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Development of Pipeline Leakage Detection and Localization System Using IOT

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Abstract

Various health concerns, explosions, injuries, and financial setbacks result from leaks occurring in transmission and distribution pipelines due to factors such as corrosion, material aging, climate-related effects, deliberate sabotage, and the transportation of petroleum products like crude oil, natural gas, and LNG. The unavailability of timely detection of the leakage and point of leak causes huge financial losses as we are already short of natural resources. Most of the equipment is installed at the inlet and outlet of the pipeline making it difficult to detect leakage and point of leak in the mid-span. To address this problem, a hybrid method consisting of volume-mass balance and Real-time Transient Modeling (RTTM) is used to develop an automated system that detects leakage in the pipeline, locate the point of leak, estimate the leak volume and to send an alert message. RTTM technique presents leak as a function of pressure and density of the working fluid. Real-time data is obtained from the pipeline using HK1100C and DS18B20 sensor by acquiring pressure and temperature of the working fluid respectively. Domestic gas meters are used to compute upstream and downstream flow rate, while NODMCU esp. 8266 is used as a microcontroller to transfer data from the pipeline to the IOT server Thing Speak with the aid of a built-in Wi-Fi module. The transient model is developed in LabVIEW where the analysis has been performed on pressure and flow variation inside the pipeline to detect the leak, calculate the leak location and estimate the leak volume.

Keywords: *Leak Detection and Localization, Real Time Transient Modeling, Internet of Things, Labview, Volume-Mass Balance Method.*

Introduction

Since the earliest civilizations came into existence humans had to explore nature in search of natural resources for their living. Nature does not give us the things that we need to survive, in pure form. Humans have to refine it to make it useful. The same is the case with the exploration of natural gas, crude oil etc. Since the exploration of crude oil, the whole world has revolutionized. The most important factor in consideration for the pipelines is the leak produced in them. Leaks may be produced in the pipelines due to many reasons including corrosion, pipe aging, climatic effects or human interference to deliberately harm the system (Anjali, 2018). Leak produced in the pipelines not only affects the economy but also has a huge impact on the environment, human health etc. The drawbacks of leaks include downtime and repair costs, human injuries and causalities in case of explosion, effect on the environment and most importantly natural resources spillage.

Various studies have been performed on gas and crude oil leak incidents by various organizations. One of the studies on sub-sea pipelines states that between 1996-2006, 80 pipeline leak incidents were reported in the Gulf of Mexico and the Pacific area (Pal-stafan Murvey, 2012). Another report made on Europe and the American continent states that in Alberta (Canada) there had 1326 gas leak incidents occurred from 2001-2005 (Pal-stafan Murvey, 2012). Another report showed that in long pipelines (more than 800 miles), there is at least one leak reported per year. (Pal-stafan Murvey, 2012).

Most of the instrumentations have been installed at the inlet and outlet points of the pipelines making it difficult to counter the problems produced in the span length efficiently (chuka, 2016). To tackle this situation various sophisticated techniques and methods have been developed to detect leaks and to locate the point of leak. Each and every method has its restrictions and limitations so we should go towards the most robust and time-efficient method to tackle this situation preventing the spillage of natural resources. As systems of pipelines are laid far away from human societies and in barren lands, it is difficult to monitor the situation in these faraway areas. 24-hour surveillance has also become an ineffective and nearly impossible task to do. So, an automated system should be developed that not only detects leak efficiently but also locates the point of the leak, quantifies the leak mass or volume and also gives alert messages to the concerned persons operating the system so that they can take timely and effective action in this situation. An automated system will not only solve the problem of 24-hour surveillance but also it will minimize human involvement in the whole process and will go towards automation in the oil and gas industry. Moreover, the localization capability significantly reduces the time required for maintenance teams to address leakage issues, minimizing water loss and further damages (Michael Asakiyaaba Ayamga, 2024).

