Leak testing of heat exchanger systems using the hydrogen method

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1.0 Preface

Bacterial recontamination caused by undetected micro leakages pose a serious problem. Pasteurised product flows in the opposite direction to normal flow, encountering unheated raw product and/or cooling or heating media. One of the principal QA tasks for the operator of heat exchanger systems is therefore to detect micro leakages in heat exchangers in a dependable and timely manner in order to avert microbiological disasters (Fig.1)

Many years of alternating temperature loads, pulsations, pressure impacts and also aggressive cleaning media destroy the thin stainless steel plates in plate heat exchangers as well as the welded seams on tube heat exchangers and UHT systems. This is why plate heat exchangers are affected to an above-average extent by 'fatigue cracks'. According to the manufacturer, about 20% of all installed plate heat exchangers contain undetected defects. It is therefore appropriate to use differential pressure systems (pressure-increasing pumps) to try and detect any flow of liquid leakage through cracks in the micron range by applying positive pressure of 0.5 – 2 bar and to seek to prevent any unwanted flow (contamination) from unpasteurised to pasteurised side. The fact is that cracks of this magnitude enable bacteria to migrate in both directions. Differential pressure systems are therefore not any 100% guarantee against the mixing of pasteurised and unpasteurised product. Pathogens are also able to migrate in the opposing direction to the flow of a liquid, unlike water which can only do so when pressed against micron-sized holes at great pressure. Further to this, bacteria even have the ability to swim through an immobilised capillary water droplet, even if it is only > 0.2 microns in diameter. This means that bacteria can swim through plate defects through which no liquid has flowed in a long time, causing microbial contamination.

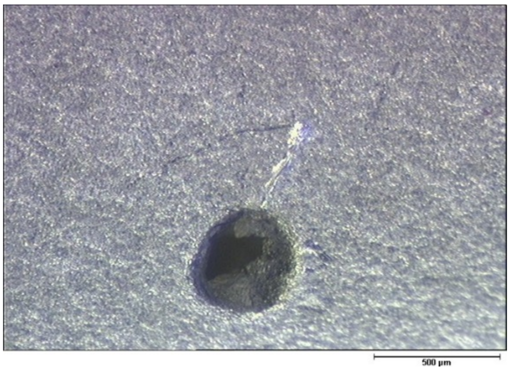

Figure 1 - Plate defect, front side

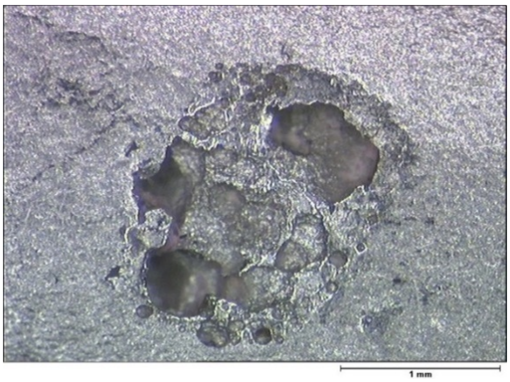

Figure 2 - Plate defect, reverse side

A test system is therefore called for to detect these microscopic cracks that also needs to be able to detect corresponding minute levels of leakage in a reliable manner.

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Figure 3 - Chafing locations at contact points

For this reason, the hydrogen test gas method has also become established in the aircraft, pharmaceuticals, chemicals and food industries because hydrogen, the smallest molecule, satisfies the demanding requirements of quality assurance.

2.0 Why hydrogen as a test gas?

Hydrogen has a wide range of advantages over other test procedures, and therefore constitutes an ideal gas for test purposes.

