and air circulation around the gaskets differ largely.

If you want to make a rough comparison you should make any permeation measurements at an equal distance from the ring gasket. In the example above this would mean measuring 32 mm above the Alfa Laval plate pack.

4. Conclusion

This white paper discusses the cause of ammonia permeation in semi-welded heat exchangers used for refrigeration applications.

We have shown that permeation is a natural and inevitable process that has nothing to do with leakage, and that it does not affect operation or an operator's health in any way.

Comparing ammonia measurements made at the edge of the plate packs on different models of semi-welded heat exchangers is pointless due to differences in plate geometry. The only way to minimize permeation is to carefully select the best gasket material for the given operating conditions.

We have also shown how you can calculate the amount of ammonia that permeates per year and that a standard system emits roughly the same amount of ammonia as a human being.

About Alfa Laval

Alfa Laval is a leading global provider of specialized products and engineering solutions based on its key technologies of heat transfer, separation and fluid handling.

The company's equipment, systems and services are dedicated to assisting customers in optimizing the performance of their processes. The solutions help them to heat, cool, separate and transport products in industries that produce food and beverages, chemicals and petrochemicals, pharmaceuticals, starch, sugar and ethanol.

Alfa Laval's products are also used in power plants, aboard ships, oil and gas exploration, in the mechanical engineering industry, in the mining industry and for wastewater treatment, as well as for comfort climate and refrigeration applications.

Alfa Laval's worldwide organization works closely with customers in nearly 100 countries to help them stay ahead in the global arena.

Alfa Laval is listed on Nasdaq OMX, and, in 2016, posted annual sales of about SEK 35.6 billion (approx. 3.77 billion Euros). The company has about 17 000 employees.

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