An Innovative Method to Detect Leaks in a Pipe-in-Pipe Active Liquid Drain System - 14005

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ABSTRACT

A unique system has been developed to locate the source of leakage through the drain pipe wall in systems with secondary containment. The benefit of being able to identify leakage within a designated length of pipe is that it enables repairs to be carried out locally to minimise resource costs.

Test results indicate that the technique was repeatable, able to identify the origin of leaks to within a maximum error of 0.64 m, and should also be able to predict the equivalent diameter of a hole or crack in the drain pipe wall.

Advantages of this invention are the simple nature of the components used, its portability and the repeatability of the results.

INTRODUCTION

A patent pending method [1] to locate leaks in underground drain systems has been developed on site at Atomic Energy of Canada Limited’s Chalk River Nuclear Laboratories (CRL). Active drain systems at the CRL site carry radioactive liquid waste from various buildings to centralized collection areas. The active drain systems consist of a primary drain pipe enclosed within a secondary containment pipe. The secondary containment protects the environment in the event of a leak through the primary pipe and it also collects and drains the leaked liquid to a low-point leak detector connected to an alarm. One of the challenges with such a system is that, in the event of a leak, the primary line is difficult to access for inspection purposes. Another issue is that a traditional pressure decay method to detect the presence of a leak cannot be applied to these specific systems since the drain lines connected to the building are made with flexible rubber couplings and as such should not be pressurised. Finally, the low-point leak detector has been sensitive to condensation resulting in frequent false positive leak indications. Thus, there was a need to develop a system that would effectively detect whether leakage is present and more importantly to identify the location of the source of the leakage with minimum changes to and interference with the current drain systems.

From a literature review of existing leak detection methods it was established that there were no existing technologies that could readily be applied to finding leakage and leakage location due to the secondary containment obstructing access to the primary drain pipe, and the long lengths of pipe, up to 900 m, that had multiple bends within them. At CRL the typical diameter of primary active drain pipes is only 75 mm. There are “high tech” inspection devices available to inspect the inside of pipes but the risk of not being able to retrieve the equipment during inspection was considered to be too high.

CONCEPT DESCRIPTION

Development of a new technique called the Leakage Location Detection System (LLoDS) is based on measuring small amounts of tracer gas that leak into the primary pipe from the “annulus” (the cavity between the outside of the primary pipe and the inside of the secondary pipe). Tracer gas is initially injected into the annulus at low pressure. The gas will find its way into the primary pipe via any breaches present in the primary pipe wall. A controlled flow rate of air is drawn through the primary pipe picking up tracer gas that leaks in. A leak can be detected by measuring the amount of tracer gas in the air flow. If the concentration of the tracer gas is above a threshold value then this means there is a leak in the primary drain wall.

The location of the leakage can be established by changing the flow rate inside the primary gas line that results in a change in tracer gas concentration. The time taken for this change in concentration to reach the detector can be measured. The distance to a leak site can then be calculated by multiplying the time taken to detect the change in tracer gas concentration by the bulk gas average flow velocity in the drain pipe.

DEVELOPMENT

The following sections are a review of the development laboratory test results.

Scoping Tests

Since drainage systems need a gradient for the liquid waste to flow, it was expected that any helium present in the primary pipe would tend to rise to the upper end of the pipe due the lower density of helium compared to air. There was also a desire to understand the effect of helium gas diffusion in air as this had the potential for the tracer gas to reach the gas detector earlier than expected and therefore reduce the accuracy of the leak locating technique. The first scoping test used a 19 mm internal diameter and 3 m long plastic tube.

The plastic tubing was connected to a pump and air was drawn through the tube. A helium source was then added at the tube inlet. Tests were conducted in both the vertical and horizontal orientations. Fig. 1 shows the time taken for the helium to reach the detector for a number of tests performed at both orientations of the tube. It can be seen there was an initial rapid increase in the amount of helium detected followed by an asymptotic-phase until a stable concentration was reached. The last horizontal phase is the final stable concentration of helium at the low flow high concentration condition. It should be noted that the initial concentration of helium is not zero. This is because there is approximately 5 ppm vol of background helium present in air [2].

From Fig. 1 it can be seen, for each test, that there were no measurable differences in the time for the helium to travel from the tube inlet and be registered by the helium detector that was located at the tube outlet. However, there were differences in the tracer gas concentration profiles subsequent to the initial rise in the amount of helium detected. Similar tests were conducted using a range of flow rates in both tube orientations, and similar profiles were attained in each case. Fig. 2 shows that the time to detect the initial helium detector reading, decreased with an increase in average bulk gas velocity, as expected.

