https://doi.org/10.67571/njeru.2021.010109
NIGERIAN JOURNAL OF ENGINEERING RESEARCH UNICROSS (NJERU)

Volume 1, Issue 1, 30th January, 2025

Monitoring of leakages in crude oil/gas pipelines using a wireless system network internet of things (IoT)

Gertrude A. Fischer [a,*], F. I. Anyasi [b], Sunday A. Ojomu [b]

[a] Department of Electrical and Electronic Engineering, University of Cross River State, Nigeria

[*]Corresponding author: gertrudefischer@unicross.edu.ng

Received: 2nd January, 2025 Reviewed: 14th January, 2025 Accepted: 30th January, 2025

ABSTRACT.

Intrusions on oil and gas pipelines entail tremendous danger, which can be quant1ified in terms of monetary implications, environmental harm, health and safety repercussions. Safe and efficient delivery of these commodities, require accurate monitoring of the pipelines, here we present the use of an internet of things (IoT) analytics platform service to perform the real-time pipeline monitoring and determine the location of damage on a pipeline. Pressure pulses, based on the principle of vibration in pipes are used for pipeline monitoring in this study. The system comprises mainly of HK1100C oil pressure sensor, Arduino Uno board containing ESP32 Micro-controller Wi-Fi, SIM900L GSM module and powered by a DC source. The ATmega328P microcontroller was programmed in C++ programming language. When deployed in pipelines, the wireless sensor network is able to monitor oil pipelines against leaks. The principle of time delay between pulse arrivals at sensor positions is also adopted in this study. The measured velocity of pulse propagation using the data logger as fluid is 355 m/s. The Arduino and Wi-Fi module are used to produce the wireless communication link that interfaced with the cloud-based Thing Speak data collection and analytics platform. Signal data is collected on the monitoring system once every 15 s and the channels created on Thing Speak are updated every 2 min. Results show that a drop in monitored pressure is associated with a leak. The experimental results also show that the performance of the wireless communication device compare satisfactorily with the data logger.

Keyword: Leakage monitoring, crude oil/gas pipelines, wireless sensor system, internet of things (IoT), real-time monitoring

I. INTRODUCTION

In this study, we demonstrated the use of an Internet of Things (IoT) analytics platform service to identify pipeline damage locations and simulate real-time pipeline monitoring. In order to gather data from the five sensors utilized in the experimental test rig using a wireless connection, a total of ten (10) channels were set up on the platform. Every 15 seconds, signal data was gathered, and every 2 minutes, all the channels received updates. [1,2,3] The wireless communication gadget posted data, which Thing Speak instantly visualized. ThingSpeak allows you to aggregate, visualize, and analyze live data streams in the cloud. Some of the key capabilities of ThingSpeak include the ability to easily configure devices to send data to ThingSpeak using popular IoT protocols and visualize your sensor data in real time.

Data processing and analysis were done online as it came in. A second test setup was constructed that processed data using a data logger. Using the data recorder and air as the transport medium, the recorded pulse propagation velocity was 355 m/s. Between 4.243 m and 4.246 m was the range of the computed estimations of event location for the 50 measurements made. In comparison to the actual measured event location of 4.23 m, this had a scatter of just 3 mm. The results of the experiment demonstrated the wireless communication performance. The testing findings demonstrated that, when utilized for real-time monitoring, the wireless communication device's performance could be satisfactorily compared to that of the data logger and was capable of locating damage on actual pipelines. [4,5] Real-time pipeline monitoring can be done on any internet-capable device from anywhere in the world using this communication tool and an analytics platform.

