Leakage Testing – SAE J1267 JUN84

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PREPRINT

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Purpose—This information report provides basic information on leakage testing, as applied to nondestructive testing, and affords the user sufficient information so that he may decide whether leakage testing methods apply to his particular need. Detailed references are listed in the Bibliography.

General—Leakage testing is a form of nondestructive testing capable of determining the existence of leak sites and, under proper conditions, measuring the quantity of material passing through these sites. The word *leak* means the hole through which fluid (liquid or gas) passes in either a pressurized or evacuated system, while *leakage* is the term used to connote the mass flow of fluid regardless of the size of the leak. Leakage rate is the quantity of fluid per unit time that flows through the leak at a given temperature as a result of a specified pressure difference across the leak. The ASTM accepted unit of leakage rate is standard cubic centimeters per second (std. cm^3/s), frequently referred to as atmosphere cubic centimeters per second (atm. cm^3/s). The SI terminology is Pascal cubic meters per second (Pa m^3/s). (1 Pa m^3/s = 10 atm. cm^3/s, approximately.)

There is no container in which a differential pressure exists (either pressurized or vacuum) that does not leak to some extent. Absolute leak tightness is an absolute impossibility. Any container must, therefore, have a maximum leakage rate specified. In considering the leakage rate that can be tolerated, one must decide whether the rate represents the total leakage from the system or the maximum leakage from a single leak. Additional factors to be considered include shelf life, product contained, toxicity, legal requirements, consequences of excessive leakage, cost of product, cost of testing, and customer requirements. Once a leakage rate has been specified then a leak test procedure describing the operating and test conditions needs to be detailed. Since leakage rate relates pressure, volume, and time, more than one set of procedural values can yield the same leakage rate. In general, the pressure used should reflect pressures that the item would see in service, however, this is not a requirement. In some isolated cases, using markedly different pressures can cause leaks to pass grossly different rates of fluid due to elastic deformation of the item being tested. Regardless of the type of leakage testing being done, safety considerations for the personnel performing these tests must be a paramount consideration.

Principles—There are eight or more primary methods which may be employed to detect, locate, and/or measure leakage. The following paragraphs identify these methods and describe their principles, as well as their capabilities and limitations.

Mass Loss and Pressure Change—These are two related methods. Traditionally, these are used for sizable leakage rates, and provide no information as to the leak site. Mass loss is calculated on the basis of change in mass at two times; accordingly, extremely accurate weighing is a requirement of this method. Pressure change methods operate in a similar fashion, except that a change in pressure is the signaling mechanism. Pressure change systems usually measure change of the gaseous systems. Since pressure is temperature dependent, the temperature of the system must either remain constant or be compensated for by use of ideal gas laws. Mass loss and pressure change methods, using most techniques, are time consuming and thus are limited in leakage testing applications.

Theoretically, these methods are very accurate if one has sufficient time to conduct the test.

Ultrasonic Leak Testing—This is a method valuable for detecting leakage great enough to produce turbulent flow. Turbulent flow in a gas occurs when the velocity approaches the speed of sound in that gas; this is approximately 10^{-1} to 10^{-2} std. cm^3/s. This method takes advantage of the fact that turbulent flow generates sound frequencies from audible upward to 60 kHz. In using only the ultrasonic component generated, fewer false signals are detected because there are fewer other sources of ambient ultrasound. Because of the highly directional nature of ultrasound, the leak can usually be accurately located. Output of ultrasonic leak detectors is an audible signal or a meter deflection, the strength of which is a function of the leakage rate. Advantages of the ultrasonic method are that the equipment is simple to operate, it can be done with the probe removed from the leak, and it does not require any material which could clog a leak and require cleaning. Its primary disadvantage lies in its lack of sensitivity to small leakage rates (less than 10^{-2} std. cm^3/s).

Chemical Penetrant Leak Tests—These are incapable of providing leakage rate information, but do clearly point out sites for repair. Sensitivities are generally conceded to be in the range of 10^{-3} std. cm^3/s, although greater sensitivities have been achieved. Two basic forms of chemical penetrants are available, liquid tracers (quite similar to liquid penetrants, see SAE Information Report J426) and gaseous tracers. Hydrostatic testing with water alone is not a substitute for leakage testing.

