Software-Aided Operation of Modern Industrial Leak Detectors

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Abstract: When leak-testing parts with the tracer gas method, the “no-indication” response of the leak detector leaves the operator with the question whether there is really no leak present or the test instrument may be in a faulty (= insensitive) condition. Moreover, an operator being absent-minded or distracted may easily move the sniffer tip to the wrong spot on the test object or at least not to all required test areas.
To make sure that the uncertainty about sensitivity is avoided specific artificial leaks (“test leaks”) are routinely used for frequent verification of the correct function and calibration of the leak detector. However, absent-minded, distracted or even lazy operators are not detected in this way.
Recent software features implemented into INFICON leak detectors can help prevent mistakes of the above kind. Such features include intelligent filtering of the signal (preventing spurious noise), suppression of interfering gas effects, dynamic zeroing of the signal, simple on-site function tests with a built-in test leak, a complete spectrum of indications (optical, acoustical, tactile,…) if the trigger for leaky objects is exceeded and more.
As an example of the latest achievements in this field the operator-controlling features of the new ECOTEC E3000 refrigerant leak detector from INFICON are described in some detail. It will become quite clear that product quality (in this case of refrigerators and air conditioners) is greatly enhanced by such supervising functions.

The Leak Testing Problem

When testing an object for leaks with a tracer gas there is no specific “leak-tight” information. Without leak there is simply no leak detector response and thus the situation cannot be distinguished from an instrument failure or an operator mistake. This ambiguity is highly undesirable for a production environment with semi-skilled personnel.

The normal routine to avoid this type of error is a regular mandatory check against a calibrated leak by the operator. However often this is not properly implemented in the production process or one cannot be sure that it is really done by the operator. High stability and reliability of the leak detector is therefore mandatory but some sort of operator supervision or a complete automation of leak testing would be highly desirable.

Sniffer Leak Testing for Refrigerants

Sniffer leak detection is normally a way to detect the location of a leak to be able to re-work the object. However, in the refrigeration industry sniffing is used not only for localization but also for quantification of leaks in one operation.

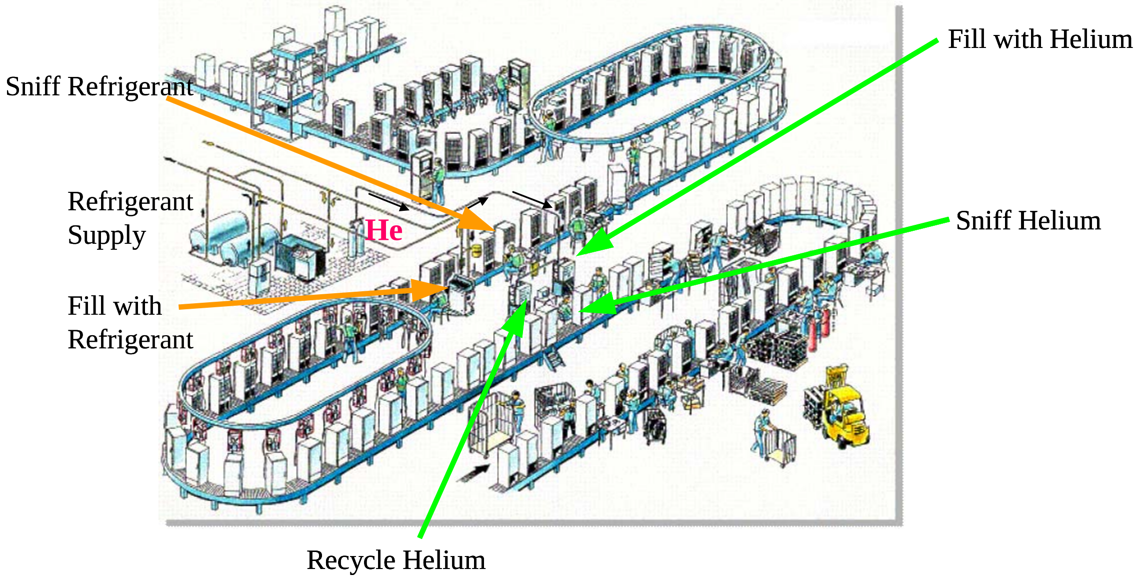


Fig.1 Assembly line for refrigerators with helium pre-testing and final inspection for refrigerant leaks.

