

Leak Detection on Water Distribution Networks Using Helium Gas

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Abstract
Water loss problems become main issues for most water operators in in around the globe. Locating invisible atau undetected leakages under the ground is not a simple task for the water operators. The emergence of undetected leakages cause severe deficits for the water operators and inadequate services for the customers. To reduce leakages, it is important that the water operators choose a suitable leak detection method for their water distribution networks. There are several leak detection methods need to be considered by the new users before they are put into practice in a particular water distribution networks such as: accoustic methods, tracer gas technique (helium gas), infrared (IR) camera thermography and ground penetrating radar (GPR). This study aims to address applicability and limitation of implementation leak detection using helium gas, especially for locating undetected leaks. The results proved that the method posses high level of accuracy (more than 80%) to identify the leak locations on various pipe materials and on various pipe diameters. Besides, the method worked properly either on high or low pressurized network, although it requires a minimum water pressure of 3 mH_2O at its inlet valves, so that the helium gas enables spread evenly to the entire networks. Furthermore, the method shows a good accuracy for locating undetected leakages that are trapped under asphalt or concrete pavement for many years.
Keywords: leak detection, helium gas, undetected leaks

1. Introduction

Urban Water Distribution System (UWDS) is one of important urban infrastructure that most of cities in the world are using in providing clean and safe water. As a part of urban infrastructure, performance of UWDS has been associated with urbanization that has given a significant impact in changing of urban water demand. In developing country, increasing water demand in urban area has increased significantly from 30% to 70%, which has put the water operators in a problematic situation regarding financial constraints, limited capacity as well as water loss both in main/supply and distribution systems. Water loss is known as a part of Non-Revenue Water (NRW), that is defined as unaccounted water in distribution network, which is determined by a comparison between distributed water and billed water. World Bank's report mentioned current water loss volume at the moment amounts to 48.6 billion m3 /year, which is nearly 14.6 billion US dollar per year (Thornton et al, 2008). Therefore, water loss has been a prominent technical problem for most water operator in the world since it influences services to customers and company's finansial condition. Nevertheless, it has been a great challenge for the water operators since identification of the leakage locations is not a simple task as the pipe networks are buried under the ground in certain depth (Taylor et al. 2011).

Undetected leakages cause complex issues to the water operators, especially in developing countries. Low pressures problems and increase of rigid pavements create emergence of new undetected leakage issues. The undetected leakages do not appear at the surfaces (pavements), so that they have become water losses under the ground for many years, which produce significant financial deficits to the water operators. Furthermore, the undetected leakages initiate sewerage water intrusion problems that are able to contaminate water quality with bacteria and germs, which can jeopardize for human consumptions. (Eyuboglu et. al, 2012).

To reduce leakages, it is essential that the water operators select appropriate leak detection methods for their water distribution networks. There are several leak detection methods need to be figured out by new users before they are implemented in a particular water distribution network. Bose and Olson (1993), Carlson (1993), and Turner (1991) have classified the leak detection methods in three groups, as follows: biological method, hardware-based method, and software-based method. Biological method is a leak detection method, which is carried out by employing several experienced leak surveyors to conduct visual inspections. While hardware-based method is a leak detection method applied by using different hardware devices, such as: acoustic sensors, tracer gas detectors, negative pressure detectors and IR camera thermography. Subsequently, software–based method is a leak detection method implemented by using various computer software packages, such as: flow/pressure change detection, mass/volume balance, the dynamic model-based system, and pressure point analysis.

Hunaidi (2000) and Hunaidi et. al. (2004) mentioned that several leakage detection methods that are currently implemented by most water operators, such as: accoustic methods, tracer gas technique, IR camera thermography and ground penetrating radar (GPR). Acoustic method is the most widely used approach (Brennan et. al., 2002). Nevertheless, Hunaidi added that the applications of non-acoustic techniques, such as: tracer gas, infrared imaging, and ground-penetrating radar, which are very limited and their effectiveness are not as well established as that of acoustic methods.

Several recent studies of leakage detections by implementing IR camera thermography were conducted by several researchers. Fahmy and Moselhi (2009) studied leak detection for identification of water leak locations in underground pipelines using IR camera thermography. The paper describes in-depth study on factors that influence the applicability and constraints of the use of IR camera technology. Carreno-Alvarado, et. al. (2014) investigated thermal images that were taken from IR camera thermography under various conditions in area containing buried pipes. Then, the thermal images were analyzed based on generated environmental and stored in an image database equipped by a data mining.