LIQUID TRACERS—Liquid tracers are usually a solution of a tracer dye and a liquid in which it is soluble. It is essential to determine the coloring power of the tracer solution in the concentration being used as this relates to the sensitivity, as does the wettability of the tracer solution. As a general rule in white light systems, basic dyes work best in a water solution and solvent dyes are better suited to an oil based system. White light liquid tracer systems are generally inferior to fluorescent liquid tracer systems. This sensitivity inferiority is due, in part, to the increased visibility of fluorescent dyes, and the inherent contrast of the dyes to the near black background used in testing. By dissolving a fluorescent tracer in a volatile liquid, very small leaks can be found, because the liquid which evaporates leaves behind a concentrated dye which is more visible. Advantages of liquid tracers lie in their cost, sensitivity, and ease of use. Foremost among their disadvantages is that they use material which could temporarily clog a leak. Also, liquid tracers require cleaning of the parts after use and care in their application so as not to create false signals. In addition, one may experience occasional difficulty in tracing large leakages to their source due to liquid spread.

GASEOUS TRACERS—Gaseous tracers are gases which color indicating media, thereby denoting the location of a leak. The most widely used gas for this application is ammonia. Indicating media for ammonia gas are:

1. Phenolphthalein which turns from clear to pink.
2. Bromocresol purple which turns from a yellow-green to purple.
3. Bromothymol blue, which turns from yellow to blue.

Carbon dioxide gas can be used for leak testing with an indicating medium of sodium carbonate and phenolphthalein in an agar-agar solution. This bright red indicator will turn white at a leak site.

There is another medium, which is much less widely used, due to the inherent danger of its chemicals. Pressurizing a component with ammonia and then allowing hydrogen chloride to be brought near, will produce a white cloud of ammonium chloride vapor which is clearly visible. These gases are highly corrosive and dangerous to human tissue. Extreme care and a high level of ventilation are needed, as well as consideration for the safety of the personnel performing the test.

There is little difference in the level of sensitivity for gaseous tracers when compared to liquid tracers; both are typically at 10^{-3} std. cm^3/s. Rates as low as 10^{-6} std. cm^3/s have been reported for gaseous tracers. Primary among their advantages is their low cost of operation since no instrumentation is needed. Disadvantages are that some gases could corrode the test object, be hazardous to personnel, require cleanup, and clog leaks.

Bubble Leak Test—These methods are widely used. They possess

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

sensitivities to a commercial range as small as 10^{-4} std. cm^3/s (10^{-2} is a practical value for an unskilled operator). In the laboratory, under ideal conditions with special combinations of liquid and gas, rates as low as 10^{-7} std. cm^3/s have been detected. The method operates on the basis of a differential pressure at a leak creating a flow of gas. This gas, upon escaping, will produce one or more bubbles in the test liquid. These bubbles mark the location of the leak and the frequency and size can be used to estimate the leakage rate.

Procedurally, the test object is fixtured and pressurized, and then the indicating liquid (not a soap or detergent solution) is brought into contact with the component. This precludes the liquid from temporarily blocking a small leak which could cause the acceptance of a leaking component. Precleaning of the test object is necessary because surface contaminants also may cause a temporary blockage of a leak. From a practical standpoint, any gas may be used to pressurize the object. Should air be used, it must be very clean, again to preclude temporary blockage of a leak. Shop air is generally too dirty, wet, and oily to use for leak testing.

Ample illumination must be provided to permit the inspector to be able to see a stream of bubbles; 1000 lm/m^2 (100 fc) is recommended as a minimum level.

Indication of leakage may be accomplished by the use of:

1. A liquid in which the test object is immersed.
2. A liquid film which produces bubbles when a leakage passes. (A vacuum box which surrounds the test area may be used to create the pressure differential.)

Liquids used in bubble testing must not corrode the object being tested. Frequently, it is desired to enhance the sensitivity of a bubble test. Enhancement can be done by increasing the time for testing or increasing the pressure. In some instances neither of these approaches is practical. Changing the gas to one of a lower molecular weight and/or lowering the surface tension of the liquid will also enhance the sensitivity. Visual inspection should be conducted at distances less than 0.6 m (2 ft) for best results.

A vacuum box places an area to be tested under a sub-atmospheric pressure. A clear window through which observations are made and a liquid in which leakage appears are necessary for the vacuum box technique. When used, (usually for welds in large vessels) adjacent testing locations must be overlapped to assure full coverage.

The advantages of bubble testing lie in its simplicity, cost, and relative sensitivity. Disadvantages include the need for cleanup, the fact that fine leaks may not be detected due to a lack of time, the possibility of clogging, and finally that bubble testing is a visual inspection, and as such, bubble testing is limited by the performance of an operator.

Thermal Conductivity Leak Testing—These methods have a minimum leakage rate detectability of 10^{-5} std. cm^3/s. They are based on the principle that certain gases have a markedly different thermal conductivity when compared to air. Equipment for this method consists of two heated filaments in a bridge circuit. One filament is cooled by air and the other by the test gas. Any differences unbalance the bridge and can be related to leakage. The two gases with the greatest difference in thermal conductivity are hydrogen and helium. Most thermal conductivity leak testing is done with argon, CO_2, neon, or R-12 (freon). Advantages include cost of equipment, reduced sensitivity to contaminants in the ambient atmosphere than other instrumented leak detectors, and simplicity of operation. Disadvantages include the limited gases which can be used.

