TEST Engineering & Management

March-April 2020
ISSN: 0193-4120 Page No. 2599 - 2606

A Review on Research Approaches in Leak Detection System

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Article Info
Volume 83
Page Number: 2599 - 2606
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 20 March 2020*

Abstract:
Water is supplied to most of the countries using the pipeline. The major problem in these pipelines is leakage and due to this a large amount of water is being lost. To improve the pipeline system and also to reduce the loss due to leakage a proper leak detection system should be used. A lot of research is being carried in the field of leak detection but analysis of leakage and its flow parameter using CFD (Computational Fluid Dynamics) is a new and unique technique that reduces the cost of experiments and bulky setup. In this paper, review of various research carried in the field of leak detection using experimental techniques and analysis using CFD is discussed.

Keywords: *Water, Pipeline, Leakage, CFD.*

INTRODUCTION

Leak in the pipeline is one of the major problems which affects the smooth functioning of the flow in pipeline. It is the unintentional flow of fluid through the passage or opening created due to the deterioration of pipe wall, corrosion, pressure surges, engineering failures, earthquakes, movement of ground or may be caused due to the human activities such as excavation, constructions or theft (Saaghi and Aval, 2015).It results in the loss of flowing commodity in the pipeline as the fluid flowing through leakage is of no use as it is not available at the required end or it may be even dangerous when the fluid flowing through pipe is of volatile nature. To continue the smooth and efficient working of pipelines and to avoid the dangerous impact of a leak in the pipeline, it must be leak-free or whenever the leak occurs it must be repaired as early as possible. Therefore, the leak must be detected, located and repaired as early as possible. To fulfill this requirement, the leak detection system must be used with the pipeline system.

Mainly, the leak detection system is categorized into two groups: External and internal leak detection systems. External leak detection system is based on the use of special sensing device for sensing leak from outside of the pipe. This system uses various methods such as optical, ultrasonic flowmeter, acoustic, vapor sampling, cable sensor, etc. for physical detection of escaping liquid. Internal leak detection system uses field sensor output that monitors internal pipe parameters such as pressure, temperature, viscosity, density, flow rate, product sonic velocity, etc. at interfaces. The inputs from these parameters are used to decide the occurrence of leak from computation. The various approach used by this system is mass/volume balance, acoustic/negative pressure wave, real-time transient modeling, statistical signal processing, rate of pressure/flow change, etc.

The external leak detection-based technologies can detect and locate leak accurately but it is not possible to fit these cables or tubes to existing pipelines. Most of the external detection system is used for routine supervision instead of continuous monitoring. Therefore, a leak is not detected before the next supervision. While the internal leak detection-based technologies can be easily fitted in existing pipelines and they continuously monitor the pipeline. The performance of these methods is based on instrumentation and communication of pipelines.

Internal leak detection is nowadays commonly used for leak detection because technologies that can continuously monitor the pipeline are desirable to avoid the consequences of the leak (Zhang Et al.,2013).

Both External based or internal based LDS has their own merits and demerits. External based system can detect and locate leak accurately but they can not be installed in the existing pipeline. They are also not feasible to use with a very long pipeline. In general, external based system such as infrared camera and vapor sensor are normally used for a routine survey i.e. leak occurred will remain undetected till the next routine survey. While internal based LDS are generally used for continuously monitoring the pipeline and it generates alarm with the occurrence of leak. It is also feasible to be used with a long pipeline and easy to install in an existing pipeline. This system is less accurate than the external based system. The accuracy of this system depends on the performance of instruments used and their communication in pipeline.

In the current trend, LDS which continuously monitors the pipeline is most commonly used so that the loss due to the leakage can be minimized. The use of LDS depends on the type of pipeline and its surroundings because an LDS used for one type of line may not serve good for the other type. Therefore, there. is a need to analyze the pipeline system with its surrounding conditions before installing the LDS.

There are two methods for analyzing the pipeline system:

- Experimental Investigation/ Field Testing: It is the traditional techniques to analyze the system and to observe the change in the flow parameter in the system when the leak occurs.
- CFD Analysis: This is the computational analysis used to observe and visualize the changes in flow parameters with the occurrence of leak.

