UNIVERSITI PUTRA MALAYSIA

PIPE LEAK DETECTION AND MONITORING SYSTEM USING PRESSURE RESIDUAL METHOD

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in the Fulfillment of the Requirements of the Degree of Master of Science

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This work is dedicated to my family, people who supported and guided me during study period specially my father and mother

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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August 2016

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The research work utilises "pipe leak monitoring by means of pressure sensors" or "leak detection and localisation using pressure sensors inside a pipe", which refers to an integrated use between the liquid, the sensor, and the PC software. Monitoring pipes is used for leak detection in the pipe, and is performed by using a residual approach which means monitoring the pressure variation inside a water district section (WDS). Sensors show the data that has been accumulated from the liquid inside the pipe. The liquid responds to the leak influence due to hydraulic rules when a drop in the pressure value occurs due to a negative wave pressure phenomenon. Leak detection methods are used to minimise the cost of pipe inspection and reduce the cost of liquid blow out in the pipe due to leak deterioration. In addition, it helps to prevent the disaster of explosions caused by gas seepage or petrol leakage. Early leak detection prevents any influence on the infrastructure around the pipe because of small leaks, which can spill much water over a long period of time. Moreover, it reduces the hazard of epidemic infections when waste water impurities enter inside the distribution system. Many detection approaches have been proposed in the past, but a monitoring distribution system using pressure sensors is preferred, because it does not need to shut down a part of the network. The use of pressure sensors gives a faster response and they are easy to maintain. In addition, the acoustic method has an influence on traffic and it is not effective in plastic material (PVC). The development of the hydraulic model and an hydraulic solution for a water distribution system enhances the ability to represent a fire flow condition in the simulation program. The EPANET program is the result of advanced research and it would be able to simulate fire flow (leak or deficiency condition) in the water distribution system. The pressure exponent in the hydraulic equation was used as a fixed value equal to 0.5 in the pressure residual approach for detecting and localizing leaks in the water distribution system. Moreover, this study utilizes different pressure exponent that used according to the material type of the network pipes and illustrates the influence on the values of sensitivity matrices. The result showed that the applied different pipe material approach (different exponent value) would enhance the result of the sensitivity matrix which is considered as a leak detection layer in the pressure residual method. Monitoring experiments have been performed in Malaysia, at the Selangor Seri Aman water district section to produce a sensitivity matrix, and examine the effect of different pipe materials (PVC, metallic

and Asbestos Cement) and other aspects on the sensitivity matrix value. The ArcMap program was used to reduce the uncertainty of customer distribution density in the EPANET program model node through an account of the base demand parameter.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGESANAN KEBOCORAN PAIP DAN SISTEM PEMANTAUAN MENGGUNAKAN KAEDAH BAKI TEKANAN

