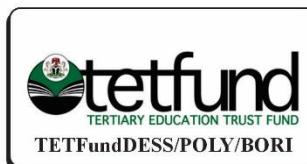


INTELLIGENT GAS LEAKAGE DETECTOR SYSTEM WITH AUTOMATIC SHUTDOWN VALVE FOR DISTRIBUTED CONTROL APPLICATION



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Abstract

The Leakage of gas or crude transportation in pipelines is a common problem of pipe network systems around Africa and other part of the world. Gas leakage is becoming a major concern in the industrial sector and residential areas. Safety has become a concern to researcher and industrial expert, due to increasing gas leakage problem across African nation and beyond. It is of great important to minimize the economic and environmental damage caused by leaks in pipe network systems, by introducing efficient leak detection methods and automatic shutdown. The use of Traditional methods are slow to rapid respond of leakage occurrence and very expensive to operate. The promising alternative to detecting leaks is to use controlled sensor (thermopiles) with an infrared light source that travel in a pipe network system at high speeds and pick up a substantial amount of information about the system condition. The infrared (IR) light source emits a broad spectrum of IR light at wavelengths which travel from the source to the sensor. The study presented in this paper is focused on to develop a gas detector system that can automatically senses gas leakage in pipe network system and at the same time shutdown the valve. This paper work also present a technique that uses leak-induced damping on fluid fluctuation in a pipeline under constant boundary conditions. However, this technique is capable of detecting, locating and synthesize a leak which is 0.1% of the cross-sectional area of the pipeline. The application of this paper work is aimed at solving the problem faced with gas transportation via pipeline network across African region.

Keywords: *gas, detector, Leakages. Sensor, pipe network.*

1. Introduction

Pipeline as one of the transportation methods is becoming increasingly important in many countries with national and international pipelines being planned and constructed every year. The latest international review conducted by Pipeline & Gas Journal, shows that 96,434 km of oil and gas pipelines are in various stages of construction or planned for construction across the globe, Tubb, (2001). Wide application of pipelines as a means of gas and crude oil transportation, has leads to a variety of pipeline failures ranging from upstream and downstream pipe rupture, gas pipe explosion to oil leakage are reported every year. The failure of a pipeline may as a result of one or several factors including corrosion of the pipe wall, abnormal pressure surges, poor quality of fittings and workmanship, soil movement, traffic loading and ageing of the pipeline, Smith, (2019). However, the most current data from the U.S. Department of Transportation (DOT) shows that, despite the policies by regulators and operators, the rate at which pipeline accidents occur showed no significant change over the last 12 years, Hovey and Farmer, (2020). Meanwhile, Rao and Sridharan, (2018), assert that the sub-African nations experience about 62% of gas leakage annually. While Some North American region have approximately 25% Makar and Chagnon, (2020). Pipeline leakage does means not only a loss of product, but also attract penalty if the environment is impacted upon. Therefore, a smart sensor leakage detector methods that enable a quick response to pipeline failure are highly demanding to reduce the loss of equipment, personnel and to minimise the risk of environmental pollution. The image shown in plate 1, described a simple pipeline gas leakage scenario.



Plate 1: pipeline gas leakage scenario (<http://www.shutterstock.com>)

The major challenges face with our today industries is the problem of pipeline leakage. This leakage in pipe line as earlier discussed are caused as a result of corrosion, crack, vandalized pipeline and disaster. When leakage occurs, gas sensor detects leakage and sends signal to the controller which closes the valve

automatically. The basic algorithms of this paper work is shown in figure 2. The other aspect of this paper is sections as follows: section II deals with the survey of other technique as related to this paper work, while section III discussed the applications of sensors for gas leakage detection, then section IV present result and discussion. Finally, section V concludes the paper.