In the experimental investigation, experiments are carried out to analyze the problem and the results obtained are interpreted to understand the behavior of various parameters. The researcher has conducted various experiments and proposed various methods to detect leakage in the pipeline which are stated below

Brunone (1999) proposed a technique for leak detection which was based on properties of the transient pressure wave. This transient test-based technique has its application for only onshore pressure control which does not require complex equipment as pressure measurement at only one section is required. The state of the outfall pipe is continuously monitored by comparing it with one recorded just after construction corresponding to the intact pipe.

Gao et al. (2005) used correlation techniques to measure acoustic/vibration signals on either side of a leak to locate leaks in a plastic pipe using different sensors. They stated that the effectiveness of the correlation technique depends on the selection of the type of acoustic/vibration sensor and their sensitivity. They concluded that pressure signals are less sensitive to the relative positions of sensors and are suitable for extreme positions. The use of pressure signals leads to the highest peak cross-correlation coefficient, therefore the measure of pressure responses is most suitable for locating leaks having small SNR. They also concluded that the use of acceleration signals results in the sharpest peak of the cross-correlation coefficient and exhibits the least spreading envelope, so they are suitable in a multi leak situation.

Khalifa et al. (2010) conducted experiments in plastic pipes to study the effectiveness of using inside pipe measurements for leak detection. For this purpose, they measured the acoustic and pressure signal due to the leak simulated in the water network of 100 mm pipe size open to the air. They found that normally broadband noise spanned in a wide range of frequency is generated due to the leak using acoustic sensors. The high frequency is reduced by the main flow and the distance by leaving only the low-frequency band as the dominant frequency. The dynamic pressure transducer can be used for leak detection by using the pressure wave generated because of the leak. They revealed that the power of the signal of the sensors depends on the leak flow rate, shape, size, flow conditions and also on the location of sensors

Pal et al. (2010) used an acoustic method to detect and locate the position of leaks in water distribution for medium density polyethylene pipes (MDPE). They found that the current correlation techniques used to detect leak may be appropriate for the metallic pipe but it is not true in case of MDPE pipe where the reduction in the rate of signal with the distance from the leak source is high and signals generated due to leak are of low frequency. They tried to locate the leak in MDPE pipelines with a correlation process that measures the speed of sound in water or pipe and the time delay between the signals which were measured at two locations across the pipe. They found that the accuracy of measuring the speed of sound is easy but the problem lies in calculating delay in time as it depends on various factors such as type, positions, and processing of the signals that are obtained from the sensors which is a difficult task to do in case of MDPE pipe. The experiments performed revealed that the frequency band of leak signals is in between 20 Hz to 250 Hz and the upper band limit changes with the flow rate and leak characteristics. The performance of existing leak correlators can be improved by using appropriate filters and amplification for the case of the MDPE pipe.

As most of the internal methods suggest that the detectors used for leak detection must be close to the leak so that it can detect leak more efficiently. Guo et al. (2014) suggested using the spherical leak detectors to detect a leak in the pipeline as these detectors will detect very tiny leakage in the pipeline and they have very little risk of pipe blockage. They conducted CFD simulation to detect the ability of the detector to pass the segment of the pipe using the sphere of different size and density with different mass flow rate. They concluded that the drag experienced by the sphere inside pipe depends on the flow velocity and diameter ratio of pipe and sphere.

Zhang et al. (2014 A) used the principle of the negative pressure wave which states that when a leak occurs, a drop-in pressure takes place at the location of the leak. This causes pressure oscillations in the fluid which propagate as pressure wave signals at the speed of sound through the fluid and away from leak location in opposite directions. Pressure sensors and associated communication equipment along the pipeline were used to detect the pressure transient wave associated with pipeline leak by the negative pressure wave leak detection system. The location of the leak was computed based on the pressure wave propagation velocity in the fluid by examining the difference between wave arrival times at two opposing sensors and the length of the pipeline segment.