Meanwhile, some studies of leak detections using ground penetrating radar were conducted by Eyuboglu et. al. (2012), David Ayala et. al. (2013), and Halimshah et. al. (2015). Eyuboglu et. al. (2012) carried out a series of laboratory experiments to determine the validity and effectiveness of GPR technology in detecting water leakage in metal and plastic PVC pipes. David Ayala et. al. (2013) studied problems of leakage in water distribution systems through the use of GPR, such as : level of expertise of the operator, complex spatial arrangement of other utilities, and steady growth of the water demand. A laboratory tests and a test in a real-world urban system were performed to extract features of water leakage from the obtained GPR images. The final objective of this study is to extract features that create intelligent automatic processes for the (automatic) detection of leaks using GPR images. Halimshah et. al. (2015) investigated the potential of Ground Penetrating Radar (GPR) to detect water mains, by using several experiments. These include instrument validation test and soil compaction test to clarify the maximum dry density (MDD) of soil, as well as simulation studies on water leakage at a test bed consisting of PVC pipe burying in sand to a depth of 40 cm. The objective of the paper is to prove that GPR can be applied as a method for water leakage detection.

From those studies explain that acoustic method is the most widely used approach as well as IR camera thermography and GPR have started to be in common use in the water industries. While, the application of leak detection using tracer gas is very limited and its effectiveness is not as well established as those methods. This study addresses its applicability and limitation of implementing leak detection using tracer gas. There are 2 (two) types of tracer gas, such as: helium and hydrogen. Since characteristic of hydrogen gas is flammable, thus the study focused on the use of helium gas as the tracer gas. The objective of the study is to provide knowledge and insights for new users who intend to apply this method in their water distribution networks.

2. Principles of Helium Leak Detector

In general, helium leak detections are able to be used for leak detections in water distribution systems. Principally, Ishii et. al. (1983) explained that helium gas are flowed or injected into a pipe system through valves or tapping points. Then, at a leaky location, the helium gas, which is mixed with other remaining gases, is released out to the air, through voids or drilled holes at the surfaces of pavements. Using a helium leak detector, the helium gas is detected at the leaking location. A partial pressure ratio of helium that reaches a helium leak detector tool (mass spectrometer tube) is raised by using a helium permeable membrane, that selectively allows helium gas to pass through, while the air components that are not necessary for detection are suppressed. The helium component ratio in the space of the spectrometer tube is made larger. The helium partial pressure in the gas thus increased helium component and then is determined or detected by the mass spectrometer..

Furthermore, Ishii (Ishii et al, 1983) mentioned that there are two kinds of helium detection methods, that are : **vacuum method** and **pressure method**. In the **vacuum method**, the helium gas flows into a pipe system, by substituting air component, then is mixed with the remaining gasses and goes as a sample gas through the helium premeable membrane which restrains the air (especially N_2 and O_2), that are not necessary for the detection. Later the helium gas come into the space inside the spectrometer tube. Here, the helium component inside the space is increased higher than that in the sample gas. Then, the helium increased component is determined by the mass spectrometer tube. The amount of helium increased component depends on the amount of substitution of the helium gas for the air elements at a leaky point. Thus, the leakages are detected according to the increase of helium gas component. On the other hand, in the **pressure method** in which helium gas having an appropriate concentration is injected under pressure into a pipe system. The gases which are released through a leaking location out of the system are sucked in by a helium leak detector, through a membrane placed at an appropriate position to the spectrometer tube, and the leakages are detected by the detector tube.

In addition, Ishii et. al. (Ishii et al, 1983) explained about helium leak detection method using sniffer method. The helium gas is injected under atmospheric pressure into the system. Then, each side of a vacuum hose is connected to test port of helium leak detector and to a sniffer nozzle, for detection the leakages in the syste. The gas volume to be tested is pressurized with 100% or a mixture of helium inside. The leaks are detected using a sniffer probe which measures the helium concentration in the trialed area.

Principally, the operating method of sniffer method is explained in Fig. 1. The detected gas molecules are analyzed using spectrometer. The molecules pass into an ionizatoin chamber. The molecules are then bombarded by an electron beam, which is produced by a heated tungsten filament. This process causes a large number of the molecules are transformed into ions. Next, the ions are accelerated by an electrical field.