In a study titled "IoT networks for monitoring and detection of leakage in pipelines" published in 2022, [12] they looked into the use of Wireless Sensor Networks (WSNs) with Internet of Things (IoT) technology in oil pipelines, which offers options to deal with these issues. Wireless wide area network technology, connects battery-operated, low-bandwidth devices across large distances. LPWAN single-hop LoRa model is also used to monitor above-ground oil pipelines. Two scenarios were used to assess the LoRa model's scalability and capacity before the results were discussed. In their Research, "Artificial Intelligence and Internet of Things-Based Leak Detection Method for the Water Supply Network" published in 2023, [16] designed and built an intelligent network of wireless sensors to monitor the water supply network. The ideal arrangement of pressure measuring stations was investigated using a matrix of pressure sensitivity coefficients. The leakage simulation was completed by setting the injector coefficient on the basis of online pressure monitoring. The monitoring requirements of urban water supply networks and the reasons why the current SCADA system and commercial monitoring equipment cannot meet the application of pipe network monitoring are presented, with a goal of building a multilevel networked water supply monitoring system to achieve the monitoring network requirements of large-scale, low-cost, low-power co.

The study "Leak detection in gas pipeline by acoustic and signal processing" [4, 6,7] The use of an acoustic approach to detect gas leaks in pipeline systems was discussed. When a leak develops, a major component of the acoustic approach is the wave propagation in the pipeline, and the friction between the pipe's walls will provide the pressure balance. In order to deconstruct the raw signal and display it in time-frequency, signal processing is performed. Future comparison studies can make use of the acoustic method's findings. The most effective approach to find leaks in gas pipelines is acoustic signal and HHT. To quickly determine leaks and estimate, more simulations and experiments must be conducted.

In 2019, [19]. A Wireless Sensor Network for Monitoring an Oil Pipeline was designed and implemented. presented a wireless sensor network (WSN) that incorporates pressure sensors, an Arduino board with an 8-bit AVR family microcontroller (ATmega328P), a GSM module, and an LCD for data acquisition, processing, communication, and analysis, to be used for the localization of leaks (whether caused by the environment or by humans). At a predetermined place along the prototype oil pipeline, an experimental assessment of the relationship between leaks or bursts and pressure changes was conducted. The findings indicated that a leak is connected with a loss in pressure and that this drop in pressure increases with the extent of the leak. The pressure parameter is monitored in the prototype pipeline (field or transmitting section) using the ideas of signal (energy) conversion and processing in a modular manner [8,9,10]. The pressure information (signal) is transformed into an electrical signal, processed, and sent as radio waves before being received at the monitor or control Centre (master or receiving section) once the monitored pressure drops below a minimum predetermined pressure point. The buzzer and LCD are driven by electrical signals that were originally converted from the radio signals that were received. By monitoring pressure changes along the pipelines, we came to the conclusion that a wireless sensor network had been set up that could monitor oil pipelines for leakage. However, more study is required. [11,12]

[13] Internet of Things wireless and mobile technologies are discussed in the book. In "Mobile Information Systems," the author suggested a multiparameter handover process optimization technique based on a vertical handover scheme for M2M communications in Hetmanate. He intends to create an optimization method based on fuzzy logic and decision modeling for subsequent work.

[17] The author of "Experimental study on leak detection and location for gas pipeline based on acoustic method" compared the leak signal with the disrupting signal using the methods for extracting the time and frequency domain from acoustic signals using test data. The methods for identifying and extracting acoustic signals are tested and compared, and the results show that while the analysis of the time and frequency domain can effectively remove disturbing signals, the new characteristics of the accumulative value difference, mean value difference, and peak value difference of signals in adjacent intervals can detect leaks effectively and significantly lower the false alarm rate.

[7] published "Wireless Sensor Networks: A Survey Computer networks." This essay explains the idea of sensor networks, which has been made feasible by the fusion of digital electronics, wireless communication and microelectromechanical systems technology. First, a review of the elements impacting the design of sensor networks is given, followed by an examination of the sensing tasks and prospective applications for sensor networks. After that, the communication architecture for sensor networks is described, and the literature's created algorithms and protocols for each layer are examined.

"Analysis of Pipelines Failures in the Oil and Gas Industry in the Niger Delta Area of Nigeria" by [14. 15,16,20]. The author claims that pipeline failures have severe negative effects. Fire catastrophes are the outcome, destroying cash crops that could have been harvested and sold for profit. Therefore, it is essential that current policy frameworks be reviewed, and that a thorough regulatory framework be introduced and put into place with effective enforcement and monitoring systems that can help to maintain proper safety management systems in order to reduce pipeline failures and vandalism incidents.

