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Transfair Engineering Survey:

Leak Detection Methods in the Household Refrigerator Industries Today

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Content

4. Leak Detection

One of the most important **criteria of quality of refrigerators is the elimination of leaks in the cooling circuit** to avoid costly refrigerator service. This chapter contains following:

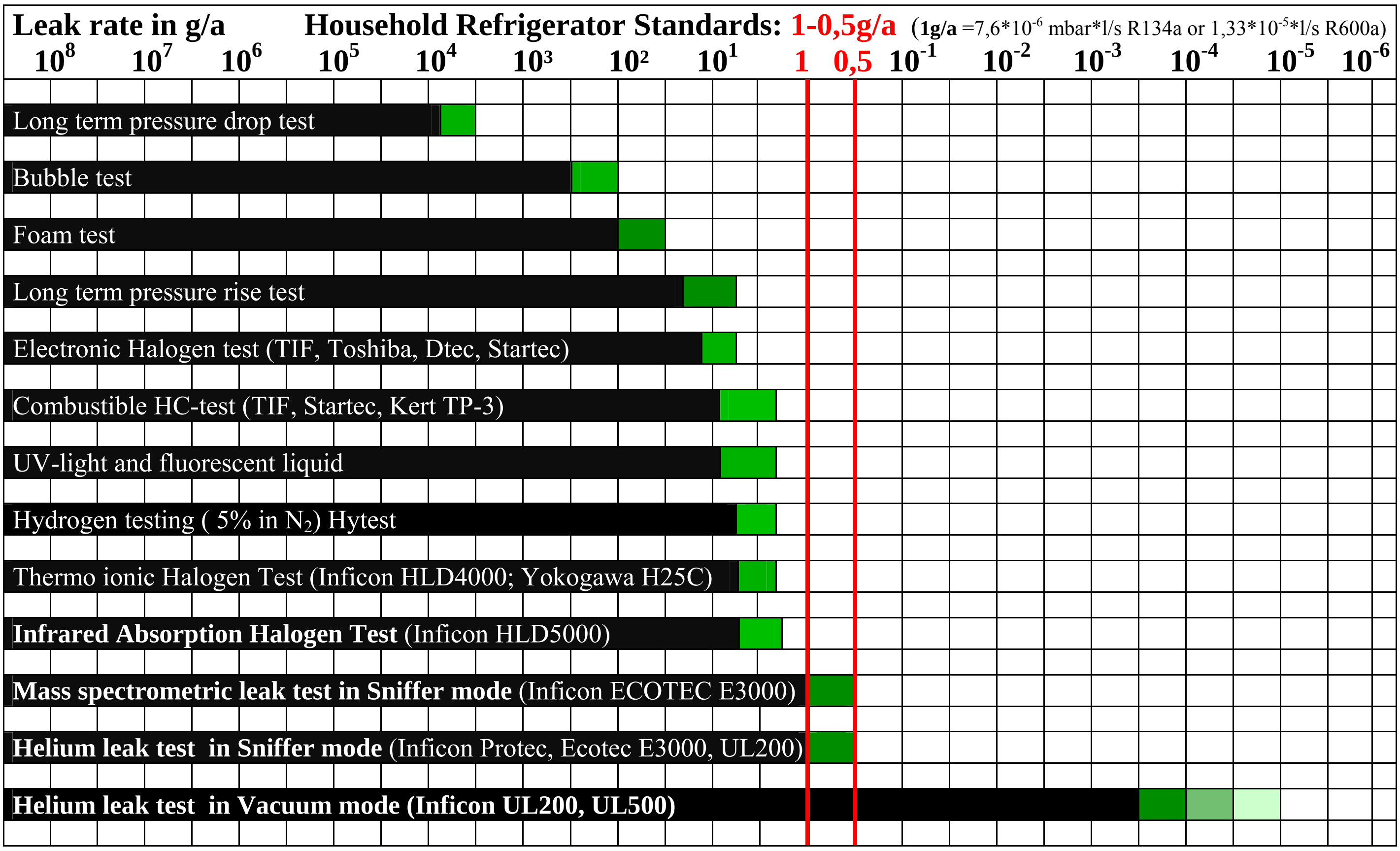
- a survey on leak detection methods in the refrigerator branch, their reachable leak rates, acceptable rates and areas of leaks,
- Halogen (thermo ionic and IR absorption), HC-combustible, mass spectrometric and Helium leak detection,
- Integration of the leak detection into a quality control system to improve the construction of the cooling circuit, the specifications of materials, the cooling circuit manufacturing, specially the brazing and closing.

It is surprising that many refrigerator producers spend a lot of money in such equipment, but often apply it wrong and under estimate the loss of market reputation, if their refrigerators have to be repaired others not.

4.1. Survey on Leak Test Methods and Reachable Leak Rates

Following leak test methods are used in the household refrigerator industries to control the cooling circuit. Such a circuit has 7-14 joints often brazed. Some leak tests are only used in pre-tests and not as final quality control test. Some low sensitive tests are still used in developing countries. To improve the application we have to know 3 items,

- the technically **acceptable leak rate standard**, which is for a household refrigerator with capillary tube as throttle device with 30-80g refrigerant charge 0,5g/a, with 80-230g refrigerant charge in the range of 1 g/a and up to 5 g for a larger charge (today often without any accumulator, in the past with small accumulator) today,
- the reliability and validity of test, its interference with background signals (Halogens or molecule fractions in air) etc. and
- the **theoretical and practical limits of existing leak test methods.** The green area in the following graph shows such limits:



It is useful to remain in industrial leak detection practice 10 times above such theoretical leak test limits reachable under certain laboratory conditions, but not in industrial practice. Sniffing cooling circuit joint leaks depends on used test **refrigerant or Helium,** its **pressure** differences between inside tube and outside, concentration (recycled Helium often in range of 50-60%) **applied method** and on **background interferences**, caused by the Ions or molecule fractions in the environment.

Refrigerant pressure. These mentioned values in g/a are only acceptable if the **pressure inside cooling circuit during test is the same as during refrigerator run.** For example **Isobutane systems** have often only 2 bars without compressor run and during compressor run the low pressure side of circuit are underneath atmospheric pressure, so no leak in this area could be measured by refrigerant sniffing. If we measure joints, which stays under 8 bar R600a pressure during compressor run only at 2 bar without compressor run the trigger value of 0,5g/a for 8 bar have to set to 0,07g/a for 2 bar to be comparable. But neither the 0,5g/a nor the 0,07g/a are measurable on the refrigerator because of background interference (next point).

Background. Leaks in our applications are detected with a sniffer. The refrigerator circuit or circuit elements are either filled with refrigerant or with Helium. Hydrocarbon (R600a) refrigerators have normally Cyclopentane foam (Europe, China, Russia etc.) and Fluor carbon (R134a) refrigerators often use similar Halogens (HCFC-141b, HCF245fa etc.) as blowing agent (USA, etc). So if we test a Polyurethane insulated refrigerators on leaks already filled with such refrigerants similar to the foam blowing agent the atmosphere contains such materials as **foam blowing agent in concentration up to 100 times higher than the trigger value for the leak, which don't allow accurate and reliable leak testing!** This concentration of blowing agent is strongly fluctuating upon distances of test joint to foam. The pentanes in foam as used on R600a refrigerators produces strong fluctuating signals up to 40-50g/a. The same we face with HFC-134a as refrigerant on refrigerators made with HCFC-141b or HFC-245fa as blowing agent (in USA etc.). How under this condition we can measure leaks with Thermo ionic Halogen or HC-combustible methods on 3-5g/a, or even with the most sensitive methods like mass spectrometry on 1g/a or 0,5g/a, if we work in an environment of up to 50g/a of the measured material? But still many household refrigerator factories **try to measure leaks on refrigerators already filled with R600a or with R134a!**

So only a **Helium leak test after brazing** could solve the problem. But even air containing already up to 5ppm Helium, which is with an old Protec (sniffer 75sccm) at 21°C a leak rate of $6,8*10^{-6}$ mbar *l *s^{-1} He (=0,04g He/a) or a new Protec P3000 (300sccm) $2,73*10^{-5}$ mbar *l *s^{-1} He and equivalent to rates of 1g R600a/a or 1,76g R134a/a. But Helium in air is quite stable (as long as there is no Helium leak of He-charging equipment or pipeline nearby), so by background deduction we have sufficient space to measure reliably such leaks by sniffing in air with our leak trigger value equivalent to 0,5g/a for R600a or to 1g/a for R134a.

The filling tube and 2nd tube on filter for 2-side evacuation are closed after refrigerant charging. So Helium is not possible for these 2 joints (see later).

4.2. Refrigerator Leak Standards

- **Today standard in household industries** (with capillary tube as throttle device) in developed countries are leak test methods which keeps the total leak rate
  - **underneath 0,5g/a for a refrigerator filled with 30-80g refrigerant charge,**
  - **underneath 1 g/a for models filled with 80-230g refrigerant** and up to 5 g/a for a larger charges.

  Modern **energy efficient models** require such low trigger values specially if they have no refrigerant accumulator and work on the low charging limit with higher superheat. The leak rates concerns the pressures as existing on the cooling circuit and if measured on other pressure it must be recalculated. The 134a models without compressor run has already sufficient pressure (>6bar) to measure joints on low pressure side. So such a system could be leak tested after filling with R134a as long as we don't use Fluor carbon as blowing agent like done in USA (see Background in last chapter), but a R600a system is different in this point and needs different solutions.

  An **R600a refrigerator cooling circuit** has about
  - 2 bar overpressure (300kPa abs.) if not in use (in storage, during transportation and shop),
  - in use with compressor run the high pressure side (compressor gas outlet, if exist on the model oil in- and outlet, condenser, anti-dew coil, filter dryer), is in the range of 8 bar rel. (=900kPa abs.) and the low pressure side (evaporator, heat exchanger, suction tube, compressor casing, refrigerant filling tube) about -0,5bar (=50kPa abs.) and
  - if in use, but without compressor run (about 50% of refrigerator life time) the refrigerant liquid will accumulate into cold freezer and reduce pressure inside the system underneath 0bar (freezer without refrigerator) up to 0,9 bar rel. (refrigerator without or only small freezer).

- **R600a household refrigerator leak standards** today accept a maximum R600a refrigerant leak of 0,5g/a on all joints together
  - on high pressure side joints under about 8 bars rel. during compressor run,
  - on all other joints under about -0,3 up to 0,9 bars rel. without compressor run and on joints on the low pressure side (-0,5 bar rel.) during compressor run, which should not **suck in air** (80% N_2 and 20% O_2) more than 0,01g/a. By this way such a system can survive for 15 year. We can measure per joint the 0,5g/a only if we have experience that we can exclude to have on the same refrigerator 2 leaks or 2 leaks rated near the trigger value. But more correct is to set the machine in a mode that this trigger value is for all leaks together or to check per refrigerator the total leak rate! Because of the strong

fluctuation pentanes signals (up to 40-50g/a) of foam blowing agent and the low pressure side lower than atmosphere such **a R600a system cannot be reliably leak tested on the refrigerant, but only with Helium**.

Refrigerator service during the lifetime of a refrigerator (which is in Europe more than 15 years**)** is rare in developed countries (2,5-5%) and service caused by circuit leaks are more in the range of 0,2-0,3%, by compressor failure 0,2-0,33% (under stable electrical supply conditions) and 0,1-0,2% insufficient cooling! Leaks are normally destroying the compressor and a service (>€ 60,- in Europe, about € 40,- in developing countries) is much more expensive. Investing in quality control systems causing costs in the range of € 0.05- 0.07 per refrigerator (using for a production of 500000/year 4 Helium leak detection lines and 2 Ecotecs E3000) while the financial damages for low quality reputation surely will cost much more.

The leak detection requirement increases because modern refrigerator design often increases the performance by reducing the charge quantity and increasing the superheat (see Transfair Engineering: Designing and Prototyping of refrigerator and freezer circuits. Düsseldorf 2000). By **working on the lower charging limit** in this case the acceptable leak rates become smaller and the technical demand on leak detection is increased, able to detect 0.5 to 1g per year.

Also for R134a Helium and mass spectrometric leak detectors are standard in developed countries today. But in developing countries still **Halogen leak detectors** for R134a refrigerators are in use with less sensitivity and more Halogen background interferences from Halogens in air (refrigerant leaks, HFC-141b foam blowing agent, PVC, cleaning liquids etc.), with the effect of higher demand on repairs, which causes more costs as needed for good leak detection.

Even most sensitive **Hydrogen leak testers** which uses as tracing gas 5% Hydrogen in 95% Nitrogen to avoid explosion (a gas which is only 10-25% of the cost of Helium gas, if Helium would not be recovered) can in practice detect leaks in the range above 3-5g/a. This is for small household refrigerators already too high, but acceptable for larger applications with charges above 250g.

Bubble test, foam tests, pressure rise test or pressure drop test are completely out of range for an application with 35-220g refrigerant inside and nearly vanished in this kind of production. 1 up to 5 g less charge decides if such a household refrigerator system will ran or not. By such methods only large leaks can be detected, but not the ones who will cause a breakdown of compressor inside of few months while good refrigerator manufacturers today make systems which will not fail because of leaks or micro leaks during the life time of a refrigerator.

4.3. Areas of Leak in a Refrigerator Production

The cooling circuit joints are normally tested on 3-4 different positions with different leak tests and different demands on equipment in use:

(1.) The **joints in the evaporator area** with one or more evaporators connected to the heat exchanger consisting of suction tube and capillary tube, accumulator, if any, so that all joints between capillary tube refrigerant entry and suction tube (later to be connected to the compressor) can be leak checked often before this group are even integrated into the refrigerator - if possible from the construction - , otherwise it will be done after their pre-assembly in the refrigerator assembly. In case that the evaporator and probably even joints are foamed in, the leak detection must always been done before foaming. The standard method in developed countries is **Helium charging (6-8bar), Helium leak test (Inficon ProtecP3000 or LDS2000) and Helium recovery**. Few joints can be done by Sniffing under air (ProtecP3000); many joints should be done under Vacuum (LDS2000).

(2.) The **backside joints in the compressor area** of compressor connected to suction, filling, and condenser tube, oil condenser, if any, filter dryer, anti-dew coil, if any, and between condensers, if more than one is used and the **front side joints**, if exist and still accessible after foaming the joints, between evaporator parts. All above mentioned joints - except closings of filling tube and tube on filter dryer for 2-side evacuation - can be made before evacuation and charging by using **Helium charging, leak testing (ProtecP3000) and Helium recovery and often combined with Nitrogen or dry air pressurisation** to 20-30 bar (according to IEC 600335-2-24 Section 22.28 equal to EN 600335-2-24), if no aluminium evaporator is used, drying and capillary clogged test. This **Helium method is standard today** in household refrigerator industries in developed countries and has the advantage that a leaking refrigerator blocks no evacuation place and brazing reworks can be made fast nearby without contamination with refrigerant or oil.