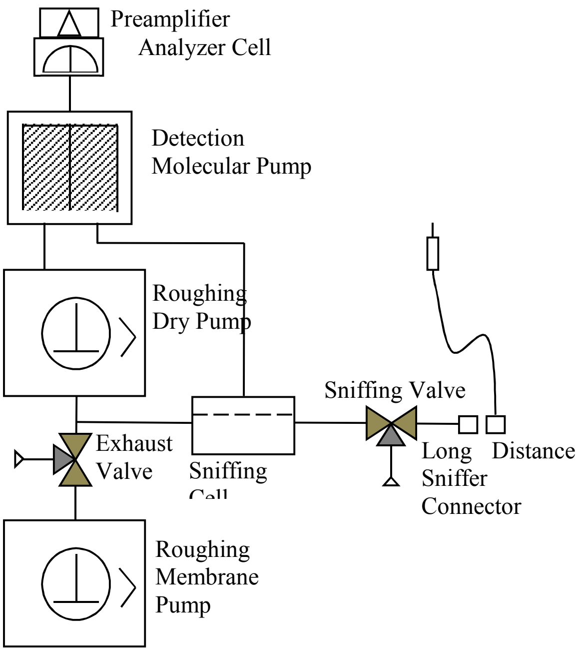


Fig 1. Principle of Helium Leak Detector

Meanwhile, the whole analyzer cell becomes a magnetic field, which its function is to deflect the ions trajectories along different curves based on the masses of the ions (m/e ratios). Therefore, the ion beam, which contains ions with various masses, is segregated into a number of beams. Each beam contains ions with the same m/e ratios. Subsequently, the helium ions (m/e = 4) are splitted from lighter ions (H_2^+, H_1^+) or heavier ions (N_2^+, O_2^+). The existence of the stable magnetic field helps to adjust accelerator electrical field, thus the helium ions (m/e = 4) enable to go along in a predetermined trajectory and arrive on the target at the input of current amplifier. The current of helium ions is proportional to the partial pressure of helium in the system of the equipment. By measuring the helium ions, we are able to find the flow of helium rate on the detected leak points.

Ishii et al (Ishii et al, 1983) mentioned that this method previously had a drawback of being clogged by dusts because of small dimension of its nozzle tip for keeping the pressure difference between atmospheric pressure and a high vacum pressure in the helium detector. However, as the new innovation has been built, a relatively greater dimension of nozzle tip has been created and the clogging problem from dusts has been eliminated. The detectability of the tool can be improved greatly.

3. Characteristics of Helium Gas

ASM 102 Helium Leak Detector User's Manual explains the application of helium gas for leakage detection. Firstly, the word of Helium is originated from "Helios" (in Greek), which means "sun" since it was dicovered in the sun's atmosphere. Helium is the second highest number element in the universe, which represents about 23% of the total matter, after hydrogen with 76%. Helium is very common in the universe, while on earth, its number is not abundant. Helium is formed in a very deep depth from the radioactive decompositions of Uranium and Thorium, which generates an internal heat inside the earth.

Helium is regularly escaping up from below the ground into space moderately quickly because it is so light. In contrast, there is a stable flow of helium gas from outer space and the sun into the earth. This gives a dynamic equilibrium of a constant helium concentration of 5 ppm (parts per million) in the air.

The user's manual also describes the reasons of using helium gas for leak detection, as follows :

a) Helium gas weight is very light
b) It is a colorless element
c) It is a noble gas, which does not react with anything
d) The gas is difficult to liquefy
e) It is an inert gas (to protect things from oxydations)
f) It is a 100% green gas and definitely has no environmental impacts to the atmosphere.

Helium gas has a various range of purity levels. For leak detection pusposes, we only require a range of purity levels of 97% - 99%. Using this range of helium purity levels, has no risk of accuracy lost during leak detection.

4. Methodology

The methodology is started by collecting network flow and pressure data, location data of tapping point for helium gas injection, and pipe network map. If the network area is too large, then the area is divided into several smaller areas with similar pipe length, This network area division aims to have an optimal helium gas spreading to the entire networks. Then, injection of helium gas into network through tapping points, as depicted in Fig. 2. After 2 hours, several samples of helium gas were taken to identify the level of helium spreading. One sample of helium gas represented a helium gas spreading on 2 kilometers of pipe length. Volume and flow of injected helium gas are calculated based on equation (1) and (2).