In 2008, [2] "An evaluation of the causes of oil pipeline incidents in the oil and gas industries in the Niger Delta region of Nigeria" presented the findings of a research that was done with a pipeline in late 2004. The respondent comes to the conclusion that the top four causes of pipeline incidents that reduce productivity are sabotage, corrosion (both internal and external), mechanical impact, and equipment failures. Pipeline integrity managers should therefore create a data integration approach that enables integrity managers, risk assessment experts, and pigging engineers to see and analyze information in order to limit the causes of pipeline incidents.

In their 2017 study "Oil Theft, Illegal Bunkering and Pipeline Vandalism: It's Impact on Nigeria Economy," [3] evaluated numerous attempts to situate the causes, effects, and implications of the phenomena of oil thefts, illegal bunkering, and pipeline vandalism in relation to Nigeria's economy, regional security, and national security. The study found that vandalism and illegal bunkering have caused the Nigerian government and oil firms to experience economic hardship, as well as environmental damage, insecurity in the Niger Delta, and a threat to global and national security. The work also looked at the attempts made by various Nigerian governments to address the issues, and it was suggested that failure had occurred because of enthroned corruption by Nigerian elites, a high rate of youth unemployment, institutional decay and dysfunction, poor governance, ineffective and corrupt law enforcement agencies, international crime collaborations, a lack of political will by those in power, wealth, etc.

[5] The writers of "Asset Integrity Management in Mitigating Oil and Gas Pipeline Vandalism in the Niger Delta Region" with the assistance of the Nigerian government highlighted the negative effects of pipeline failures because it would be a waste of resources if not done in a systematic and efficient manner. They also stressed the necessity for the Nigerian government to expressly address these threats by putting in place remedial measures and benchmarking performance against clearly defined criteria.

In a 2005 [6] "A survey on routing protocols for wireless sensor networks" is the subtitle. Recent developments in wireless sensor networks have spawned a plethora of novel protocols created especially for these networks, where energy awareness is a key factor. The routing protocols, however, have received the majority of attention because they can vary based on the application and network architecture. This research analyses current sensor network routing methods and provides a classification of the various strategies used. Data-centric, hierarchical, and location-based categories are the three main ones that are examined in this research. The relevant category is used to describe and discuss each routing protocol. In addition, protocols use cutting-edge approaches like network flow and quality of service modelling

[8] According to "A state-of-the-art model for spatial and stochastic oil spill risk assessment: A case study of oil spill from a shipwreck," For the assessment of the risk of a spatial and stochastic oil spill, a new model was provided here. A shipwreck in Kattegat is used as a case study to evaluate the danger of an oil spill using the created model. Expert elicitation and Bayesian updating are used in an FTA framework to assess the likelihood of spill from the wreck. [9] According to the study "Attacks on Oil Transport Pipelines in Nigeria: A Quantitative Exploration and Potential Explanation of Observed Patterns. presented an innovative approach to (a) collect divergent spatiotemporal data on pipeline interception of oil, (b) statistically assess regional variations in pipeline interception, and (c) connect interception with socioeconomic characteristics to assist identify patterns. The coarse spatial resolution at which the pipeline-related data are collected at source is a drawback of this investigation. Examining interdiction statistics, identifying spatiotemporal patterns, and discussing correlations with socioeconomic variables revealed the following findings: (a) a strong inverse relationship between pipeline interdiction and poverty; and (b) statistically and non-statistically significant mean differences in the pattern of interdiction occurrence among the five geographic regions. Finally, we emphasize the importance of improving data collecting and reporting in order to lessen the adverse socio-environmental effects of interdiction incidents.