The Internet of Things (IoT) is one of the growing technologies in today's world. It is the gateway or connection between the physical and digital worlds. It is the network of things, connected to digital tools; sensors, actuators etc. over the internet to exchange and communicate data with other devices. Pipelines are laid away from human societies and in barren lands for their safety making it very difficult to monitor the pipeline system. 24-hour surveillance is a very difficult task to do and it involves manpower. So, in these conditions, the role of IoT becomes very significant. IoT connects the physical instruments installed on the pipelines to the digital computational software and devices over the internet and will efficiently monitor the situation (C. I. Nakpih and M. A. Ayamga, 2023). In this case, human intervention will also be minimized, making the application of IoT very significant in these conditions.

Methodology

Leak Detection System

There are multiple leak detection methods (LDS) available to date. Each method has some advantages over the others. There are also some limitations related to each method as well. By going through a detailed

literature study, we decided to use volume-mass balance and real-time transient method (RTTM) in a combined form. Details for both the methods are listed below whereas the objectives of the developed system are:

- Leakages detection and localization using smart tools
- To develop a LabVIEW based GUI for data storage and processing
- Incorporation of automation and user friendly devices in leakage detection system

Volume-Mass Balance

This method works upon the volume or mass balance at the input of the pipeline. It cannot be used to locate the point of the leak.

Depending upon our requirements, this method is used for two functions in our developed system.

i. Leak is detected by balancing pressure at the inlet and the outlet of the pipe. If the pressure drop in the pipeline goes beyond a threshold value, then there will be a leak present. If the pressure drop in the pipeline is less than 1 KPa, it indicates there is no leak. If the pressure drop is greater or equal to 1KPa, it indicates the presence of a leak.
ii. In case of a leak produced, estimation of leak size will also be performed by using this method. The difference between the volume flow rates at the inlet and the outlet will give the leaked flow rate.

Real-Time Transient Modelling

This method is used to find the leak location by developing an algorithm. Actual dynameters like pressure, temperature and volumetric flow are acquired by the sensors and flow meters installed. Expected values of flow will be calculated using parameters with the help of mathematical expressions.

The difference between the actual flow rates and expected flow rates at both the inlets and outlet will give the point. Air is taken as a fluid inside the pipeline and the developed algorithm is shown in figure 1. The analysis procedure is given below.

- Calculate the pressure drop between the inlet and the outlet by using the expression

$$\Delta P = Pi - Po$$

Where Pi= inlet pressure in bars, Po= outlet pressure in bars

- Calculate the velocity of working fluid by using

$$V = \frac{D^2}{32\mu} \times \frac{\Delta P}{L}$$

Where D =pipe inner diameter, L = pipe total length, ΔP =total pressure drop
μ = Dynamic viscosity of the working fluid

- Calculate Reynolds Number by using

$$Re = \frac{\rho \times V \times D}{\mu}$$

Re =Where D =pipe inner diameter, V= velocity of fluid, ρ =Density of working fluid

μ = dynamic viscosity

- Calculate state pressure at x where x =state point by using

$$P_X = \sqrt{Pi^2 + (Po^2 - Pi^2) \times \frac{x}{L}}$$

Calculate pressure drop at state location, x by

$$\Delta Px = Pi - Px$$

- Calculate expected inlet flow at x by using

$$V_{in(theoretical)} = \sqrt{\frac{D^5 \times \Delta Px}{8 \times x \times \rho}}$$

- Calculate expected outlet flow by using

$$V_{out(theoretical)} = \sqrt{\frac{D^5 \times \Delta P}{8 \times L \times \rho}}$$

- Calculated the difference between actual and expected flow rates at the inlet

$$X = V_{in(theoretical)} - V_{in}$$

- Calculated the difference between actual and expected flow rates at the outlet

$$Y = V_{out(theoretical)} - V_{out}$$

- Calculate the Leak location by using the following expression

$$X_{Leak} = \frac{Y}{X + Y} \times L$$

- Calculate leaked volume by using the expression

$$V_{leak} = V_{in(actual)} - V_{out(actual)}$$

Experimentation

A lab-scale model of a transmission pipeline is fabricated and experiments are performed on a 4-meter length of plastic pipe. The components of this setup are discussed below.