(3.) The leak testing on the sealing of **filling tube** with **mass spectrometric methods (Ecotec E3000)** searching for the refrigerant mass. In this case the leak test is made after refrigerant charging and closing of the filling hole.

(4.) The leak testing on the closing of the second side evacuation **tube on filter dryer** with **mass spectrometric methods (Ecotec E3000)** to be done under compressor run, if R600a as refrigerant is used. Without compressor run, that means at 2 bar R600a, we cannot measure this leak of 0,5bar/a at 8 bars, as we have to set by this lower pressure the trigger to 0,07g/a, not measurable on a foamed refrigerator – even not with the new Ecotec E3000.

Till 5/2005 the Ecotec versions **Ecotec 500 and Ecotec II, can not measure leaks after R600a filling** in the needed accuracy and reliability, because the degasing Cyclopentane foam (C-Pentane with n- and Iso-pentane, sometimes even Isobutane) could cause alarm up to 40-50g/a. So the method as practiced in refrigerator factories to measure leaks on refrigerators already charged with R600a is technically nonsense; it has more the character of gambling, 40-50g/a alarm signals of blowing agents regular cause fail alarms, and leaking refrigerators with leak rates between of 0,5/a and 5g/a regularly passed such test. Under these conditions even the measurement of leaks on the closed filling tube and filter dryer tube (item (3.) and (4.)) did not make sense, except to eliminate quite large leaks. But such large leaks probably could be done much cheaper with rough test methods in same low accuracy and reliability. The new Ecotec E3000 now solved our problem in this area.

So we normally need for the places following lines:

- **Helium leak detectors** (Inficon Protec P3000 or LDS2000) with **Helium charging** to control the **evaporator groups (1.),**
- **Helium leak detectors** (Inficon Protec P3000 or LDS2000) **with Helium charging** to control the **cooling circuit after** brazing in the compressor area **(2.)**, normally by sniffing under air (sometimes even under vacuum of the complete unit),
- **Helium recovery systems** to limit the cost of Helium, and
- **Mass spectrometric leak detector (Inficon Ecotec E3000)** for refrigerant after filling tube and filter dryer tube closing (for 2 side evacuation).

The **cycle time of the for helium leak control after brazing** without pressurisation, flushing/drying, humidity control and capillary control, **is 35-50 s** including 2 hoses connection and disconnection. By using in this configuration **a separate Helium recovery station**, the **cycle time is reduced to 20-30 s** If the process is **extended by the a.m. additional features** 13-19 s have to be added to the cycle time to reach **48-69 s** and with separate Helium recovery **33-49 s.**

The mayor part of cycle time is a full automatic process, so that operator is idle. To double the output on such a line only another Helium charging board can be added - all operated by 1 worker, resulting in 18-32 s cycle time per refrigerator, with pressurisation, drying, clogged capillary control etc., to 25-40,5 s. Nearly the same effect is reachable by connecting 2 refrigerators at the same time to a Helium charging board as long as we don't make pressure and capillary test.

The system price for 2 complete Helium leak detection lines with Helium charging, pressure test, helium leak detection and one Helium leak detector is in the range of € 115000 (system costs). This is the cost per line of 25-60s cycle time. € 15000-20000 has to add to double the capacity.

4.4. Halogen Leak Detector for HFC-134a: Inficon HLD4000A and Inficon HLD5000

12 years ago in developed countries, today in developing countries halogen leak detectors are used in the household refrigerator industry to detect R134a. Under aspect of sensitivity of leak detection and application design the best ones are the ones of Inficon USA.

In the past model **Inficon HLD4000A** for R134a (or HLD4000C for R12, the older version is the HLD4000A and the 3000) which measure theoretically leak rates down to 0.28g/a, but practically the measurable leak rats are more in the range of 3-5g/a. A similar model exist from Yokogawa (Model H-25C), but it is not as sensitive and not as strong as the Inficon one, which practically has a monopoly in this market segment in the world. The measurement principle is the **thermo ionic method**. A sniffer with a small pump is drawing gas flow into the positive ion emission detector containing an anode of about 800°C and a cathode filled with substances promoting ion emission under 300Vdc. Halogens have low ionisation energy, can easier than other ionised and the electrical load can be detected on the anode by measuring the current resulting of the positive ion flow into the anode. Other Halogen leak detector models with less sensitivity (5-8 g/a theoretically, in practice even lower), but much cheaper exist from GE, Toshiba, TIF and other companies, today used mainly in the service sector or for application with higher refrigerant charges (larger air conditioners, cooling units for commercial refrigeration. Also Inficon has such a model called D-TEC for the service sector.

Disadvantage of all Halogen leak detectors are the following:

- the acceptable leak rate in a household refrigerator production today is lower than the one reachable by Halogen leak detectors, even the most sensitive one of Inficon HLD4000. **Micro leaks which can cause a compressor break down after few months of use cannot be identified.**

- The **high theoretical sensitivity is in practice strongly reduced because of Halogen contamination of the air in the** area of leak measurements, even by using leak test room with air from outside the building. By suppressing the basic noise (the measurement of contamination, the leak rate that can be identified is strongly increased.
- The probe contaminated with leaked gas needs time for regeneration, often not existing inside the short production cycle, so that refrigerators with leaks can in worse case pass the control.
- The HLD4000A was originally not designed for a permanent and continuous use in a production. The sensor itself has a quite limited lifetime, the small ventilator inside the sniffer, and the capillary can be blocked in a dusty environment and need regular maintenance.

The succeeding model of the Inficon HLD4000 is the **Inficon HLD5000**, which has improvements to the previous model, because it **is fast with a response time of 1s, more sensitive with a leak rate of 1g/year, in industrial practice 2-3g/a, more reliable with low false alarm** – different to other thermo ionic halogen leak detectors with higher failure alarms - **and lower maintenance with long life IR-sensor**. The features in details:

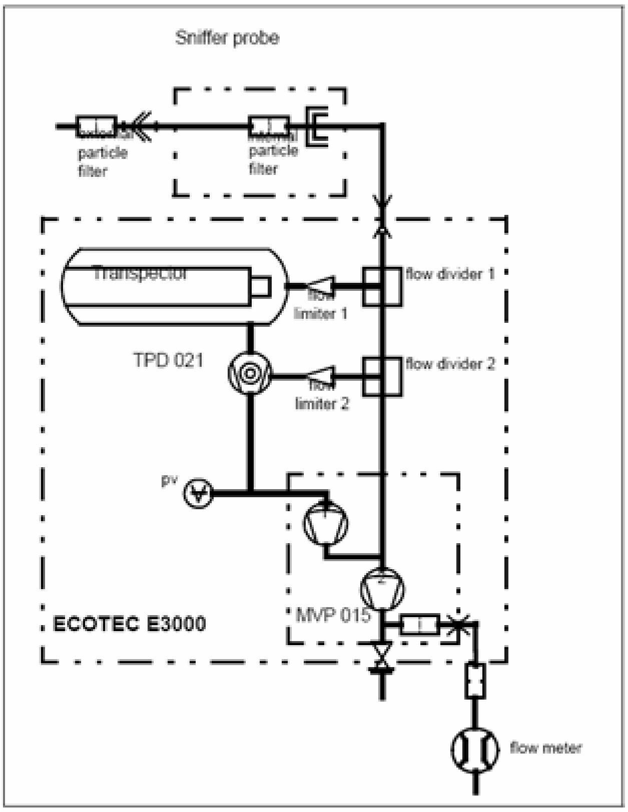
- **Fast (1s/joint)** and easy to use with **less false alarms**, no more time wasted looking for nonexistent leaks. The acoustic alarm changes pitch as the leak rate changes, so leaks can be pinpointed quickly. A LED in the hand piece provides additional confirmation. Dual gas inlet dramatically reduces false alarms by comparing the sniffer inlet with the refrigerant in the ambient and the Zero level setting as used in past is removed by this feature. Ergonomic hand piece design minimizes fatigue. A lamp on the hand piece changes color to provide additional confirmation when the leak threshold is exceeded. A half circle of lamps on the front-panel display responds like a bar graph to show the relative leak level. And with the press of a button on the hand piece, you can immediately switch the unit to its maximum sensitivity to isolate the smallest leaks.
- **Calibration is fast and automated** with built-in internal calibrated leak, which compensate the leak rate for temperature changes to ensure accurate calibration and also monitors the lifetime of the cal leak and provides warning when it needs to be replaced.
- **Lower cost of** ownership by improving the lifetime of components, superior stability, **long life of infra red absorption sensor and only few** consumables (filter, calibration test leak). It has an **automatic standby function**; if the hand piece is idle for longer than a preset time, the unit turns off the pump and valve to reduce wear and filter contamination. Operation automatically resumes as soon as the operator picks up the hand piece.
- **Easy programming** of rejection level, signal volume, calibration intervals and other parameters using the eight front-panel "softkeys". There exist versions for many refrigerants to ensure that the HLD5000 reliably detects the leaks you want it to detect while ignoring everything else; each sniffer line is tuned to a specific refrigerant. Versions are available for R134a, R22, R404A, R407C, R410A, R744 (CO_2) and SF6. Units can be switched to a different refrigerant by connecting a different sniffer line.

But refrigerator industries request higher accuracy and higher reliability with less interference from other halogens in atmosphere.

4.5. Mass Spectrometric Leak Detectors for Refrigerant and Helium: Inficon ECOTEC E3000 (and old PROTEC)

Sensitivity and Selectivity Improvement. The low sensitive and selective **thermo ionic halogen leak detectors** (5-8g/year), even the improved version of IR detectors in comparison to mass spectrometric leak detectors should not be continued to be used to measure leaks of refrigerators with low charges as they measure all molecules with Halogen-Ions in the air (Chlorine, Fluor etc.) and their sensitivity must be strongly reduced (so called basic noise level). A modern refrigerator factory have to prevent that any refrigerator - even with a micro leak - will be passed to the market and will cause damages in the first years. Therefore 8 years ago nearly all refrigerator producers in developed countries **replaced Halogen leak detectors by mass spectrometric leak detectors** (<1g/year, specific for a refrigerant molecule fraction and not only for an Ion group) **to avoid that any refrigerator with even a micro leak can be delivered to the market** and fail after a while of use because of leakage –often not identified as leak but as compressor failure. For environmental friendly refrigerants, like **R600a**, anyhow such Halogen leak detectors did not work, but mass spectrometric ones.

Pre-Control of Component. Evaporators, heat exchangers and capillary tubes should be controlled if possible from the construction, before inserting wrong materials into the production and to dismantle them again. This has to be made by **Helium leak detection** using evacuation pumps, Helium charger, leak detectors and a Helium recovery unit. In this case a simpler mass spectrometric leak detectors can be used which only can detect Helium and not heavier refrigerant molecule masses.

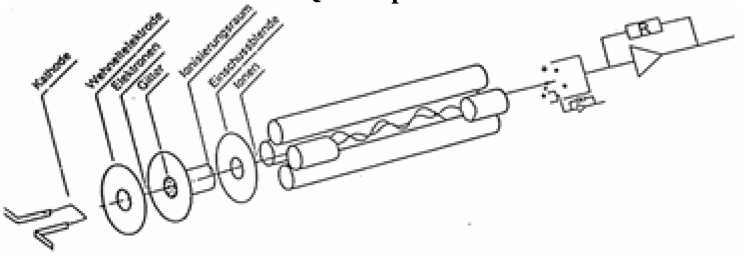


Today's Standard. Today's standard in developed countries is the use of **3-4 high sensitive mass spectrometric leak tests on each line**, one for the evaporator and heat exchanger with capillary (under Helium charging and recovery), the second for leak testing of the completely assembled cooling circuit on the compressor compartment side only before evacuation (under Nitrogen or dry air charging, Helium charging and recovery) and the third and forth after charging and filling tube and filter dryer tube closing, in case of R600a the filling tube before running and the filter tube after running.

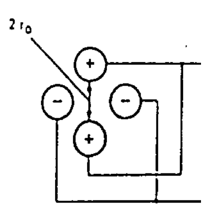
Vacuum Diagram of the ECOTEC E3000

- Dry Diaphragm pump 2-stages MVP015
- Piezo-resistive pressure sensor Pv
- Turbomolecular pump TPD921
- Transpector Quadruple mass spectrometer
- Sniffer probe with line
- Gas flow limiters and
- Flow meter

HQ 200 Mass Spectrometer
Ion Source Quadruple Mass Filter Ion Detector



The HQ200 mass spectrometer as built in the Ecotec consists of an ion source, a quadruple mass filter and an ion detector (see assemblies in figure on left). The figure underneath schematically shows the pattern of the electrical potential. The ionization chamber is formed by a grid and the subsequent cylinder. It is connected to approx. +150V relative to ground. The iridium cathode coated with thorium oxide is connected to approx. +50 V relative to ground.



$U_{\text{field axis}} +(U_{DC} + 1/2 \text{ x } _{\text{URF, Peak*Peak}} \cos \omega t)$

$U_{\text{field axis}} -(U_{DC} + 1/2 \text{ x } _{\text{URF, Peak*Peak}} \cos \omega t)$

The filament current of 2.5 to 3 A heats the filament to such a high temperature that electrons emerge from the filament. These are bundled in the Wehnelt electrode and the grid draws them into the ionization chamber. In the ionization chamber whose edges are connected to 150V the gas particles are ionized through electron bombardment. The generated ions are accelerated toward the injection orifice and injected into the quadruple mass spectrometer because the latter is connected to an average voltage of 140 V.

The quadruple mass filter consists of four parallel cylindrical rods arranged in a square. Each pair of opposite rods is electrically interconnected. Between the two rod pairs there is a high-frequency AC voltage on which a constant DC voltage is superposed. The relationship of the two voltages is chosen in such a way that only the ions of a certain mass, in this case mass 4 AMU for helium or masses 41 for Isobutane, can pass the rod system.