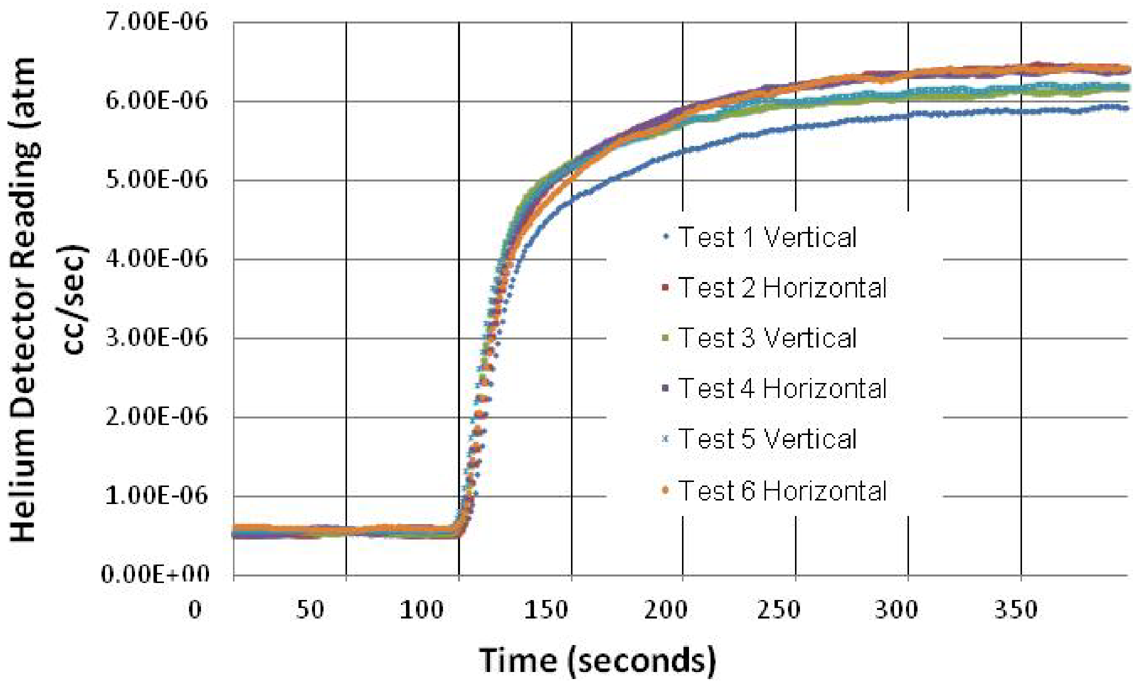

Fig. 1 Helium Detection in Horizontal and Vertical Orientation using 3 m long Tube

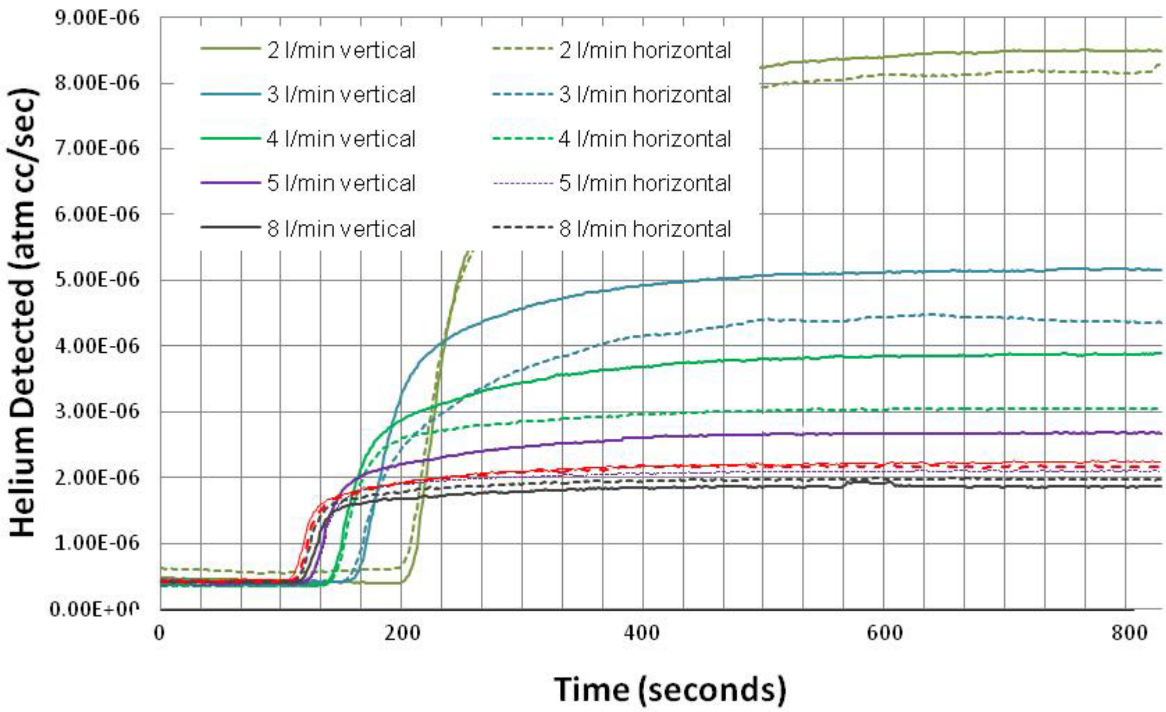

Fig. 2 Helium Detected Following Flow Switch for Various Flow Rates and Tube Orientations

The next test involved using long lengths of tubing representing actual lengths of pipe used in drain systems at CRL.

Two tests were performed using 91.4 m, 182.9 m and 274.3 m of tube, at a bulk gas flow rate of 3 L/min. The time taken for helium to reach the detector versus the length of tube was linear as shown in Fig. 3.