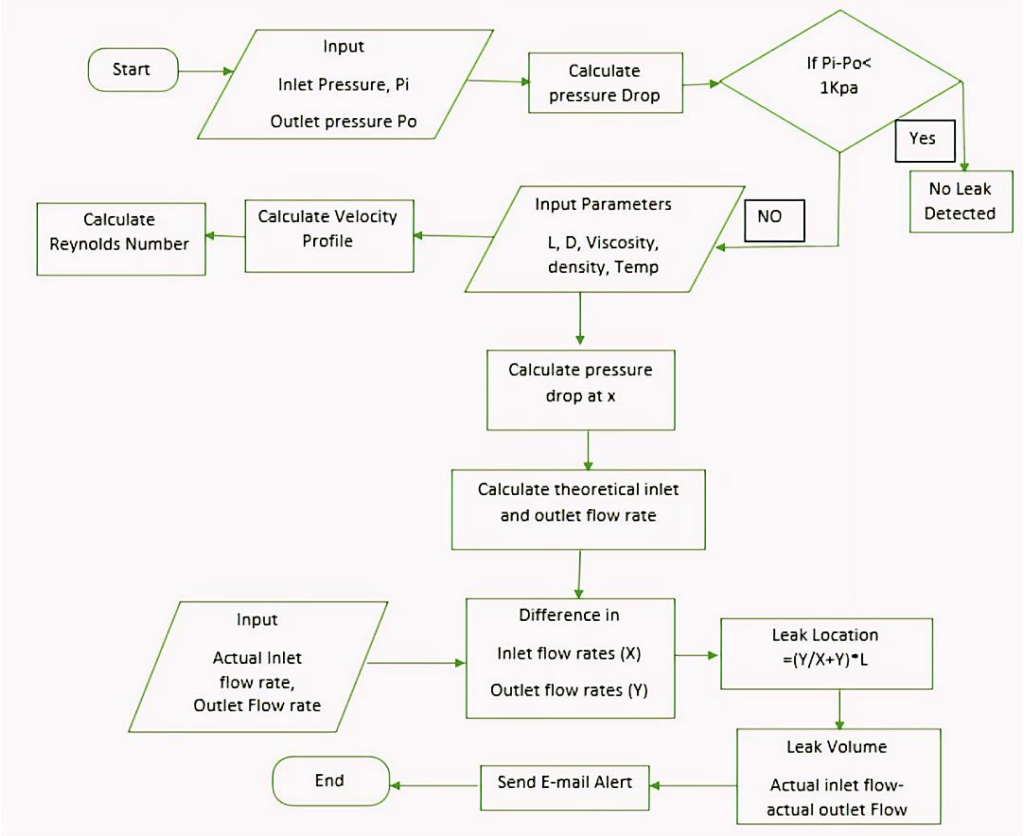

Figure 1: The developed algorithm

Analog Pressure Gauge and DS18B20 Temperature Sensor

Analog pressure gauges are used to measure the build pressure in the pipeline. These are dial gauges that have a measuring instrument, a needle and a graduated scale. The needle will move according to the pressure built into the tube on the calibrated scale. The dial gauge that we used in our system is in the range of 0-1 bar. The temperature sensor is used to acquire temperature values at the inlet and the outlet of the pipeline.

Figure 2: Analog Pressure Gauge

Figure 3: DS18B20 Temperature Sensor

HK1100 C Pressure Sensor

This pressure sensor is used to acquire pressure values from the pipeline. This sensor takes input from the pipeline and converts it into a voltage signal that is in turn converted into pressure value in the desirable unit (bar).

Figure 4: HK1100C Pressure Sensor

NodeMCU ESP8266 CP2102

A microcontroller equipped with a built-in Wi-Fi module. It is a cheap built-in Wi-Fi microcontroller that is mostly used in IoT applications. It gets input data from the sensors and an external analog-to-digital converter (ADC) converts this signal into the voltage. A program is burned inside the microcontroller and based upon those instructions it sends the data to the IoT server or applications.