It has a very low viscosity, the lowest molecular weight and a low background concentration (Fig. 4), and it practically does not occur in ambient air. Furthermore, H_2 is environmentally compatible, it is non-corrosive, non-toxic, volatile and is approved for use with foods (E949). It can therefore be used as a test gas in the food industry. Hydrogen testing does not require any additional consumption of water (an environmental bonus) and no toxic chemicals are used.

	air	hydrogen	helium
molecular weight	**29 g/mol**	**2 g/mol**	**4 g/mol**
density	**1,2 g/l**	**0,09 g/l**	**0,18 g/l**
viscosity	**18,3 10^{-6} Pa s**	**8,7 10^{-6} Pa s**	**19,4 10^{-6} Pa s**
background concentration	**100 %**	**0,5 ppm**	**5 ppm**

Figure 4 - Physical data of hydrogen compared to helium and air

3.0 Leak testing methods for heat exchanger systems

In principle, a distinction can be made between evidence-based and prevention-based leak testing processes. The level of differentiation depends on the verification limit of the extent of leakage (Fig. 5)

Evidence-based test methods:

- Pressure-retaining method with water
- Conductivity measurement
- Tracer – water method
- Red – White method

Preventive test procedures:

- Helium test method
- Hydrogen test method

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Advantages of the hydrogen mixture compared to helium as a test gas:

Hydrogen spreads much more rapidly which helps to achieve a uniform concentration inside a test component within a short period of time. The background concentration of hydrogen is 10 times less than that of helium which makes measurement errors in an air atmosphere much less common.

Also, hydrogen is very volatile, and it does not adhere to the surface of the object being tested. You therefore require no additional ventilation to remove the test gas from the test object, which eliminates any further error source from the test gas in the air. Hydrogen mixes very quickly with other gases. This is important because it avoids the build-up of local concentrations, which could otherwise lead to fires and explosions. The gas evaporates ecologically after this test. In addition, unlike helium, hydrogen is a renewable resource. This has a positive effect in respect of the environmental audit defined in ISO14001 and on the price of the test gas. In practice, a commercially available forming gas is used (5% H_2 and 95% nitrogen) that is classified in accordance with ISO10156 as a non-combustible gas.

		Matrix of detectability methods					
		Plate break	Micro leakage > 30 microns	Micro leakage < 30 microns	Corrosion	Material fatigue	Condition of gasket
Method	Pressure-retaining method	X	O	O	O	O	O
	Conductivity measurement	X	O	O	O	O	O
	Tracer water method	X	X	O	O	O	O
	Spray process, Red/White	X	X	X	O	O	O
	Helium test method	X	X	X	X	O	O
	HLD 600automatic with hydrogen	X	X	X	X	X	X

Figure5 - Detectability limits of different test procedures

4.0 HLD600*automatic* hydrogen leak detector

The recently developed HLD600automatic measuring system is a logical further development of the HLD400 manual version that has already been tried and tested on multiple occasions and is a valued solution.
The new test system guarantees absolutely precise and fully automatic leak testing of heat exchangers in assembled condition.
(Fig. 6)

In addition, the measuring device also features an internal calibration unit that enables the measuring sensor to be calibrated easily before every test. For this, a calibration gas with a defined concentration of hydrogen is mixed with synthetic air. This fast and simple calibration process (each calibration lasting about 1 min.) guarantees that the measuring system can be used safely, and eliminates the possibility of measuring errors.