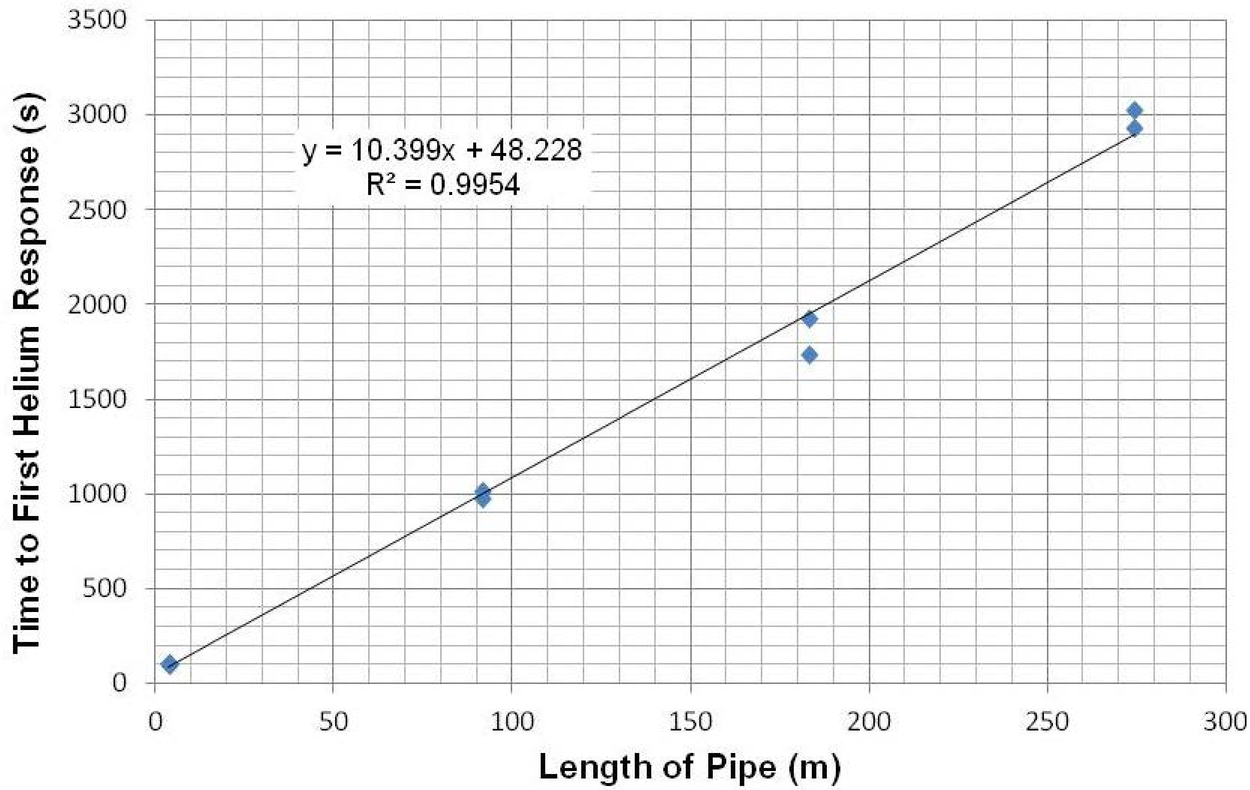

Fig. 3 Helium Detection over Long Lengths of Tubing

Hole Location Prediction

In subsequent phases of development, the entire liquid waste drain system was represented by experimenting with tube-in-tube arrangements with holes added to the inner tube to represent breaches through the primary drain pipe wall. The primary drain pipe was represented with both 19 mm and 50.4 mm internal diameter tubing inside appropriately sized secondary containment tubes. Holes of 0.099 mm diameter were added to the inner tube at different locations.

A vacuum pump (blower) was used at the exit of the drain line as shown in Fig. 4 to draw air through the primary line. The LLoDS technique requires two flow rates to be used per test. Therefore, two parallel flow paths are included between the blower and the primary pipe, one for the high flow and one for the low flow condition. Other components that were added include two accurate thermal dispersion type mass flow meters to measure both the high and low flow rate regimes, and limit switches to indicate when switching occurred from high to low flow. Thus, the time delay between the flow rate switch and detection of the change in helium concentration can be measured. It is this time delay that enables the distance to the leak site to be calculated.