Figure 5: NodeMCU Esp. 8266

Experimental Procedure

In the first step, manual testing is performed on pressure and temperature data from the dial gauges and thermometers respectively. After manual testing results. Automated testing is performed with the help of a developed program in LabVIEW and data is collected. The Experiments are carried out in the following sequence:

First of all, the air is compressed by the air compressor up to a maximum of 4-4.5 bar. The compressed air from the compressor is then stored in the air storage cylinder. The zero error in the pressure gauges is removed and the temperature sensor is set to Degree Celsius. Now the compressed air is made to flow from the storage cylinder to the main pipeline at a constant pressure with the help of an air pressure regulator. Using pressure gauges, the pressures at both the inlet and outlet of the pipe are obtained. The temperature of the compressed air at the inlet is also noted. Finally, the Volumetric flow rate is calculated with the help of domestic gas meters for that span of constant inlet pressure of the air. Based on these obtained values, calculations are performed and results are obtained. Several experiments have been performed and the above steps are repeated sequentially.

Assumptions

The following assumptions are made while carrying out the experiments:

1. Air is treated as a perfect gas.
2. The density of the air remains constant throughout the pipeline length and it is a function of inlet temperature and pressure of air.
3. Frictional losses in the pipeline are neglected because of non-viscous character of air.
4. Variation in the temperature of the fluid does not affect any properties.

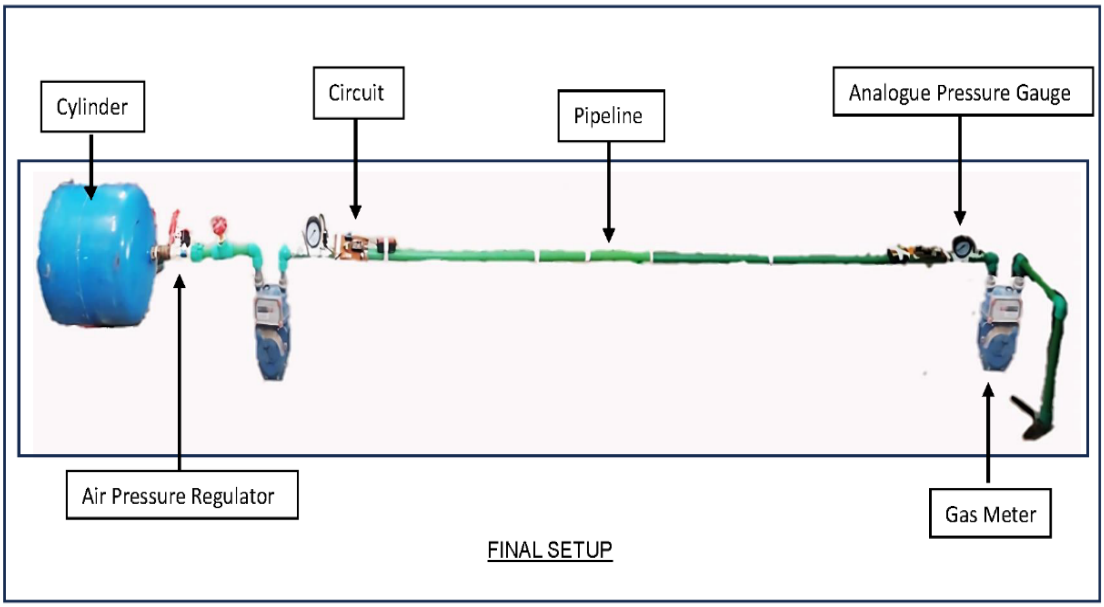

Figure 6: Lab Scale Experimental Setup

Results and Discussion

Pressure drop along the length of the pipe is given in the first graph shows how pressure variation takes place in different leakage cases. Figure 7, depicts no variation in pressure when there is no leak. However, in case of leakage, the pressure drops substantially along the length of the pipe.