As shown in Fig.1 air conditioners or refrigerators are put together from pre-tested parts and assemblies and are then filled with helium in a first testing step. With a helium sniffer leak detector these units are tested for leaks and afterwards filled with refrigerant gas. The final inspection is then done with a refrigerant sniffer leak detector set to a threshold level, e.g. 0.5g Isobutane per year for refrigerators (according to DIN 8964-2). Keeping in mind that this leakage rate is equivalent to only approx. 1ppm of refrigerant in front of the leak and on the other hand the dwell time in front of the leak is only a few seconds and position and speed of the sniffer probe are highly unknown a quantitative measurement seems to be impossible (that is why the European standard EN1779 says that this method is not suitable for quantitative determination of leakage rates). Nevertheless, it is done every day and manufacturers of leak detectors have to comply with the requirements resulting from this situation.

A further difficulty results from the ambient contamination with refrigerants, which are also used as foaming agents in the thermally insulating walls of refrigerators. Ambient contaminations often are much higher than the small refrigerant concentrations generated by leaks.

Last but not least the position of leaks is often concealed and the sniffer probe cannot be brought close to the escaping tracer gas. This can lead to overlooking of leaks if the operator is not extremely careful.

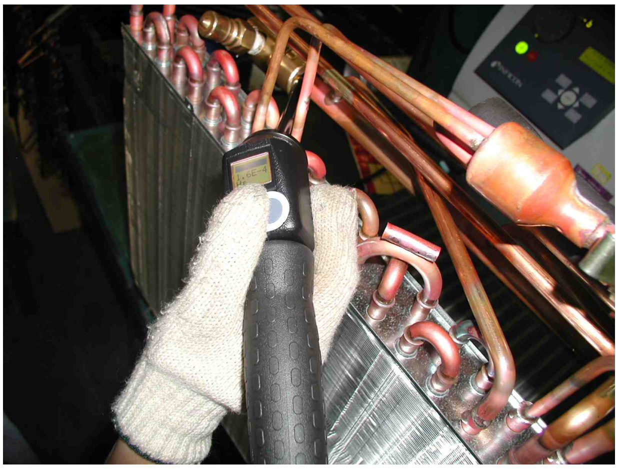


Fig.2 Sniffer probing a complicated assembly of a heat exchanger with a great number of soldered joints

Customer Requirements on Industrial Sniffer Leak Detectors

The above leads to the following explicitly or implicitly expressed customer requirements:
detection limit for usual refrigerants less than 0.1g/a
response time for sniffer less than 1s
no cross sensitivity against foaming agents
easy or automatic handling of background contamination
continuous supervision for instrument failure
continuous control of operator action
continuous documentation of instrument status and results

Solutions in the ECOTEC E3000 Refrigerant Sniffer

There are lots of refrigerant sniffer leak detectors based on rather primitive principles like the alkali-ion cell or more advanced like infrared light absorption. Still the most versatile and powerful tool is the mass spectrometer based detection method used in the ECOTEC E3000 instrument. It uses a quadrupole mass spectrometer operated in a high vacuum system.
Although this is the most expensive solution it offers unique advantages, which have to be put into practice by an intelligent instrument software design. By a careful customer requirements analysis one can also improve some hardware features to yield outstanding performance in the difficult job of leak testing. There are three levels of leak testing:
Detection of a leak
Indication of a reproducible leakage rate value
Quantification of a leak in traceable units
The E3000 Leak detector supports all three levels and has features to set a new standard of detection capability, reproducibility and accuracy.

Operator Support in the Detection of Leaks

Remembering the basic leak-testing problem from the beginning of this paper, the most important task to fulfill is a continuous supervision of the leak detector for proper function to make sure that with a“no leak” indication the operator can be sure there is no leak on the test object.

A first self-test is done during start-up of the instrument: all functions will be tested in the first seconds after switching on the unit including all supply voltages and currents and the signals of flow and pressure sensors. While this is a standard check in modern instruments additional supervision exists in the E3000.