Volume of injected helium gas = (Q_{He} x T) / 37 liter/bar ……………………………………(1)

(37 l/bar for 1 tube of helium gas = 6 m3 with pressure of 165 bar)

Flow of injected helium gas = 1% x Q (lps) x 60 s/minute …………………………………(2)

(2a) (2b) (2c)

Fig. 2. Helium flow meter (2a); Process of helium gas injection into the pipe network (2b and 2c);

The samples of helium gas can be taken from existing tapping points, air valves or water taps from house connections, which the helium gas can release to the air. The samples of helium gas are placed into bottles and detected using a sniffing probe (Fig. 4). If the sniffing probe detects any presence of helium gas from the sample, then it indicates that the helium gas has spread throughout the networks and the detections are ready to be carried-out.

Fig. 3. Helium Leak Detector

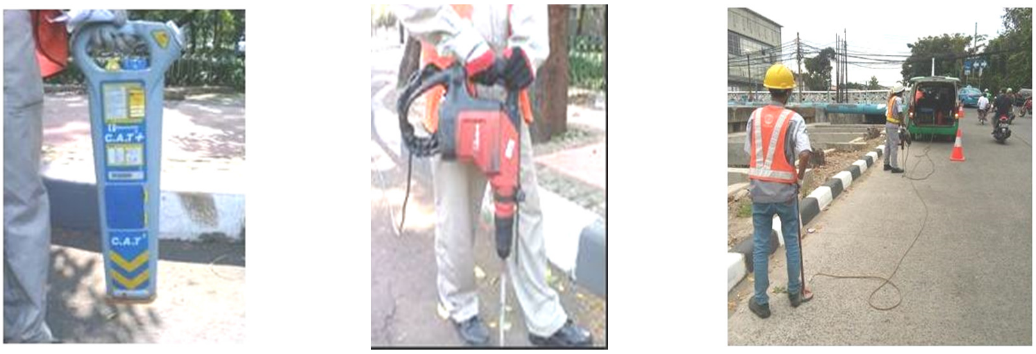
Fig. 4. Sniffing Probe

Subsequently, the pipelines on-site are traced by using a pipe locator and the detection could be done accurately. The pipe locator is used, so that the drilling bit does not hit other utilities located adjacent to the pipe lines during the drilling process. Afterward, the pavements along the pipe lines are drilled using several types of drilling machines, as listed in Table 1. Selection of the drill bit length depends on the pavement thickness on-site.

Table 1. Types of drilling machines

No	Types of drilling machines	Drillbit Diameters and Lengths
1	Hilti TE 40	Diameter = 12 mm ; Length = 47 cm
2	Hilti TE 56	Diameter = 16 mm ; Length = 55 cm
3	Hilti TE 70	Diameter = 16 mm ; Length = 92 cm

The drill holes are used to release the helium gas that is trapped under the pavements to the air, out from leaking points on the pipes. These allows the released helium gas is detected by the helium leak detector. The helium leak detector brand is Adixen and its type is ASM 102 S. It is manufactured by Alcatel Vacuum Technology, as illustratrated in Fig. 3. Helium gas in the pipe networks remains well-detected until 5 days. Otherwise, the helium gas should be reinjected into the network to have a better detection. In order to have a correct helium gas reading value, it is suggessted to calibrate the helium leak detector using internal calibrated leak (autocalibration) at regular intervals.



(5a) (5b) (5c)

Fig. 5. Process of pipe locating by using a pipe locator (5a); Drilling and detection along the pipe lines (5b and 5c)

Leak detection activities are mostly conducted during the day. However when traffic conditions during the day are high and congested or need a traffic re-routing, where it is not possible to conduct the leak detections, then they must be conducted during the night, when the traffic volume are decreasing and this activity requires a permit from Local Government Authorities. After carrying-out the leak detections, a validation of the leakages is made by excavating and repairing the findings of the leaking points on the detected locations.

5. Results and Discussions

The leak detection were implemented in 2 boundaried zones, at Pasar Pesing Kedoya (Zone B6) and Puri Kembangan (Zone B9), that are located in the area of Palyja, the Water Operator, in the Western Part of Jakarta, Indonesia. As Hunaidi et. al. (2004) mentioned that leak detection is a part of leakage management systems, which comprises several actions as follows: quantification of the total water loss, monitoring of leakage, locating and repairing leaks, and pipe pressure management. Quantifying the total amount of lost water is achieved by conducting a system-wide water audit, known internationally as a water balance. Water balance accounts for all water flowing into and out of a utility's water delivery system.