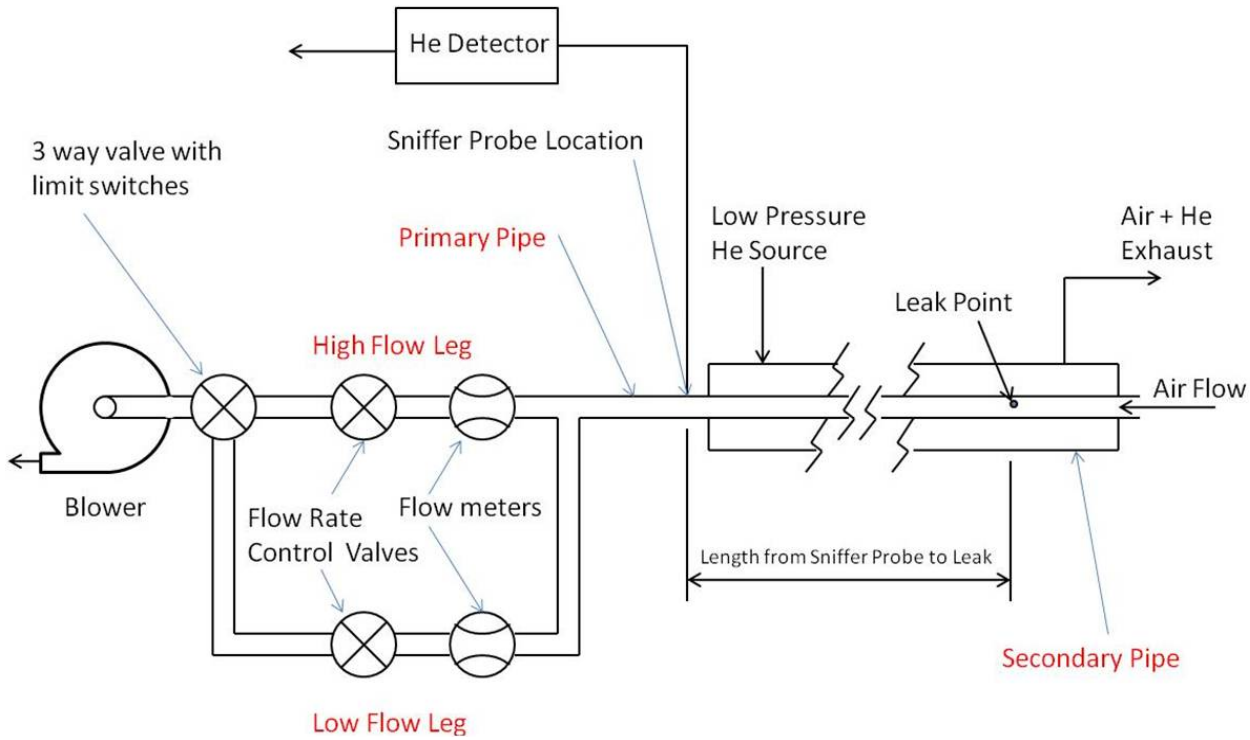

Fig. 4 Schematic Showing Test Apparatus for Determining Leakage Location

The distance to the leak site was expected to be representative of the flow velocity multiplied by the time taken to detect a change in helium concentration after the flow rate was switched. From a series of tests that were performed a simple equation, see Eq. 1, was produced by regression of the test data. Eq. 1 is a calculation of the distance to the leak site which is a function of bulk flow velocity and the time to detect the initial rise in helium once the flow switch had occurred.

$$D = (1.0561 \times V_{\mathrm{av}}) \times (t - 3.6) \qquad \text{(Eq. 1)}$$

where, D = Predicted distance,
V_{av} = Bulk flow average velocity (L/min), and
t = residence time (s)

The constant, 1.0561, shown in Eq. 1 is close to unity which provides confidence in the data regression and the accuracy of the measurements recorded. The correction factor of 3.6 seconds was required. A correction factor was expected since there were known to be a number of time delays that would affect the results. These time delays are associated with the helium travel time between the sensing of helium at the “sniffer” probe and delivering it to the helium detector and the time to process the presence of helium inside the helium detector.

A series of tests were conducted with various flow rates and distances to the hole location and this data has been plotted, see Fig. 5. Fig. 5 shows the model (Eq. 1) plotted for various flow velocities that is represented by the solid lines. The individual data points have also been added to Fig. 5 which shows the model is in close agreement with the actual test data.

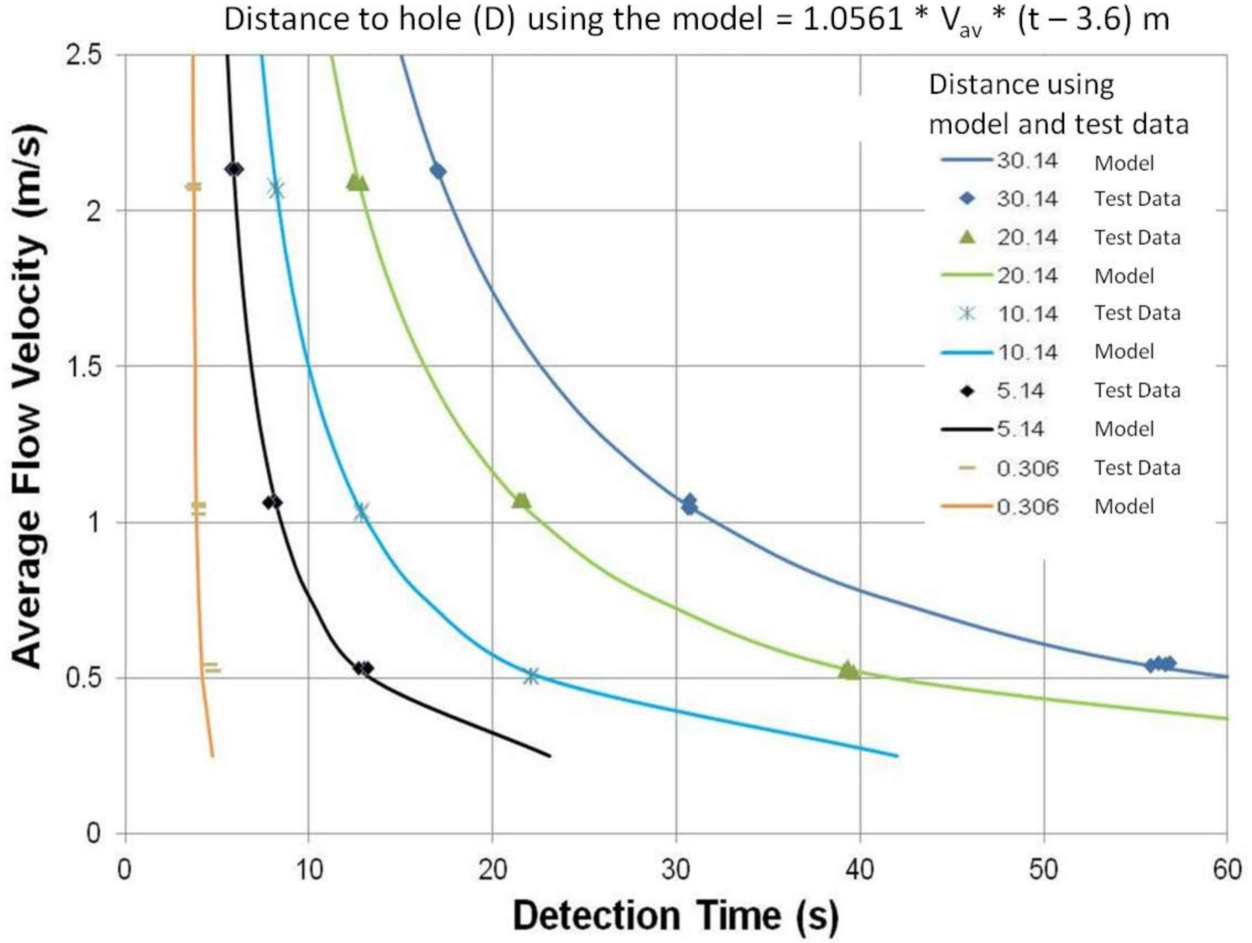

Fig. 5 Average Flow Velocity versus Detection Time for Various Hole Distances and Flow Rates

The maximum error between the actual hole location and the predicted location using Eq. 1 was +0.64 m for the hole located at 20.14 m and -0.64 m for the hole located at 30.14 m. For hole locations at 10 m and below, the error was shown to be less than ± 0.5 m. Errors were typically much lower than these, and it should be noted that the error did not show a trend of increasing when the distance to the hole location was increased. These tests were performed at a nominal 20 ^{o}C.