Problems and limits on mass spectrometric leak detection methods. Household refrigerator producers in mayor parts of the world – except main producers in USA – are using as foam blowing agent Cyclopentane, mainly in the version Cyclopentane 70 with Iso-Pentane and/or with other Hydrocarbons, even Isobutane. The mass spectrometric measurement of Isobutane use molecular fractions with AMU **41**, 42 and 58, which are also produced from Cyclopentane, Iso-Pentane and some other Hydrocarbons entering into the mass spectrometric leak detector. On an already foamed refrigerator using such blowing agents such gases from the foam produce fluctuating signals in the range up to 40-50g/a. The today's total acceptable leak rate on such systems only filled with 30-120g R600a on all joint together is only 0,5g/a, which is far underneath the signals of Pentane fractions of the foam. The same problem exists with HFC-134a in USA. We use for the leak detecting 69 AMU signal which also is produced by blowing agent HFC-245fa or HFC-356mfc.

Even by deduction the background signals (ZEROing), the signals from foam blowing agent is so strongly fluctuating on distance to foam and geometry of the refrigerator, that failure alarm is received regularly and the method is unreliable, only larger leaks could be eliminated (>4-5g/a).

Consequences. Under these conditions it does not make sense to test refrigerator cooling circuit leaks already filled with R600a, if the cabinet was foamed with Pentanes. The only reliable leak test method on such refrigerators is **Helium leak detection** with mass spectrometers like Inficon Protec before filling with R600a, which can reach such a threshold value of 0,5g/a in a reliable way.

But how to control the closing of the filling hole and – if two side evacuation was practiced - the service tube on the filter dryer?

In the past there was no real chance to control filling tube closing leaks (or any other joint) of a system already filled with R600a on the required level of 0,5g/a, if Cyclopentane foam was used. With the **new Inficon Ecotec E3000** with the so called **IGS feature** (also called fingerprint) first time we can control the closings of the filling tube and the service tube on the filter dryer with the required trigger value as needed. With an algorithm of evaluation of the molecule fractions quantities, the sensitivity interferences are reduced by a factor of 100, Inficon claims, so that the background signals of the pentane of foam up to 40-50g/a can be squeezed near or underneath of level of the trigger of 0,5g/a, which must be tested now in practice. We still are near the trigger value and we could get sometime failure alarm, so that we have to repeat the leak test.

Leak control on the filling tube closing can be done by the Ecotec E3000 with a trigger value of 0,5g/a R600a = 6,65 E-6 mbar l/s at 20°C. This is the maximum acceptable leak if the compressor is not running. If Inficon is right with the new IGS algorithm, the interference by Pentane molecule fractions could be pushed near or underneath the threshold value of 0,5g/a, at least in a way, that if no leak is detected and the work was correct done, we should not have a filling tube leak; and if a leak is detected, we have to repeat the test, to eliminate fail alarm of interferences of Pentane in foam, before we let it repair.

But how this measured R600a leak rate correspond to air sucked into the cooling system with -0,5 bar during compressor run on the low pressure side?

A measured leak rate of 0,5g/a R600a (= 6,65 E-6 mbar l/s at 20°C) with 300kPa abs. inside the tube and 100kPa outside (maximum pressure difference without compressor run) is equivalent to a leak rate of 0,01g/a 80% N_2 (=2,83E-7 mbar l/s) and 0,00g/a 20% O_2 (=6,11E-8 mbar l/s) with 50kPa inside tube and 100kPa outside (low pressure side under compressor run at 20°C). Normally the pressure difference outside-inside tube relevant for leak rate is during use of a refrigerator in time the compressor is off less because refrigerant condensate in cold freezer evaporator and by this way reduce pressure and therefore the real leak rate, depending on size of freezer in comparison to total cooling circuit volume. So if we can measure with this trigger value of 0,5g/a R600a all leaks we are on the save side. The Ecotec E3000 now allows reducing strongly failure alarms.

The **leak test on the service tube can only be done with compressor run** (900kPa abs.) and a trigger value of 0,5g/a R600a = 7,33 E-6 mbar l/s at 50°C, but it should not be done without running the compressor. If we measure this joint without compressor run with only about 2 bar rel. the corresponding trigger value under these lower pressure has to be 0,07 g/a at 2 bar rel. to be equivalent to the trigger of 0,5 g/a under 8 bar rel. And the instrument set on such a trigger will often give leak alarm as result of the Pentanes in the foam – even with the new Ecotec E3000.

Helium leak detection lines for R600a refrigerators foamed with Cyclopentane. Even with the Inficon E3000 and its new fingerprint intelligence to reduce the Pentane interferences of Cyclopentane foam, these interferences are still near the trigger value. To avoid failure alarm, to increase the reliability and validity of the leak test, the Helium leak test method on nearly all joints is strongly recommended and cannot be replaced by a leak test with Ecotec E3000 only after R600a charging without Helium pre-test.

A R600a leak rate of 0,5g/a (at 8bar a. against atmosphere) is equivalent to Helium leak rate of 1,6- 3,39E-6 mbar l/s for 50-100% Helium as inside He-charge.

4.6. Helium Leak Detector Protec P3000

2006 Inficon introduced a new helium leak detector not anymore working with mass spectrometer, but with an evacuated gas cell with a pressure sensor behind a quartz membrane only permeable for Helium, now even maintenance free; but not free of running costs. The vacuum cell sensor has a lifetime. The Helium molecules remain inside the cell. To keep vacuum in the cell to prolongate its lifetime so called "getter" material absorb the He^{+}, ionisated by about 7000Vdc, in ion getter. We aspect at moment that this cell unit must be refurbished after 4-5 years (costs €540 in 2006) depending on Helium quantities exposed to this sensor, which are limited by standby stops. The detector is still too new to know it more accurate. On long term of use the new Protec should be cheaper as the older version, not having to repair and to replace expensive mass spectrometers and molecular pumps anymore inside. The system is with $1*10^{-7}$ mbarl/s more sensitive as in past the mass spectrometric Protec, 30% faster and the gas flow with 300 sccm 4 times bigger which allow detecting a leak even in 10mm distance from hole. Furthermore a build-in i-Guide allow to guide operator to test programmed joint areas one after the other with minimum time and to sum total leak rate of a cooling circuit. All these new features improve reliability of leak detection method significantly and its correct recording.

4.7. Helium Charger Boards and Recovery Units

Helium Leak Detection Lines. The right and today best test method to control an assembled refrigerator circuit is the **Helium leak test by using a Helium charger, a Helium leak detector (Protec P3000) and a Helium recovery unit** (Helium is expensive and it is recommended to recover and to reuse it). In case of the use of Helium a mass spectrometer like Inficon ECOTEC E3000 for € 22500 (system price € 25000) which can measure every mass (all gases) are not needed and cheaper Helium detectors like Inficon Protec for € 15000,- (system price € 18000) is sufficient.
The test is made before evacuation and charging with refrigerant on the already mounted and brazed system and on the evaporator before integrating the evaporator group into the assembly to avoid reworks. All is done dry (no water, no soap).

Helium Charging Boards. There exist different Helium charging boards (Galileo, Agramkow) on the market, like Galileo Astra and Agramkow HRS6, each in different versions, some versions not only used to charge Helium for leak detection and to recover it, but with additional **further functions like Galileo Astra III:**

- To **stress the brazed joints** (up to 30 bar, if not roll bond) of parts or on total cooling circuit,
- To **dry the circuit** by dry air or dry Nitrogen,
- To **control the dryness** of the system by a humidity sensor,
- To **control the pressure drop of capillary and**
- That **capillary tubes is not closed (system chokes),**
- **If the capillary is correct in diameter and length,** as option

Depending on the position on the line, if evacuated from 2 sides or not, from cycle times and individual needs different feature can be used or not.

Survey. Main Helium leak detection is made after final assembly of the circuit and brazing before evacuation. Without the a.m. additional features normally done on same machine before Helium charging - it contains of following 5 phases:

- Evacuation (10-45 s, the longer the evacuation, the less contamination and consumption of Helium) by Vacuum pump,
- Helium charging (3-6 s),
- Helium Leak detection by Inficon Protec, (about 2 s per joint, normally 6-8 joints, 12-16 s),
- Recovery of Helium from refrigerator circuit (5-7s) by air compressor, and
- Helium exhausting of last fraction to reduce Helium contamination (2-5 s) by vacuum pump and to replace it by fresh Helium.

Agramkow's typical layout of their actual machine model HRS6-IS distributes the above mentioned 5 Helium leak detection work phases **on 3 places:**

1. Evacuation and Helium charging with a Helium charging board with vacuum pump,
2. leak detection with Protec and
3. Helium recovery by an compressor with a separate recovery hose, without complete removal by a vacuum pump

to reach minimum cycle times of 32-36 s including 2 hoses connections and disconnections.
Galileo's typical layout is a single, combine work place, which allow in case of the model Astra III to add a.m. further quality relevant processes (drying, drying control, capillary tube control, stress test). Galileo is recovering normally through the charging board and not by a separate Helium recovery hose, allowing to remove the last fraction of helium as non- condensable gas out of the system by a vacuum pump and to exhaust strong contaminated Helium separately, which takes 45-59 s including 2 hoses connection and disconnections. To reach in such a combined work place by 1 worker a lower Helium leak detection cycle time Galileo has 3 possibilities:

1. a **separate Galileo recovery station** – as offered now- with vacuum pump connected to the recovery pipeline (like Agramkow's solution, but with additional features) with 32-36 s/refrigerator),
2. to **connect 2 refrigerators** on the Helium charging board parallel by 4 hoses, with 30-52 s/refrigerator, or
3. to use a **second Helium charging board** on the same line or on a parallel line, to use the idle time of operator to detect leaks with 1 leak detector on 2 refrigerators, alternately, with 23,5-32 s /per refrigerator.

In countries with higher wages the 3rd solution with second Helium charging board are best as it needs 10 s less works. In countries with limited financial resources and medium and lower wages a solution with separate recovery station are quite useful.

But **refrigerator manufacturers today needs standardized circuit drying, drying control to insure quality and to limit evacuation time and pump quantities and space**; they want to be able to control the capillary tube before wasting capacity on evacuation and testing, they want to make sure that the brazing joints can be stresses and will not break during transportation or later during run vibration, therefore have asked the machine manufacturers for such extended quality relevant features which results in longer cycle times (pus 14-24 s) as only needed for the Helium leak detection and 2 hoses connections to a system. The Astra III can do all these features. In a version IIIS with big tubes and valves even much faster. Even if not all features are needed and possible in the given cycle time on all places, this board is still cheaper than the board of Agramkow, and demands are changing so that machines have to be flexibly regrouped, without being scrapped. Galileo cover the version and features as offered by Agramkow, but can do a lot more.

Let's take first a closer look to different Helium leak detection equipment on the market and afterward their configurations and layouts to optimize the process under the aspect of utilisation of equipment investment and running cost (mainly work cost) to look on optimal work operation timing.

4.7.1. Agramkow Helium Charging and Recovery Station HRS6

The Agramkow Helium charging and recovery station HRS6 are supplied in 3 versions, depending on cycle times to be reached:

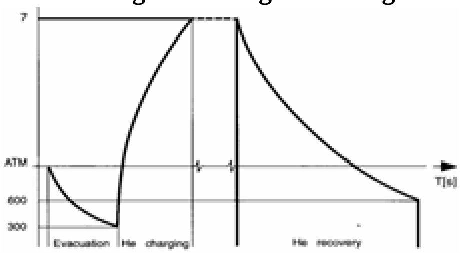
- HRS6-I – Charging station with integrated recovery, the basic machine,
- HRS6-IS – Charging station and a separate satellite recovery unit or
- HRS6-ISE – Charging station and separate satellite recovery and pre-evacuation unit

The evacuation and charging station HRS6-I evacuate down to 100 mbar, typically to 300 mbar because of time limitations, and to charge from 2-7 bar with Helium, and afterwards recovery the Helium. Last can be done separately (HRS6-IS), which cut the cycle time to nearly half. The Helium recovery is done to a level of 800 to 100mbar, typically 500 mbar for time reasons by an air compressor with 2 hoses. The Helium from the refrigerator can be recovered by a separate hose not using the charging hose (HRS6-I) or in a separate station (HRS6-IS) in up to 10m distance. To speed up the process even pre-evacuation can be done separately. Beside the HRS6-I or between the 2 stations (HRS6-IS) a Helium leak detection board normally Inficon Protec are used. The evacuation, charging and recovery process is controlled by PLC timers; a pressure drop test can be executed to identify systems with rough leaks. The system price without Protec is about € 42.500.

The **first stage** of operation consists of

- Connection 2 hoses with female Hansen to the refrigerator circuit in 5 s (if the 2 tube squeezing male Hansen quick couplers have to be fixed to the system additional 10 s in this stage);
- Evacuation from atmospheric pressure to 300 mbar in 14 s to 200mbar in 19 s and to 100 mbar in 25 s (the lower evacuation the less Helium consumption)
- Helium Charging to 7 bar in 6 s, and
- Disconnection of the 2 hoses in 5 s.
- If the Helium from the filling hose has to be recovered and not wasted, further 2-3 s are needed, before fixing the hoses again to a refrigerator.

1st Stage 2nd Stage 3rd Stage



The **total cycle time of the first stage is min. 32 s up to 44 s**, if more evacuation is wished to reduce Helium consumption (The fixing of the 2 quick coupler male Hansen tube squeezing adapter on the refrigerator is not yet added to the cycle time).

In the **second stage** - parallel to the fist stage to be executed – leaks are searched by a Helium leak detector, normally for a trained person 2 s per joint, so that it results to a time of 10-16 s.

In the **third stage** the refrigerator has to be connected to the recovery unit by 2 hoses (10 s.), The Helium recovered from the refrigerator system (5-6 s), and finally shortly evacuated to eliminate Helium as non- condensable out of the system (3 s)

If the work is done by 1 worker it results to a minimum cycle time of 32 s (for 5 joints) up to 36 s (for 9 joints) plus 10 s if the 2 quick coupler male Hansen tube squeezing adapter on the refrigerator – needed to connect the hoses by Hansen females - have to be fixed. With 2 workers the cycle time could be reduced to 32 s.

The **newest Version** now from Agramkow combine the 2 boards of HRS6 to one board with 1 SPS and add a small simple Satellite Helium recovery station with 2 hoses connected to the combined board which reduces the costs to €36.500.

Technically equivalent with the HRS6 for €42500 or with the new system with Helium recovery satellite for €36.500, are Galileo charging board Astra C (€12700), slightly technically lower, or Astra III (€17000), technically better than Agramkow, combined with their Ecomass R2(€17300) and a separate Helium recovery place (€4000) totally €34000 respective €38300, but the recovery board of Galileo can recover from up to 3 charging boards so that a second line and 3rd line would be much cheaper, than 2 or 3 Agramkow lines. The Astra III has further quality relevant features (pressurization/flushing/drying, capillary flow test etc.), some of them could also be added in the Agramkow line, but in this case the price would grow up again.