In this study, the water balance quantification was firstly conducted in the Zone B6 and Zone B9 as a base for conducting leak detection. Water flows in B6 and B9 valve inlets were 70 lps (liter per second) and 30 lps correspondingly. Nevertheless, the water consumptions that were billed to the customers were about 50 lps and 21 lps. Thus, the amount of the un-billed water in Zone B6 and Zone B9 were 20 lps (28,6 %) and 9 lps (30 %) respectively. Therefore, the leak detection was carried out to locate the water losses due to leakages. The data of network characteristics as well as helium gas injection in Zone B6 and Zone B9 are described in Table 2.

Table 2. Data of Network Characteristics and Helium Gas Injection in Zone B6 and Zone B9

No	Descriptions	Zone B6 (Pasar Pesing Kedoya)	Zone B9 (Puri Kembangan)
1	Types and diameters of pipes	- Distribution Pipes : 160 mm PVC pipe, 200 mm DCI pipe (pipe depth = 1,8 m) - Transmission Pipes : 800 mm steel pipe (pipe depth = 2,0 m)	- House Connections : 25 mm HDPE pipe (pipe depth = 1,2 m) - Distribution pipes : 63 mm PVC, 90 mm PVC, 110 mm PVC (pipe depth = 1,2 m) - Transmission pipes : 500 mm PVC pipe (pipe depth = 2,0 m)
2	Pressure at inlet valves	1 bar (= 10 mH_2O)	0,4 bar (= 4 mH_2O)
3	Flow of helium injection	133,2 liters per minute	100 liters per minute
4	Pressure in helium gas tube before injection	Total of 2 tubes, where 1st Tube = 50 bar; 2nd Tube = 150 bar	150 bar (Used 1 tube)
5	Pressure in helium gas tube after injection	0 bar	0 bar
6	Locations of sample helium gas taking and helium gas level of the samples (measured in "ppm" or parts per million)	• Daan Mogot Street at 250 mm DCI Pipe Bridge (250 ppm). • Daan Mogot Street at Air Valve (180 ppm), • At Pipe Bridge on Daan Mogot Street (160 ppm)	• Kembang Molek 9 Street (200 ppm). • Pipe Bridge of 500 mm PVC pipe in front of West Jakarta Mayor Office Building (150 ppm). • Kembang Sakti Street (250 ppm). • Kembang Utama 2 Street (200 ppm).
7	Date of detection	02-Mei-17	16-Jun-17
8	Types of pavements	Asphalt and rigid (concrete) pavements	Rigid (concrete) pavement

Both zones B6 and B9 have characteristics of high noise backgrounds (from vehicle sounds). Zone B6 is an area of public housing that has a public market and school. Whilst, zone B9 is area of modern real estates, schools as well offices and apartments. Although those areas had high noise backgrounds, leak detection using helium gas was able to be conducted appropriately, where these cannot be done reliably by acoustic methods.

At first, pressures at the inlet valves in the zones of B6 and B9 were measured using manometer gauge. A minimum required pressure must be 3 mH_2O at the inlet valve in order to have an optimum helium gas spreading to the entire network. From field measurement, its pressure readings at the inlet valves of B6 and B9 were 10 mH_2O and 4 mH_2O, respectively. Thus, the pressure minimum requirement was fulfilled. Then, the helium gas was injected at each inlet valve on each zone, and let the helium gas spread evenly on each network for 2 hours. Subsequently, the helium gas samples were taken on each zone through tapping points that are available on each network. Numbers of the samples in the zones of B6 and B9 are 3 samples and 4 samples correspondingly. The helium levels of each sample in the zone B6 were 250 ppm, 180 ppm, and 160 ppm, while the samples in the zone B9 were 200 ppm, 150 ppm, 250 ppm and 200 ppm (see Table 2). These samples indicated that the helium gases had spread throughout the networks on each zone, thus the detections could be carried-out.

The leak detection in the zone B6 was carried-out along the lines of 800 mm steel pipe, 160 mm PVC (polyvinyl chloride) pipe, and 200 mm DCI (ductile cast iron) pipe. A 30 cm-thick concrete pavement along the pipe line was drilled and the line was detected by the helium detector. The detector identified 4 findings, which the helium levels exceeded the normal helium gas rate in the air (4,5 x 10^6 ppm). The leak findings are depicted in Fig. 6.