Tuck and Lee (2013) have suggested the that the leak in pipe can be detected by analyzing the transient signal of pressure wave due to the occurrence of leak, blockage, and degradation of pipeline wall thickness. They found that the degraded section can produce a reduction in wave speed which will change the transient response of the pipeline that can be used to detect and classify the degraded section of pipe.

Siebenaieret al. (2014) performed a field testing of negative pressure wave technology that uses the dynamic pressure wave generated by the breakdown of a pressure boundary during leak on 41-kilometer segment of 30-inch diameter heavy crude oil pipeline. For this reason, they installed the discrete dynamic sensor on the pipeline at the various interval which will measure these pulsations and they synchronized these transmitters to GPS so that the accurate arrival time of these waves will help it to identify the location of the leak. They found that these techniques cannot provide the information on leak size and is also prone to false alarms.

Gill and Davey (2014) attempted to calculate the leak rate through the narrow cracks so that it can be easily detected before it can cause a large leak. They found that at the narrow crack, heating of crack face takes place due to the leaking fluid which causes the surrounding material to expand resulting in enlargement of narrow crack.

Zhang et al. (2014 B) suggested to use a dynamic pressure transmitter (DPT) to measure leakage in long-distance oil or gas pipeline as a conventional method such as NPW does not hold good if the collected signal is poor or there is a small pressure change. The DPT has high sensitivity and resolution as compared to an ordinary pressure transmitter. The test performed by them suggested that it is stable and feasible to use DPT and this system can identify pipeline leak correctly and it reduces false alarm with improving the efficiency of leak detection and location accuracy.

Prihtiadiet al. (2016) used the gradient intersection method to determine the location of the leak in the pipeline which uses the phenomenon that when a leak occurs pressure drops linearly for each point in the pipeline but at the same time pressure before the leak drops significantly and pressure after the leak drops slowly. The location of the leak can be calculated using the intersection point of these two curves. This method was applied on the 4 m long PVC pipeline having a diameter 15 mm which was equipped with 12 pressure sensors to measure pressure at each point and leak was modeled between sixth and seven sensors. This method calculated leak with an error of 3.67%.

Kiatet al. (2017) revealed that the water leakage is not desirable as it will decrease the supply of freshwater and sometime it will also contaminate the water which is very costly. So, leakage must be detected as early as possible to minimize its consequences. Therefore, they designed a leak detection device to continuously monitor the water pipelines and the leak can be confirmed and located by listening to the recorded sound of that particular line.

He et al. (2017) studied the accidental leakage of the long-distance pressurized oil pipeline which is the major area of risk as it can cause high damage to human health and the environment. The complexity of the leaking process makes it difficult to calculate the leakage volume so they divided the leaking process into 4 stages based on the strength of transient pressure and they established 3 models to calculate leakage and flow volume. They used a negative pressure method to calculate the size of leak orifice, then they used the transient pressure model consisting of continuity, momentum conservation, energy conservation, and orifice flow equation to calculate leakage volume. Then a steady-state oil leakage model was employed to calculate leakage after valves and pumps shut down. They also analyzed the sensitive factors that affect leak coefficients and also conducted two types of leakage test with different size of leak holes. They found that the transient and accumulated volume of leakage can be calculated using the negative pressure model, transient leaking model, and the steady-state model. The influence made on the leaking parameter was less effective from the location of leak point to pressure, inner diameter, upstream flow rate, density, and time step size. The factors which affect the volume of leakage according to the severity are categorized as the size of the leak, upstream/downstream pressure, flow rate, and temperature. The model can also be applied to the other transporting liquid to calculate equivalent leak diameter, leakage volume during unsteady leak process and ultimate volume of steady leakage.

Choi et al. (2017) proposed a leak detection and locating technique based on vibration sensors. When a leak occurs in a pipe, the vibration is generated due to the internal flow of fluid and they spread in both directions from the leak and vibration sensors attached at both sides of the pipe can sense that vibration. The time difference between the arrival of the vibration wave at both the sensors can be used to locate the position of the leak.