[11] "Design of pipelines for the simultaneous flow of oil and gas" Pressure drops for simultaneous oil and gas flow in pipelines with a diameter of four to ten inches were measured. These findings were compared to information from the literature for pipelines with a diameter of 1.5 to 3 inches. For the purpose of forecasting the pipeline flow pattern, a generalized chart was created using previously disclosed data. The flow patterns mentioned include stratified flow, annular flow, bubble flow, plug flow, wavy flow, slug flow, and plug flow. It was demonstrated that the generalized flow pattern chart and our experimental results were compatible. A modified version of the aforementioned method is described, with a separate equation for each type of flow pattern [20,21,22,24].

This study shows a thorough, rigorous investigation of the literature on data aggregation, specifically as it relates to WSNs. In this study, a methodical examination of data aggregation in WSNs was presented. This research covered data aggregation methodologies, tools, methodology, and problems. The research literature has also proposed potential research questions and directions.

II. METHOD

The method of monitoring the crude oil leakage system was successfully carried out using a flow sensor which gave the flow rate, and total volume by simulating the output of the total flow/volume of the system. Moreover, the Hall-effect-based Temperature and Humidity Sensor (DHT11). A Hall effect sensor is a type of sensor that detects the existence and amplitude of a magnetic field utilizing the Hall effect.

VH = -VdBd where Vd is the drift velocity of the charges.

The Hall voltage (VH) was employed to measure the drift velocity since it is proportional to the magnetic field. A Hall sensor's output voltage is inversely proportional to the field's intensity. a piece of magnet placed on a circumferential disk that revolves around the Hall effect sensor, which is read by the microcontroller unit (ATMEGA328P, Arduino), serves as the basis for how the flow sensor evaluates the flow rate and volume. By identifying the first change or threshold for the system's flow, the Temperature/Humidity Sensor (DHT11) provided a real-time picture of the rise and fall in temperature and humidity as it influences crude oil leakage. However, the magnetic field perpendicular to the electric current induces a voltage differential in a conductor, according to the Hall effect calibration. In this case, a tiny fan or propeller-shaped rotor was placed in the fluid flow path to take advantage of the Hall effect in the flow meter from which all simulated readings were viewed and analyzed via a cloud server (thingspeak.org).

This study's goals are to examine potential solutions to the problems caused by oil pipeline vandalism for the Niger Delta's population, economy, and agriculture. Human existence and economic progress are the dependent variables, and oil pipeline vandalism/vandalism is the independent variable. The link between the variables can be described as follows:

$$HE = f(OPV) \tag{1}$$

$$ED = f(OPV) \tag{2}$$

Hence, the models to be adopted for this study are as follows:

$$HE = 0 + 1OPV + U \tag{3}$$

$$ED = 0 + 1OPV + U \tag{4}$$

Were
HE = Human Existence
ED = Economic Development
OPV = Oil Pipeline Vandalization
0 = Constant
1 = Parameter estimate
U = Error term or stochastic variable
Apriori Expectation: 1< 0

A. *Design of the communication (GSM) unit*

The communication (GSM) unit was made up of a SIM800L GSM module and a DC power source. The SIM800L is a cellular module that allows for GPRS transmission, sending and receiving SMS, and also for making and receiving voice calls. Low cost, small footprint, and quad-band frequency support marked this module the perfect solution for this project work. After connecting power, the module boots up, searches for cellular networks, and logs in automatically. Selecting SIM800L for this design, was based on the following specifications:

1. Supply voltage: 3.8V - 4.2V
2. Recommended supply voltage: 4V
3. Power consumption:
   (i) sleep mode < 2.0mA
   (ii) Idle mode < 7.0mA
   (iii) GSM transmission (avg.): 350 mA
   (iv) GSM transmission (peak): 2000mA
4. Module size: 25 x 23cm
5. Interface: UART (max. 2.8V) and AT commands
6. SIM card socket: micro-SIM (bottom side)
7. Supported frequencies: Quad Band (850 / 950 / 1800 /1900 MHz)
8. Antenna connector: IPX
9. Status signaling: LED
10. Working temperature range: -40 do + 85 ° C
11. RING (not marked on PBC, first from top, square) - LOW state while receiving call
12. DTR - sleep mode. Default in HIGH state (module in sleep mode, serial communication disabled). After setting it in LOW the module woke up.
13. MICP, MICN - microphone (P + / N -)
14. SPKP, SPKN - speaker (P + / N -)
    (I) Pinout (bottom side - right):
15. NET - antenna
16. VCC - supply voltage
17. RESET - reset
18. RXD - serial communication
19. TXD - serial communication
20. GND - ground
21. In this design, the GSM module was interfaced to the Arduino microcontroller through the serial pins.
22. Communication was provided by the MTN network provider using the SIM card.