A validation of leakages was made by excavating the findings of leak locations after helium leak detections. The results indicated that 2 leaks occurred on 800 mm steel pipe lines (Leak 1 and Leak 4) and 1 leak occurred on 160 mm PVC pipe (Leak 2),as well as 1 leak (Leak 3) occurred on 200 mm DCI pipes. Leak 1 occurred on a steel plate for patching a previous leak that cracked on its welded area and caused a leak. The water leaks infiltrated into a river near the pipeline and did not appear to the pavement surface. Since the pipeline is located near the river, the water table level is slightly higher than the pipe. However, Leak 1 could be accurately detected by the helium detector. While, Leak 4 took place on loose bolts and nuts of valve joint. Leak 4 was an interesting finding because the valve is placed inside a valve chamber that had been layered by a new asphalt pavement around 2 years before, so that the chamber location was completely disappeared on-site. Thus, this finding was not only able to find the leakage, but also it was able to discover "the lost valve chamber".

Leak 2 was detected in 160 mm PVC pipe line, which was caused by a broken accessory (clamp saddle). Similarly, Leak 3 was detected in 200 mm DCI pipeline, which took place a on a broken accessory (clamp saddle). All those leakages did not appear to the surfaces due to a thick asphalt pavement. Estimated leak flows and leak causes are displayed in Table 2. Although, the detected area is very congested due to vehicles and a public market, its high noise backgrounds did not affect the helium detector accuracy in locating the leakages.

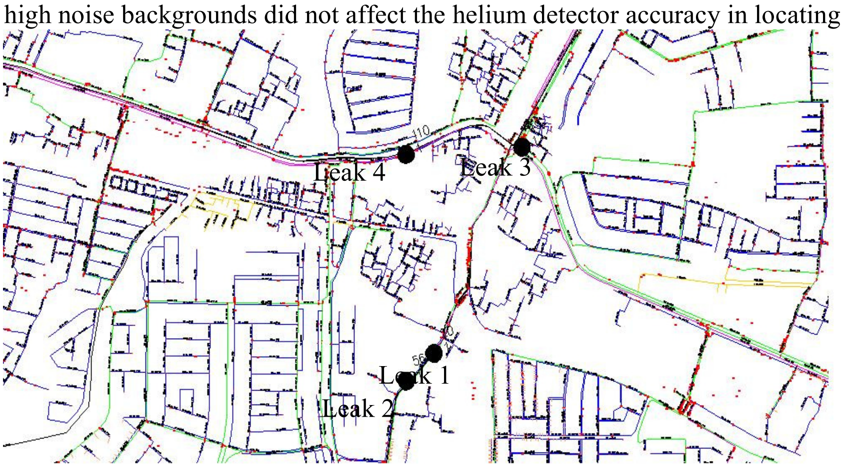


Fig. 6. Locations of leak detection findings at Pasar Pesing (Zone B6), West Jakarta

Fig. 7. A leak on 800 mm steel pipe due to crack on its patching plate (Leak 1)

Fig. 8. A leak on 800 mm steel pipe due to loose bolts and nuts on its valve joint inside a layered valve chamber (Leak 4)

Table 3. Estimated leak flows and leak causes in zone B6

No	Leak Number	Pipe Types and Diametres (mm)	Estimated Leak Flows (Lps)	Helium levels on detected locations (ppm)	Leak Causes
1	Leak 1	800 mm steel pipe	1	56	Crack on welded parts of a steel plate for patching the previous leak.
2	Leak 2	200 mm DCI pipe	0,25	49	Broken accessory (broken clamp saddle)
3	Leak 3	160 mm PVC pipe	0,25	20	Broken accessory (broken clamp saddle)
4	Leak 4	800 mm steel pipe	0,25	110	Loose bolts and nuts on a valve joint
		TOTAL	1,75		

Meanwhile, leak detections in the zone B9 were performed differently from the ones in the zone B6. Since the zone B9 is a large area with various pipe types and diameters (from 25 mm to 500 mm pipes), then the area was divided into 4 subzones (small zones), with each subzone was equipped by a tapping point to inject the helium gas into the pipe network. Helium gas samples were also taken in the subzones (see Table 3). There were 3 types of pipes laid in the zone B9, as follows : house connections 25 mm HDPE (High Density Polyethylene) pipe ; distribution pipes (63 mm PVC, 90 mm PVC, 110 mm PVC, and 160 mm PVC); and transmission pipes (500 mm PVC).

The leak detections were carried out and the results showed that there were 98 findings identified by the helium leak detector, as illustrated in Fig. 7 until Fig. 13. A validation of leakages was performed by excavating the 98 findings and repairing the leakages. Those findings are completely leaked and the results are listed in Table 4.

