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Research Article

Comparative Analysis of Leakage Behavior in Continuous and Intermittent Water Distribution Systems

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Abstract

This study investigates the experimental work on identifying the difference between continuous and intermittent water distribution systems using equivalent and series pipeline systems. The (WDS) will be monitored digitally at an accurate rate, and the data will be stored in a real-time database as graphs. As a result, in continuous water distribution systems, higher flow rates are directly linked to increased leakage severity, which is further aggravated by system losses and valve issues, as evidenced by the declining trends in the graph. In contrast, intermittent systems exhibit consistent leakage behavior across different scenarios and valves. The uniformity in sensor responses supports the effectiveness of current monitoring strategies and highlights the necessity for tailored management approaches for each system type. Research findings indicate that leakages lead to a decrease in flow rates that intensify with higher flows, underscoring the critical need to preserve the integrity of the system. In continuous water distribution systems (CWD), leakages occur at higher rates compared to intermittent systems (IWD), with instances of single leaks (SL) proving more detrimental than multiple leaks (ML) due to their concentrated impact. Particularly, the second valve shows increased vulnerability in both systems and thus necessitates focused monitoring and preventive maintenance. Furthermore, a detailed analysis quantified the variations in leakage rates and discharge volumes between continuous and intermittent systems, as well as across single and multiple leakage scenarios within each system, highlighting key areas that require attention.

1. Introduction

Water distribution systems are typically established using underground pipelines. Monitoring these subterranean pipes poses greater challenges compared to those located in more accessible above-ground areas. Any disruptions, such as leaks in these pipelines, can lead to continuous losses. Addressing leaks is critical for enhancing the efficiency and effectiveness of water supply and sanitation services [1-3]. Over the last two decades, there has been a heightened focus on the issues of bursts and leaks within these systems. These incidents not only result in financial losses for the water industry but also pose environmental threats and public health risks due to potential water contamination [4, 5]. The extent of water loss due to leaks varies significantly across different countries and systems. For instance, well-maintained systems in the Netherlands report leakage rates as low as 3–7% of total distribution input [6]. On the other hand, bursts and leaks cause China to lose approximately six billion cubic meters of water annually.

The degree of leakage in water distribution systems is influenced by a multitude of factors: the age and corrosion of pipes, their depth, the impact of heavy traffic loads, movements in the surrounding ground, fluctuations in pressure, and the mishandling or improper storage of materials during construction. Additional contributors include substandard workmanship, damage incurred during the installation of other utilities, and the level of operating pressure. Notably, excessive operating pressure is often a significant cause of leakage, especially pronounced in intermittent water supply systems prevalent in many water-scarce cities globally. Typically designed for continuous operation, these systems often operate intermittently at excessively high pressures. Efficiently managing this pressure can greatly diminish leakage rates and help preserve a critical natural resource [7].

In many instances, the adverse impacts stemming from leaks in water distribution systems can lead to significant challenges, necessitating prompt detection, localization, and repair of leaks. The urgency of addressing these leaks escalates when they threaten the essential supply of fresh water to communities. Beyond the squandering of water, there is also the risk of contaminants entering the water supply, which could potentially result in public health crises. The critical need to avert such environmental health emergencies has driven research efforts aimed at developing advanced techniques for detecting leaks and contaminants within water infrastructure systems [8].

To enhance water conservation and usage efficiency, there is a pressing need for more effective strategies for managing bursts and leaks. Detection and localization techniques for such water system issues fall into two principal categories: hardware-based and software-based approaches. The hardware-focused methods encompass the use of advanced equipment like leak noise correlators, loggers, gas injection systems, ground-penetrating radar, and infrared cameras. While these technologies offer high accuracy in identifying and pinpointing leaks, they come with several limitations. Notably, they are costly, demand considerable manpower, operate slowly, and might necessitate halting pipeline operations for extended durations [9]. Consequently, researchers have increasingly shifted their focus towards developing quicker, software-based methods that are more cost-effective to implement. This shift has sparked our interest in creating a mobile floating sensor designed to detect leaks with high precision within water distribution networks [8].

In recent years, techniques utilizing fluid transients for detecting bursts and leaks have become widely adopted, including methods like inverse transient analysis, time domain analysis, and frequency domain analysis (FDA). These approaches enable the rapid collection of extensive data sets, ensuring that the inverse problem is always well-defined. Despite their efficiency, these methods tend to require a large number of sensors throughout the pipeline network, which can significantly increase costs. Moreover, transient-based techniques are primarily applied to single, accessible above-ground pipelines due to the challenges associated with monitoring underground pipelines within the complex layout of most systems.