Halogen-Based Leak Detectors—These use a halogen gas as the pressurizing medium and may take several forms, including the halide torch, the heated anode detector, and the electron capture detector. The upper limit of sensitivity is 10^{-9} std. cm^3/s. Halogen leak detector tests are normally not conducted using elemental halogens as a detector gas. Halogen leak detector tests are conducted using a chlorinated, fluorinated, or chlori-fluorinated hydrocarbon as the tracer gas.

Simplest and least expensive in the halogen family of leak detectors is the *halide torch*. It consists of a halide free source of gas, frequently acetylene, and a search tube to look for leaks, both of which feed a burner with a copper plate. In operation, the flame of the torch is blue when no halogens are present. The flame turns green when small leaks are detected, and turns violet when exposed to larger leaks. Search rates are approximately 6 mm (¼ in)/s. Halide torches have a leakage detectability of 10^{-4} std. cm^3/s. Since torches generate toxic vapors they must be used only in areas with adequate ventilation and cannot be used in flammable environments.

Due to the widespread use of the *heated anode halogen detector* in the refrigeration industry, this instrumentation is the most widely used of the halogen leak detectors. Operationally, ions are emitted from a hot plate to a collector. These positive ions increase in proportion to the amount of halogen present. Sensitivities of 10^{-9} std. cm^3/s are obtainable. This detector has the advantages of high sensitivity, and the ability to operate in air. Its disadvantages include responding to halogen containing suspended particles from sources like cigarette smoke and chlorinated hydrocarbons used in cleaning compounds, and that the decomposed products are toxic and corrosive. Further, the anode operates at 900°C (1650°F) which makes it unusable in a flammable environment, and there is a need to recalibrate the unit regularly as the calibration changes with use.

The *electron capture leak test* method uses a non-electron capturing gas (argon or nitrogen) as a background gas. The electron capture test gas is ionized producing tritium. In operation, the halogens drawn through the sensor reduce the ion content which produces a current. This current is proportional to the amount of halogen. Electron capture is frequently used with sulphur hexafluoride as a tracer. Sensitivities of 10^{-10} std. cm^3/s or better have been achieved. Advantages include very good calibration sensitivity, the absence of a heated element, and non-production of toxic or corrosive gases. Cost is the primary disadvantage of this system.

One of the most sensitive types of leakage testing equipment is the *mass spectrometer*. Leakage rates of 10^{-11} std. cm^3/s are achievable under ideal conditions. This method is the most accurate form for vacuum testing. A mass spectrometer operates on the principle of sorting gaseous ions with respect to their molecular weight. In a helium mass spectrometer, baffles with slits allow He^+ ions to pass through to the detector while all other ions are blocked. The number of He^+ ions which arrive at the collector per unit time is a measure of the leakage rate. Rates are typically displayed on a calibrated meter. As in any tracer gas system, care should be exercised to keep false signals from being sensed and displayed as leakage. Grease, oil, rubber, and other materials can act as storage reservoirs for helium.

Sensitivity is usually considered to be the greatest advantage of the mass spectrometer, also the fact that it is not affected by background contamination (other than He) is a great asset. Using helium provides inherent safety when compared with other gases which are toxic.

Cost is the greatest disadvantage of the mass spectrometer; however, many thousands are currently in use.

Applications—Any attempt to list the more common products evaluated by these test methods would be cumbersome and fail to serve the user. Briefly, any product containing a pressure different from atmospheric can be leak tested. The decision to leak test or not to leak test should be based on economic considerations and applicable legal requirements.

With the capability to sense leakage rates to 10^{-11} std. cm^3/s, there is no reasonable leakage rate that cannot be detected using available leakage testing technology.

Table 1 is presented to give the reader a better understanding of leakage rates.

TABLE 1—COMPARISON OF LEAKAGE RATES

Leakage Rate (Std. cm^3/s)	Approximate Time to Fill	
	1 cm^3	1 in^3
10^{-1}	10 s	3 min
10^{-2}	2 min	27 min
10^{-3}	17 min	4 h
10^{-4}	3 h	2 days
10^{-5}	28 h	19 days
10^{-6}	12 days	6 months
10^{-7}	4 months	5 years
10^{-8}	3 years	52 years
10^{-9}	32 years	520 years
10^{-10}	320 years	5200 years
10^{-11}	3200 years	52 000 years

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