Once Eq. 1 was established, another series of tests were carried out and validated using Eq.1. One of the variables tested was the temperature of the system. Tests were carried out at laboratory temperatures of 8 ^{o}C and 25 ^{o}C and the maximum error between the predicted (calculated) distances versus actual distances was less than 0.62 m indicating system temperature does not have a major impact on the prediction of hole location.

Another variable tested was the tube diameter representing the primary drain pipe. Only two internal diameters (19 mm and 50 mm) were tested. Testing of the larger diameter resulted in a maximum error in the predicted length calculation of 0.55 m compared to 0.64 m for the smaller diameter. Again a range of hole locations up to 30.14 m was included in these tests. Based on the test data there is an indication that a larger pipe diameter may lead to improved leak location accuracy although more tests with larger diameters would need to be tested to verify this.

The error values mentioned above indicate the LLoDS technique is a promising technology in determining the distance to the source of a leak inside the primary pipe with secondary containment. The errors in the hole location were shown not to be proportional to length thus for longer length drain pipes, beyond the 30 m length tested, validation would need to be carried out to quantify the accuracy of the LLoDS technique.

Prediction of Hole Size

If the leakage path is assumed to be cylindrical, it becomes possible to predict the diameter of the leak. To do this the concentration of helium in the annulus, the concentration of helium in the drain pipe, the flow rate through this pipe, and the pressure of the helium inside the annulus need to be established. The LLoDS technique allows these variables to be determined so the hole size can be calculated. Once the hole size can be predicted then it becomes possible to establish whether liquid will leak through it or not.

To be able to determine the helium concentration in the annulus it was proposed to purge the annulus with helium to remove the air inside. If the air in the annulus can be removed then only helium, via a breach in the primary drain wall, would enter the flow stream inside the primary pipe.

Purging tests were carried out by injecting helium at one end of an annular space and exhausting out through the other end. An oxygen sensor was used to measure the depletion of air within the volume representing the annulus. Within minutes the oxygen content was reduced to 2% or a helium concentration of greater than 92% (2% O_2 and 6.9% N_2).

To obtain an accurate measure of the concentration of helium in the primary drain pipe, additional bulk gas flow tests were required. It was not known whether the reading indicated by the helium leak detector could readily be converted to a true helium concentration value since these instruments are not intended to measure the concentration of helium in a gas flow. A helium detector is typically used to measure the helium leakage rate from a closed system. It can also be used to ″sniff″ for the presence of helium to detect whether or not leakage is occurring, but not to determine a leak rate or the concentration of helium in a gas mixture.

Tests were conducted with calibrated gas bottles containing different certified concentrations of helium in air. The relationship between the leak detector readings and the calibrated gas concentrations was found to be linear, as shown in Fig. 6, with the regressed line passing through the origin.