Leaks within water pipelines generate acoustic emissions that can be detected to pinpoint and localize the leaks. Techniques such as leak noise correlators and acoustic listening devices have been recognized in scholarly articles as effective methods for leak detection; however, these approaches often encounter practical challenges related to cost, sensitivity, reliability, and their ability to scale. An innovative and potentially more effective solution is the development of an in-pipe traveling leak detection system. This method allows the sensor to be near the source of the sound, enhancing both accuracy and efficiency. Despite its advantages, the application of in-pipe technologies has so far been restricted primarily to detecting substantial leaks in pipes with larger diameters [8].

Walski et al., developed a computer model that illustrates the impact of pressure reduction on leakage rates, noting that variable-speed pumps are crucial in minimizing pressure and flow within water distribution systems [10]. However, they determined that reducing pressure during peak hours might not always be an effective leakage control strategy, as it could lead to insufficient pressure across the network. Colombo and Karney, emphasized the significant role of demand reduction in lowering energy consumption and observed that pressure management techniques are particularly beneficial in modern water distribution systems (WDS) equipped with smoother pipelines[11]. Additionally, Spiliotis and Tsakiris demonstrated the effectiveness of fuzzy linear programming in accurately calculating demand patterns to optimize pressure control in WDS, enhancing overall system efficiency [12].

Various techniques are employed to identify and pinpoint leaks in piping systems [13]. The primary strategies for monitoring pipelines include acoustic and pressure measurements, which capture sound and pressure changes caused by leaks. Additionally, vision-based systems, ground penetrating radar (GPR) systems, and fiber optic monitoring provide detailed insights into the pipe's condition. Multimodal systems, which integrate multiple sensing technologies, are also utilized to enhance the accuracy and reliability of leak detection.

Ahmed and Aminpour studied a leak detection system by comparing intermittent and continuous water systems to reduce leakage and enhance monitoring [14]. Various scenarios were examined, including no leaks (NL), a single leak (SL), and multiple leaks (ML), with intermittent water distribution (IWD) and continuous water distribution (CWD) systems operating at consistent flow rates ranging from 10 to 25 l/min. Initially, the pipeline of the intermittent water distribution system is not fully water-filled, but the discharge changes over time to achieve the desired flow rate. To realistically simulate these conditions in the lab, manual main valves were used to adjust the flow rate, targeting adjustments within 20 to 25 seconds. As a result, the continuous water distribution system exhibits higher leakage than the intermittent system. Specifically, opening the first valve in the loop system leads to greater losses compared to multiple leaks. The branched system suffers significant losses due to increased leakage points, whereas the CWD experiences higher leakage rates across all comparisons. Overall, across all system types, the CWD has a higher leakage rate than the IWD for the same flow rate.

As noted by [15], no major city in Iraq currently operates a continuous water distribution system (CWS). However, multiple Iraqi cities have embarked on pilot projects or crafted proposals to transition from intermittent to continuous water supplies, as documented by various sources, including the World Bank reports of 2010 and 2003. One of the frequently cited advantages of converting an intermittent water system (IWS) to a continuous one is the potential improvement in water quality. Yet, there is limited research comparing water quality between these two systems, with one such study [14], which was constrained by its small sample size. Given the substantial costs associated with upgrading to a continuous system, it is crucial to provide robust quantitative evidence of water quality improvements to support decision-makers in developing cost-effective strategies for enhancing intermittent water supplies.

This research proposes a model designed to create an advanced, efficient leak detection system that ensures rapid and precise data transmission. It assesses water leakage across various water distribution frameworks, including equivalent and series pipeline systems, in both intermittent and continuous operation settings. This study is instrumental in minimizing water losses due to leaks and theft, offering real-time monitoring capabilities. The findings are valuable for comprehending the advantages of transitioning from intermittent to continuous supply systems and can guide investment decisions aimed at expanding access to safe water via piped distribution networks.

2. Methodology

2.1. Head Losses and Leakage Location

The Bernoulli equation is a fundamental formula used to describe steady-state fluid flow under specific conditions. It posits that the total mechanical energy remains constant in scenarios involving steady, incompressible, inviscid, and isothermal flow where there is neither heat transfer nor work performed. Despite its restrictive assumptions, this equation can accurately represent a wide range of physical systems.

The equation is stated as

$$\frac{P_1}{\rho g} + \frac{{v_1}^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{{v_2}^2}{2g} + z_2 + H_L \tag{1}$$

Where Z= elevation head, P= pressure, ρ= density of water, v= velocity, g= gravitational constant, H_L= head loss. Darcy's equation further expresses head loss:

$$H_L = \frac{fLv^2}{2Dg} \tag{2}$$

$$\Delta P = 0.0013\frac{fPLv^2}{d} \tag{3}$$

where f= Moody friction factor, dimensionless, L= pipe length, D= pipe diameter, ΔP= pressure drop, d= pipe inside diameter. The Reynolds number is a dimensionless parameter that is useful in characterizing the degree of turbulence in the flow regime and is needed to determine the Moody friction factor [16].