Apart from researchers who worked in a field of detecting leak using a change in flow parameters due to leak, there are some researchers which have considered the leak as a crack in structure or pipeline and this crack will change the stiffness of the pipe. So, by calculating the change in the natural frequency of the pipe due to a change in stiffness leak can be detected. A few of these research are reviewed below.

Naniwadekaret al. (2007) used the technique based on the measurement of change in natural frequencies and modeled the crack by a rotational spring to detect the crack having straight front with different orientations in the section of a straight hollow pipe having outer diameter 0.0378 m and an inner diameter of 0.0278 respectively. They found the change in stiffness of the spring due to crack size and its orientation experimentally with the help of the deflection and

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vibration method. The stiffness of spring decreases with an increase in the crack size but it increases with an increase in crack orientation angle.

Al-Wailyet al. (2017) studied the effect on vibration and natural frequency of pipe due to the flow as the frequency of pipe depends on the velocity and properties of the liquid flowing through it. They found that the frequency of pipe decreases with an increase in the velocity of the fluid and the crack length decreases the stiffness of the pipe which reduces the frequency of the pipe. The increase in crack angle also decreases the frequency of the pipe which increases the response of vibration with different mode shapes.

The above researchers have used the approach of conducting experiments to analyze the problem of leakage and provided various approaches through which leak can be detected in the pipeline. But in the current scenario and advancement in technologies researches have been focused to minimize the cost associated with experiments and to make use of various numerical simulation to solve the problem. CFD simulation is one of the most trending and promising approaches to solve the problem related to fluid flow and its popularity is increasing day by day. Various researches have used CFD simulation to analyze the leakage in the pipeline and its effect on various flow parameters.

Ben-Mansour et al. (2012 A) developed a 3D turbulent flow model in which they modeled a pipe with a diameter 0.1 m and length 1m with a small leak (1 mm x 1 mm) in it. Both steady and transient simulation was performed. Steady-state simulation was performed using the k-ε model which shows the influence of leak on both pressure and pressure gradient. They also reported that for a very small leak this influence is not strong in pressure but very clear in pressure gradient. They also concluded that the leak flow rate is greatly affected by line pressure and the size of the leak. The transient simulation was performed using Detached Eddy Simulation (DES) in which pressure fluctuation was measured for different locations around the leak position and was processed through Fast Fourier Transform (FFT). The results indicated that the leak causes a clear increase in the magnitude and frequency of the pressure signal spectrum.

Ben-Mansour et al. (2012 B) studied the flow characteristics around a leak where two leaks were considered in a single pipe. The objective of their study was to identify the clearly observable trend in the flow variables which can be adopted for reliable and robust leak detection methods. The CFD simulation was carried out for this purpose and they identified pressure gradient and flow acceleration as the variables that showed the clear influence of the leak.

Zeng and Luo (2017) carried out the CFD modeling to simulate the leakage in water pipeline under different conditions to understand how different parameters such as leak-pipe diameter, inlet mass flow, and main pipe length can affect the leak. To understand this behavior two different pipe length, four different leak diameter, and two different inlets mass flow was taken into account while the diameter of the main pipe, leakage location and pressure at the outlet were not changed. The simulation result showed that the inlet mass flow rate has a more significant effect on total pressure drop and pressure change at leak location as compared to the pipe length.

Vasconcellos Araujo et al. (2014) performed a hydrodynamic study of oil leakage in pipeline in which they tried to investigate the transient dynamic behavior of pressure and velocity fields of oil flow in pipes containing one or two leaks including a tee junction and the behavior of flow on the emergence of leak when there already exists a leak in the pipeline using ANSYS CFX. They observed that a pipeline containing two or more leaks has same pressure measured at the input section regardless of the time of opening of the leaks and inlet fluid velocities and also the pressure drop due to a leak may vary based on the other pre-existing leak which can make their detection in the pipeline difficult.

Chalgham et al. (2016) had made an attempt to develop a correlation between leaks and their effect on fluid characteristics inside the pipeline such as fluid velocity, the variation of pressure and sound level due to the presence of leaks along the pipeline. They found that at the leak location the fluid velocity increases and the pressure decrease with the increase in pump input velocity. They also simulated the acoustic propagation from the leak location and the way the magnitude of sound energy density decreases as it gets farther from leak location.