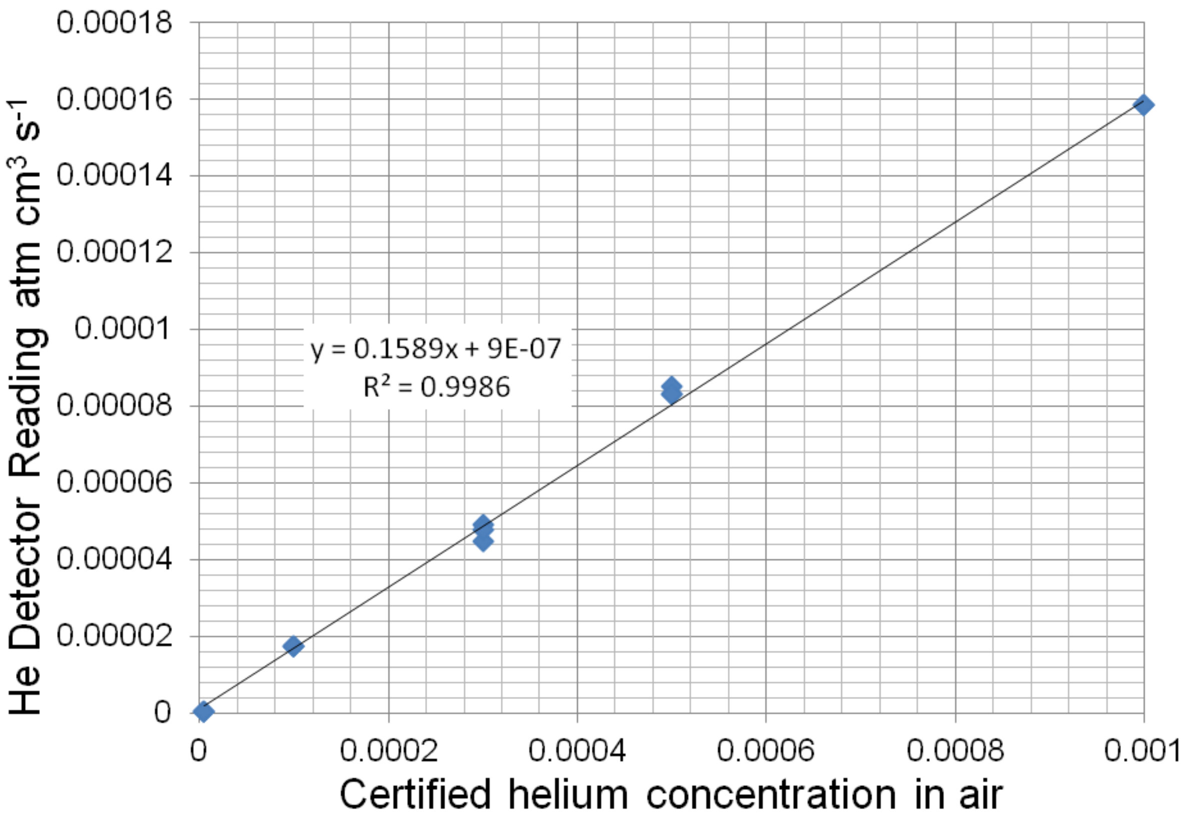

Fig. 6 Correlation of Calibrated Mixtures of He in Air with Helium Detector Readings

Once it was confirmed that helium leakage rate could be measured it then became possible to calculate a theoretical value for the measured leak rate as a function of the hole size. Thus, Eq 2 was derived which is a function of hole geometry, pressure and viscosity.

$$L = 38.1\frac{D^3}{l}\left[0.000319\frac{D}{\eta}\left({P_u}^2 - {P_d}^2\right) + \sqrt{\frac{T}{M}}\left(P_u - P_d\right)\right] \qquad \text{(Eq. 2)}$$

where, L = Leakage rate, (Pa m^3/s)
D = Diameter of leak path, (m)
l = Length of leak path, (m)
η = Dynamic viscosity of the gas, (Pa s)
P_u = Pressure upstream of leak, (Pa)
P_d = Pressure downstream of leak, (Pa)
T = Temperature, (K)
M = Molecular weight, g/mol

Eq. 2 assumes that the hole through the drain wall is cylindrical which is not likely to be the case as a breach through a wall can be present due to many different causes. Causes could include mechanical or corrosive means that could create a hole or a crack. However, this equation can be used as a way to establish an equivalent hole size with a flow path represented by a cylinder.

In the case where there is more than one hole in the drain pipe wall, the LLoDS technique can be used to identify these provided holes are at least 1 m apart. Specific LLoDS testing was performed with three holes located in the tube representing the primary drain. The technique was able to identify the three holes by multiple increases in helium concentration. Once the first hole was identified, additional holes were shown to be present by a further increase in helium concentration. This increase in helium concentration can be used to calculate each hole in a similar manner to way in which the first hole was calculated. Therefore Eq. 2 can be used to find the equivalent diameter of each of the holes. If the holes are so close together that the LLoDS technique cannot distinguish them apart, then the combined leakage area of a local cluster of holes can be calculated.

To provide a practical means of establishing the flow of helium and liquid through holes, testing was carried out on specially manufactured capillaries. These capillaries were made from glass tubing that was heated and stretched. Hole diameters ranging from 0.0254 mm up to 0.114 mm diameter were manufactured. The diameter of each capillary was measured using micro photo apparatus together with ImagePro software. Each capillary was cut into lengths of approximately 6 mm to correspond with the actual drain wall thickness.

The flow test equipment consisted of a test module that was connected to a tube located within a reservoir that could be heated so that tests at different temperatures could be conducted. The tube protruding from the reservoir was connected to a manometer to measure both flow rate (in conjunction with a stop watch) and pressure differential (the outlet was connected to atmosphere). A schematic of the test apparatus, for helium gas testing, is shown in Fig. 7.

A more simplified version of this flow test rig was used for liquid flow where distilled water was used as the representative liquid.

Using Eq. 2, the measured helium leakage rates were compared to predicted leak rates. A summary of the comparisons using two different temperatures, for a capillary diameter of 0.0254 mm is shown in Fig. 8. This graph shows the leak rate versus pressure differential across the capillary. The data of each line has been regressed using a polynomial equation and each line is color coded and presented either as a solid (as tested) or dashed (predicted using Eq. 2). It can be seen the calculated lines are in close approximation to the measured lines. It is also noted that the flow rates associated with the higher temperature is lower because helium viscosity increases with increase in temperature.