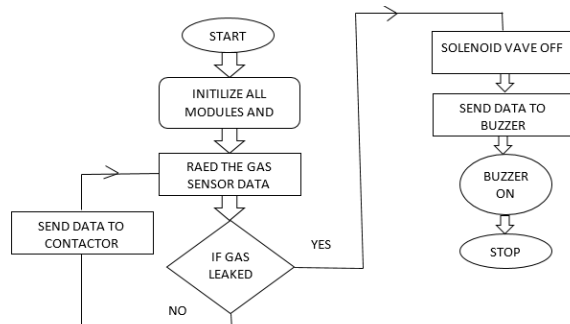


Figure 2: system operational algorithm

2. Literature Survey of Techniques.

Pipeline gas leakage is one of the unsafe conditions that leads to environmental degradation, loss of life and poor economy. While solving the problem of gas leakage, there is need to consider an adaptable technique that can best provide constant monitoring and control of gas leakage in pipeline and vehicle transportation. Vishnu and Kowsalya, (2021), uses Arduino UNO to carry out the desired task of sensing gas leakage, Arduino is connected to gas sensor (MQ-2) and temperature sensor (LM-35). Gas sensor is used to detect leakage of gas and temperature sensor is used to detect temperature constantly. The acoustic wireless sensor node using Proteus Design Suite for detecting frequency of sound exited by jetting gas, leaking from higher pressurised gas pipeline is develop, Lawrence and Ramadhani, (2014). These acoustic sensors transmit a pulse of acoustic sound toward a target, which reflects the sound back to the sensor. The system then measures the time for the echo to return to the sensor and computes the distance to the target using the speed of sound in the medium (air). Boga, and Venkata, (2021), develop a gas sensing device with MQ-2 and LM 35 gas sensor that utilizes a normally closed solenoid valve to shut off the gas valve before signal for assistance through loud alert to the operator of the system. The system is clever in that it does not cause a loud nuisance by constantly sounding the alarm, but rather the siren stops beeping once the concentration of the gas in the atmosphere after leaking falls below the predetermined value and the valve is opened again for regular operations. The algorithm of arduino block diagram for gas leakage detection using LM35 and MQ-2 is as shown figure 3. Other technique such as tuneable diode laser

spectroscope are also use to detect gas leakage in pipeline transportation. In 1962, less than two years after T. Maiman operated the first (ruby) laser, four American research groups announced, almost at the same time, that they had achieved laser action in semiconductor junctions, Holonyak, and Bevacqua, (1999) and Quist, et al, (2001). However, there are other technique for monitoring and tracking of leakage in pipe. These includes not only but the pig-based leak detection method. A pipeline pig is a free moving piston inside the pipeline, sealed against the inside wall using a number of sealing elements. Various pigs are widely used in the oil and gas industry for pipeline commissioning, cleaning, filling, de-waxing, batching and pipeline monitoring, Fumess and Reet (2020). Pigs generally need a specially designed apparatus for launching and receiving vessels for recovery. Pigs can be located using fixed signallers along the pipe or an electronic tracking system mounted inside the pig, (Pipeline Engineering Inc 2001). Recently, pipeline pigs that carry a wide range of surveillance and monitoring equipment, such as acoustic or ultrasound instruments, Furness and Reet (2020), have been used for monitoring in the oil and gas industry. The pigs are normally used at regular intervals to check the internal conditions of pipelines. By analysing the data transferred from pigs, not only can leaks be located accurately, but also pipe wall corrosion, pits and weld characteristics can be assessed regularly, British Gas, (2019).

Nevertheless, the pig-based leak detection methods are impressive for monitoring the integrity of pipelines, their application is limited to pipes with diameters larger than 200mm, and also limited to pipeline with different sizes of flanges, elbow, different diameter, and valves. Also, even in the oil and gas pipelines, the pig-based leak detection methods need to work with other techniques to ensure a quick response to pipeline failure since pig-based monitoring is still a batch rather than a continuous process.

3. Valves and Sensors Application

Valves and sensors are applied in pipeline gas leakage detections, as to control and monitor leakage at different point in the pipeline.



Plate 3: the solenoid valve

The solenoid valve is use to either open or close an aperture in a valve body, by allowing or preventing flow through the valve as shown in plate.3, this happen as a results of energizing the coil, a plunger opens or shuts the aperture by raising or lowering it inside a sleeve tube. Solenoid valves are made up of a coil, a plunger, and a sleeve assembly. The solenoid valve received information from the intelligent sensor and respond according to the command.



Plate 4: PIR sensor

The PIR sensor detects the presence of gas leakage. It emits the electromagnetic field and wait for the changes in the field or return signal. When leakage is detected at a point in time, then the valve goes off automatically as the PIR sensor gives signal to the controller, as to prevent leakage. These system requires a steady power supply. When there is no power supply, leakage cannot be detected and it will cause a failure, therefore a battery is connected to intelligent controller for providing power supply.