B. *Design of software for the field sensor node*

The development environment for the system software was Arduino Software (IDE), and the programming language was C++. The system software was divided into two programs: the main processor program, which was responsible for processing the pipe pressure parameters collected by the sensor(s), and the GSM communication program, which was designed for sending the pipe pressure parameters. The integration of the two programs enabled the node to sense, collect, process, and transfer the low-pressure information to the master node.

The microcontroller was programmed in the C++ programming language to follow the flowchart shown in Figure 1

III. Results and Discussions

A. *Energy equations and flow rate*

The following energy types exist in a flowing liquid or gaseous medium. Potential energy due to position energy, pressure energy and kinetic energy.

Position energy	Pressure energy	Kinetic energy
= m x g x	hm x p/ρ	m x v^2/2
m = mass	p = static pressure	v = flow velocity
g = gravity	ρ = density	h = height

According to Bernoulli Law of conservation of energy, the sum of energy at every location in the flow passage or pipeline must remain constant. So, the mass flow qm is constant giving

$$g \times h + p/\rho + v^2/2 = \text{Constant} \tag{5}$$

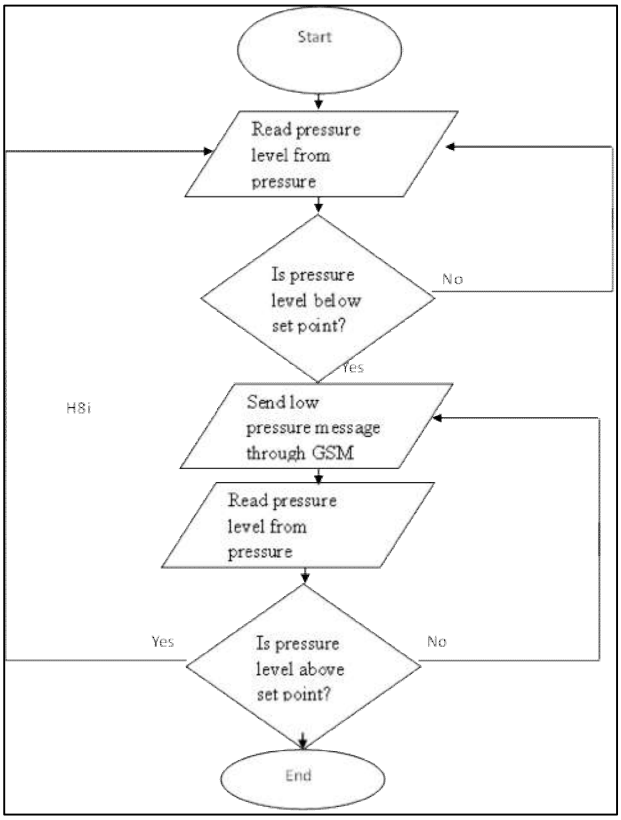
For pipelines, position changes are minor so qm becomes:

$$p/\rho + v^2/2 = \text{Constant} \tag{6}$$

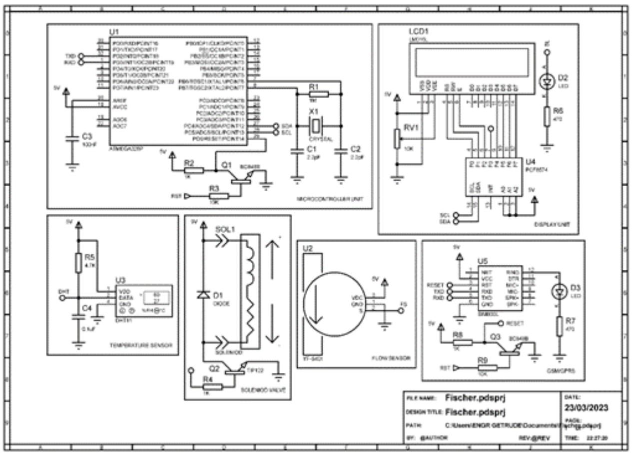
So, for monitoring at different locations or points1 and 2, etc. along the pipeline,