4.7.2. Galileo PQ Helium Charging and Testing Board

The PQ Helium (€12700) is mainly used to execute Helium leak detection, but not further quality processes like the Astra III (€17000). Today it can even make few further tests as option.

PQ Helium is a machine for leak pressure testing of hermetic units. It is especially designed for the test of refrigerators and air-conditioners. PQ Helium evacuates the unit under test up to a programmed vacuum level, check if pressure rises by rough leak, if not pressurise it with Helium, check if Helium pressure is kept. Parallel the leak search is manually performed by using an external Helium leak detector (by sniffer of Inficon Protec P3000, not included). The frame of PQ Helium includes a special support to house the leak detector. It is possible to connect the external sniffer with the PQ Helium by a normally open relay contact: by detecting a leak, the contact closes and the PQ Helium displays the leak condition. As option 2 RS-232 serial interfaces can be linked to a **bar code reader** starting process, selecting cycle program and reading model/serial no. and a **PC or printer** allow to store or only print out all data of model and serial no. forming the result of the test (passed, no passed).

After the test, the Helium can be exhausted or recovered by using an external Helium recovery system (i.e. our Ecomass-R machine, not included). If the Helium leak-sniffing test is not required, PQ Helium can be used to charge Nitrogen (dry air) just for washing-stressing purposes and pressure decay leak tests. As option second filler can be added to do it in addition.

Technical Features. PQ Helium allows up to 20 work phases per cycle and storing of up to 10 different cycle programs. It has 1 filler and an optional 2nd one. It has 2 RS232C interfaces for bar coder reader and PC or Printer, a 2-stages vacuum pump of 8m³/h and can work with up to 30 bar Helium and N_2 or air.

Typical Phases of the Working Cycle and Cycle Times: 1. Evacuation (14-19s), evtl. a vacuum leak test (8s), 2. Helium charge (5-7s), Helium decay test and Stand-by (for manual leak search), 3. Helium leak test by separate Helium leak detector (8-12s 2s per joint), 4. Helium exhausting or recovery (5-6s) and 5. Final evacuation (3s), **Totally 35-55s**.

Operation. The parameters of the working cycle are programmable by the user, using the keyboard. The programmable data are the following: evacuation time and set-points, vacuum leak test time and set points, max and min Helium pressure set-points, Helium charging and exhausting times, Helium decay test time and set-points, etc.. The cycle starts either by pressing the START button or by bar code identifying model to select adequate program and to store as option test data under refrigerator serial no.. After the vacuum phase, the Helium charge and decay test, it comes in stand-by condition, waiting for the manual sniffing. After the test, by pressing a button, the Helium is exhausted (or recovered). When using Nitrogen (dry air) instead of Helium the manual sniffing phase is jumped. If options are needed it is economical more feasible to select Astra III with more features.

4.7.3. Galileo PQ Leak

Pliers sniffer clamp

Galileo PQ leak looks like PQ Helium, but it works with pliers sniffer clamps to be fixed upon leak joints. Up to 7 sniffer clamps can be connected. Such clamps reduce operator mistakes using only sniffer tips to fail leak points and even allow sniffing in contaminated atmosphere (see chapter 4.5. p.35). Different clamps are available. It needs the leak detector Inficon Protec or Ecotec to be added and linked to the machine. All other features like option for bar code and PC connection to store data are like PQ Helium.

4.7.4. Galileo ASTRA-III, Nitrogen or Dry Air and Helium Charging and Test Board

Astra-III is the mayor machine of Galileo for leak pressure testing, drying/washing and stressing of hermetic units of refrigerators and air-conditioners. Astra-III is able to evacuate the unit under test and to pressurise it with dry air or Nitrogen. To speed up cycle time on larger cooling circuits >5l or to become fast in household models it is recommended to use the Astra III S with larger inner diameter tubes and valves. Two fillers are standard feature of Astra-III: they allow both the quicker Helium charge and the flow test, i.e. through a capillary, to verify whether it is fully open, or clogged (squashed) or partially clogged. This test can be carried out either by using Nitrogen, dry air or Helium. By using an optional kit, the flow can also be measured. Special circuits (optional) can detect both the purity of the Helium used for leak test and the humidity of the gas, Nitrogen or Helium, used for washing and pressurising. The cycle phases are fully programmable: the user decides and programs not only the parameters proper of each phase, but also the sequence of the phases and their eventual repetition. Also the use of the 2 different gas lines, even in the same working cycle, is programmable by the user. An RS-232 serial interface (optional) can automatically select the working cycle by using a bar code reader (optional device). Normally, a "typical" cycle starts with the washing - stressing phase by dry air or Nitrogen. After the gas exhausting, the evacuation phase starts: when the vacuum is reached, it performs the leak test under vacuum, by the pressure rise method (rough leak test). Then, the unit is pressurised with Helium: the machine tests the Helium tightness (Helium decay test). After that, the leak search (fine leak test) is manually performed by using an external Helium leak detector (sniffer, not included). It is possible to connect the external sniffer with the Astra-III by a normally open relay contact: by detecting a leak, the contact closes and the Astra-III displays the leak condition. The other tests (Helium purity, humidity, clogged capillary tests) can be also carried out at different phases of the cycle. After the tests, the Helium can be exhausted or recovered by using an external Helium recovery system (i.e. our Ecomass-R machine or Herec N200, not included). An RS-232 standard serial interface (optional) allows the availability of the data forming the result of the test (passed, no passed) on external PC or printer (not included). The Hansen connectors as option can be automatically open and closed to speed up process and to enable further automatic test cycles and test configurations.

Typical phases of the programmable automatic **working cycle** (in brackets the ones often not used) and needed **cycle times**:

1. **Pressure test** (up to 40bar) consisting of a) pressurisation/washing/stressing by N_2 or dry-air (6-8 s), b) pressure stabilisation (2-3 s), c) a N_2 or dry-air decay leak test (3-8 s), d) N_2 or dry air discharge (6-8 s), totalling to 17-24 s which can be combined with Flow test (right mounted and not clogged capillary), option: Flow value measurement (+/-10% accuracy) and option: Moisture test (by hot filament) during discharge.
2. **Evacuation** with 12 m3/h, double stage pump consisting of a) evacuation for fast cycle down to 200mbar (recovery at 300mbar) (5 s) and for slower cycle down to 40mbar (recovery at 100mbar) (20 s), in cooling circuit, the set values are 20 times smaller (dynamic problem), eventually a vacuum leak test (only a rough leak test) for slow cycle time useful (8s), totally 5s (in fast systems) up to 28s.
3. **Helium charge** (up to 30 bar) consisting eventually of Helium decay test during stand-by for Helium leak test (9-34 s) and as option: Helium purity test (which is already part of recovery units).
4. **Helium leak test** with separate unit of He- leak detector (Protec) either by manual leak search or as option automatically with Multisniff using above mentioned pliers and a multivalve system totally 8-14 s (2 s per joint)
5. **Helium exhausting (or recovery)** (3-6 s) with the option of gas humidity test and elimination of rest of Helium (3s)

Totals of cycles: 40-81 s.

By separation of this work into 3 workplaces using a separate recovery station the cycle time will be 30-32% less (see underneath).

Power supply and consumption:	400Vac 50Hz 3ph (others on request) 570W
Dimensions of cabinet and weight:	700x800x1500 mm, with wheels, 165kg

The Astra III machine is very flexible and can be used on different work places with very different test jobs on evaporators, capillary tubes, condensers on complete cooling cycle. **50 different programs** can be stored each with up to **20 different work phases** and different parameters settings. Having to 2 fillers with 3,5m hose and ¼" Hansen female which as option can open and close separately we can program adequate individual test solutions. Furthermore it has as option a programmable communication interface using 2 RS232 plugs for bar code reader, PC/printer or as RS-485 for PLIS system allowing to integrate the machine into a centralized **databank quality control and evaluation system**, either the one from Galileo called **PLIS** as ready made system or to any other already existing or new made databank and evaluation system, as long as it allow to program a driver to read out the transmitted data of Astra on the PC RS232 interface and to store it into own databank.

Option: Galileo Astra Rec Helium recovery Satellite Station

Programming. The parameters of each phase, as well as the sequence of the phases in each working cycle, are programmable by the user, using the keyboard. Some programmable data

1. Evacuation time and set-points
2. Vacuum leak test time and set-points
3. Max and min gas pressure set-points in gas line 1
4. Max and min gas pressure set-points in gas line 2
5. Helium - Nitrogen charging and exhausting times
6. Helium - Nitrogen decay leak test time and set-points
7. Flow test time and set-points
8. Helium purity test set-points

Operation. Once the user programs the Astra-III, it is ready to work. The keyboard can select the working cycle either by bar code reading or manually. After the connection of one or both fillers, the cycle starts by pressing the START button on the keyboard. The phases of the working cycle are carried out automatically according to the programmed sequence, timing and set points. After the vacuum and the Helium charge, there are 2 versions depending on separate recovery with Astra REC or not. If not it comes in stand-by condition (if programmed), waiting for the manual sniffing. After the test, by pressing a button, the Helium is exhausted (or recovered) and the cycle ends. The flow test (capillary test) is performed only if the two fillers are connected to the unit under test. If separate Astra REC is used, it can be disconnected after helium charge and the cycle starts again used for a new refrigerator. Here below, a short description of the possible phases available to compose the sequence of the working cycle:

· **Evacuation** by a double stage vacuum pump either till a certain vacuum set point is reached or programmed time. If using the two fillers, using both of them carries out the evacuation. A **vacuum leak test** to check that pressure increase in set time do not exceed fixed set point can be executed.

· **Pressurisation from Gas Line 1 or 2.** The unit under test is pressurised for the programmed time by using the gas connected to the programmed gas line l or 2. The pressure is also programmable between a minimum and a maximum level. Pressurisation can be performed by using Nitrogen or dry-air, Helium, for washing, stressing or leak testing (He only) purposes. If using the two fillers, the pressurisation is carried out by using both of them. After pressurisation, it can be checked if in programmed time the pressure drop is less when the set-point (**Pressure Decay Leak Test).**

· **Stand-by for Manual Leak Search (only useful without Astra REC).** During this phase, generally after the Helium pressure decay test, Astra-III is waiting instructions from the operator. He is busy in the manual leak pinpointing by using an external sniffer. This phase can end either by the decision of the operator by pressing a button, or automatically in case of leak if Astra-III is connected to the sniffer by a normally open contact that closes on the sniffer in case of leak detection. It is possible to have acoustic and visual alarm in case of leak.

· **Flow Test from Line 1 or 2.** By using the two fillers, Helium or Nitrogen (dry-air) and by knowing the approx. volume of the unit under test, is possible to evaluate the gas flow at the working pressure. This test is not an absolute value measurement of the flow, but it allows the detection of clogged or partially clogged circuits, i.e. when crushing damages them. If using one filler only, the flow test cannot be carried out.

· **Flow Measurement from Line 1 or 2.** This measurement can be performed only if the optional "flow measurement kit' is installed on Astra-III. This test is strictly connected to the previous flow test phase: the advantage is that, by using a flow meter, the absolute measurement of the flow is performed.

· **Gas Exhausting.** The exhausting of the gases used for washing or leak testing (Nitrogen, dry-air, Helium) is carried out in atmosphere for the programmed time. If using the two fillers, using both of them carries out the exhausting phase.

· **Gas Humidity Measurement.** This test can be performed only if the optional "gas humidity measurement kit" is installed on Astra-III. This measurement of the residual humidity of the gas is performed during the gas-exhausting phase. The gas can be Nitrogen, dry-air (after washing phase) or helium (after Helium leak testing). If using the two fillers, using both of them carries out the exhausting phase with humidity measurement.

· **Helium Purity Test.** This test can be performed only if the optional "Helium purity test kit" is installed on Astra-III. This is not a proper phase of the working cycle, but a check test. The purity of the Helium that can be compromised in case of leaks and consequent recovery can be kept under control by using this option. This analysis can be activated with regular internals.

· **Helium Recovery.** If Astra-III is connected to a Helium recovery machine (i.e. our Ecomass-R or Herec) is possible to recover almost the totality of the Helium used for the test and to re-use it. There is also the possibility of programming recovery pressures below the atmospheric value. If using the two fillers, using both of them carries out the Helium recovery phase.

4.7.5. Galileo Multisniffer

The Multisniffer kid can de installed to Astra III. It allows connecting a Sniffer leak detector by a valve group with up to 8 sniffer pliers to clamp over tube and other leak joints. Automatically one after the other are tested by leak detector and leak test results are passed by Astra III via interface (option) to a PC under the refrigerator serial No. if a bar code reader is connected as well (option). This reduces strongly operator mistakes and also background signals and air contaminations.

4.7.6. Galileo Astra V Vacuum Chamber Helium Testing Unit

On evaporators, condensers and heat exchangers with many joints or potential leak points like wire-on-tube welded condensers or some evaporators, the sniffer solution in air (Astra III or C with Protec) is not practical, but a test of the complete piece in vacuum chambers should be applied, as done by the Astra V.

The component is pressurized with Helium and a built-in Helium leak detector **Inficon UL200** is connected to the chamber to measure total leak. The system also allows executing pressure test at 30 or even 40 bar (like Astra III). The size of Vacuum chamber depends from the size and quantities of pieces to be tested. Normally 2 items are tested together. To double the capacity one unit can be connected with 2 chambers (Astra V-2), so that one can be de-loaded and reloaded during evacuation and test run of the other. A roots pump and a rotary vane pump are used to evacuate (minimum 0.01mbar). The leak rate sensitivity is in the range of 0.1-1g/a, depending on evacuation level. To identify leak points the Inficon UL200 can also work as Sniffer system (on Saturdays).

Galileo Ecomass R2

4.7.7. Galileo Helium Recovery: ECOMASS R2 or Herec N 200

The ECOMASS R2 and Herec N200is are systems to store, distribute and recover helium gas. They are used with Galileo's Astra charging boards to minimize Helium costs. Connected with a helium bottle, these units automatically maintain the needed amount of helium in its storage tanks, so there is no need to stop periodically the system to refill. During the recovery of helium from the components, being tested, it is possible to recovery a significant amount of air from leaks and/or other sources. To compensate, the recovery system can automatically determine the helium concentration in the recovery tank and restores the concentration back up to 90% helium. With this option, when the helium concentration goes below a pre-set threshold (e.g. 50%) an alarm occurs. The operator can chose to ignore the alarm or evoke the replenishment of the helium levels in the recovery tanks. A complete change-out, of the "contaminated" helium is also possible. The procedure involves the release of the helium and evacuation of the primary tanks prior to filling with "clean" Helium.