Oleh

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Kerja penyelidikan ini menggunakan "pemantauan kebocoran paip melalui sensor tekanan" atau "pengesanan kebocoran dan penyetempatan menggunakan sensor tekanan di dalam paip", yang merujuk kepada penggunaan bersepadu antara cecair, sensor, dan perisian PC. Paip pemantauan digunakan untuk mengesan kebocoran pada paip, dan dilakukan dengan menggunakan pendekatan baki yang bermaksud memantau perubahan tekanan di dalam sesuatu bahagian daerah air (WDS). Sensor-sensor menunjukkan data yang telah terkumpul daripada cecair di dalam paip. Cecair itu bertindak balas kepada pengaruh kebocoran disebabkan peraturan-peraturan hidraulik apabila penurunan nilai tekanan berlaku disebabkan fenomena tekanan gelombang negatif. Kaedah-kaedah pengesanan kebocoran digunakan untuk meminimumkan kos pemeriksaan paip dan mengurangkan kos hamburan cecair di dalam paip kerana kemerosotan kebocoran. Tambahan lagi, ia membantu mencegah bencana letupan yang disebabkan oleh resapan gas atau kebocoran petrol. Pengesanan kebocoran yang awal menghalang sebarang penjejasan ke atas infrastruktur di sekeliling paip disebabkan kebocoran-kebocoran kecil, yang boleh menumpahkan banyak air dalam tempoh masa yang panjang. Selain itu, ia mengurangkan bahaya wabak jangkitan apabila kekotoran air buangan masuk ke dalam sistem pengagihan. Banyak pendekatan pengesanan telah dicadangkan pada masa lalu, tetapi sistem pengagihan pemantauan menggunakan sensor tekanan menjadi pilihan, kerana tidak perlu untuk menutup sebahagian daripada rangkaian berkenaan. Penggunaan sensor-sensor tekanan memberi tindak balas yang lebih cepat dan mereka mudah untuk diselenggara. Di samping itu, kaedah akustik mempunyai pengaruh ke atas trafik dan ia tidak berkesan di dalam bahan plastik (PVC). Pembangunan model hidraulik dan suatu penyelesaian hidraulik untuk sesuatu sistem pengagihan air meningkatkan keupayaan untuk mewakili keadaan aliran api di dalam program simulasi. Program EPANET adalah hasil daripada penyelidikan yang lanjut dan ia akan dapat mensimulasikan aliran api (kebocoran atau keadaan kekurangan) di dalam sistem pengagihan air. Eksponen tekanan di dalam persamaan hidraulik telah digunakan sebagai nilai tetap sama dengan 0.5 di dalam pendekatan baki tekanan untuk mengesan dan menyetempatkan kebocoran di dalam sistem pengagihan air. Sebagai tambahan, kajian ini menggunakan eksponen-eksponen tekanan yang berbeza yang diguna pakai mengikut jenis bahan paip rangkaian dan menggambarkan pengaruh ke atas nilai-nilai matriks kesensitifan. Hasilnya menunjukkan bahawa

pendekatan bahan paip berbeza (nilai eksponen yang berbeza) yang digunakan akan meningkatkan hasil matriks kesensitifan yang dianggap sebagai lapisan pengesanan kebocoran oleh kaedah tekanan baki. Eksperimen-eksperimen pemantauan telah dilaksanakan di Malaysia, di bahagian daerah air Selangor Seri Aman untuk menghasilkan matriks kesensitifan, dan mengkaji kesan bahan paip yang berbeza (PVC, logam) dan aspek-aspek lain pada nilai matriks kesensitifan. Program ArcMap digunakan untuk mengurangkan ketidaktentuan ketumpatan taburan pelanggan di dalam nod model program EPANET melalui akaun parameter permintaan asas.

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I certify that a Thesis Examination Committee has met on 22 August 2016 to conduct the final examination of Ali Mohammed Ali Abdulshaheed on his thesis entitled "Pipe Leak Detection and Monitoring System using Pressure Residual Method" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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AE0	The effective Area of leak in the case of the pressure Value Equal to zero	m2, cm2, mm2
A_l	Area of the Leak Orifice	m^2, cm^2, mm^2
AC	asbestos-cement Pipe	-
AZP	The average Water Pipe Zone Pressure	(psi)-(m)
C	Correlation	-
C_d	Leak Discharge Coefficient	-
DLL	Dynamic Link Library	-
DMA	A District Metered Area	-
g	Fluid Acceleration	(m/ sec^2) -(ft./ sec^2)
h	Pressure Inside the Pipe	(psi)-(m)
Hl	Roughness head loss	-
ITA	Inverse Transient Analysis	-
LMA	Levenberg-Marquardt algorithm	-
LRM	Leak Reflection Method	-
MNF	Minimum Night Flow	ft^3/sec) (L/s) (m^3/s) (L/h)
N	Exponent leak coefficient	-
σ_θ	The angle of the Maximum Fluid force that effect in the	-
PRV	Pressure Reduction Valve	-
PRBS	Pseudo-Random Binary Signal	-
Q	Leak Discharge	(ft^3/sec) (L/s) (m^3/s) (L/h)
r	The Pressure Residual	(Psi)- (m)
Re	Reynold Number	-
S	Sensitivity Matrix	-
SCADA	External Monitoring for Pipe Supervisory Control and Data Acquisition	-

SVM	Support Vector Machine	-
S_w	Tensile stress applied to the opening edge	-
UARL	Unavoidable Annual Real Losses	(ft^3/sec) (L/s) (m^3/s) (L/h)
V^2	Square of fluid velocity	m/s, ft./sec
WDS	Water District section	-
Z	Vertical distance between two point	m, ft.