$$R_e = \frac{\rho VD}{\mu} \tag{4}$$

where μ= viscosity. To calculate the acceleration produced by changes in water flow, the data on water velocity and the duration of these changes will be analyzed using Eq. (5). Following this, Eq. (6) will be employed to determine the exact position of the leak within the pipeline. This equation factors in the distance (x), final velocity (v), initial velocity (u), acceleration (a), and time (t) to pinpoint the leakage location [3].

$$v = u + at \tag{5}$$

$$x = \frac{v^2 - u^2}{2a} \tag{6}$$

There is a physical relationship between leakage rate and pressure. This relationship can be expressed in the general form of the orifice Eq. (7):

$$Q = a\ \ p^n \tag{7}$$

where Q is the leakage rate, P is the pressure, a is the coefficient, and exponent n is the constants determined from the field investigations.

2.2. Apparatus and Tools

Leak detection in pipeline systems relies on a flow meter sensor, with Arduino used in this study to gather data from the sensor. The research examines two different pipeline scenarios: simple pipelines of the same diameters and series pipelines, continuous and intermittent water distribution, applied across all cases. In continuous systems, the discharge remains constant at a set pressure, which influences both leaks and minor losses. These losses are recorded in graphs that indicate leakage, regardless of the type of leak, as the system detects loss through graphical data. Discharge, measured in liters per minute, is the key variable for comparing continuous and intermittent systems, which is central to this research. The hydraulic bench is used for calibration of the discharge accuracy. The water flow sensor uses the effect to measure the flow of liquids or gases, recording rotor rotations as pulses, with the flow rate influencing rotor speed. The sensor operates within a voltage range of 4.5V to 5V. Fluid flow is measured by flow meters, which use methods such as positive displacement or turbine-based systems. In this project, a turbine-type flow meter is employed. The Arduino Uno microcontroller, based on the ATmega328, supports the system with digital/analog inputs, a crystal oscillator, and power sources to ensure effective data collection and system management, as shown in Figure 1 [14].

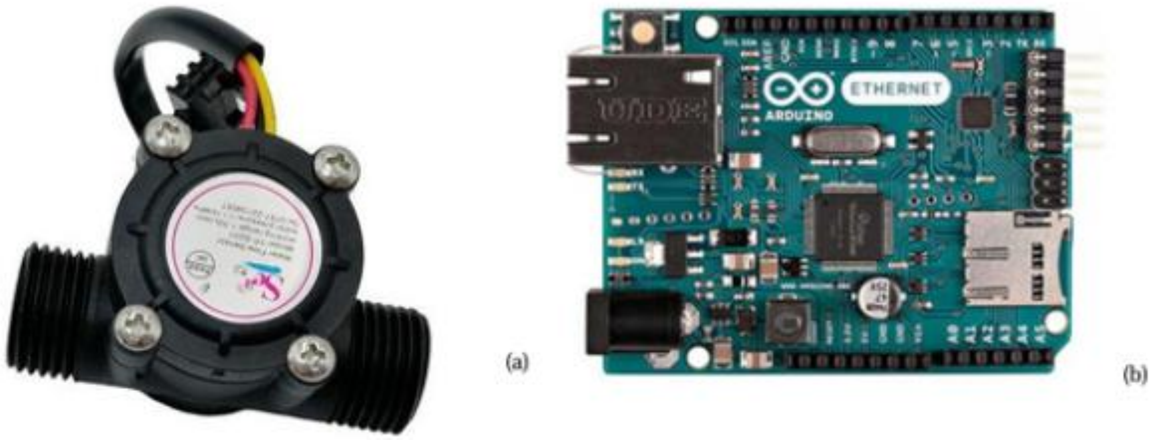

Figure 1. Turbine-type flow mete

2.3. Case Study

Figure 2 shows the equivalent pipeline system model, including sensor (S) and valve (V) positions. The pipeline, with a 12.7 mm diameter, has two sensors at the inlet and outlet to measure water flow, connected to computers wirelessly. Two valves fixed in the proper locations are used to simulate leaks, which are detected by comparing the readings from both sensors. In continuous systems, discharge differences help identify leaks and minor losses, with baseline data collected at 10, 15, 20, and 25 l/min. In the first trial, a valve is opened near the inlet, showing no change at the first sensor but detecting a leak at the outlet. Data is graphed to compare the effects of leaks. The process is repeated with the second valve and for multi-leak scenarios at different discharges. Both leak and non-leak conditions are recorded and graphed to show the differences between continuous and intermittent systems. For the intermittent system, the setup remains the same. Discharge is gradually increased from 0 to 25 *l*/min, and data is collected for leak and non-leak conditions. A graph highlights the differences between the continuous and intermittent systems, providing a clear comparison of the impacts of leaks and losses.