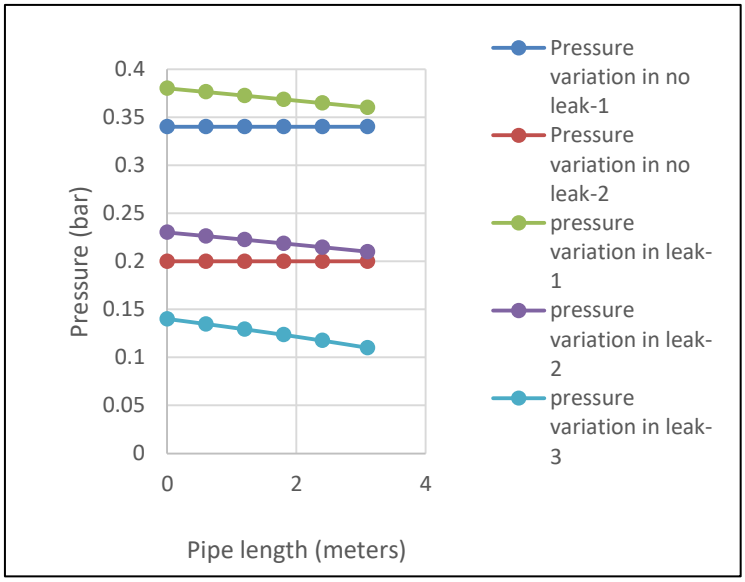

Figure 7: Pressure drop along pipeline length

In Table 1, minimum and maximum leakages are shown. Minimum volume of 11.6% leaks at 1.59m when the inlet pressure is 0.16 bar. A maximum leak of 83.4% takes place at 1.1m when inlet pressure is 0.2 bar.

Table 1: Percentage of Total Volume leaked

Input pressure (bar)	% of Total volume leaked	Leak Location
0.4	21.2	1.59
0.14	60	2.2
0.075	37.5	2.2
0.16	11.6 (minimum leak volume)	1.59
0.38	22.3	1.59
0.26	50	1.59
0.06	57.14	1.1
0.14	82.4	1.1
0.2	84.3 (maximum leak volume)	1.1
0.1	41.2	2.2
0.1	41.7	1.3
0.12	41.64	1.3
0.075	50	1.3
0.2	40	2.2

Table 2, shows the difference between the estimated and actual leak location with inlet and outlet pressure and leaked volume. It is obvious from the table that the pressure drop indicates the presence of a leakage. According to the obtained results, it is observed that the maximum pressure drop is 0.04 bar at the exact leak location of 1.2 meters with a leak volume of 0.0014 m^3/sec.

Table 2: Observations

Inlet pressure (bar)	Outlet pressure (bar)	Pressure drop (bar)	Exact leak location (meters)	Estimated leak location (meters)	Leak volume (m^3/sec)
0.34	0.34	0	-	-	-
0.2	0.187	0.013	2.2	2.26	0.0005
0.075	0.055	0.020	1.3	1.26	0.0006
0.23	0.21	0.02	1.59	1.56	0.0002
0.14	0.12	0.02	2.2	2.11	0.0005
0.14	0.1	0.04	1.2	1.12	0.0014
0.1	0.075	0.025	1.3	1.3	0.0004

The ThingSpeak GUI also reflects the pressure drop in case of leakage. In this case the pressure at the inlet is 0.23 bar whereas at the outlet it is 0.21 bar as shown in Figure 8. The pressure difference of 0.02 bar between inlet and outlet indicates the presence of a leak along the length of a pipeline.