$$p_1/\rho + (v_1^2)/2 = p_2/\rho + (v_2^2)/2 \qquad (7)$$

In this research, monitoring is expected at several locations along the pipeline through different terrains and from equation (8) the mass flow or volume flow should normally be the same at each location.



Field sensor microcontroller



Logic diagram of the system circuit

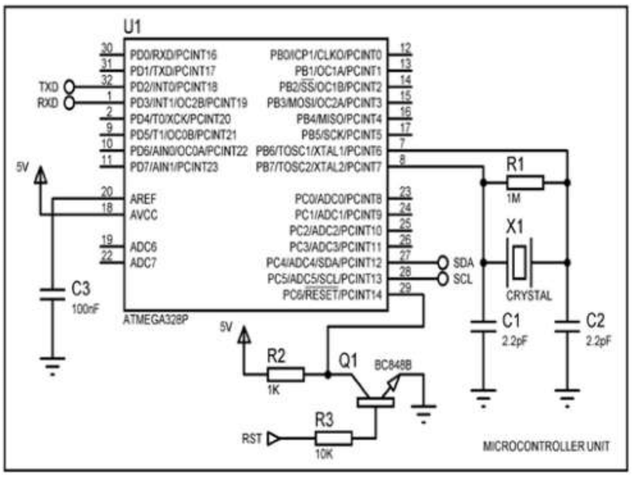


Figure 1: Microcontroller unit.

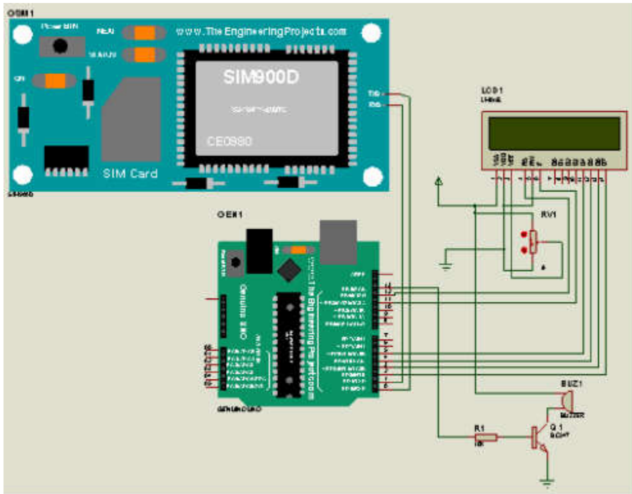


Figure 2: Complete simulated master circuit diagram.

Re-arranging equation (8) provides the equation when a pressure drop occurs due to significant leakage or damage to the pipeline.

Change in pressure,

$$\Delta p = p1 - p2 = \rho/2\ (v_2^2 - v_1^2) \qquad (8)$$

The Flow sensor was configured to measure either Flow volume V or the velocity, v.

B. Experimental results presentation, analysis and discussion

Using the experimental circuit built, the flow rate, temperature and pressure data were measured and recorded using data log software and Sim800L 5V Wireless GSM GPRS Module.

The data were saved in the cloud using “thingSpeak.org”. The measured and recorded results were presented.

C. Simulation results for flow rate conditions

With an Arduino-uno and a water flow sensor, a IoT-based monitoring system was created in this research. It was connected to the YFS201 Hall Effect Flow Sensor. A cloud visual was displayed to show the total volume and flow rate. The hardware was integrated with the IoT Server. The "Thing speak App" as an IoT server was created. The information about the flow rate and volume was uploaded to Thing speak Server and accessed/ monitored from anywhere in the world by login in into with ThingSpeak.org using the email and the password that was created with it. Looking at the figure above being the Simulation Results for Flow Rate Condition, the flow rate shows drop of pressure indicating that there was a leakage at the pipeline. As shown below.