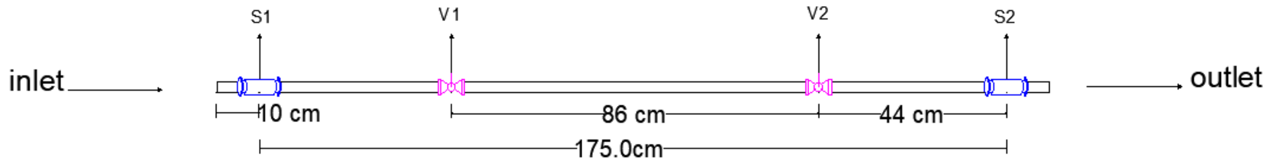

Figure 2. Equivalent pipeline system

Figure 3 illustrates a series pipeline system with varying diameters, showing the exact locations of valves and sensors. The system consists of interconnected pipes of the same length, with three valves positioned at different points to simulate single and multiple leaks. To collect data, the sensors are connected to a computer for data transfer. The system requires careful monitoring due to the different pipe diameters and specific lengths, with three sensors strategically placed to ensure accurate data collection. In the first test, a flow rate of 10 l/min is passed through the pipeline. The sensors are used to verify the flow rate, with the first sensor confirming the correct value. As the flow reaches the third sensor, the rate decreases compared to the second and first sensors, due to minor and major losses in the pipeline. This process is repeated for flow rates of 15, 20, and 25 l/min. When the recorded values across sensors are close, it indicates no leaks in the system. To compare this with leakage scenarios, the same flow rates are applied, but with valves opened to simulate leaks. In a single-leak scenario, one valve is opened, and data is collected from all sensors, with the process repeated for each valve. For a multi-leak situation, all valves are opened simultaneously, and data is recorded at each flow rate.

For the intermittent system, water flow starts at 0 and increases to 25 l/min. Due to losses in the pipeline, the second sensor reads a lower value than the first, and the third sensor, located at the outlet, records even less due to additional losses. This process is first carried out without leaks to establish a baseline graph. Then, the procedure is repeated with leaks, causing the sensors to record lower values, and the data is used to create a second line on the graph, illustrating the impact of leaks.

3. Result and Discussion

3.1. Equivalent Pipeline System

Figure 4 and Table 1 illustrate the observations from a continuous water distribution system, examining the impact of valve operations that result in both single and multiple leaks. The study assessed four different flow rates: 10, 15, 20, and 25 l/min, to analyze how varying flow rates affect leakage levels. In each experimental setup, two scenarios were conducted: the initial scenario involved collecting data from the main sensor with no leakage present, serving as a control for comparisons.

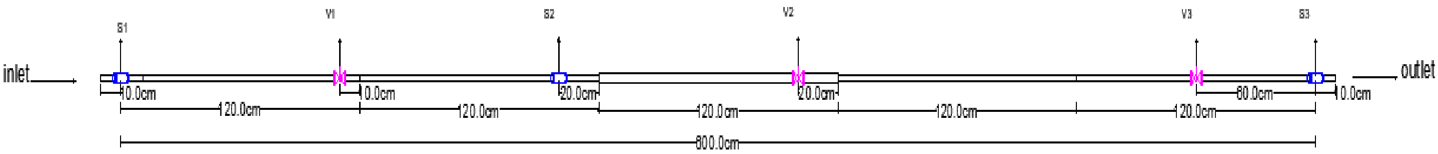

Figure 3. Series pipeline system

In the subsequent scenario, measurements were taken from a secondary sensor after opening both the first and second valves, aimed at delineating the contrast in leakage under no-leak (NL) and multiple-leak (ML) conditions at different flow rates. The overall results revealed a direct correlation between rising flow rates and increasing leakage. The data clearly showed that higher flow rates led to more significant leakage issues, visible through declines in the graphical lines. These reductions graphically represent the combined effects of internal system losses and specific valve leakages, highlighting how increased flow rates can magnify the overall leakage severity in the system.