Figure 6 - Resom HLD600automatic hydrogen leak detector

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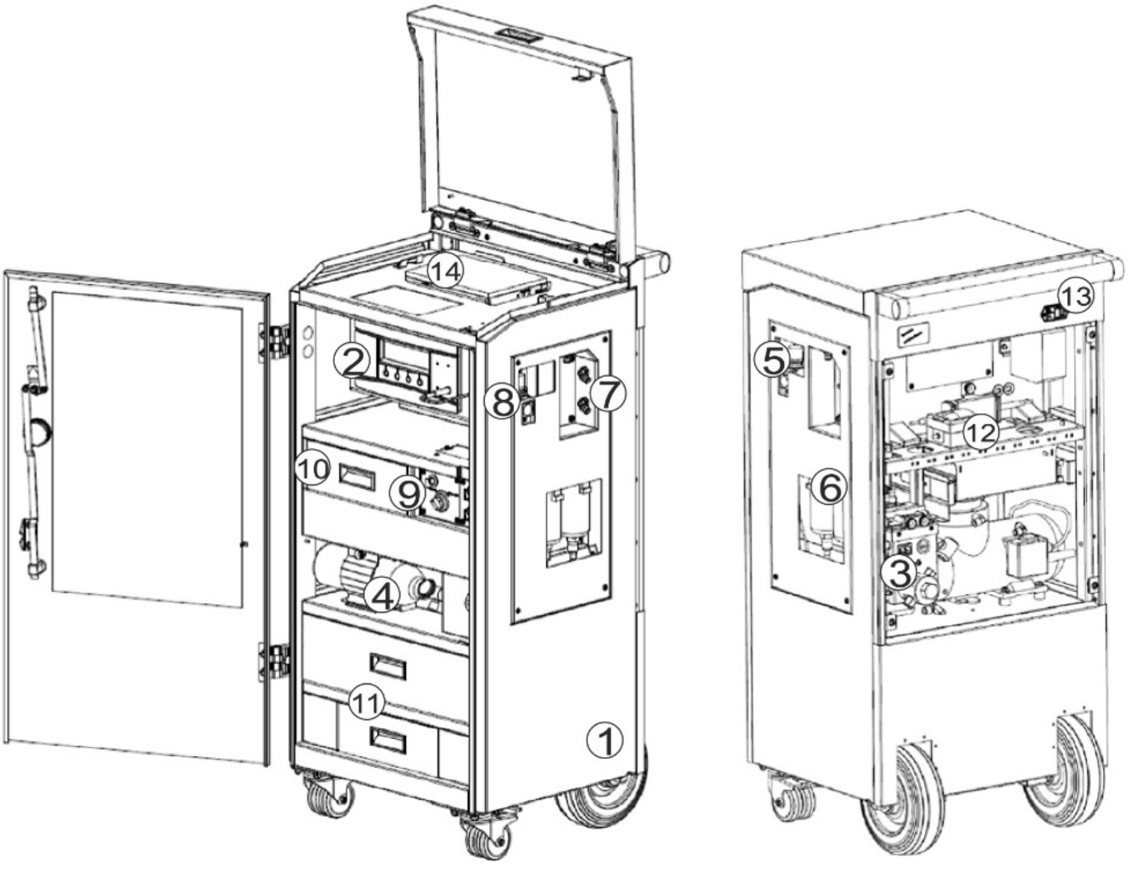
4.1 Functional method and layout

The highly sensitive hydrogen measuring system detects the tiniest of leaks and material weaknesses. It detects the diffusion of H_2 molecules through the metal and this also enables it to detect material fatigue at an early stage – even before leaks start to occur. It is also possible to detect with pinpoint accuracy poorly installed gaskets and/or gaskets that have already become brittle.
Fully automatic control of the new system eliminates any possibility of operator error on this device which in turn prevents a multitude of sources of error, making the work of the inspector much safer as well as a great deal easier. At the same time, the integrated HLDsoft software stores all plant-related data. This greatly simplifies the comparison of measuring results. The test report created automatically during each measurement provides a quick overview of all relevant parameters and makes seamless documentation much easier for Quality Management. (Fig.7)



1	Housing	8	Connection for compressed air
2	HLDetector	9	Calibration device
3	Measuring cell with Two-way valve	10	Drawer with manual measuring sensor
4	Calibration gas device	11	Tool and accessories drawer
5	Adjustable air regulator	12	Connector strip
6	Water separator I and II	13	Power connection
7	Air connections for heat exchanger	14	PC / Notebook

Figure 7 - Layout of the HLD600automatic measuring system

4.2 Leak testing of plate heat exchangers

Essentially, a plate heat exchanger is always inspected internally and externally for defective areas. The corollary of this is that a leak detection system must enable plate defects to be detected as well as problems with gaskets and seals.

With the hydrogen method, an inspection of this kind is an easy matter because the hydrogen – given its physical properties described earlier – once introduced into the heat exchanger, permeates and passes through plate defects as well as brittle gaskets, escaping outwards where it can be detected by gas sensors.

The following table (Fig. 8) shows the detectability of hydrogen at atmospheric pressure (1bar) based on the example of a plate heat exchanger with a volume of 180 litres.