The figure 5 shows the rate of flow of the fluid from 2nd August to 5th 2023. August indicating a rise from zero to ten, a drop and then a consistent rise through 3rd, 4th and 5th August, 2023. This means that between 2nd August and 5th August, 2023. There was a drop and then rise in the flow rate of the fluid as seen in the chart below.

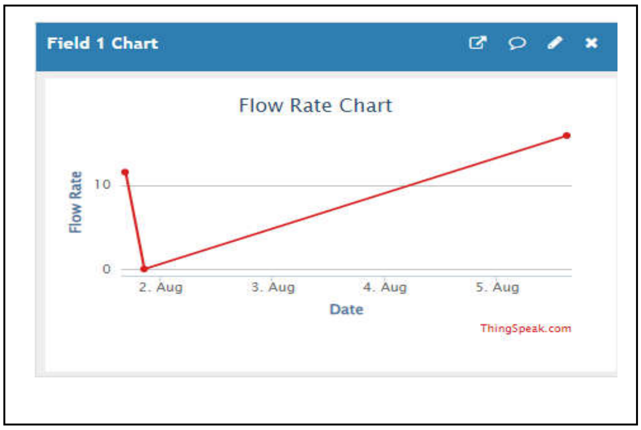


Figure 3: Flow rate measured 2nd to 5th August

This chart above depicts a consistent drop in the flow rate of the fluid as it flows through the pipe. This drop happened between 3:00 and 3:20 PM. It indicates a leakage in the pipeline.

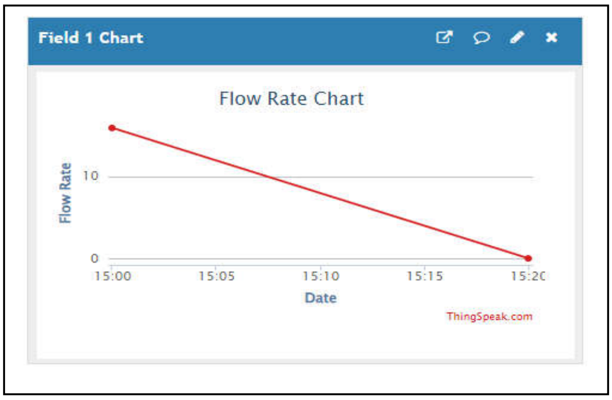


Figure 4: Graphical simulation showing drop in flow rate

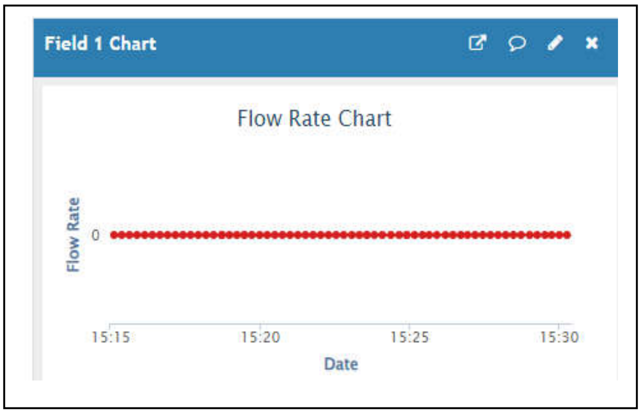


Figure 5: Graphical simulation showing steady ideal flow rate condition

The flow rate as seen in Figure 5 shows that the flow rate remained at zero indicating that there was no flow of fluid between 3:15 and 3:30 PM. Nevertheless, the flow remains stable when there is no vandalization, leakages or corrosion.

D. Simulation results for volume condition

The volume of the fluid as seen in Figure 6 shows the volume rising from zero at about 3:35 through 6.75 liters even beyond 7 liters up to about 7.15 liters then remained constant.