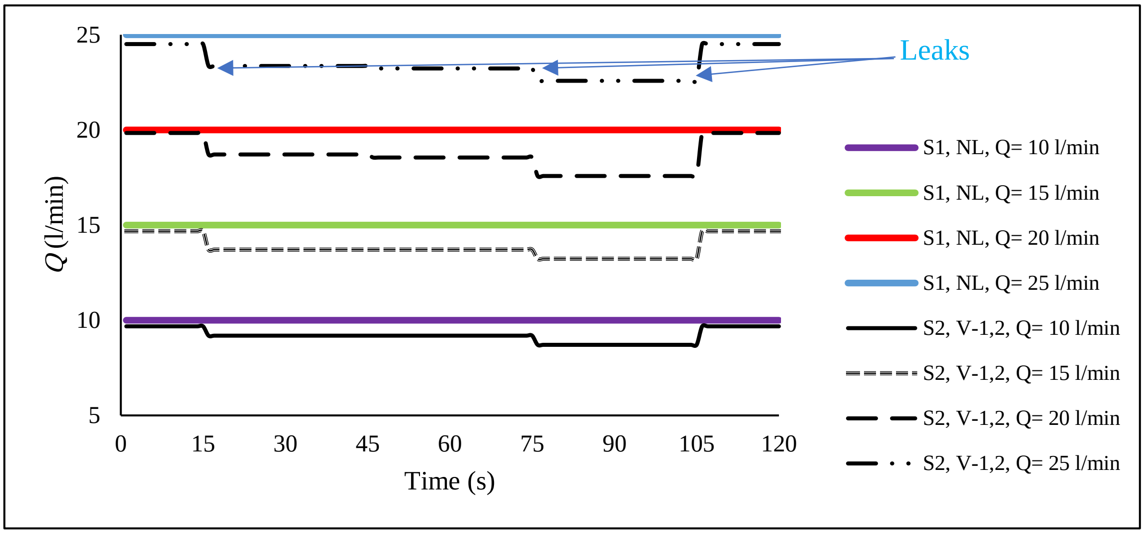

Figure 4. Continuous water distribution system

Figure 5 illustrates measurements from an intermittent water distribution system analyzed under four distinct scenarios. The initial two-line graphs show data from the first and second sensors under conditions where no leaks are present. The subsequent graphs detail measurements from the second sensor, each under different conditions: the first scenario with the opening of the first valve, and the second with the opening of the second valve independently. Analysis of the data from the initial two graphs indicates that the first sensor, unaffected by leaks, registers a higher flow rate compared to the second sensor, which shows a reduced flow in the subsequent graph. This variance in flow measurements between the sensors can be linked to system losses affecting downstream sensor readings. A detailed analysis of the measurements recorded by the second sensor during leak scenarios indicates negligible variations between the two cases studied. This uniformity implies that activating either the first or the second valve results in a comparable influence on the leakage rates observed by this sensor. Such findings underscore a consistent pattern: operations involving a single valve uniformly affect the system's leakage behavior, irrespective of the specific valve utilized. This consistent impact on leakage dynamics, noted across different tests, suggests that any single-valve operation in this system may lead to similar outcomes in terms of leakage.

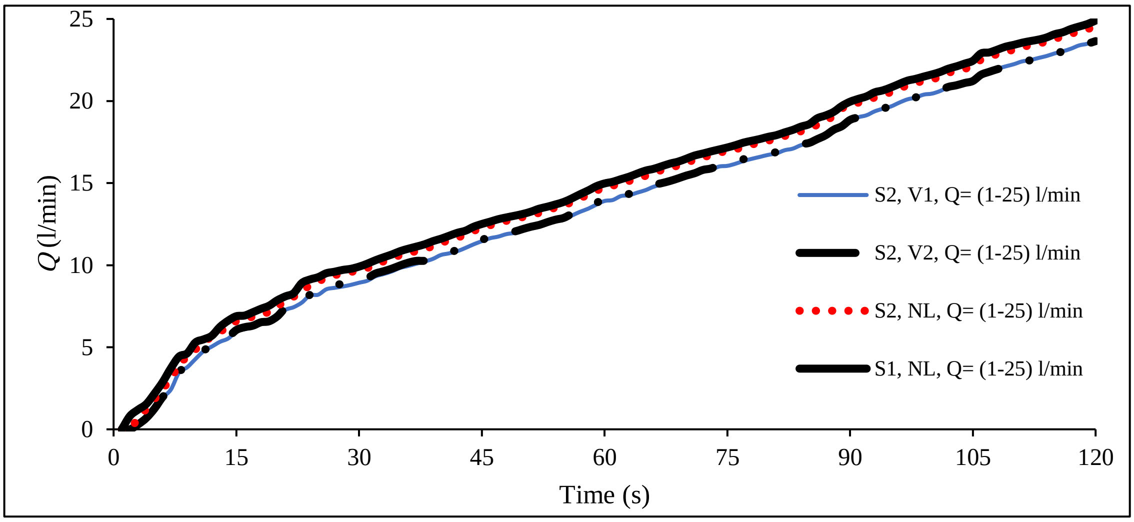

Figure 5. Intermittent water distribution system

Table 1 presents an exhaustive examination of leakage data within both continuous (CWD) and intermittent water distribution systems (IWD), scrutinizing how valve positions influence leakage occurrences. The study investigates both single leak (SL) and multiple leak (ML) scenarios in CWD while focusing exclusively on single leak conditions in IWD. Observations from CWD indicate that SL conditions tend to result in more pronounced leakages compared to ML situations, suggesting that having only one open valve increases leakage more significantly than when multiple valves are open. Notably, leakages under ML conditions appear more severe in CWD than in IWD, a disparity attributed to the continuous flow characteristic of CWD as opposed to the gradual increase in flow seen in IWD. Further analysis within CWD points out differences in leakage outcomes between SL and ML scenarios for individual valves, where SL consistently shows greater leakage, attributed to the concentration of leaks at a single valve point. This contrasts with ML scenarios where leakage is distributed among multiple valves, potentially impacting the precision of sensor measurements. Data also reveals that leakage variations correlate with different flow rate intervals. Specifically, in CWD, the second valve experiences higher leakage rates at flow rates of 10-

15 l/min and 20–25 l/min, whereas the first valve records higher leakages at the 15-20 l/min interval. In contrast, in IWD, the second valve shows greater leakage for the flow rates of 10-15 l/min and 15-20 l/min, with measurements of 59.55 ml and 24.14 ml, respectively, and for the 20-25 l/min range, the first valve displays a higher leakage measurement of 28.72 ml.