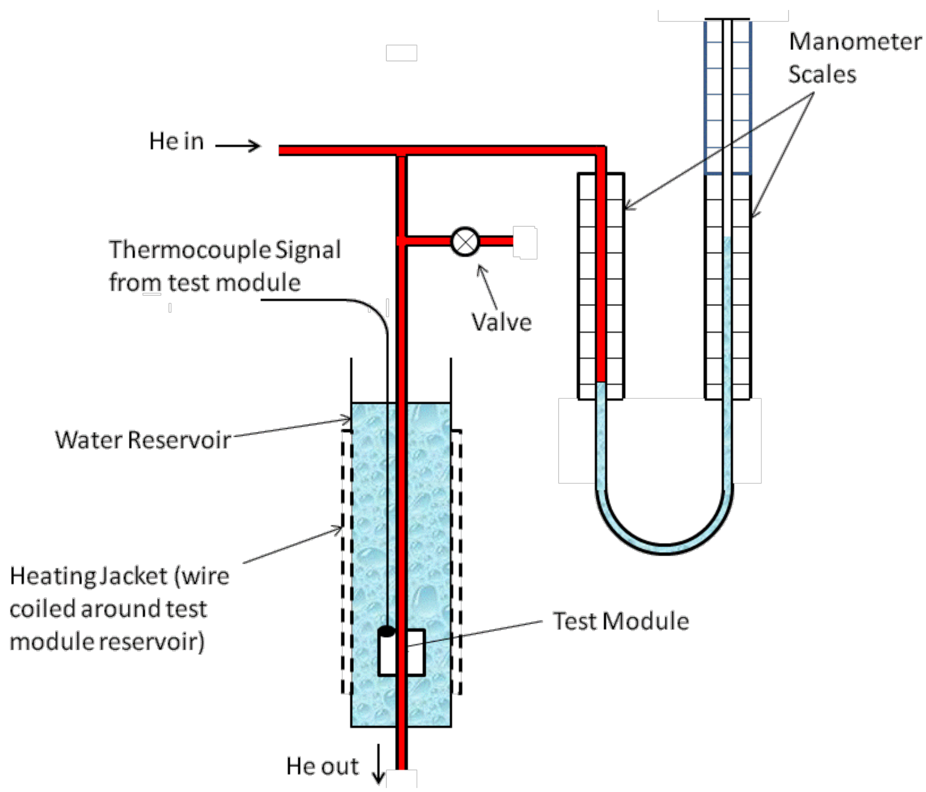

Fig. 7 Schematic of Helium Leak Test Equipment

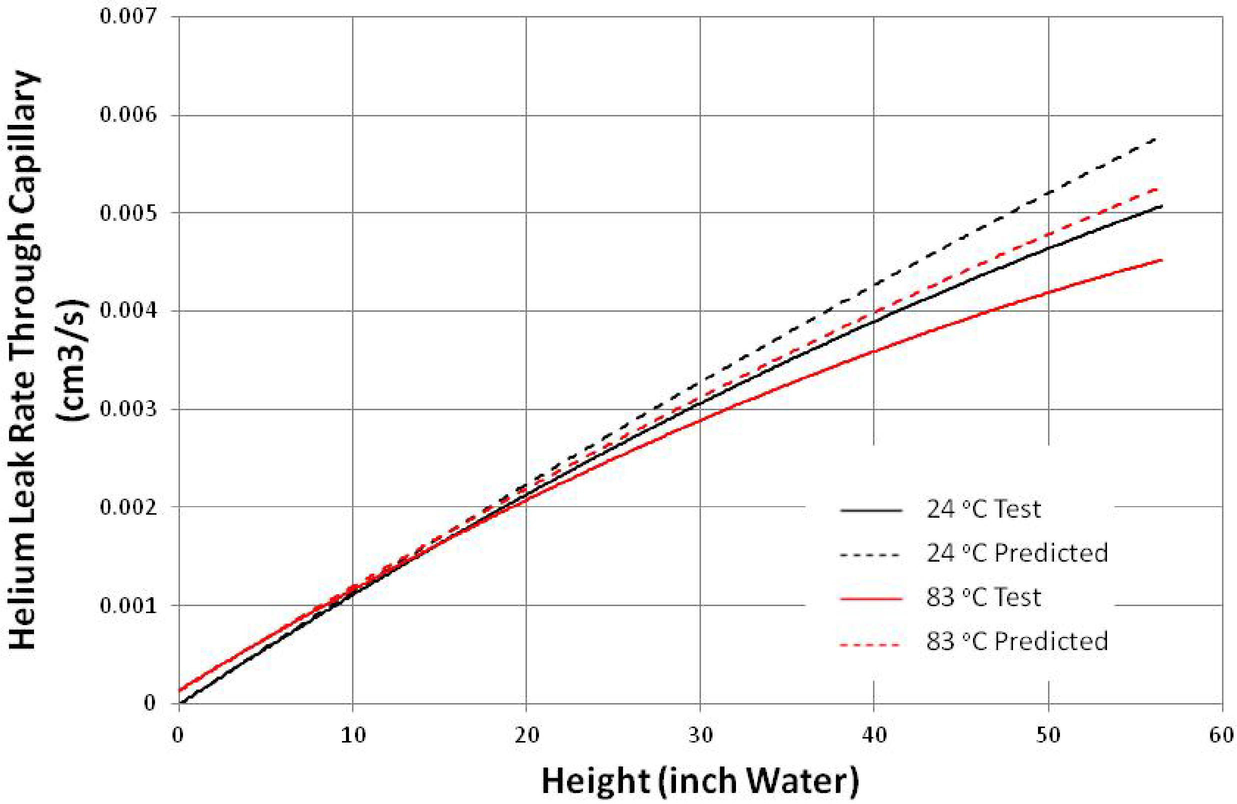

Fig. 8 Comparison of Measured and Predicted Helium Leak Rate at Two Temperatures

Tests were conducted to measure the liquid leak rate and establish the threshold hole diameter for liquid (in this case distilled water) to leak through a hole at a given pressure differential. Threshold leakage diameter is defined as the size of hole that would be sufficient to overcome the surface tension of the liquid. The 0.114 mm diameter capillary was the only capillary observed to leak liquid at a rate that would be significant in the field.

Eq. 2 was transposed to predict the capillary diameter using measurements obtained using the 0.114 mm diameter capillary. Calculated diameters for three temperatures tested (20 ^{o}C, 40 ^{o}C and 80 ^{o}C) ranged from a 0.103 mm to 0.111 mm, against a measured diameter of 0.114 mm, which is an error of between 2.5% and 9.6%.

Thus, an equivalent hole diameter can be calculated and its effect on actual leakage can be determined. This information can help formulate decisions in the field on whether to continue operations or take other actions when a hole has been detected.

Leak Location and Hole Size Prediction Equipment

The equipment that is required to provide data to measure leak location and provide data to predict hole size is both portable and manoeuvrable. Fig. 9 shows all the equipment needed to perform a LLoDS test for a field application. A single cart houses most of the equipment that is shown schematically in Fig. 4.