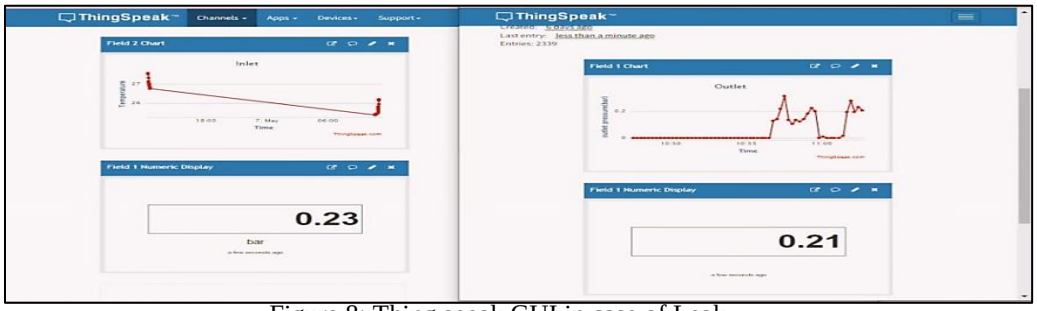

Figure 8: Thing speak GUI in case of Leak

Lab View GUI shows the results in more easy way for the understanding of a layman. With LabView, the understanding of the results becomes easier. Lab View GUI gives the status of the leak by monitoring the variations in pressure and volume flow rate at the inlet and outlet of the pipeline as shown in Figure 9.

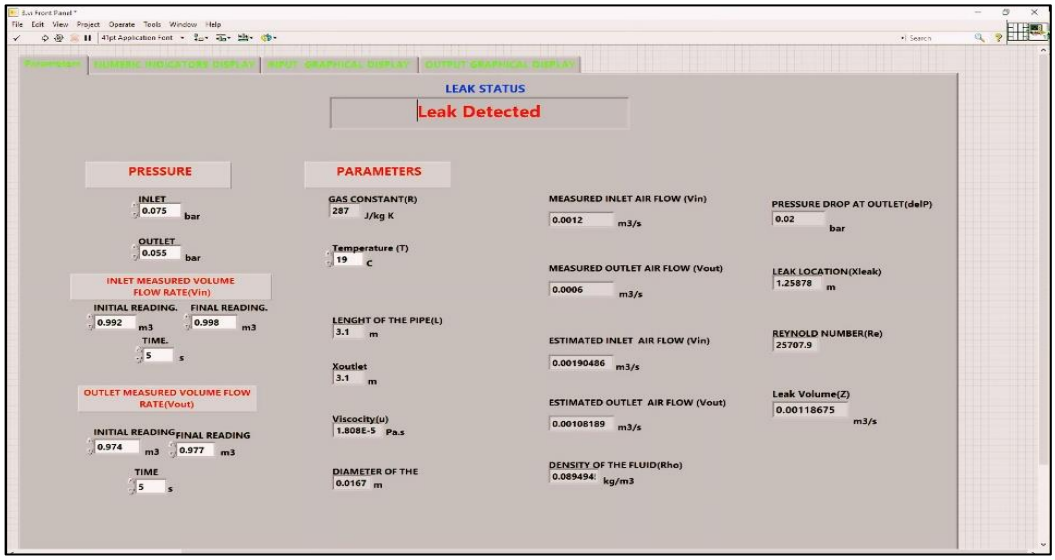

Figure 9: LabVIEW GUI

Conclusion

The volume-mass balance method offers a straightforward approach for pipeline leak detection, simply by comparing the actual pressure drop against a predetermined threshold. Meanwhile, the volume balance method stands out as both easy to use and highly accurate in calculating leak volume, quantifying it as the disparity between inlet and outlet flow rates. Transient modeling, notably the Real-Time Transient Model (RTTM), emerges as a dependable and time-efficient technique for pinpointing leak positions, although the exact location remains elusive. Notably, observed discrepancies between estimated and actual leak locations suggest a margin of error, with leak fractions varying based on proximity to inlet and outlet states.

Leak location is calculated with an error of ±6% and it is observed that the maximum fraction of total volume leaked about 85% when the leak location is nearer to the inlet state and the minimum fraction of total volume leaked about 24% when the leak location is at the mid between inlet and outlet point. This modeling framework, applicable across a pressure range of 0.07-0.5 bar, relies on empirical adjustment of state locations for constant inlet pressure scenarios. However, adaptations for systems involving viscous fluids necessitate incorporating frictional losses into flow rate estimations. Nonetheless, this adaptable system, tailored for air as the working fluid, boasts versatility for various fluids without necessitating alterations to system design. Future advancements could explore non-linear pipeline configurations and algorithms for detecting multiple leak points, necessitating enhanced equipment precision and real-time data transmission capabilities, possibly leveraging GSM technology for remote areas lacking internet connectivity.

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