CHAPTER 1

INTRODUCTION

This first chapter of thesis presents the research background and the current methods for monitoring the water distribution system to reduce real losses including leak losses. The objectives, the scope of research as well as the problem statement, are also included in this chapter.

1.1 Research Background

Understanding all the causative and influential factors that affect water loss in a water distribution system is the cornerstone of the effective and solid management strategies to circumvent this issue (Koelbl et al. 2009). Municipal authorities face many challenges to maintaining an effective water distribution service due to factors related to climate change or shortage of financial resources. There is a need to improve the coverage and efficiency of basic urban services (Robert Goodwin, 2012). In urban areas, about one third of the supplied water is lost due to leaks or bursts in the piping system or the failure of water retrieval through the revenue and financing systems (Mounce et al. 2010; Nazif et al. 2010). Estimated non-revenue water (NRW) values for different countries in the level of developing were 15 % and 35 % of the annual system input volume, respectively (Kanakoudis and Tsitsifli 2012). It was estimated that the annual water loss reached in both developed and developing countries such as Africa, Asia, Latin America and the Caribbean, and North America are 39 %, 42 %, 42 %, and 15 %, respectively (WHO-UNICEF-WSSCC 2000; Islam et al. 2011). Moreover, in European Union (EU) countries the non-revenue water was found to be 20 %, whereas several countries have non-revenue levels of a percentage which is less than 10 % (Öztürk et al. 2007).

Leak detection methods mainly depend on human observation and periodical routine inspection. These examples of old leak detection methods do not provide the right information to make a decision to stop leaks instantaneously in order to reduce the cost of losses. Leakage monitoring may be performed on a routine basis or when high losses are suspected such as a large drop in the pressure value. Advanced techniques are used for pinpointing leaks, ranging from ground-penetrating radar to acoustic wave devices. Some of these techniques require isolating and shutting down part of the network. Real time pipeline monitoring systems based on wired or wireless sensors have been studied in the past. The wire based techniques connect the sensors along a pipeline by using wires. The monitoring information measured by each sensor is transmitted to the monitoring control centre through these wires and the information can be analysed to determine the location of the leak.

Experimental work has been conducted which was dedicated to monitoring the water distribution system in Selangor, Malaysia. A DMA (District Meter Area) has been created with fixed borders and the work has been performed with the co-operation of the Innovation and Creative Department of the Puncak Niaga Water Company. Flow sensors measured the flow at two feed points including the base information about the network pipe material, the length and the date of installation. The network was underground. Three pressure loggers were implemented at precise locations inside the distribution network. The pressure loggers were implemented using hydraulic sensors in order to monitor the pressure or flow rate. This work focuses on the use of pressure monitoring points as they are used more frequently than flow rate sensors. This is because pressure monitoring equipment is cheaper and it is easier to collect pressure data rather than flow data. The pressure transducers give instantaneous readings and are easy to maintain whereas most flow meters do not respond immediately to changes in flow (Schaetzen et al. 2000). Flow rates are usually measured at all entry points to the network, including on the main pipes at the entrance into sub-networks (i.e., inflow to bounded demand zones), and/or at the outlet of elevated tanks and pumping stations. Thus, the selection of flow rate measurement points is straightforward and is limited to specific locations. This work attempts to monitor a distribution system through the analysis of pressure variations using the EPANET program. A pipe distribution model was created and a simulation process for the Seri Aman distribution system was undertaken using the SCADA system information which recorded the pressure and flow for seven days a week for 24 hours at a rate of every 15 minutes. The distribution network was monitored for 30 days, and data and the water consumption amount were collected. Monitoring the distribution was also used to determine the minimum night flow (MNF). This was because discrepancies at night between reality and the model were smaller than during the day, so it was the best time to do the test (Pérez. et al, 2009).