Galileo Herec 200 Helium Recovery Unit looks like the Ecomass R2 only larger 1600x1400x1500 (l*w*h) mm

Construction. Both units consist of 3 process tanks (R2: 3x50 l, N200 3x200 l), two helium compressors, and a metal cabinet containing the electronics. The controlling and monitoring panel is on the front side of the cabinet. The various components are mounted in an open frame with height adjustable casters.

Recovery Capacities. Household refrigerators have about 2-3,5l circuit volumes. For Helium leak detection they are charged with 5-7 bar helium, so that 10-21 N l Helium are needed per refrigerator and nearly the same quantity has to be discharged. The smaller R2 unit with 75 l/min recovery capacity is sufficient to recover from up to 3 Helium charging places working in 45-50 s cycle times each. The Herec N200 a recovery capacity of 145l/min can recover the double, for example up to 3 charging places with cycle times of 25 s or up to 5 charging places with cycle times up to 45 s.

Operation. The microprocessor control logic operates the system according to the pre-selected commands and set points maintaining different helium gas pressures in its tanks and a minimum Helium concentration. The units runs as following:

Normal Operating Cycle. A pressure transducer on each tank interacts with the control electronics to check the operation processes. According to the monitored values and the systems operating condition, the control system activates the required work cycles or sounds an alarm to pinpoint possible trouble. The compressor C1 maintains a vacuum level of about 400 mbar in tank 1 which is connected to the Astra II and Astra Rec to recover Helium from the units under tests. In the 2nd stage tank the gas is kept at a pressure of 1 to 1.5 bar. If the pressure exceeds 1.5 bar (as detected by transducer BP2), compressor C2 is started until the pressure drops down to 1 bar. In the 3rd stage tank the gas is kept at a pressure of about 8-9 bar. The discharge lines of each compressor are equipped with non-return valves to maintain the tank pressures. Furthermore, there is a pressure compensation circuit mounted in the compressor casings. The system periodically checks the helium concentration in the circuit; should the helium percentage be lower than the pre-set alarm level, the system activates a visual/audible signal (which can be silenced), to warn the operator that a helium "restoration" in the circuit is needed.

Helium Pressure Restoring Procedure. The RECOVERY unit continuously checks the tank pressures. If the pre-set pressure values cannot be reached, the unit can automatically perform a refilling operation, provided an external helium bottle is connected. In this case the EV5 valve is energised (opened), so that pure helium is let in the 2nd tank until the pre-set pressure level is attained.

Partial Restoring Procedure for the Helium Concentration. The control system periodically analyses the helium concentration. If the system is correct programmed and has no leak in pipeline the Helium concentration remain automatically on the level as programmed and possible in the cycle time. In case of failure an Helium concentration alarm is sounded and the exceptional "restoring" process must be initiated by the operator (about 10 min.).

Helium Sensor Calibration. This step is used to adjust the sensor's offset and full-scale.

When the system is stopped, it automatically equilibrates the pressure between 1st and 2nd tank occurs to avoid contamination due to the vacuum in tank 1.

Programming and Diagnostic Functions. In the program mode the operator can modify the parameters that define the unit operation and activate the various devices in diagnostic routine. The threshold values (set points) of the three pressure transducers (PT1-PT2-PT3) and of the helium concentration alarm can be altered to follow different operating needs. The two compressors as well as each solenoid valve can be individually powered to check their proper operation. Also the visual and audible alarms can be individually actuated to check their efficiency. Furthermore, a complete diagnostic test on the control electronics is possible.

Controls and Signals. Hand operated valves are located in the following positions: On the helium inlet and outlet connections, the discharge line, and external helium source connection. Each tank is equipped with a mechanical gauge. All the other controls and indicators are located on the cabinet. The **control panel** is equipped with EMERGENCY switch, ON/OFF switches , a Touch-panel keyboard and alpha-numerical display (2 rows, 20 digits), Status lights READY / FAULT and a visual/audible signalling device: red (Emergency), orange (Warning) and green (Normal Operation).

Safety Devices. The following are on board: Control of correct 3ph cyclic direction to protect compressors, EMI-RF filter, magneto-thermal cut-out switches an main supply (3-Ph) and on vacuum pump (3-Ph), fuses with protection device against voltage surges in the electronic control unit; 3 safety valves on the 3 tanks, On the 1st stage tank, the relief valve SV1 opens at the pressure of 1.5 bar; the 2nd stage SV2 at 3 bar and the 3rd SV3 opens at 10.5 bar. All the tanks are equipped with external mechanical pressure gauge (M1, M2, M3).

	Models:	**Ecomass R2**	**Herec N200**
Technical data:	**Dimensions** (h*w*l): **Weight**	1300 x 1100 x 1000 mm 250kg	1500 x 1600 x 1400 mm 400kg
	Power supply: **Power consumption:**	400Vac 50Hz 3-Ph (other on request) 3kW	400Vac 50Hz 3-Ph (other on request) 4kW
	Operating Conditions	Temperature: +5-45°C.	Temperature: +5-45°C.

4.8. Helium detection after final assembly and brazing: Cycle Times, Layouts, Work Phases and Stages

In this chapter all theoretical possible helium leak detection line configurations to control the complete circuit after brazing are described. To decide about optimal layout and equipment configuration it is important to take a closer look on process timing and quality standards reachable in each configuration including the work to connect and to disconnect the refrigerator to equipment, often not mentioned by equipment manufacturers. This would allow finally to adapt the configuration and their timing to the needed cycle times in the production **or** to adapt the final assembly lines to the process and machine times.

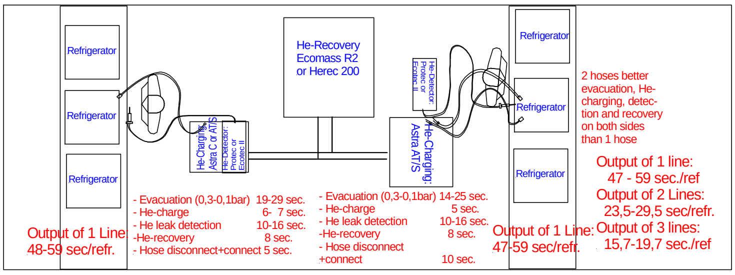
Phases of the Helium leak detection	**and Cycle Times:**	
1. Evacuation (fast to 100-300mbar, slower to 30-80mbar)	14-25 s	
2. Option: vacuum leak test	(8 s)	
3. Helium charge	5-7 s	
4. Helium decay test		
5. Stand-by (for manual leak search)		
Helium leak test by separate Helium leak detector	8-16 s	(2 s per joint)
6. Helium exhausting (or recovery)	5-6 s	
7. Final evacuation	3 s	
8. Quick couplers disconnection and connection (1 or 2 hoses)	5-10 s	
Totals:	35-65 s	

The Helium leak detection can be made by a Galileo Helium charging board with 1 hose, like Astra C or with 2 hoses like Astra III always in connection with a Helium leak detector, like Inficon Protec and a Helium recovery board like Ecomass R2 (75l/min recovery) to which up to 3 Helium charging boards can be connected or a larger recovery board like Galileo Herec 200 (145l/min recovery capacity). Refrigerators, which have access on high and low pressure side can be faster and better evacuated, the Helium faster charged on the high pressure side and the recovery is faster with less contamination. Therefore it is recommended to evacuate from 2 sides and to use Astra III instead of Astra C. In the above mentioned evacuation time of 14 s we reach with 2 side evacuation 30-50mbar. So we can reduce air contamination significantly.

The cycle times including disconnection and connection of hoses of 40-75 s can be reduced by different means, like splitting the process in stages or parallel processing on refrigerators at the same time on further lines:

4.8.1. Helium leak detection lines – complete operations on each machine and parallel lines

a) 1 Helium charging board and 1 Helium leak detector

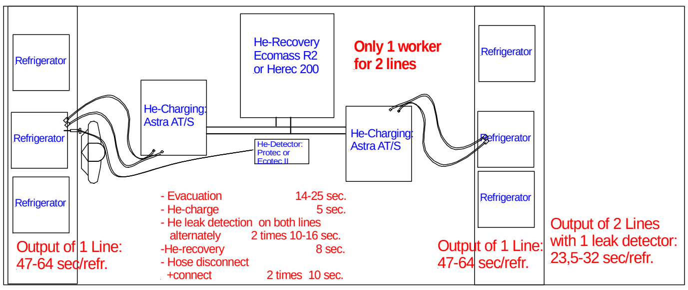


On such lines 20-26 s (leak search by leak detector of 10-16 s and hose connections and disconnections of 10 s) of the total 47-59 s are used for work operations. The mayor part of cycle time is idle, if not used for further checks or work, like pre-evacuation or flushing by dry air (see next chapter extended Helium leak detection). But the idle time also can be reduced by other configurations (version b) and c).

If the factory has to produce one refrigerator inside of 20 s 3 Helium leak detection lines in the final assembly is needed, each with a Helium charging board and a leak detector, but all 3 lines connected to only 1 recovery board; while an output of 30 s per refrigerator could be reached with 2 Helium charging and leak detectors, connected to 1 Helium recovery board.

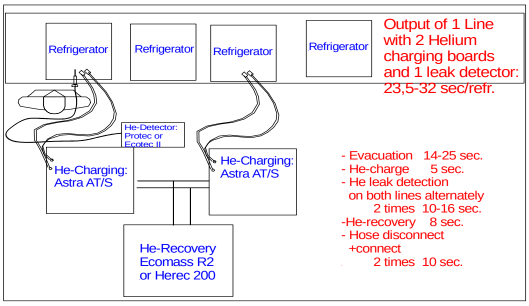
To optimize use of investment following configurations can be made:

b) 1 Helium Charging board per line on 2 parallel lines, but 1 worker and 1 Helium leak detector for both lines



In this configuration 1 worker make the full job on 2 lines with only 1 Helium leak detector, but 2 Astra III. In this case the worker has no idle time. The same can be reached in the version c).

c) 2 Helium Charging board with 1 worker and 1 Helium leak detector



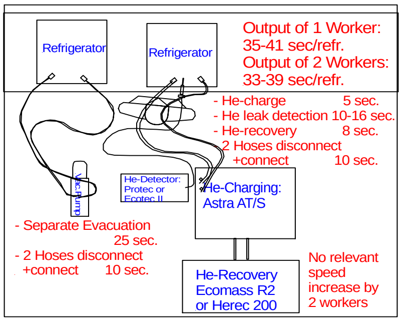
As the time consuming evacuation (14-25 s) and the fast Helium recovery are full automatic, so that no workers is occupied with it except connecting and disconnecting the Helium charging and Helium recovery board (Astra III), he has only to detect leaks normally 5-7 joints, each about 2 s So he can do it on 2 refrigerators one after the other while the other operations are done with 2 separate boards automatically.

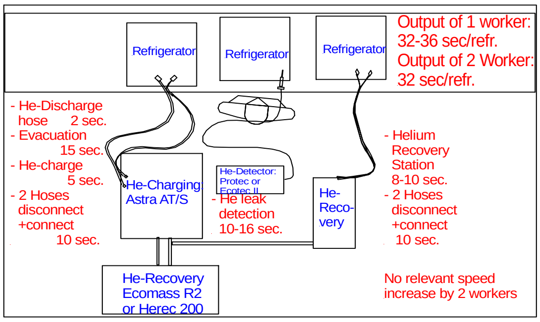
This is an optimal solution for investment and work cost: either to be done on 2 parallel lines (version b)) or to be done on one fast line (version c) with 2 Astra III and only 1 Helium leak detector by 1 operator. But let us see if other remaining theoretical solutions provide improvements concerning utilisation of investment or work.

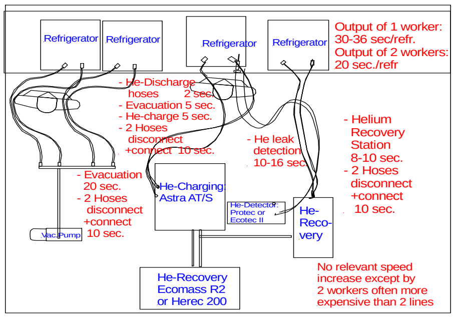
4.8.2. Helium leak detection lines – split in stages

Another possibility to increase output per line is to split the leak detection phases in stages. Two process parts can be split on a separate stage, the evacuation or the Helium recovery by a Helium recovery station (Agramkow or Galileo option) or even both:

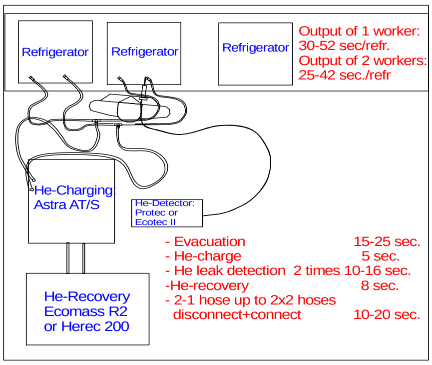
a) Separate evacuation stage b) Separate Helium recovery stage c) Separate evac. and He-recovery







By splitting in 2 stages (version a and b) the cycle time can be reduced by 30-32%, though 17-21 % more work (2 x 2 hoses to be connected and disconnected) has to be done by the operator, which could be used for other works or by the versions 4.7.1. b) and c) combining 2 Astra with 1 Helium leak detector to be operated all by 1 worker, which is anyhow faster than any of these split versions, but more expensive in investment.



The Agramkow standard configuration is the version b). Same could be done by Galileo with Helium recovery station Astra REC. Agramkow catalogue gives a wrong impression by mentioning as minimum cycle time of 20 s Agramkow ignoring the 20 s already needed for the 4 operations to connect 2 hoses 2 times (1 time on each stage) and to disconnect 2 hoses 2 times and just calculate the minimum time for evacuation to 300mbar and Helium charge (20 s) without any Helium recovery from the Helium charging hoses (2 s). In addition an evacuation only to 300 mbar and a Helium recovery to only 600mbar would also increases Helium consumption.

By splitting in 3 stages the cycle time can be reduced by 30-39 %, though 34-43% more works has to be executed, which could be used for other needed operations. The splitting in 3 stages becomes fast (about 20 s) if 2 operators are used. But in this case no other work could be executed in this area as possible under the version 4.7.1.

A separate Helium recovery stage could easily be combined with the pre-evacuation of refrigerators. Pre-evacuation of 1-2 min. as today normally done in the production, anyhow follows the Helium leak detection on the final assembly line (See the chapter after the next one).