Once the equipment has been delivered to the field, only connections to and from the annulus and to the exit end of the primary drain line are needed. The helium detector comes with a “sniffer” probe that connects the flow in the drain line to the helium leak detector. The “sniffer” probe is located in the instrumentation line on the LLoDS equipment cart. The instrumentation line that connects to the exit of the drain pipe houses two flow circuits and the flow control and measuring hardware as shown in Fig. 4.

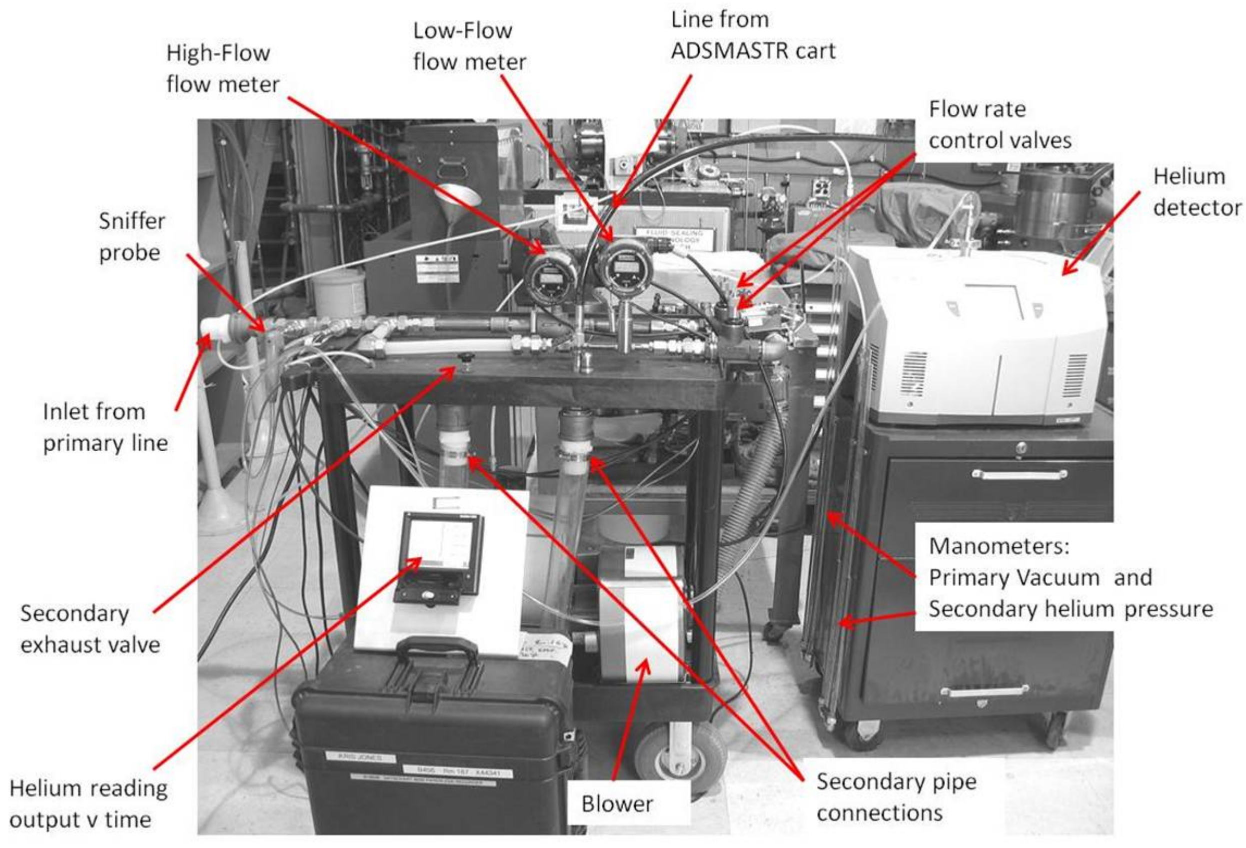

Fig. 9 Portable Equipment used for LLODS Testing

This equipment was used in the development tests performed in the laboratory and a form of this equipment has also been applied in the field on an actual active drain system that was known to have leaked. For the field test the equipment was set up within a half of a working day. Six tests were performed, in one morning. Repeatable recorded helium traces confirmed there was only a single leak source and the distance to the hole was calculated.

CONCLUSIONS

A new Leak Location Detection System (LLoDS) has been developed to identify the source of leakage through the primary drain wall in pipe-in-pipe type systems. The technique does not interfere with the drain system and there is only one connection required at the exit of the primary drain pipe and two connections to the secondary containment annulus.

The equipment has been validated in the laboratory and has been applied in the field. From validation tests, holes in the primary drain pipe located up to 30 m from the LLoDS access point have been calculated to be at an axial location within an accuracy of 0.64 m compared to the actual hole location. The errors in the hole location were shown not to be proportional to length thus for longer length drain pipes, beyond the 30 m length tested, validation would need to be carried out to quantify the accuracy of the LLoDS technique.

Further development is ongoing to predict the health of an active drain system by predicting the size of the hole. Initial developments show that using data from a LLoDS test can be used to predict hole size.

The LLoDS technique and the equipment that has been developed have the potential to be used in other pipe-in-pipe systems.

REFERENCES

1. Patent Application serial number 61/618208 “Leak Location Detection System” filed 2012, March 30.
2. Lie-Svendsen, Ø. and Rees, M. H., "Helium Escape from the Terrestrial Atmosphere: The Ion Outflow Mechanism", *Journal of Geophysical Research* 101 (A2): 2435–2444, 1996.

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