Pressure in the distribution system tends to increase as the flow demand increases. According to (Kunkel and Strum 2010), however, in most water distribution systems the pressure decreases as the flow demand increases while the pressure increases when the flow demand is low. This means that the lowest pressure exists in the distribution system when the demand is high, resulting in high pressure in the network at night when demand is the lowest. An MNF of less than 35% of the average daily use indicates little leakage, whereas an MNF greater than 50% of the average rate indicates substantial leakage. Most importantly if MNF > MNF0 then there are leaks. MNF0 is the lowest acceptable MNF (determined by testing a typical area, without water leaks). Water loss can simply occur naturally in networks for many reasons. For instance, it could be a result of the head loss increasing when the demand is high causing pressure to drop in the pipes, or it could be due to centrifugal pumps providing low pressure when the flow increases. In some cases, the water department may intentionally increase the pressure at night in order to refill the depleted tanks at night (Abu and Faraj, 2013). The experiment employed applied modelling which was developed to help the operators of the network deal with the detection and localisation of leaks in the district metered areas (DMA) of a water distribution network.

The leakage detection procedure was performed by comparing the pressure data of certain DMA inner nodes with their estimation using the simulation of the mathematical network model. This approach differs from other methods in the literature, such as the reflection method (LRM) or inverse transient analysis (ITA), since it is not based on the transient analysis of pressure waves (Ferrante 2003a; 2003b) (Misiunas, 2005) (Verde 2007). Alternatively, the simulation program used was EPANET which is able to analyse the flow and pressure in every node (customer connection point). The required parameters for a successful case simulation in the EPANET program are roughness, the length and diameter of the pipes, the valve loss coefficient and the base demand and the demand pattern of every node in the network model. In addition, topological parameters are needed such as the node elevation relative to the level of the sea. Several studies on pressure - leakage dependencies have shown that the leak discharge amount is subject to many parameters such as leak hydraulics, the pipe material's behaviour, soil hydraulics and water demand.

1.2 The Problem Statement

In any old water system there will be small 'background' leaks at the joints and fittings, and large leaks from avoidable sources. An investigation by Greyvenstein and Van Zyl, into the effects of leakage in water distribution systems indicated that the pressure exponent is dependent on the geometry of the orifice Table 1.1. In addition, the material and the crack size have a significant influence on the emitter exponent. The most important problem is the influence of the pipe material (different pressure exponent of hydraulic equation) on the sensitivity matrix result that is used in the leak detection methodology as a finger print of the exact water distribution system. Corrosion has been declared as the main cause of deterioration in metallic, cast iron pipes. The most common shapes for the corrosion impact of ductile iron and steel are the spot, cluster and hole. These kinds of defect do not exist in PVC, since the mechanical properties of the material prevent corrosion forming and the flexibility is quite enough to handle the external load. Around leakage shape is formed in the metallic material so, the pressure exponent value of the metallic material is 0.6. Moreover, the crack leak shape is imposed on the PVC pipe material thus the exponent value is 1.9 and for asbestos cement is 1.1 as shown in Table 1.1.

Table 1.1: Leakage exponent for different pipe materials (Greyvenstein, 2004)

Failure Type	Leakage Exponent for pipe materials		
	uPVC	**Asbestos cement**	**Mild Steel**
Round hole	0.52	-	0.52
Longitudinal crack	1.38- 1.85	0.79-1.04	-
Circumferential crack	0.41-0.53	-	-
Corrosion cluster	-	-	0.67-2.30

The specific environment creates an exact kind of pipe failure, from circumferential cracking, longitudinal cracking and bell shearing to corrosion pitting and blow-out holes (Misiunas et al. 2005).

Circumferential cracks frequently occur due to the bending stress caused by soil movement, which results in this type of crack being common.

Furthermore, the change in liquid velocity inside the pipe of a distribution system affects the leak discharge exponent in the hydraulic model equation. The exponent coefficient would be 0.5 and 1, if the flow status through an orifice is transitional, when the Reynold Number (Re) is below 4000; Re equal to 4000 is considered the beginning of the turbulence status as illustrated in Figure (1.1). For a circular orifice, a relationship can also be derived between pressure(P) and discharge (Q). When the flow status through the fixed area orifice is transitional, the output flow through the orifice is less than expected. In contrast, the laminar flow status through the fixed area orifice delivered a discharge equal to or more than the flow that was expected (Thornton et al. 2005). The very high exponents point out that the maximum exponents in excess of 2.5 as reported in field tests (Farley and Trow 2003) are not unrealistic. Such high exponents can play a predominant role in the leakage behaviour of a system, and thus have important indications for the pressure management, material selection and maintenance of operational systems.