4.8.3. Helium leak detection on 2 refrigerators at same time

Nearly similar cycle times as by splitting the operations can be reached by Helium leak detection of 2 refrigerators at the same time, if 1 hose per refrigerator is used 30-36 s/refrigerator (each with 5-8 joints to be checked). Using 2 hoses per refrigerator, which improve quality, the 20 s as needed to connect and disconnect 4 hoses has to be added to the leak detection time of 2 times 10-16 s, so that the total cycle time per tested refrigerator is with 40-52 s slower than reachable by splitting the Helium leak test in 2 stages.

4.8.4. Résumé of chapter 4.8.

To execute complete leak detection operations in one stage causes the less work possible, but reduce only work costs, if idle time of operator will be used for further needed operations; the best use of costly work capacity is to combine 2 Astra III with 1 Helium leak detector all operated by 1 worker. This is an optimal solution for developed countries with higher labour costs. € 17000 for a second Astra III to double the capacity on a line already equipped for a Helium leak detection would have a high financial internal rate of return, if the capacity is needed. The process can be easy integrated into a process information system using bar code readers.

For countries with lower labour costs and companies with limited investment resources other solutions could be still favourable, like splitting the operation in 2 stages by a separate Helium Recovery Station for about €6000 (4.7.2. b) saving 30-32% cycle time) or even 3 stages, if work costs are cheap, or combining 2 refrigerators together during the operation on one Astra III (4.7.3.), which reduce cycle time by 12-36 %.

The Galileo equipment has the advantage that all configurations can be realized and that they are cheaper.

After final assembly a lot other works and controls normally have to be done - in addition to the Helium leak detection - to improve refrigerator performance quality and lifetime, to reduce reworks and last not least to avoid any failure after the sales in the first 15 years. Therefore refrigerator manufacturers demanded equipment manufacturers to add at this stage further works and controls, described in next chapter.

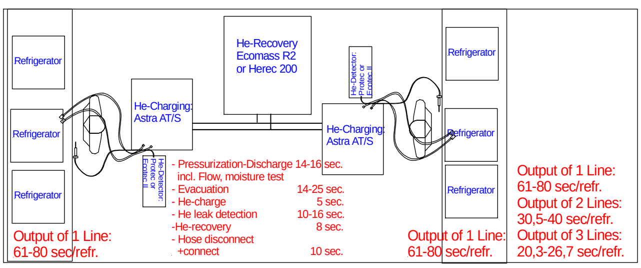
4.9. Extended Helium leak detection after final assembly and brazing

An **Astra III** in combination with a leak detector like **Inficon Protec** and a recovery board, like **Ecomass** R2 or Herec 200 can make additional processes from pressure test, drying, moisture control, capillary tube test, (last only, if circuit has 2 connection hoses like by evacuation from 2 sides), till Helium charging, leak detection and recovery, while an **PQ Charge** can make only Helium charging or pressure test, but not both.

If all possible processes including pressure test, flushing/drying, capillary tube test is made on an Astra III with Protec and recovery board by 1 worker about 50-70 s cycle times is needed including the needed operations to connect a refrigerator to the system and to disconnect it again; if only Helium leak test is executed an Astra with Protec by 1 worker 47-59 s is needed. These standard configuration and involved cycle times can be modified by additional equipment, by removing parts of phases on separate machines in a parallel work stage or by charging and recovery of 2 refrigerators in parallel operation similar as we have seen in last chapter.

A:	**Phase of Pressure, drying and capillary tube test**	**Cycle times:**
1.	Pressurisation/washing/stressing by N_2 or dry-air	5-7s
2.	Pressure stabilisation	2-3s
3.	(evtl. N_2 or dry-air decay leak test)	(3-7s)
4.	Dry air or N_2 discharge	5-7s
5.	Flow test (right mounted and not clogged capillary)	Subtotal12-24s
6.	Option: Flow value measurement (+/-10% accuracy)	
7.	Option: Moisture test (by hot filament) during discharge	
B:	**Phases of the Helium leak detection**	
8.	Evacuation (fast to 300mbar, slower to 100mbar)	10-25s
9.	(Evtl. vacuum leak test)	(8s)
10.	Helium charge	5-7s
11.	Helium decay test	
12.	Stand-by (for manual leak search)	
	Helium leak test by Helium leak detector (2s per joint)	8-16s
13.	Helium exhausting or recovery	5-6s
14.	Final evacuation	2-3s
15.	Quick couplers disconnection and connection	10s
	Totals:	**52-99 s**

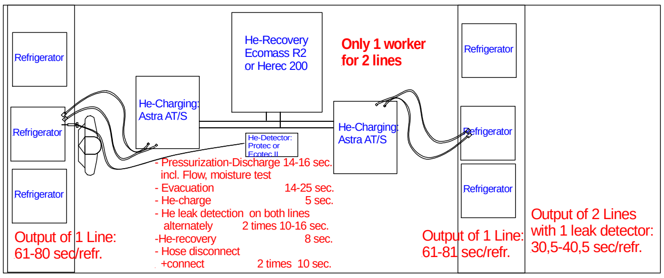
4.9.1. Extended Helium leak detection lines: Complete cycle on each machine and parallel lines



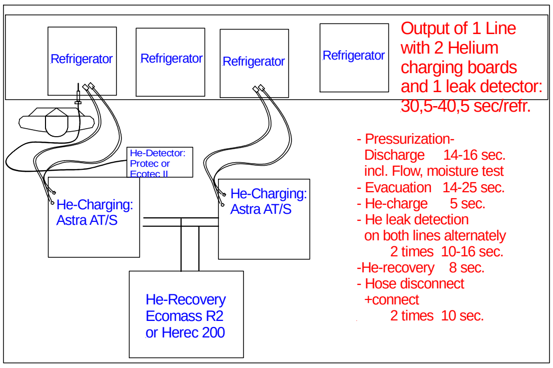
a) 1 Helium Charging board and 1 Helium leak detector per Line

Inside the cycle time of 61-80 s the worker has to execute 20-26 s work and can do in the remaining time further operations. For this reason the same capacity can be reached on 2 Helium charging and recovery lines with only 1 leak detector (version b)) or on 1 lines with 2 Helium charging boards and 1 leak detector (version c)).

b) 1 Helium Charging board per line, but 1 worker and 1 Helium leak detector for both lines



In this configuration 1 worker make the full job on 2 lines with only 1 Helium leak detector, but 2 Astra III. In this case the worker has low idle time without being exhausted in his work. The same can be reached in the version c).



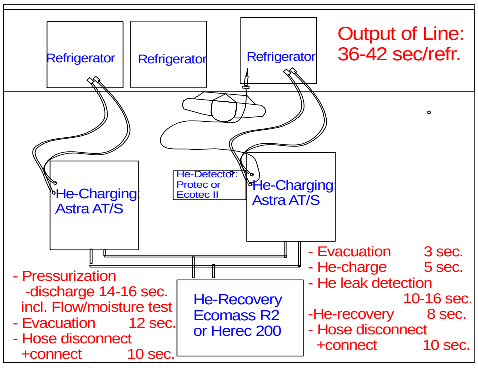
c) 2 Helium Charging board with 1 worker and 1 Helium leak detector

As the time consuming pressurization, flushing/drying, evacuation, discharge operations are full automatic, so that no workers is occupied with it except connecting and disconnecting the Helium, dry air and Nitrogen charging and Helium recovery board (Astra III), he has only to detect leaks normally 5-7 joints, each about 2 s So he can do it on 2 refrigerators one after the other while the other operations are done with 2 separate boards.

This is an optimal solution for investment and work cost:
- either to be done on 2 parallel lines (version b)) or to be done on one fast line (version c) with 2 Astra III and only 1 Helium leak detector by 1 operator.

But let us see if other remaining theoretical solutions provide improvements concerning utilisation of investment or work.

4.9.2. Extended Helium leak detection lines split in stages

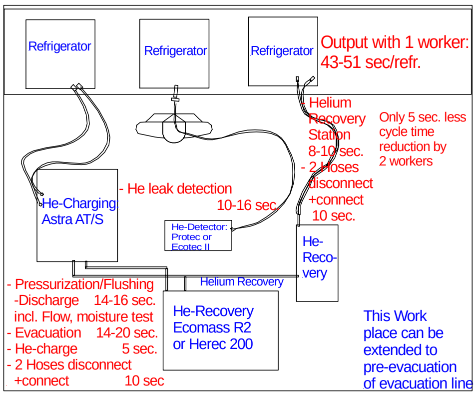


a) 2 Helium, dry air and Nitrogen charging boards on same line with 1 operator and 1 leak detector

This configuration looks very similar to the last one (4.8.1. version c): the full process is split on 2 Helium charging boards Astra III, but only 1 Helium leak detector and 1 operator is used. This is not faster as if the full cycle operations with all needed phases are done by each board in parallel. So we discard such a solution as it does not have any advantage in comparison to the solutions 4.8.1. versions b) and c).

b) Separate Helium recovery station on extended Helium lines

Such a solution with relatively low investment of about €6000 for the Helium recovery station reduces the cycle time by 30-36%, in comparison to a second Astra III for about €17000 which reduces the cycle time by 50%. In countries with limited investment resources this could be a solution.



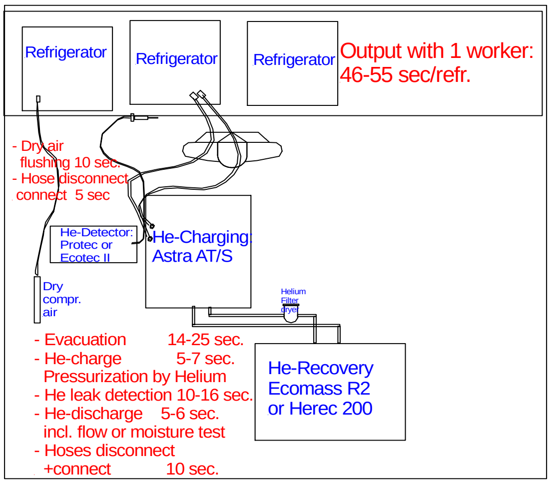
The recovery station can be combined with the pre-evacuation, which has to be done anyhow at this stage if today's evacuation know how is applied which pre-evacuate a refrigerator system by 1-2 min, stop evacuation by 5-8 min. and execute afterwards the final evacuation by 7-15 min. Such a separate Helium recovery station consists of a vacuum pump (5m³/h if only used for Helium removal; 12-18m³/h) if combined with pre-evacuation as step of evacuation, 2 solenoid valves and a control board.

The Helium leak detection after final assembly and brazing of the cooling circuit are followed by the evacuation process, today done in 2 stages: pre-evacuation 60-120 min., waiting time of 6-8 min. and final evacuation of 15 min. Therefore it is useful to combine the Helium recovery with the pre-evacuation to an automatic station with red and green signal lamps to remove Hansen connections when it is finished and reconnected it to next refrigerators for Helium recovery and pre-evacuation.

c) Separate Drying by dry air on extended Helium lines

If drying was already done before the 2 phase groups A and B can be combined to speed up process as following:

Operations:		**Cycle Times:**
0.	Flushing by dry N_2/dry-air on separate hose cycle time	10-20s
Phases of Pressure, capillary tube test and Helium leak detection		
1	Evacuation (fast to 300mbar, slower to 100mbar)	12-25s
2	Option: vacuum leak test	(8s)
3	Helium charge	5-7s
	Pressurisation/stressing by Helium, Pressure stabilisation, Helium decay test	
4	Stand-by for Helium leak test by Helium leak detector (2 s per joint)	8-16s
5	Helium exhausting or recovery	5-6s
6	Flow test (right mounted and not clogged capillary)	
7	Option: Flow value measurement (+/-10% accuracy)	
8	Option: Moisture test (by hot filament) during discharge	
9	Final evacuation	3s
10	Quick couplers disconnection and connection	10s
	Totals:	**43-75s**

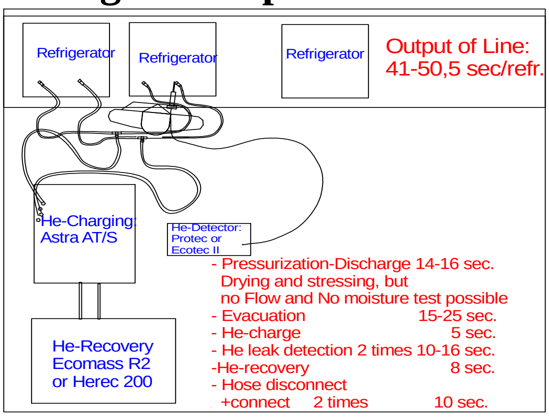


To avoid humidity inside the Helium in case drying failed, a filter dryer should be added and the filter insert regularly exchanged by a dry one.

4.9.3. Extended Helium leak detection lines on 2 refrigerators parallel

Using only one Astra III to connect with 2 Te 2 refrigerators parallel and 1 leak detector all operated by 1 operator is a quite cheap solution. Inside of 82-101 s 2 refrigerators are made, that means per refrigerator a cycle time of 41-50,5 s instead of 61-80 s by connecting only 1 refrigerator to the Astra III. This is an increase of capacity by 30-37 % only by adding few meters of hoses, 2 ¼" female Hansen and 2 Te's).

The disadvantage is that the humidity test is useless (an average humidity of 10% does not mean that both refrigerators are good. It could be one good and the other bad). Also a flow test parallel made on 2 refrigerators has limited validity.



4.9.4. Résumé of chapter 4.9. Extended Helium leak detection

To execute extended leak detection operations including stressing, drying, humidity and/or capillary tube control the technically best way are configurations using 2 Galileo Astra III and 1 Helium leak detector Inficon Protec all operated by one worker, either installed on one line or on 2 parallel lines. This is an optimal solution for developed countries with higher labour costs. € 17000 for a second Astra III to double the capacity on a line already equipped for a Helium leak detection would have a high financial internal rate of return, if the capacity is needed. The process can be easy integrated into a process information system using bar code readers.

For countries with lower labour costs and companies with limited investment resources other solutions could be still favourable, like splitting the operation in 2 stages to separate the Helium recovery station (€6000) (4.8.2 b)), which increases the capacity by 22-31%, if work costs are cheap, or combining 2 refrigerators together during the operation on one Astra III (about €160) (4.8.3.), which increases the capacity by 30-36%. A second Astra III(€17000) on a complete Helium leak detection line is doubling the capacity, while a separate recovery station is increasing the capacity by about 22-31%, so that under financial aspects the difference can be neglected, if the capacity is fully used. The best cost/capacity ratio is reached by the connecting 2 refrigerators on one Astra III without increasing work operations.