Permanent Sensitivity Monitor with Argon from Natural Air

To make sure that the whole measurement chain from gas intake to the output of an ion current stays within a defined basic sensitivity window the ion current on mass 40 generated by natural Argon is continuously monitored in the background. Since Argon is a noble gas with a very stable concentration in natural air (1%) this measurement makes sure that the leak detector output signal is always alive and sufficiently high to detect leaks even close to the detection limit.

Function Check at the Line with Intelligent Test Leak

In addition to this background monitoring for base sensitivity the operator has the chance to check for refrigerant sensitivity whenever he decides to do so at the manufacturing line. For this purpose an intelligent test leak filled with R134a refrigerant is on board the leak detector. It has a photoelectric barrier so each time the sniffer tip is inserted an automatic sensitivity check is triggered and an OK or error code is issued (this has to be distinguished from an automatic recalibration the test leak can also be used for, see 4.3.1 for details). The leak is intelligent by its own built-in microprocessor.
To make use of the test leak more flexible at the line it can be taken out of the base unit and put where it is most convenient for the operator. The detached leak is still connected to the leak detector by an interface cable to exchange the necessary data from its built-in temperature sensor, the light barrier and its filling data. Fig.3 shows the detached leak with its data link to the E3000 and the sniffer tip.

Fig.3 Simple on-site function test with an integrated yet detachable test leak that can be moved to the test site keeping interfaced to the base unit for complete control of actions

Reproducible Detection of even Smallest Leaks

Reproducible results are the most important requirement for a measurement instrument. When it comes to the very small currents that have to be measured at the output of a mass spectrometer (in the 10^{-15} A range) there are all kinds of noise and drift preventing the reproducible detection of small signals. To achieve a low detection limit defined as the sum of drift and noise under definite conditions (see EN1518) not only optimized hardware is necessary but specific software methods have been implemented in the E3000 leak detector.

Intelligent Filtering (I·CAL®)

There is a very simple way of achieving a low noise level of a signal: simply average it. However, the disadvantage of this conservative way of noise reduction is a corresponding long signal response time unacceptable for a sniffer leak detector.
An intelligent way out of this dilemma is a variable measurement dwell time depending on the specific situation of the instrument. If there is a longer idle period the software sets the dwell time to many seconds to keep the noise low and achieve a stable zero. If a change of input signal occurs the instrument detects whether this signal change is significantly higher than the noise and if so, immediately reduces the dwell time to less than a second. This results in a very quick response combined with the lowest possible detection limit. Fig.4 shows the result of noise reduction and immediate signal response achieved with the I·CAL®-function.

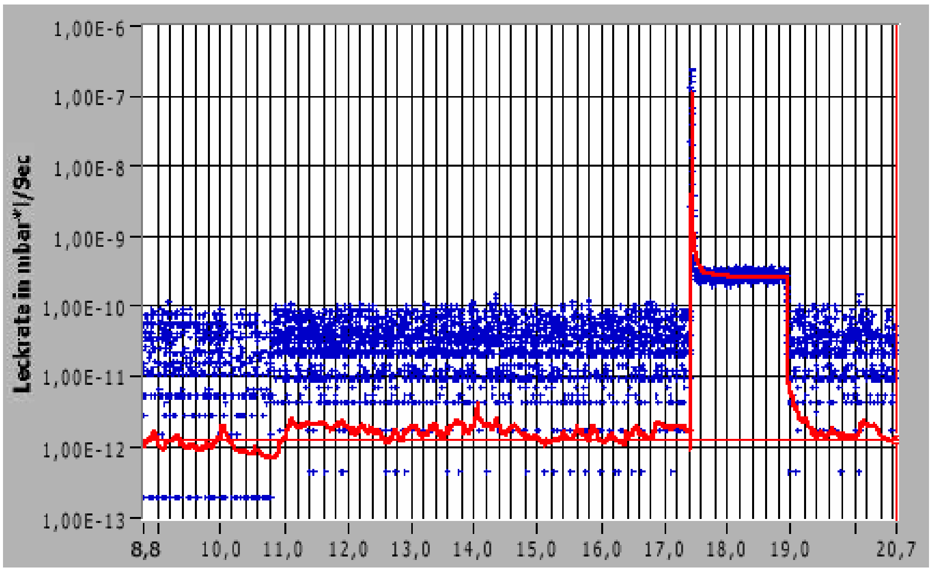


Fig.4 Background noise and leak response with and without I·CAL (Blue: unfiltered signal, Red: filtered signal). The spike is the event of finding a leak resulting in a short overshot but very quickly showing a stable leak signal which decays equally fast when the leak is removed (this measurement was done with a vacuum leak detector with much smaller leakage rates than in a sniffer)