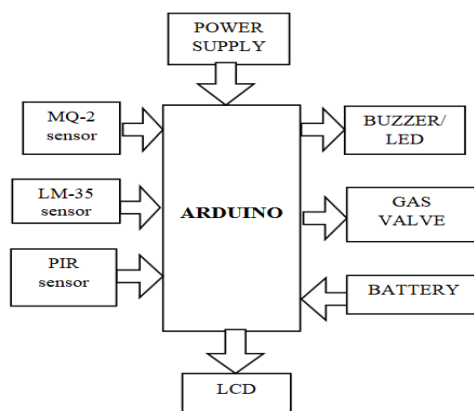


Figure 5: Arduino block diagram for gas leakage detection using LM35 and MQ-2

The gas leakage as shown in plate 1, can be described by a set of non-linear, hyperbolic equations derived from the conservation of mass and Newton's second law of motion (conversation of linear momentum) Wylie and Streeter (2019).

A similar solution for these equations is impossible due to the nonlinearity of the momentum equation. However, a number of methods have been developed to solve these equations analytically where the nonlinear term is either neglected (Allievi 2015). However, Chaudhry (2018), assert, these equations can also be solved numerically using the method of characteristics.

A control volume located between points 1 and 2 in Figure 3.1 is considered for the derivation of the unsteady flow equations (continuity and momentum) with leakage. The pipe is assumed to be horizontal with a leak located at $x = x_L$, as shown in Figure 3, where Q_L is the discharge out of the leak.

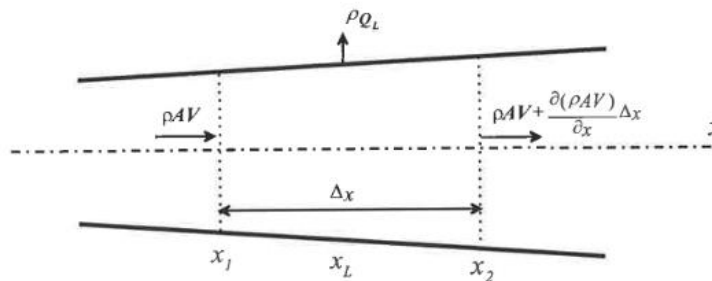


Figure 6: Cross section of pipe with leakage point

Applying the conservation of mass in control volume in the non-leakage equation, gives;

$$\frac{\partial}{\partial t} (\rho A) \Delta x + \frac{\partial}{\partial x} (\rho AV) \Delta x = -\rho Q_L \quad (1)$$

Where x = distance along the pipeline, t = time, ρ = fluid density, A = cross-sectional area of the pipe, and V = velocity of flow. However, by dividing Equation (1) by Δx and allow Δx approach zero gives:

$$\frac{\partial}{\partial t} (\rho A) + \frac{\partial}{\partial x} (\rho AV) = -\rho Q_L \delta(x - x_L) \quad (2)$$

Similarly, applying conservation momentum in the control volume with respect to x - direction gives:

$$\frac{\partial}{\partial t} (\rho AV) \Delta x + \frac{\partial}{\partial x} (\rho AV^2) \Delta x = \sum F_x \quad (3)$$

Considering the free body flow diagram of figure 4, and develop the derivative for the momentum equation.

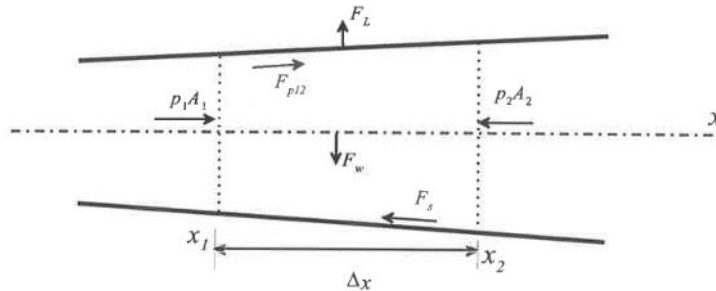


Figure 7: Free-body flow diagram for derivation of the momentum equation.