For clarification: 10 microns → $1 cm^3$ in 100 seconds → 5.4ml gas emerged after 9 minutes **without** pressure.

Size of Leakage	Declaration	Volume of Gas/9min	Detection with water method	Detection with HLD600*automatic*	Amount in PPM
100µm	Water can pass	540mL	Y	Y	3000
30µm	Boundary of water passage	54mL	Y	Y	300
10µm	Waterproof	5,4mL	N	Y	30
3µm	Steamproof	0,6mL	N	Y	3,25

Figure 8 - Relationship between size of leak and hydrogen concentration in ppm (parts per million)

4.2.1 Plate inspection

In the plate inspection, also known as the integral pressure test, a defined test pressure is applied. The level of this is dependent on the maximum permitted operating pressure of the system being tested. After that, all system-related parameters such as plant designation, manufacturer, serial number, system volume, number of sections etc. is recorded in the software. On the basis of the volume and pump performance, a computer program calculates the optimum circulation time for the individual test samples. Using an integrated 2-way valve, and based on the test times computed, samples are removed from the air flow to the heat exchanger and directed past an integrated hydrogen sensor. This sensor measures the hydrogen concentration levels, and the values obtained from this are transferred to a diagram. Depending on the concentration and the measuring time, on completion of the measurement, a statement can be made about the actual status of the inspected plate packs. (Fig. 9)

Figure 9 - Test layout during the plate test

4.2.2 Gasket inspection

The gasket inspection, also known as the leak detection process, is conducted to find external points of leakage due to defective or brittle gaskets. For this, the plate heat exchanger is pressurised up to max. test gas pressure, then a handheld hydrogen sensor is passed externally down the length of the gaskets. This enables to detect leaks with pinpoint precision and then remedy them. Since these external leaks are usually the result of embrittled gaskets, the unit can, if necessary, be clamped even more tightly. In a best-case scenario, a subsequent test then indicates an improvement in the leaking gasket problem since hydrogen concentrations are reduced. (Fig.10)

Figure 10 - Test layout during the gasket inspection

4.2.3 Various damage patterns on the plate heat exchangers obtained from practical tests

The following types of plate damage could be detected by means of this hydrogen test.

Figure 11 - Contact corrosion at the support points caused by resonances in the plate pack

Figure 12 - Damage under a light microscope

Figure 13 - Plate crack in the deflection plate. Resultant product deposits are not recorded by CIP cleaning

Figure 14 - Plate crack in the reversing group with product settlement

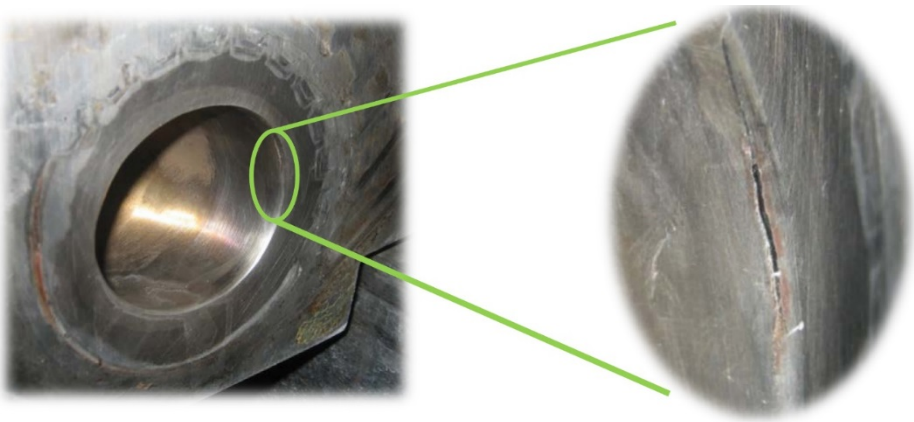


Figure 15 - Stress crack in the top plate. Product can therefore build up in the top plate, infecting the pasteurised end product

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Figure 16 - Disintegration of the gasket caused by excessively aggressive cleaning agents