Dynamic Zero

In a sniffer leak detector particular attention must be paid to the stability of the zero signal. Most of the time in normal operation, there is no leakage signal present and the user expects a perfect zero indication not only without any spurious spikes or noise (the above described I·CAL is taking care of) but also free of any drift that could mask a small leakage signal. Signal drift into the negative is the worst case since with a negative zero small leaks (and that is what operators look for) would not be shown on the display.
In a software-aided instrument negative drift is avoided by permanent dynamical tracking of the zero signal. The signal value is set to zero in the moment it starts getting negative. Alternatively it can be set to zero at any moment the operator chooses, even with rapidly falling signal after a leak has been detected. The signal is kept zero until there is any positive rise, which will be indicated immediately. If the signal had already arrived at the detection (noise) limit the I·CAL dynamic dwell time management helps producing the fastest possible rise.

Interference Gas Suppression

Testing for leaks on refrigerators poses specific problems because of interfering gases. Mostly foaming agents in the thermally insulating foams in the walls of refrigerators are interfering. Often these are gases of the same kind as the refrigerant fluid in the cooling system.
An important feature of a mass spectrometer leak detector is its principal capability to discriminate the interfering gas against the measurement gas. Thus even leaks close to or embedded by foams can be detected and measured against a given trigger level. This discrimination is done because each gas has a very specific "fingerprint" spectrum consisting of several mass peaks forming a pattern. It can be used to identify a gas even in the presence of other gases.
In reality, however, the job is not simple to perform. Basically, with known gases, it is only necessary to measure more than one mass peak of every gas and perform the necessary subtractions to isolate and measure the characteristic peak of the leakage gas. The specific problem in leak detection is time: the calculation has to be done in milliseconds and slight deviations in spectral patterns have to be accounted for.
In the E3000 leak detector, there is an interference gas suppression ("IGS") implemented for the most frequent measurement gas R600a (Isobutane) in home refrigerators against the most often used foaming agent "Cyclopentane 70" (a mixture of 70% Cyclopentane and 30% Isopentane).

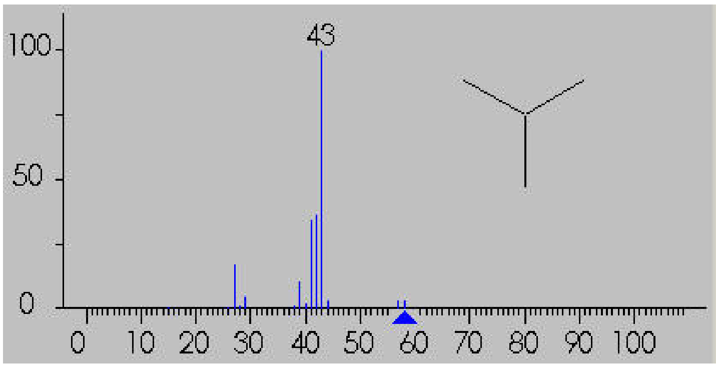
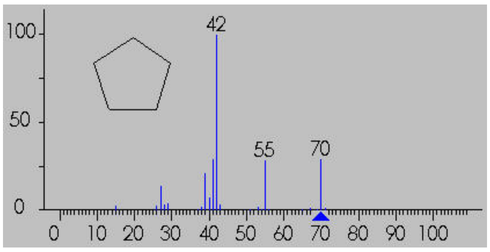


Fig. 5 Mass Spectrum of R600a (Isobutane)



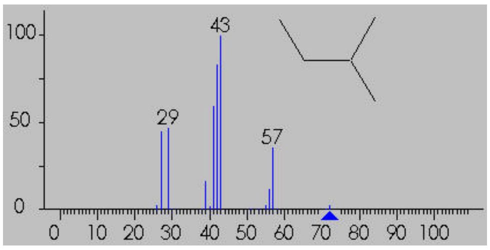


Fig.6 Mass spectra of interfering gases from foaming agents:
a) Cyclopentane b) Isopentane

As the mass spectra show, Isobutane is measured with its main peak on mass 43 but Isopentane also has its main intensity there and Cyclopentane still has an appreciable intensity on this mass. In consequence, the masses 55 and 57 respectively have to be used to evaluate the contribution of the two interference gases.