A separate Helium recovery station would still allow operations like humidity test and flow test, while this is not possible respective strongly limited in their validity by connecting 2 refrigerators to 1 Astra III parallel(4.8.3.), the cheapest solution to increase the capacity.

4.10. Capillary tube testing, evaporator drying and Helium leak detection on evaporator group

To avoid the leaking evaporator groups are integrated to the production with more reworks in case of leaking, normally the evaporator group is pre-tested on leaks before. If joints are underneath foam, like in European style foamed in evaporators a pre-test is a must because after foaming leaks cannot be identified in the factory before distribution of the refrigerator to the field. The equipment used for this test is the Astra III with 2 hoses. The group is connected to the suction tube and to the capillary tube quick couplers and following phases are executed during test in the times mentioned:

A:	**Phase of flushing/pressure, drying and capillary tube test**	**Cycle times:**
1.	Pressurisation/flushing/stressing by N_2 or dry-air	6-8s
2.	Pressure stabilisation	2-3s
3.	Dry air or N_2 discharge	6-8s
4.	Flow test (right mounted and not clogged capillary)	
5.	Option: Flow value measurement (+/-10% accuracy)	
6.	Option: Moisture test (by hot filament) during discharge	
B:	**Phases of the Helium leak detection**	**14-19s**
7.	Evacuation (fast to 300mbar, slower to 100mbar)	12-18s
8.	Helium charge	3-5s
9.	Helium decay test	
10.	Stand-by (for manual leak search with Protec) Helium leak test by Helium leak detector(2s per joint)	2-6s
11.	Helium exhausting or recovery	3-5s
12.	Final evacuation	1-2s
	Totals:	35-55s

To speed up the total process to a cycle time down to 20 s the drying with dry air or Nitrogen can be made separately and Helium can be used for stressing, flow test and moisture control as following:

A:	**Phase of flushing and drying on separate hose**	**Cycle times:**
1.	Flushing by dry N_2 or dry-air	12-15s
B:	**Phases of the Helium leak detection**	
2.	Evacuation (fast to 300mbar, slower to 100mbar)	10-15s
3.	Helium charge	3-5s
4.	Helium decay test	
5.	Stand-by (for manual leak search with Protec) Helium leak test by Helium leak detector (2s per joint	2-6s
6.	Helium exhausting or recovery	3-5s
7.	Flow test (right mounted and not clogged capillary)	
8.	Option: Flow value measurement (+/-10% accuracy)	
9.	Option: Moisture test (by hot filament) during discharge	
10.	Final evacuation	1-2s
	Totals:	18-31s

4.11. Helium consumption costs and reduction possibilities

The Helium consumption is caused by 2 effects, under the condition that the circuit is leak tight:

1. The **difference between evacuation pressure** (for example 0,2 bar) and **Helium recovery pressure** (for example 0,3 bar) is the main loss of Helium, for example for a test on a 3l cooling circuit and a pre-test on a 1,2 l evaporator group at:

    - At Delta p=100mbar 0.3Nl Helium per refrigerator without pre-test and 0,42 Nl Helium including pre-test;
    - At Delta p=200mbar 0.6Nl Helium per refrigerator without pre-test and 0,84Nl Helium with pre-test;
    - At Delta p=300mbar Helium 0.9Nl Helium per refrigerator without pre-test and 1,26Nl Helium with pre-test.

2. The contamination of air remaining inside the circuit because of short time for evacuation before Helium charging, the lower the circuit to be charged with Helium is evacuated the less Helium contamination and consumption, which needs replacement of contaminated Helium (normally after 50% of contamination), for example

    - At 0,1 bar of 3l volume of 0,3l per cooling circuit, with pre-test 0,42l air contamination per refrigerator
    - At 0,2 bar of 3l volume of 0,6l per cooling circuit, with pre-test 0,84l air contamination per refrigerator
    - At 0,3 bar of 3l volume of 0,9l per cooling circuit, with pre-test 1,26l air contamination per refrigerator

These 2 effects together cause the Helium consumption. In high speed cycle without separate evacuation pump evacuation is often made only down to 0,3 bar and recovery at made down to 0,5bar so that it results to 1,5Nl per cooling circuit, with pre-test 2,1Nl per refrigerator; In lower speed cycle or by evacuation on separate pump, the delta p is normally 0,1bar and evacuation down to 0,1 bar so that a consumption would be in the range of 0,6l per cooling circuit, with pre-test 0,84l per refrigerator. The pre-testing of the evaporator group (about 0,7-1 l volume) is in all cases useful, but a must in case of foamed-in evaporator with joints behind the foam, not anymore testable after foaming.

Helium density: 0,069g/cm³=0,069kg/l = 0,069 t/m³

A Helium are supplied in bottle up to 50l with 150-200bar. The Helium gas market today is practically monopolized - at least in regions - and its price (Grade 4.6 =99,995%) per Nm³ is quite high, between €10-16 in industrial purchase. Such high purity (Grade 4.6 =99,995%) is not needed, as we use it down to 50% Helium content. A Balloon gas purity of >95% or a grade of 2,5 (=99,5%) is more than sufficient as long as the humidity is kept under control (<25ppm).

Helium test on 500000 refrigerators per year consumes 420m³ Helium (delta p=100 mbar, pre-evacuation 0,1 bar), up to 1050m³ Helium (delta p=200mbar; pre-evacuation at 0,3 bar), which causes the consumption of 46 up to 114 of a.m. bottles and results to a Helium leak test costs of € 0.008 up to €0,03 Helium 4.5 per refrigerator. The costs for Helium consumption is negligible and often less than the loss of R600a refrigerant for leak detection, cause by re-works.

By modification of some machines like the Astra REC Transfair is able to reduce Helium consumption by about 57%. We recover much more Helium as in the standard machines and by this way we reach such large savings. But we work with higher air contamination degree of Helium, which does not have effect on He-leak detection and quality of the cooling circuit as we program it into the machine. To reach optimal configuration we have an MS-Excel simulation program, which based on empirical measurement data.

Suppliers of Helium in Europe are German Linde (www.linde.com), Swedish AGA and BOC (both belong to Linde) and French Air Liquide (www.airliquide.com). In Russia UralTechGas Ekatarinburg and Technical Gas Izvesk and in USA Air Products and Chemicals (www.airproducts.com) and Praxair (www.praxair.com).

4.12. Costs and Amortisation

Such Helium leak detection lines including Helium recovery (Helium is expensive and should be reused) are quite expensive:

- a Galileo complete line about € 53.000 for first place with Astra III, Astra REC, Protec and Ecomass R2 and additional € 35000 for a second place , because in case of Galileo as the same recovery unit can be used,
- Agramkow complete lines about €60000 (HRS6 and Protec) for each places, because Agramkow needs practically for each Helium charging board a recovery board because the distance between recovery board and refrigerator is limited to 10m so that the second place costs the same as the first.

For such application a Helium leak detector Protec is used (€16.500). A mass spectrometric leak detector which measures all gases and refrigerants -starting from the molecular weight of Hydrogen (2), Helium (4) up to 200 containing all known and theoretically in future existing refrigerants like the ECOTEC E3000 would cost more (€ 27000) and such a mass spectrometric leak detector is needed to control sealing of filling tube and tube on filter dryer, if the system was evacuated from 2 sides. This investment is quite high. On a refrigerator production for up to 300000 refrigerators per year consisting of 4 leak testing places (2 with Helium and 2 for refrigerant) the investment is in the range of € 150000. The leak cost per refrigerator with 10 years equipment amortisation is in the range of €0,06. But taking into consideration the costs of repairs in the field and image damage in case of failing, the investment is justified.

- For example in developing countries, if 1% of products are leaking, which will fast damage the compressor and the service cost reaches ranges of € 50 such an investment would already be amortised after the production of 300000 refrigerators already, that means inside of 1 year and in further produced refrigerators € 0,5 per refrigerator would be saved. If the service rate is 0,5 % the amortisation is reached inside of 2 years, in case 0,33% fail, inside of 3 years etc. And service rates of 0,33-1% are quite realistic in developing countries.
- In developed countries such failure rates do not exist. Even if every 10000 refrigerator would fail (=leak failure rate 0,0001%) the damage on refrigerator product and trade mark reputation would be so strong, that the company and trade mark will not survive. So such Helium and mass spectrometric leak detection lines are standard in household refrigerator production today.

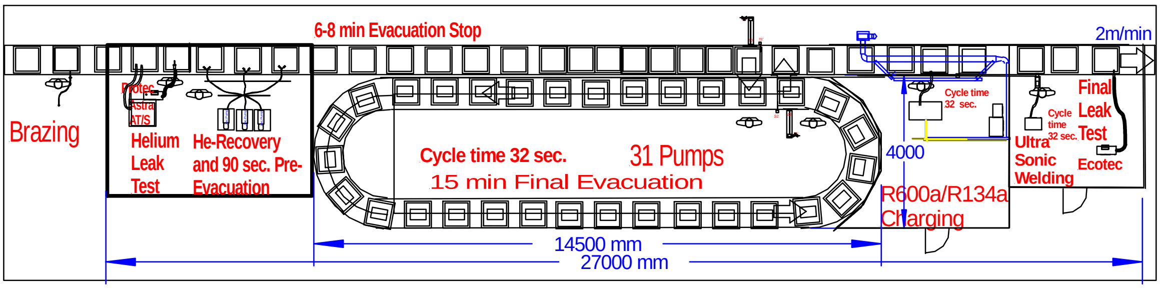
See the technical description of such leak detectors, Helium chargers and recoveries in the different chapters.

4.13. Selected layouts for Helium leak detection and evacuation

All layout configuration for a leak test place are already shown in the chapters **4.7. Helium detection after final assembly and brazing** and **4.8. Extended Helium detection after final assembly and brazing.** We select here only some layouts with integration to the other lines.

4.13.1. Helium leak detection and evacuation in 32s cycle time

In case **only Helium leak detection** has to be executed without pressurization, drying, humidity or flow tests following layout can be made to realize 32 s cycle time.



1 Helium charging board Galileo Astra III,
1 Helium leak detector Protec
1 Helium recovery board Galileo Ecomass R2

3 Galileo He-recovery and pre-evacuation stations

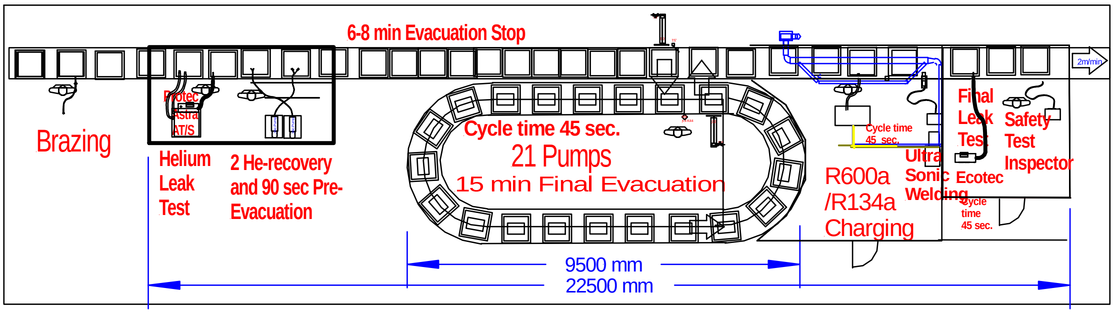
31 Galileo pumps D18

1 charging board Galileo Frigus H11/H22

1 Ultrasonic weld. Stado RSA-3000
1 leak detector Ecotec

4.13.2. Extended Helium leak detection and evacuation in 45s cycle time

In case extended **Helium leak detection** has to be executed with pressurization, drying, humidity or flow tests following layout can be made to realize 45 s cycle time.



1 Helium charging board Galileo Astra III,
1 Helium leak detector Protec
1 Helium recovery board Galileo Ecomass R2

2 Galileo He-recovery and pre-evacuation stations

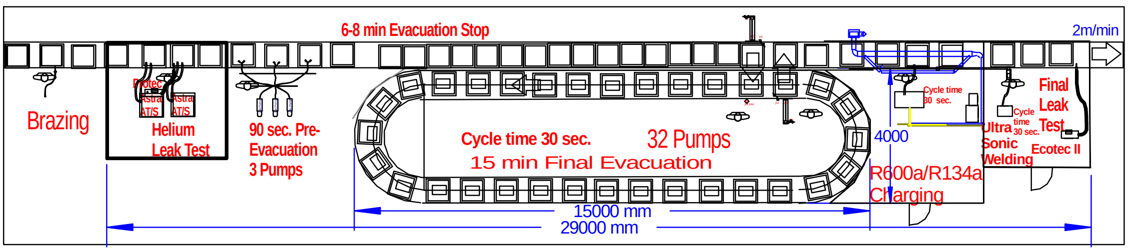
21 Galileo pumps D12

1 charging board Galileo Frigus H11/H22

1 Ultrasonic welding Stado RSA-3000

1 Inficon Ecotec
1 Safety tester

4.13.3. Extended Helium leak detection and evacuation in 30s cycle time



2 Helium charging boards Astra III,
1 Helium leak detector Protec
1 Helium recovery board Galileo Ecomass R2

3 Galileo pumps D18

32 Galileo pumps D18

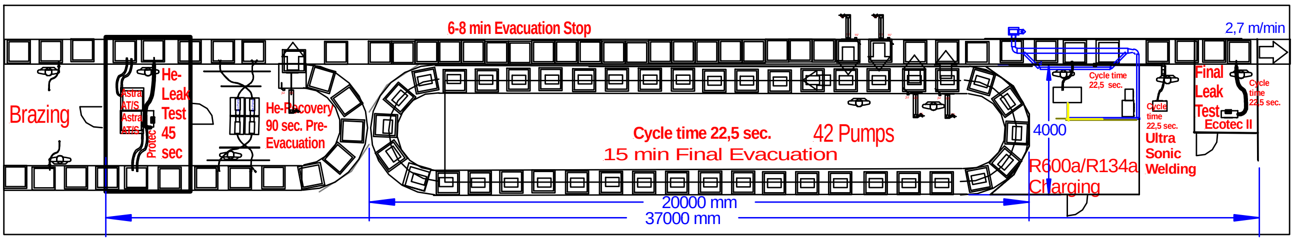
1 charging board Galileo Frigus H11/H22

1 Ultrasonic welding Stado RSA-3000

1 Inficon Ecotec

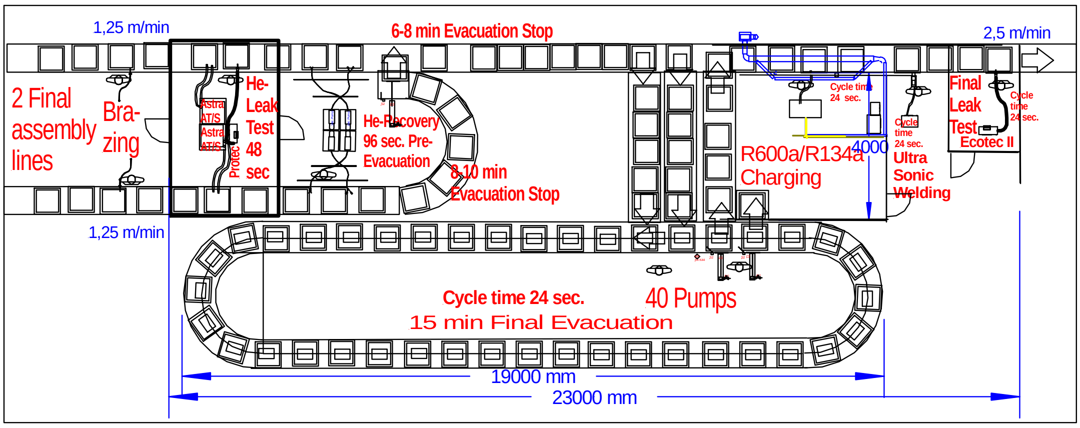
4.13.4. Extended Helium leak detection and evacuation in 22,5 s or 24 s cycle time