Jujulyet al. (2016) suggested that a numerical approach using CFD can be a better approach to investigate subsea pipeline leak and their impact as it can provide a better understanding of pipeline internal flows and impact of leaks in distinct scale, minimizing the cost and also the experiments required. They concluded in their simulation that with an increase in pipeline operating pressure the flow rate of fluid through leak also increases and static pressure shows a clear change in its signature at leak location in axial length.

Sousa and Romero (2017) studied the steady-state behavior of oil flow through a pipeline in the presence of a leak. For this purpose, they modeled a one-meter pipeline with a diameter of 0.15 m in an onshore environment with three different sizes of leaks in ANSYS Fluent 15.0. They concluded that the volume of fluid leaving orifice is more when the diameter of leak orifice is larger which affects the hydrodynamics in the vicinity of a leak inside the pipe. Therefore, the leak can be identified by monitoring the pressure and velocity fields as these fields are affected by perturbations in both upstream and downstream leak positions.

Zheng and Hong (2017) made an attempt to determine the impacts of initial pressure and leakage size on leak rate and their fluid dynamic characteristics such as velocity and pressure distribution near the leak hole with help of the CFD using Ansys Fluent. They concluded that the leak rate through the same leak size increases with an increase in the initial pressure and leak rate also increases with an increase in leak size at a constant initial pressure. They also tried to determine the impact on leak rate due to change in position which is a very difficult experimental problem and they found that leakage position has a small effect on leak rate and it decreases when the position of a leak increases with respect to the inlet.

Wei and Masuri (2019) examined the effect of fluid velocity and the emergence of the second leak on leak flow rate, pressure distribution and turbulence kinetic energy near the leak region and compared these parameters between single and double leaks in subsea pipeline models. They concluded that change of pipeline velocity has little effect on flow behavior at leak region and occurrence of the second leak does not cause much effects on flow behavior at first leak but leak flow rate at first leak is always higher than flow rate at the second leak.

Zeng and Luo (2018) simulated incompressible fluid water with leakage using CFD to recognize how different parameters such as leakage diameter, inlet mass flow rate and length of pipe affect the flow phenomenon at the location of the leak. They found that the diameter of the leak has a dominant effect on the mass quantity and leak quantity is affected by both inlet mass flows rate and main pipe length. When leak takes place in the pipeline, large velocity and low pressure take place at upstream but the low velocity and high pressure is created at downstream which causes an adverse pressure at this region. The change in pressure at leak location increases with an increase in leak size ratio and due to this increase in local pressure, there is a sudden change in pressure gradient at this location along the direction of flow. The magnitude of this pressure gradient is larger as compared to the pressure change at the location of leak but this effect reduces with an increase in distance from leak location due to the diminishing of leakage effect.

CONCLUSION

The literature reviewed discussed above shows that a leak is a major concern and numerous works have been done in the field of leak detection. Some of the researchers used the external technique of physical detection of escaping fluid to detect leak but it cannot be used in the existing pipeline and they are not feasible to use for a long pipeline. Most of the research is based on the internal method which can be easily installed in the existing pipeline which

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measures the field output parameters such as pressure, temperature, viscosity, density, flow rate, etc. through sensors and correlates changes in flow parameters with the occurrence of the leak and detects the existence of leak. Some of the researchers have considered a leak in the pipe as a crack in structure and they detect a leak by measuring the change in natural frequency and vibration of pipe.

Numerical simulation using CFD is a promising technology used by the researchers to analyze the behavior of change in flow parameters due to the occurrence of the leak instead of performing experiments. A very handful amount of data is available on numerical simulation of the leak in pipeline using CFD where they have tried to capture the behavior of the flow parameters such as pressure, pressure gradient, leak mass flowrate and outlet velocity due to different sizes of the leak. The researchers have not considered the sensitivity analysis for changes in flow parameters due to the effect of the size and location of leak. Therefore, there is a need to analyze the change in the above stated flow parameters with changing the leak condition using CFD which can be helpful in developing a proper leak detection strategy

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