Basically the evaluation of the measurement peak intensity is an easy subtraction of the interfering intensities of these gases on mass 43. In practice, however, the following problems had to be solved:
No chemical interaction (production/elimination of gas species) in the hot filament ion source (to keep the correct concentrations of gases)
Correction of time shift between subsequent measurement of mass peaks (to make the computations with mass peak intensities meaningful)
Instantaneous distinction between the presence of background of measurement gas or of interfering gases (to either trigger the zero or discrimination algorithm)
These three problems could be solved because of the hardware capabilities of the quadrupole mass spectrometer (ion source materials and temperatures, low noise amplifier enabling dwell times below 50ms for ion currents in the 1E-14A range) and a software algorithm taking care of the time structure of signals and a possible slight drift in mass peak intensities. The latter is achieved by an initial individual adjustment with test leaks containing the measurement gas and the two interfering gases respectively.
Up to now, several hundred of these instruments have been produced and sold in the refrigerator market and no customer complaints have been received regarding the IGS feature.

Quantitative Leak Detection

Like every modern leak detector the E300 has built-in software to enable an “AutoCal” function. This means that an automatic adjustment of the leak detector’s sensitivity with a known leak of the required gas is possible. This requires that the user have a calibrated leak of the required gas species at hand, which may be sometimes difficult in remote locations. The E3000 therefore also offers an “internal” calibration for all library gases with the built-in leak.
Moreover, for leak testing in series production the operator is aided and supervised by a program called “I-Guide” helping him not to miss any leaks and check for the total leakage rate of a unit.

Internal Calibration

Basically, in a mass spectrometer each gas has specific intensities on each mass peak. This constitutes what is called its “fingerprint spectrum” or cracking pattern of ions. Since these intensities can be found in tables and stored in the instruments library relative sensitivities for all gases are known with given uncertainty.
In the E3000 the built-in leak is filled with R134a, the most frequently used refrigerant that is not inflammable and therefore can be shipped in the instrument without problems. To perform a so-called “internal” calibration this leak is used by the E3000 as a reference to determine the sensitivity of any required gas (provided it is in the library) by using the known cracking pattern factors of library gases.
The user simply has to choose the measurement gas and start the internal calibration routine to make the unit indicate “true” leakage rates for the required gas. The uncertainty of measurement will exceed the normal limits of ±10% and can be up to ±30% but this is normally sufficient for standard leak testing (for R134a the uncertainty of an internal calibration is the same as for a calibration with an external leak, since this gas is really in the test leak reservoir).

I-Guide leakage accounting and documentation

Since the E3000 is an instrument developed for the user at a manufacturing line there is a feature available called “I-Guide” that supports quantitative leak testing. It is a guiding function for the operator designed to make sure that no leak is overlooked, each measurement is done properly and the total leakage rate of a unit is easily determined. I-Guide can be pre-set to a certain number of checkpoints in a measurement cycle and it will then

give an audible signal to the operator: “Start Measurement”

store the measured leakage rate value

add up the measured values of each measurement position

count the number of measured positions and indicate and store the total leakage of the unit under test at the end of a measurement cycle

This function can help not to overlook leaks and it avoids off-line calculations of total leakage rate. A bad unit is thus found immediately at the line.

Improvements of I-Guide are imaginable, e.g. additionally supervising the position of the sniffer tip in space to make sure that each leak position has really been reached.

Conclusion and Perspective

The presented software aids of the E3000 refrigerant sniffer leak detector are a example for the specific adaptation of modern leak detectors to the requirements of operators in a manufacturing environment. Product quality (in this case of refrigerators and air conditioners) is greatly enhanced by supervising functions like those shown here. Since software plays a more and more dominating role in modern instruments more improvements and more advanced leak detectors can be expected. Continuously refined methods of eliciting user requirements are however necessary to implement only really useful functions and avoid operator distraction by overwhelming him with too much information at a time.