Considering the downstream flow direction as positive, the total x direction force components acting on the control volume can be expressed as:

$$\sum F = p_1 A_1 - p_2 A_2 - 0.5(p_1 + p_2)(A_1 - A_2) - \tau_0 \pi D(x_2 - x_1) = 0.5(p_1 - p_2)(A_1 + A_2) - \tau_0 \pi D(x_2 - x_1) \quad (4)$$

Recall that, the weight force and pressure force at the leak orifice do not act in the x-direction and are not considered in the conservation of momentum. Substituting Equation (4) into Equation (3), then divide it by Δx and allow Δx approaching zero gives:

$$\frac{\partial}{\partial t} (\rho AV) \Delta x + \frac{\partial}{\partial x} (\rho AV^2) + A \frac{\partial p}{\partial x} \tau_0 \pi D = 0 \quad (5)$$

Meanwhile, by applying the Darcy-Weisbach formula for shear stress, where $\tau_0 = \frac{PfV^2}{8}$ to equation 5, gives:

$$\frac{\partial}{\partial t} (\rho AV) + \frac{\partial}{\partial x} (\rho AV^2) + A \frac{\partial p}{\partial x} + \frac{\rho AfV^2}{2D} = 0 \quad (6)$$

Where f = Darcy-Weisbach friction factor and D = pipe diameter. But in Equation (6), the unsteady shear stress is approximated by the steady state shear stress, and the pipe friction during the transient event is described by the steady state Darcy-Weisbach friction factor-a common assumption. However, pipe friction during unsteady events has been shown to be significantly larger than that predicted by the steady state Darcy-Weisbach friction factor.

4. Results and Discussion

The result as presented in this paper, shows the flow rate and leakage size. Figure 8, however describes linear relationship between mass flow rate at 70 bar gas pressure inside pipeline and the size of the orifice (hole) when gas escape from pipeline. The mass flow rate increase with the increase of leak size, and the sensor

will at that point communicate the controller that will signal the normally open solenoid valve to close the section that leads to the gas leakage.

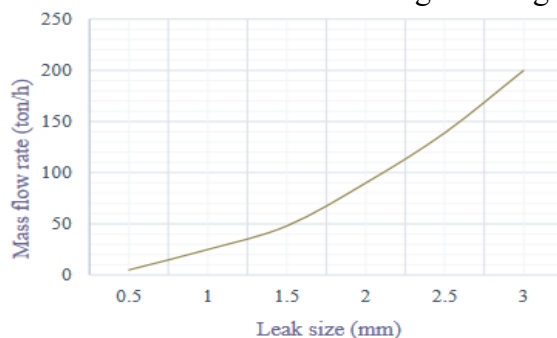


Figure 8: The characteristics response between flow rate and leakage size.

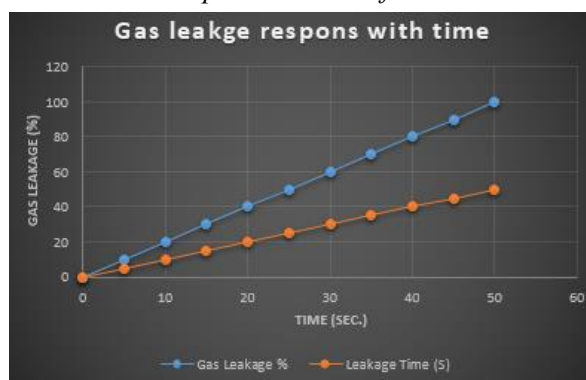


Figure 9: The characteristics response of Gas leakage with time.

The characteristic response of the gas leakage with time indicates that the percentage leakages increase with respect to time, as shown in figure 9.

Table 1: Gas leakage response with time

Gas Leakage %	Leakage Time (S)
100	50
90	45
80	40
70	35
60	30
50	25
40	20
30	15
20	10
10	5
0	0

The response as shown on figure 8, indicate that, at leakage size 3, the flow rate is high at 200. This implies that, the higher the orifice size, the higher the flow rate, which means the higher the leakage.

5. CONCLUSION

Gas leaks cause serious mishaps that result in material losses and human injuries. Gas leakage is caused mostly by poor equipment maintenance and a lack of public knowledge. Wireless sensor nodes in wireless sensor networks perform several key functions like gathering sensory information, information processing and communication with other connected nodes in network. For long gas pipeline, it involve numerous nodes for accurate monitoring. This paper described a method for detecting and automatically shut down valve as to stop the flow of gas leaks. This method is basic yet dependable. As a result, detecting gas leaks is critical for avoiding accidents and saving lives.

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