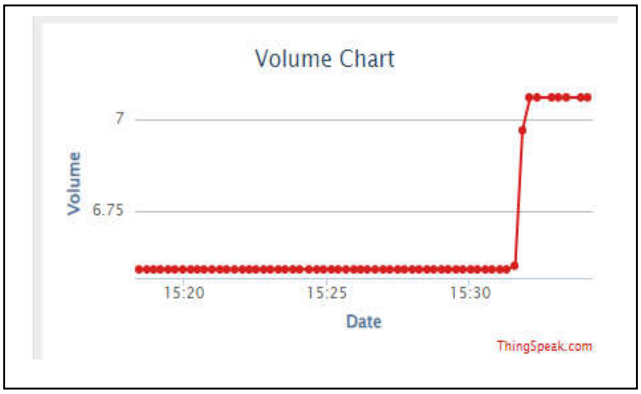


Figure 6: Graphical visualization of the ideal volume condition

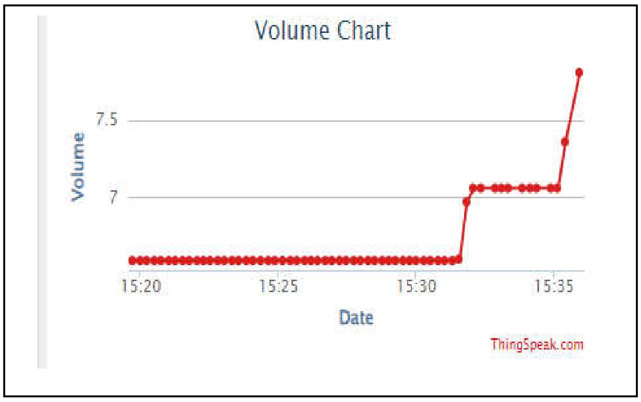


Figure 7: Graphical visualization of the volume condition

Here the volume of the fluid remained at zero from 3:20 up to 3:31 and then rises to 7 litters and then further rises to 7.5 litters at about 3:35.

IV. Conclusion

Gas and crude oil pipeline monitoring is essential for the safe and effective transit of these resources. One advantage of a wireless system network is that it is scalable, allowing pipeline operators to easily add new sensors or expand their network as needed. This is especially important for pipeline that are located in remote areas, where access is limited and traditional monitoring method may not be feasible. A wireless system network for monitoring crude oil and gas pipeline is also relatively low-cost compared to other monitoring method, as it eliminates the need for physical infrastructure, such as wiring and communication towers. This makes it attractive option for pipeline operators who want to monitor their pipeline without incurring significant expenses. By implementation of a wireless system network (IoT), pipeline operator can ensure the safe and efficient transportation of crude oil and gas, and minimize the impact of any incidents that may occur.

In this study, we have presented the use of an internet of things (IoT) analytics platform service to mimic real-time pipeline monitoring and determine the location of damage on a pipeline. Pressure pulses, based on the principle of vibration in pipes were used for pipeline monitoring in this study. The principle of time delay between pulse arrivals at sensor positions was also adopted in this study. An Arduino and a Wi-Fi module were combined, programmed and used to produce a wireless communication device which communicates with the Thing Speak internet of things (IoT) analytics platform. A total of ten channels were created on the platform to collect data from the ten sensors that were used in the experimental test rig that made use of wireless communication device. Signal data was collected once every 15 s and all the channels were updated every 2 min. Thing Speak provided instant visualizations of data posted by the wireless communication device. Online analysis and processing of the data was performed as it came in. A second test rig was built that made use of a data logger for processing of data. The measured velocity of pulse propagation using the data logger to transport fluid was 355 m/s. The computed estimates of event location for the 50 measurements taken ranged between 4.243 m and 4.246 m. This had a scatter of just 3 mm against the actual measured event location of 4.23 m. The experimental results obtained showed that the performance of the wireless communication device compared satisfactorily with the data logger and is capable of detecting the location of damage on real pipelines when used for real time monitoring. Using this communication device and an analytics platform, real-time monitoring of pipelines can be carried out from any location in the world on any internet-enabled device.

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