This detailed analysis demonstrates how specific flow rates and valve operations distinctly influence leakage rates differently in CWD and IWD configurations, underscoring significant variations in leakage severity between the systems. Single leaks in CWD are shown to cause more severe leakage compared to multiple leaks, highlighting the necessity for tailored management strategies that cater to the unique dynamics of each system [14].

Table 1. Amount of leakage in the simple pipe for continuous and intermittent water distribution systems

***Q* (l/min)**	**CWD (ml)**				**IWD (ml)**					**Comparison**				
	SL		***ML***		***ML***		**CWD and IWD (%)**		***ML* and *SL* in CWD (%)**	***Q* (l/min)**	**CWD (%)**		**IWD (%)**	
	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1 and V_2	Intervales	V_1	V_2	V_1	V_2
10	192	178	183	165	95	89	50.52	50	5.95	10-15	20.33	27.94	55.81	59.55
15	241	247	235	230	215	220	10.79	10.93	4.71	15-20	32.68	31.39	24.03	24.14
20	358	360	350	345	283	290	20.95	19.44	3.2	20-25	21.32	22.08	28.72	27.5
25	455	462	450	435	397	400	12.75	13.42	3.49					

3.2. Series Pipeline System

Figure 6 offers a comprehensive depiction of the water distribution process in a continuous system and evaluates the influence of single and multiple leaks on system efficiency. The assessment was conducted using four varying flow rates: 10, 15, 20, and 25 l/min, each subjected to three specific scenarios. The initial graph line, known as the top line, captures readings from the first sensor and serves as a crucial baseline, displaying conditions without any leaks, which acts as a control for assessing the impact of subsequent leaks. The middle line of the graph represents data from the second sensor, which becomes active upon the opening of the first valve, thereby introducing a leak. This occurrence leads to a noticeable reduction in the graph's trajectory, consistent across all tested flow rates, signifying the direct impact of a single leak on reducing water pressure and flow at the measurement point. The last graph line, referred to as the bottom line, records outputs from the final sensor when multiple leaks are induced through the simultaneous opening of the first, second, and third valves. This scenario results in a more pronounced decline across three sensor points on the graph, illustrating the exacerbated effect of multiple leaks, which disrupt flow and pressure more substantially than isolated leaks.

The collected data indicates that leaks result in a quantifiable reduction in the water flow rate moving to subsequent system components. Additionally, the results confirm that as flow rates increase, even with consistent leak severity, the proportional decrease in flow rate also escalates. These dynamics highlight the critical impact of leaks on the efficiency of water distribution systems and emphasize the necessity for vigilant maintenance of system integrity [14].