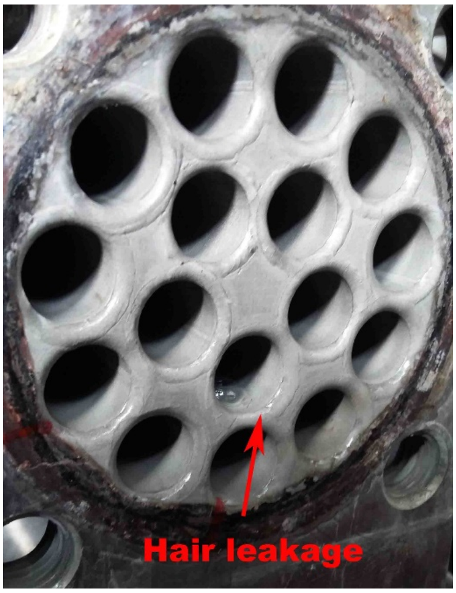
Figure 17 - Gasket defect due to the impact of pressure shocks

4.3 Leak testing on pipe-type heat exchangers and on UHT systems

When testing for leaks on tube heat exchangers or UHT systems, the most frequent types of defect encountered are hair leackages or broken seams on the top plates of pipe bundles. These micro leakages, usually measuring only a few microns, occur in response to extreme temperature loads and/or to high production pressures and their associated impact pressure loads and/or resonances.

With the automated hydrogen test, these defective locations can be located with pinpoint precision. This involves the test gas being introduced to the mantle side of the system at an appropriate level of test pressure. Air circulation occurs in the pipe bundles. This automated measuring process removes and evaluates samples from the air circuit at defined test cycles, just like with the plate test, doing so without any involvement by the operator. The hydrogen concentrations obtained in this way immediately indicate any damage pattern in the pipe bundle.

In the event of a defect, the pipe bends are then dismantled and each pipe is then tested using the handheld sensor. This enables defective pipes to be located reliably and any leaks to be sealed immediately and on location to prevent any further mixing of products. (Fig.17)



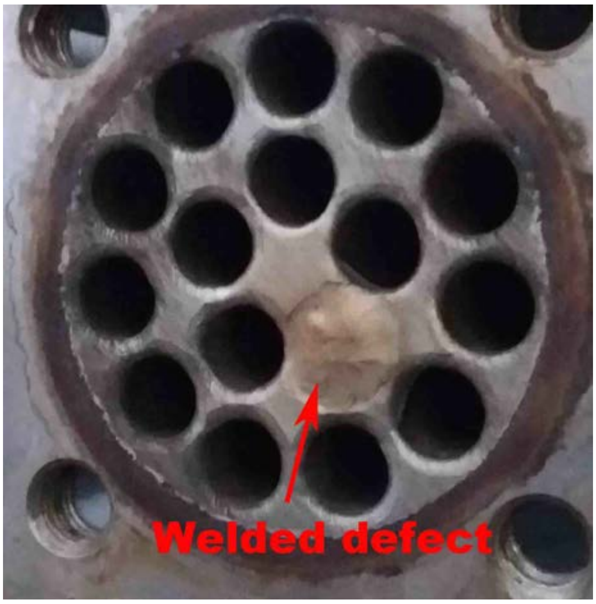


Figure 17 - Detected and then welded defect point on a UHT system at 40000 l/hr

Conclusion

Heat exchanger systems are an inexpensive standard technology for pasteurisation with a minimum adverse impact on the product. The differential pressure system does not constitute suitable technical equipment for preventing 100% recontamination inside the heater. It therefore seems advisable to validate these systems at regular intervals, defined by experience-based risk analyses.

Leak testing with hydrogen has established itself as an industry-standard process. The smallest molecule with the highest molecular speed guarantees the highest rate of leakage (5 x 10^{-7} mbarl/sec) that is technically and physically possible. Regular inspections of heat exchanger systems can assure early detection of material fatigue, hail leakages and plate cracks, which in turn prevents contamination of the product.

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Literature

1) Wutz Adam – Theory and practice of vacuum technology
2) Raimund Kalinowski – Brewing industry journal [Brauindustrie 08 / 2007]