On 2 final assembly lines, extended Helium leak detection and Helium recovery are made in 45 s cycle time and joint together for evacuation, refrigerant charging, closing and final leak testing in 22,5 s cycle time



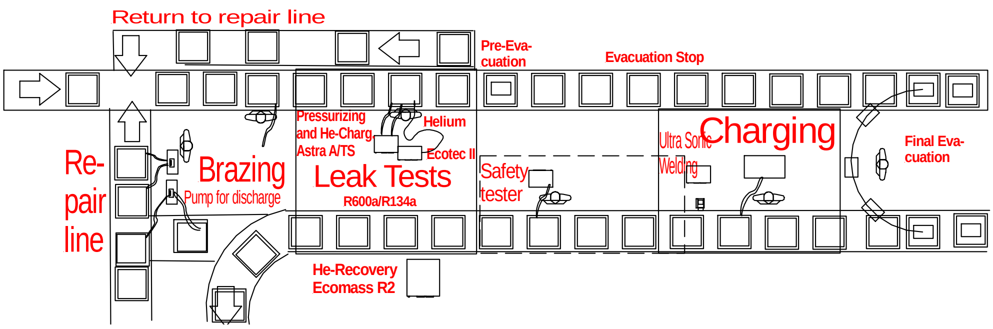
- 2 Helium charging board Galileo Astra III, 1 Helium leak detector Protec, 1 Helium recovery board Galileo Ecomass R2
- 4 Galileo He-recovery and pre-evacuation stations
- 42 Galileo pumps D12
- 1 charging board Galileo Frigus H11/H22
- 1 Ultrasonic welding Stado RSA-3000
- 1 Inficon Ecotec

2 Helium charging board Galileo Astra III
1 Helium leak detector Protec
4 Galileo He-recovery and pre-evac. stations
40 Galileo pumps
1 Galileo Frigus charging board
1 Ultrasonic welding Stado
1 Inficon Ecotec
1 Galileo Ecomass



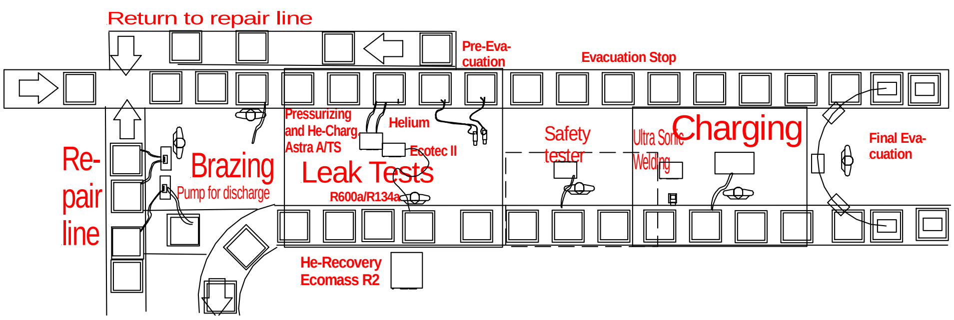
4.13.5. Combined Helium leak test after assembles and Refrigerant leak test after filling hole closing

For cycle times of **47-64 s for helium leak detection** or **61-80 s for extended Helium leak detection** using only 1 mass spectrometric leak detector Ecotec II for 2 different tests: Helium leak test on the complete cooling system before evacuation and final leak test on R600a after filling tube closing.



The ultrasonic welding could be made together with the refrigerant charging and the pre-evacuation together with safety test.

By using a separate Helium recovery board and combine it with pre-evacuation the cycle time would be **32-36 s for helium leak detection** or **36-42 s for extended Helium leak detection** still using only 1 mass spectrometric leak detector Ecotec II for 2 different tests: Helium leak test on the complete cooling system before evacuation and final leak test on R600a after filling hole closing.



4.14. Leak Test Rooms

Refrigerator leak testing without a slightly pressurised leak test rooms is useless! Too much refrigerant and also Helium in use for leak testing in the production atmosphere would strongly reduce the sensitivity by removing the background signal noise.

Test Room Construction. To improve the leak test sensitivity needed for quality and safety reasons and to protect the probe against dust, if any, we recommend to build leak test rooms, normally 2 on each line, for example in the dimensions 2500x2500x2800mm (l*w*h) for cycle times >35 s and max 9 leaks for fast mass spectrometric measurements. For shorter cycle times, faster conveyors and or more leaks to be tested the test room dimension parallel to the conveyor have to be prolonged to 3 up to 5m. Steel or Aluminium construction (T-bars or special profiles), wooden walls and acrylic glass or normal glass around the room in the height of 800-2000mm, one door for the worker and 2 opening of 1900mm height above the roller conveyor (normally in the height of 600-700mm) with PVC plastic stripes so that the refrigerators can pass. A Second ceiling of PEG board ceiling or jute textile 200mm underneath main ceiling is needed for slow air flow (see Transfair Engineering: R600a Charging lines, Düsseldorf 2000, p. 56f).

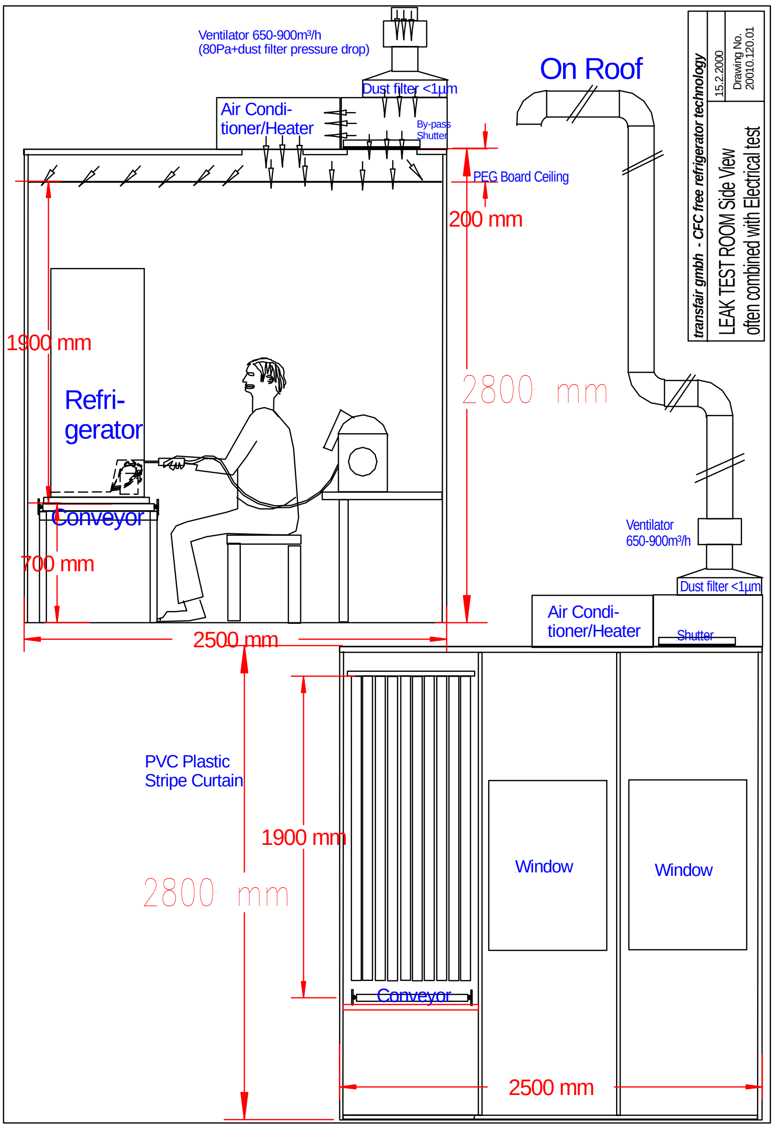
Ventilation and Dust Filtration. The test room has to be slightly pressurised by a ventilator taking the air from outside the building. If the air is pullulated by dust a fine filtering normally in the range of 1 µm of the in-going air is needed to protect the leak detector probe, their filters, pumps, pump motors against dust and electronic against overheating as result of thermo-isolating dust. The filter surface should be increased (at least to double or triple) to avoid strong pressure drop, or the pressure differential of the ventilator must be increased (to doubles or triple).

A contaminated test room of the size of 2.5x2.5x2,8m has a net volume of 16m³; To exchange completely the air inside of 1 ½ Min. a 650m³/h ventilator with 80-100Pa plus dust filter pressure drop (!) is needed which would be sufficient for a cycle time of 45 s For cycle times of 35 s already 835m³/h at 80-100Pa plus dust filter drop are recommended for such a net volume.

The leak detector should be positioned >700mm above ground to avoid dust.

Air Conditioner, Heater or Cooler-Heater Combination. The operation conditions to be kept for the leak detector Inficon ECOTEC 500 plus or UL200 is 10-35°C and for an ECOTEC II or Protec II 10-45°C – all under the condition that inside machine is clean from dust so that the heat can be removed by convection. On days with temperatures above 32°C the leak test room have to be air conditioned and on days underneath 17°C heated (out-door temperature because of ventilation!) to insure operation conditions of leak detector and aid in the comfort of test personnel doing this most relevant work in refrigerator production. Fan ventilators cannot be used as no leaks can be measured in such an airflow.

The cooling as well as the heating capacities of such equipment depends mainly on the temperature difference to be reached. Because of overpressure ventilation air to be cooled or heated are not recycled. For many areas the cooling power is in the range of 2-4 kW (not electrical power, which is much smaller) for the a.m. ventilation to bridge 8-10°C temperature difference and the heating power in the range of 4-8kW to bridge 14-18°C.



Electricity. There exist 3 different Voltages versions (220-230V, 100-120V, 127V) 1Ph, N, PE, underneath 400VA, internal fuse of 2.5A, for a.m. mass spectrometric leak detector with +10/-15% deviation tolerance. The major needs concern the a.m. ventilation and air conditioning depending from the local conditions.

High Voltage Filter. Developing countries often have bad electrical supply conditions which concerns voltage stability, frequency, cosinus Phi, line impedance (V/A) during start up of motors, Short power interruptions and High voltage sparks. In addition a lot of factories neglect inside their own area the fundamental rules of installations, so that a lot of electrical effects can under-supply, overload or high voltages even can destroy electronic equipment. Practically all modern machines and equipment containing electronic controls and are not made for such extreme conditions. 10% Lower voltages can stop electronics and leak measurement, the Ecotec II and Protec II can run under a quite wide range of voltages and frequency, but high voltage sparks can destroy electronic boards, even if there are fast fuses and other protections already built in. **At least a small high voltage filter on the electrical supply plug as used in household should be installed between this expensive leak detector and the electrical network. For additional safety.**

4.15. Integration of Leak Testing into a Quality Control System

Detection of leaks is not only used to identify cooling circuit leaks, but **to improve cooling circuit construction, material specification and manufacturing processes.** The leak rates on each joint depend on
- the **construction** itself,
- the used **components (**compressor, condenser, anti dew coil, dryer filter, capillary tube, heat exchanger, freezer and refrigerator evaporator, etc.) **and their specification** specially at the joining points,
- their **assembly**, brazing and closing process **as specified, trained and practically executed,** the work tooling, the consumables (brazing rods, flux), cleanness on joint areas, and last not least on
- **the process and quality control.**

There exist mathematical **statistical methods -** mainly developed and practised in the car industries - to analyse empirical **data collected on each model and each leaking joint** per line and time, which allow

(1.) to control the **level of performance**
   - per shift and time period (day, week, month), if it has been improved or not,
   - per line, working group, working place and individual employees,

   to feedback group wise and individual performance,

(2.) **to identify joints with significantly higher leak rates**, inside a model or model group and across all models.

In combination with **technical know how on materials, construction and manufacturing** processes these methods allow to attack the most **critical points** systematically, if needed **to improve construction, specification, material supplier control and/or entry control, manufacturing instruction and training, controls during processing and manpower selection, motivation and management.**

Such methods if not yet existing has to be introduced with serial no. s on each model, computers, software and bar code scanners on the lines. Galileo and also Agramkow have software solutions which allow integrating these leak testing data together with the performance test data /electrical safety and functional tests. Galileo called such integration PSIS and Agramkow PLIS.

This investment will improve the quality, reduce service in the field and reworks in the factory and wasting on materials.

4.16. Practical Problems in Mastering the High Technology

Inficon made from time to time bad experience with wrong applications of their High Tec and expensive leak detectors. Some customer aspects from their equipment that it can tolerate all conditions. But this is not possible with such an equipment. There are parts to be maintained other should not be touched. But sometimes the local service try to repair parts which needs high knowledge, special training, special tools and measurement equipment and long experience (quadruple, molecular pump, calibration on board circuits). Some do not understand the machine, but try to intervene and this can be very costly for the customer. Previous detector generators were much more sensitive against overheating and dust as the actual models, but precautions have to be taken and intensive training of qualified staff can increase strongly the live of these kind of equipment. The

Quadruple spectrometer , the molecular pump, the electronic boards can only be repaired by authorised Inficon service centres and are not subject of any trial and error methods. The damage and costs caused in such cases can be very high.

Leak detection is part of the refrigerator quality control system and the machine data has to be read out automatically upon each single refrigerator (bar code or RFID serial no.) and stored into a databank. This is part of the separate Transfair Engineering: Quality Control booklet.