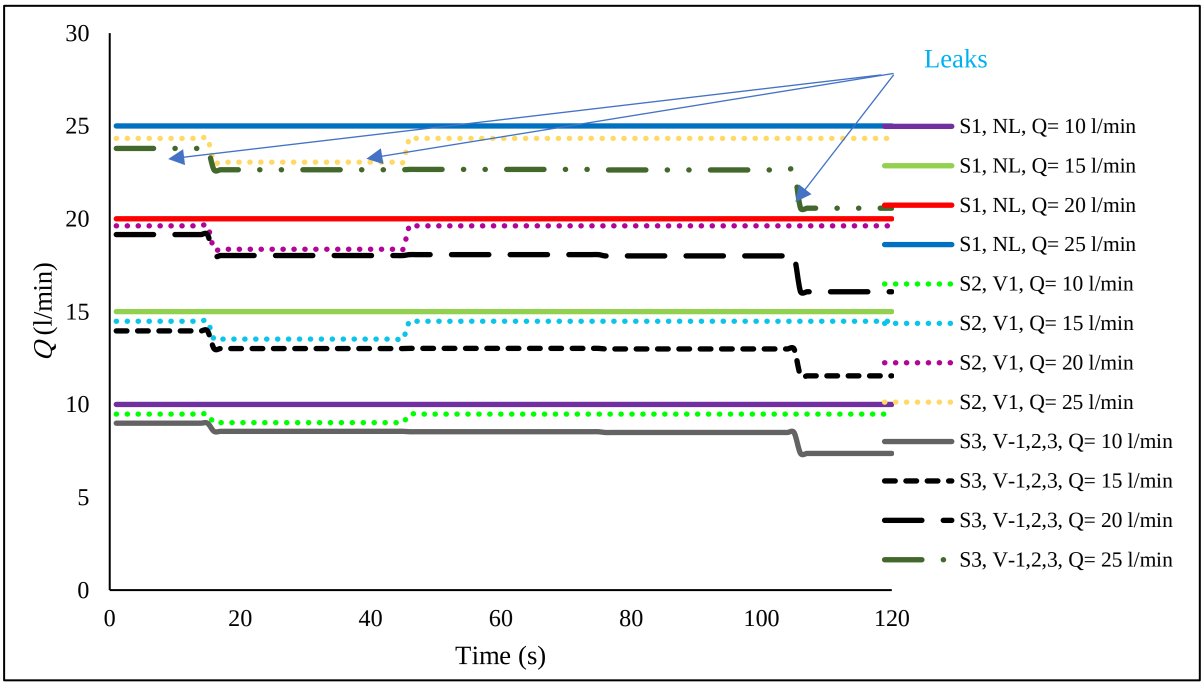

Figure 6. Continuous water distribution system

Figure 7 presents an analysis of an intermittent water distribution system operating across various flow rates from 1 to 25 l/min. The water flow in this system gradually increases to its maximum rate. To assess the system's response under various conditions, the study implemented tests across seven distinct scenarios, comparing conditions with no leaks (NL) and conditions with simulated leaks (SL). The results from these tests show that all three sensors, the first, second, and third, successfully captured data when there were no leaks present. The recorded data showed that the first sensor typically registered the highest flow rates, with the second and third sensors recording progressively lower flow rates, respectively. This sequence is due to significant losses within the system, with the third sensor registering the lowest flow rates because it is furthest from the source, thereby experiencing the greatest losses. One particular scenario involved activating the first valve, which was depicted in the figure showing a decrease in flow rate due to the leak's impact. In another scenario, the readings from the third sensor were specifically analyzed across three conditions where the first, second, and third valves were opened sequentially. The results demonstrated that apart from the initial flow rate, the third sensor consistently recorded the same data, suggesting that the position of the valves did not affect the measurements recorded by this sensor.