A validation, through excavations and repairs in the zone B9, revealed that the leakages were completely accurate and they were from the findings on detected locations. It proved that the leak detection using helium gas was very accurate (more than 80%) to detect the leakages because all helium detection findings were completely leaked after excavations and repairs were conducted.

Table 4. Estimated leak flows and leak causes in zone B9

No	Leak locations based on pipe types	Pipe Types and Pipe Diameters (mm)	Number of Leakages	Estimated Leak Flows (Lps)	Leak Causes
1	On house connections	25 mm HPDE	29	0,58	Fractured pipes, leaks due to non-standard joints, loose accessories, broken accessories
2	On distribution pipes	63 mm PVC, 90 mm PVC, 110mm PVC, 160 mm PVC	67	3,35	Perforated pipes, leaks due to non-standard accessories installations, loose bolts and nuts of accessories.
3	On transmission pipes	500 mm PVC pipe	2	2,50	Loose bolts and nuts of repair collars due to corroded bolts and nuts.
		TOTAL	98	6,43	

This study also explores advantages of helium leak detection compared to other leak detecting methods that are most-wide used today, such as: acoustic method, IR camera thermography, and GPR. A study conducted by Hunaidi (Hunaidi, 2000; Hunaidi et. al., 2004) revealed that leaks are frequently identified by acoustic devices. However, these acoustic devices cannot be reliable to detect quite (small) leaks, leaks on cast and ductile iron pipes, most leaks in plastic pipes, and most leaks in large-diameter pipes. Besides, Hunaidi (2000) added that acoustic methods cannot identify leak signals much clear on clay soils and on grass as well as areas with high noise backgrounds. In addition, the leak signals detected by acoustic devices sound muffled if the pipes are below water table level. Moreover, the devices induce stronger signals in detecting leaks due to high pressure, while the leaks due to low pressure sound very low signals.

A study of applicability and limitation of IR camera termography was conducted by Fahmy and Moselhi (2009). The study mentioned that the IR camera termography is able to investigate relatively large areas in less time and less cost comparing to current leak detection methods. However, its drawback is that the IR camera thermography fails to detect water leaks that infiltrate to adjacent sewer pipes, which avoid moisture movement from reaching the pavement surface and detected by the IR camera. Likewise, the IR camera cannot capture water leaks when the pipes are below the water table. Meanwhile, Eyuboglu et. al. (2012) studied a series of laboratory experiments to determine the validity and effectiveness of GPR technology in detecting water leakage, using a prototype laboratory model. Although the method shows the effectiveness of GPR device in detecting water leaks in metal and plastic pipes, however the method has not been tested in a real network situation for leak detection on many pipe sections.

Those problems that appear during the implementation of leak detection using acoustic methods, IR camera termography and GPR can be overcome by implementing leak detection using helium gas. The helium detection method works well to detect leaks on various pipe diameters (from small to large diameters) and on various pipe materials (HDPE, Steel, PVC, DCI, etc) in the studied areas (Zone B9 and B6). Besides, the method enabled to find leaks on different types of pavements, such as: asphalt pavement, concrete pavement, soils, grass, paving block, etc. It must be ensured that the field crews drill the pavement correctly in order to release helium gas that is trapped under the pavement into the air, so that it can be detected by the helium detector. In addition, high noise backgrounds do not affect the helium detector accuracy to detect leakages precisely, as the finding of leakage on 800 mm steel pipe in the studied area (Zone B6) in Fig. 7, where the area was very crowded and had high noise backgrounds, that came from vehicle noises. Moreover, the leakage on 800 mm steel pipe did not appear to the pavement surface, but it infiltrated to river near to the pipeline and it could be detected. Likewise, the field findings showed that small leaks due low pressure until big leaks due to high pressure can be accurately detected. It was shown in the studied areas that had relative low pressure networks, but many leakages were accurately detected (See the pressure at inlet valve in Zone B6 and B9 in Table 1). In order to have optimum helium spreading in the entire pipe networks, it must be ensured that it is required a minimum pressure of 3 mH_2O at the inlet valve. When the leak detection in conducted in areas where the pipe lines are laid under various utilities, it must be ensured that the field crews drill carefully the pavements in order not to hit the utilities above the pipes. Additionally, it is possible to conduct leak detection in areas where the pipelines are below water table level. In those areas, the helium gas released from the leaking points can still be detected. However, it must be ensured that its detecting stick did not suck the water table into its sniffing probe (inside an Erlenmeyer Tube). This will cause an error reading of helium level. Thus, detecting in areas with high level of water table cannot be conducted.