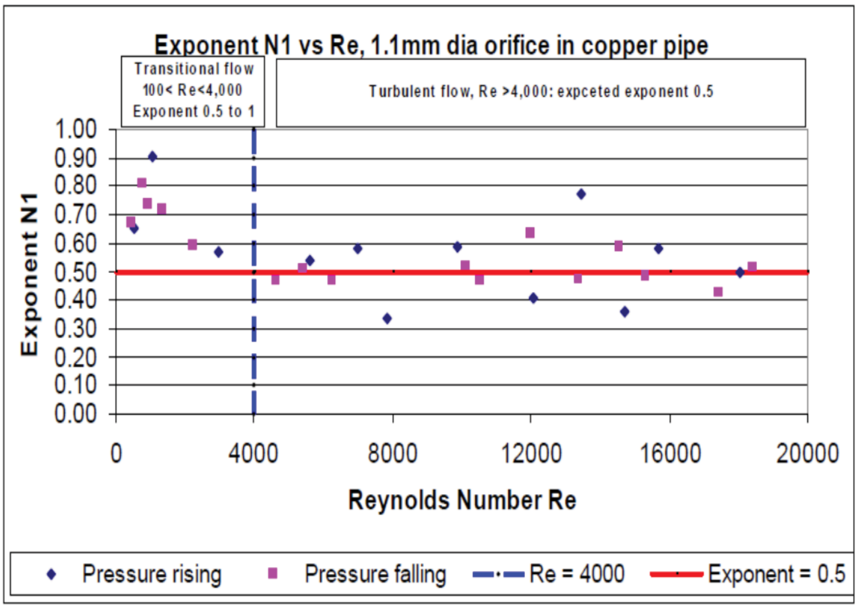

Figure 1.1: Exponent N1 vs Re for a 1.1 diameter. orifice in a copper pipe (Thornton & Lambert, 2005).

There are two limitations that should be taken into account to estimate the pressure exponent value by which to produce this value in a hydraulic equation so the emitter coefficient can be deduced. The applicable solution for the non-linear complexity of a distribution system can be found by simulation and analysis of flow such as in the EPANET program, and the use of the node pressure results to create a sensitivity matrix.

1.3 Justification of the study

Loss reduction and health concerns regarding the water distribution system impose the need for strict monitoring to work, and it needs a fast responding system to treat any fault situation inside the piping distribution system. The pressure residual method is considered to be a promising way to detect leakage in the pipe network. The proposed study discusses the effect of pipe materials in the distribution system in a matrix sensitivity, which is part of the pressure residual method that detects and locates leaks in the water pipe network. In addition, it detects and locates a leak in the typical water distribution network.

1.4 Research Objective

The research utilises pipe leak detection and a localised approach for a water distribution system. The study was conducted with real monitoring of a typical water network located in the Selangor district zone of Seri Aman. The leak discharge was subjected to many parameters within the hydraulics of the distribution system and the pipe material had an obvious effect on the amount of leak discharge which caused different pressure variations inside the pipe network. To investigate the pressure residual method and the influence of the piping system material, the following steps illustrate the objectives:

1- To detect of leaks within a water distribution system and explain the influence of the pipe material (different exponent value) on the sensitivity matrix.

2- To localise leaks in a water distribution system depended on the correlation value between each column of sensitivity matrix and the pressure residual value.

3- To determine the minimum leak size that can be detected by EPANET program.

1.5 Scope of research

The research is dedicated to the detection and localisation of leaks in a distribution system. A distribution system is usually designed and installed according to its purpose, to deliver different fluid types including oil, gas, fuel and water. Some of these fluids are dangerous, so there is the danger of explosion that may occur during leaks. For that reason, the experiment focused on a water distribution system without considering the other kinds of fluid. In addition, the Puncak Niaga Company adopted the experiment represented by the Innovation and Creative Department and all the selected options were included due to the company rules, staff time and available network material and the technologies used. In addition, customer demand value uncertainties, a noise measurement of the pressure and flow sensors. Furthermore, the difficulties of change boundary condition (pressure and flow) because of the network is under operation. Moreover, the monitoring of the pipe distribution system during one month. The uncertainties result from simulation by applied a mathematical model.

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