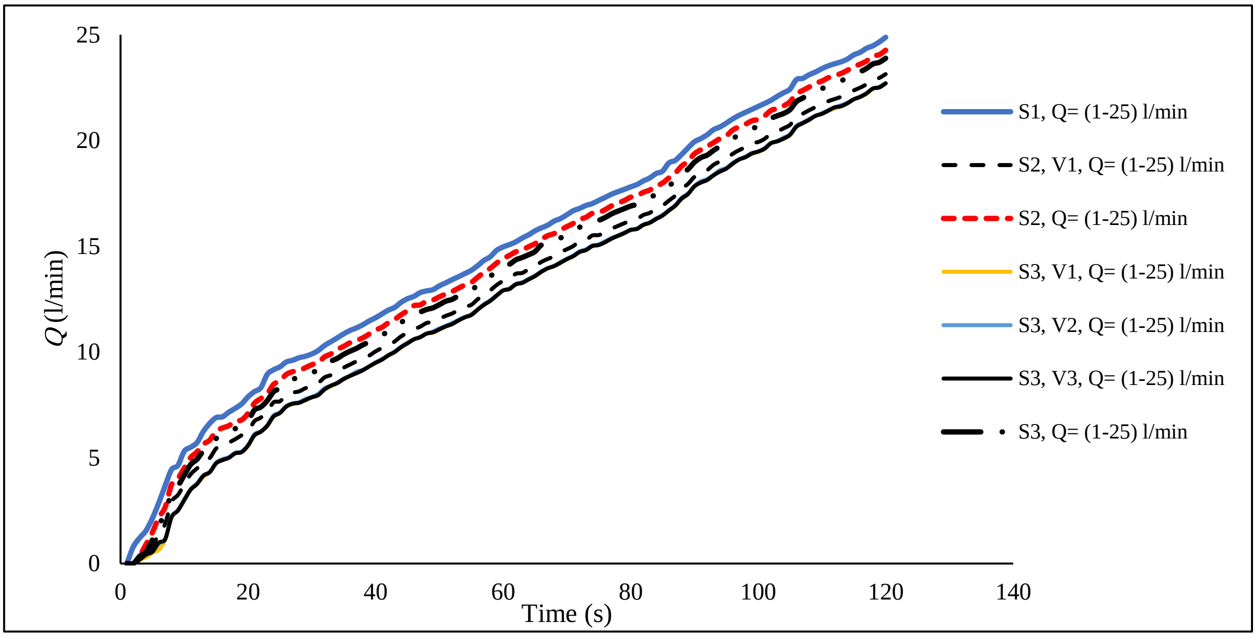

Figure 7. Intermittent water distribution system

Table 2 shows the precise measurements of leakage in both continuous and intermittent water distribution systems, emphasizing the varying impacts of leaks depending on the operational mode of each system. This table contrasts the two systems, illustrating noticeable disparities in leakage effects. In CWD, scenarios involving both single leaks (SL) and multiple leaks (ML) are analyzed, whereas IWD focuses solely on ML scenarios. For each condition, measurements are taken when all valves are operational. Observations across both the continuous (CWD) and intermittent water distribution systems (IWD) consistently show that leakage escalates in proportion to increases in flow rate. Comparative analyses reveal notably higher leakage rates in CWD, attributable to its consistent water flow, unlike the fluctuating flow observed in IWD. Detailed examination within the CWD identifies significant differences in leakage under single leak (SL) and multiple leak (ML) scenarios, with SL scenarios generally exhibiting more substantial leakage. This is explained by the dispersion of leakage across multiple valves in ML scenarios, reducing the impact on any single valve. Furthermore, when assessing the effect of different flow rate intervals on specific valves, the second valve consistently shows higher leakage in both system types, underlining its particular vulnerability compared to other valves. This pattern of vulnerability is crucial for understanding and addressing leakage dynamics within these systems [14].

Table 2. Amount of leakage in the series pipe for continuous and intermittent water distribution systems

	CWD (ml)						IWD (ml)								Comparison					
Q (l/min)	***SL***			***ML***			***ML***			**CWD and IWD (%)**			***ML* and *SL* in CWD *(%)***	***Q* (l/min)**	**CWD (%)**			**IWD (%)**		
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1, V_2, V_3	Intervals	V_1	V_2	V_3	V_1	V_2	V_3
10	195	157	231	183	141	211	96	77	115	50.77	50.96	50.22	8.23	10-15	29.6	35.39	19.23	54.5	58.38	54.2
15	277	243	286	275	227	267	211	185	251	23.83	23.87	12.24	4.59	15-20	28.05	30.97	27.04	34.27	37.92	31.2
20	385	352	392	382	341	371	321	298	365	16.62	15.34	6.89	3.1	20-25	21.75	24.3	21.29	26.54	28.71	21
25	492	465	498	489	452	469	437	418	462	11.18	10.11	7.23	3.09			----------				

5. Conclusion

This study underscores the utilization of flow meter sensors in different pipeline systems, including both equivalent and series configurations, within continuous and intermittent water distribution systems. These sensors are strategically placed at crucial locations, such as inlets and outlets, to ensure thorough monitoring. This setup enables effective detection of leaks, providing a critical tool for maintaining the integrity of the water distribution networks. Data from both leaking and non-leaking conditions is collected and displayed on graphs, where deviations from normal flow lines indicate potential leaks. This consistent method applies across different pipeline configurations and operational modes, allowing for effective leak identification and measurement. The below results are found:

The results revealed a direct correlation between rising flow rates and increased leakage in continuous water distribution systems (CWD), with higher flow rates exacerbating leakage severity due to internal system losses and valve issues, as shown by the declines in the graph lines. In contrast, intermittent water distribution systems (IWD) exhibited consistent leakage behavior across various scenarios, regardless of which valve was activated, with sensor data indicating potential systemic losses affecting downstream measurements. This uniformity in leakage responses highlights the effectiveness of current monitoring approaches and the strategic placement of sensors for accurate detection. The analysis further demonstrated that leakage levels differed markedly between CWD and IWD, with single leaks in CWD typically causing more substantial leakage compared to multiple leaks in IWD. These findings emphasize the need for tailored management strategies to address the unique characteristics of each system type. The experimental findings clearly demonstrate that leaks lead to a significant reduction in the flow rate delivered to subsequent parts of the system. Furthermore, even with constant leakage, an increase in flow rate results in a more pronounced decrease in flow, underscoring the substantial impact of leaks on the efficiency of water distribution systems and highlighting the critical need for maintaining system integrity. Data from the third sensor remained consistent regardless of the initial flow rate, indicating that the positioning of the valves did not influence its readings. Regarding leakage frequency, both continuous (CWD) and intermittent (IWD) water distribution systems experience increased leakage as flow rates rise, with CWD systems exhibiting more severe leakage due to their constant flow, in contrast to the fluctuating flow in IWD systems. Analysis revealed that single leaks (SL) in CWD cause more significant leakage than multiple leaks (ML), as ML disperses leakage across several valves, thus minimizing the impact at any single point. Additionally, the second valve emerged as particularly prone to leakage in both systems, emphasizing the need for focused monitoring and maintenance. The continuous water distribution system is superior to the intermittent system for detecting leaks within pipeline systems. This advantage stems from having more time to identify leaks, among other reasons discussed in previous chapters, making the continuous system the preferable choice. We recommend further research to precisely locate leaks within the pipeline system and assess the quality of water entering the pipes, utilizing more advanced flowmeter sensors.

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