Fig. 9. Locations of leak findings in Puri Kembangan (Zone B9), West Jakarta (● = leak findings)

Fig. 10. A leak due to a broken 500 mm PVC pipe joint

Fig. 11. A process of leak repair on the 500 mm PVC pipe joint

Fig. 12. Perforated 63 mm PVC pipe (marked by a circle)

Fig. 13. A leak due to a corroded tapping point on 90 mm PVC pipe

Fig. 14. A leak due to a broken clamp saddle, on a distribution pipe (110 mm PVC)

Fig. 15. A leak due to non-standard installation of a house connection pipe (25 mm HDPE)

6. Conclusions

The leak detection using helium gas is accurate (more than 80%) to detect all leakages, both small leakages and big leakages, as well leakages due to high or low pressurized network. It is required a minimum required pressure of 3 mH_2O at the valve inlet to enable the helium spreads optimally to the whole networks. The method is able to effectively detect leakages that are trapped under different types of pavements and become undetected leakages for many years. The method detects leakages precisely on various pipe materials and on various pipe diameters. Besides, high noise backgrounds do not affect its detection accuracy in identifying water leaks. In addition, the method enables to locate leakages where the water leaks infiltrate into adjacent sewer drainages or rivers. Furthermore, the method works successfully to detect leakages under different types of pavements. Detecting leakages on pipelines, which are laid under various utilities, requires careful drilling actions in order not to hit the utilities above the pipes. Additionally, it is possible to detect leakages in areas where the pipelines are below water table level. However, if the water table level is high, then the detection cannot be conducted.

7. Acknowledgement

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8. References

Brennan, M. J., Joseph, P., Muggleton, J. M., and Gao, Y. 2008. Some Recent Research Results on the use of Accoustic Methods to Detect Water Leaks in Buried Plastic Water Pipes. Posted at : https//www.researchgate.net/publication/252581653

Hunaidi, O. 2000. Detecting Leaks in Water-Distribution Pipes. Construction Technology Update No. 40. pp. 1-6. National Research Council of Canada.

Hunaidi, O., Wang, A., Bracken, M., Gambino, T., and Fricke, C. 2004. Acoustic Methods for Locating Leaks in Municipal Water distribution networks. International Conference on Water Demand Management, Dead Sea, Jordan, May 30-June 3,2004, pp. 1-14. Posted at : http://irc.nrc-cnrc.gc.ca/ircpubs

Fahmy, M. and Moselhi, O. 2009 . Detecting and locating leaks in Underground Water Mains Using Thermography. 26th International Symposium on Automation and Robotics in Construction (ISARC 2009), pp. 61 – 67

Eyuboglu, S., Mahdi, H., and Al-Shukri, H. 2014. Detection of Water Leaks using Ground Penetrating Radar. Research Gate Journal. Posted at : https://www.researchgate.net/publication/253625408

Ayala–Cabrera, D., Herrera, M., Izquierdo, J., Oca˜na–Levario, S. J., and Perez–Garcıa, P. 2013. GPR-Based Water Leak Models in Water Distribution Systems. Sensors 2013, 13, 15912-15936; doi:10.3390/s131215912. www.mdpi.com/journal/sensors

Ishii, H., Seki, K., Morishita, H., Kawasaki, Yamazaki,T. 1983. Leakage Detection Method using Helium./United States Patent No. 4,410,882.

Carreno-Alvarado, E. P., Ayala–Cabrera, D., Izquierdo, J., and Perez–Garcıa. 2014. Identification of Buried Pipes using Thermal Images and Data Mining. ProcHuedia Engineering 89 (2014), pp. 1445 – 1451. Posted at :http://creativecommons.org/licenses/by-nc-nd/3.0/

Halimshah, N. N., Yusup, A., Mat Amin, Z., and Ghazalli, M. D. 2015. Visual Inspection of Water Leakage from Ground Penetrating Radar Radargram. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-2/W2, 2015. doi:10.5194/isprsannals-II-2-W2-191-2015. Joint International Geoinformation Conference 2015, 28–30 October 2015, Kuala Lumpur, Malaysia.

J. Thornton, R. Sturm, And G. Kunkel. Water Loss Control. 2nd Edition. 2008.

Taylor, P. et al., 2011. Estimation of the Benefits Yielded by Pressure Management in Water Distribution Systems. *Urban Water Journal*, 8 No. 2(April 2011), pp.65–77

-------------------- ASM 102 Helium Leak Detector. User's Manual. 2009. Manual Refence #109714.Adixen.