IoT-Based Detection and Early Warning System for Acid Leaking in Underground Pipeline

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***Abstract* – Leaks in pipelines caused by acid are destructive to both economic growth and capital which should be avoided at all costs. Damage to underground pipelines is caused by a hard-to-find leak, the unavailability of a real-time monitoring system and the lack of a pipeline history database. The aim of this work is to develop an early warning system to detect acid leaking in the pipeline using Internet of Things (IoT) technology. To detect changes in the pH of acid soil parameters near the pipeline, two mechanisms are required: first, to provide an early warning before the leak is detected and second, to report the occurrence of the leak. The notification system is equipped with three LED indicators, each showing the offline, online and signal detection status. The novelty of the work is a prototype that can detect the acid leak in the pipeline and record the pH values in a database for future research. Using continuous pH monitoring, real-time analysis and a database, this system can detect leaks before they become a major problem. Consequently, the manufacturing industry will benefit from this initiative as it is automated, efficient and cost-effective.**

***Keywords* – Internet of things (IoT), underground pipeline; pipeline leakage, microcontroller.**

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1. Introduction

There are more than two million kilometers of pipelines in the world, and pipeline damage can result in accidents and disasters that have major consequences for ecology [1]. Typical accidents caused by acid leakage based on an underground pipeline are the major source of severe destruction such as buildings, injuries, and, most importantly, death [2]. The occurrence of underground leaks has a negative impact on the national economy and results in loss of life and property. It was discovered while researching a case study in Taiwan involving a catastrophic underground pipeline gas explosion as a result of gas pipeline properties consisting of flammable, explosive, and toxic materials that are prone to cause leak, combustion, explosion, and poisoning accidents [3]. There are numerous variables that influence underground pipeline leaks, including corrosion, pipeline faults, natural environment, and damage from external forces. The elements that induce underground pipeline corrosion have been identified as soil moisture content, pH value, organic content, and temperature [4].

It is extremely essential to examine the pH value while considering about leaks in the underground pipeline. Acidic chemicals with lower pH values are more corrosive to the pipeline, and if the problem is not addressed, it can cause leaks in the pipes [5], [6]. The alkalinity, neutrality or acidity of the underground pipeline can be determined by measuring the pH of the soil on site, which can range from zero (0) to fourteen (14) on the scale [7]. Since acid soils exhibit a pH value of less than seven (7), this indicates that the soil is acidic [8].

However, there are still concerns regarding the current condition of the underground pipeline. Therefore, it is important to perform pipeline inspections to detect the presence of acid leaking and ensure that these pipeline networks continue to function efficiently. Monitoring leaks in pipelines is usually done through manual pipe inspections using CCTV and human personnel. Despite being the most common strategy, this method is prone to human error [9],[10],[11]. To ensure efficient operation of underground pipelines, a system that can efficiently monitor the condition of the pipelines is essential.

Monitoring pipelines that transport hazardous products can be made more efficient through the use of early warning signatures and environmental monitoring [12],[13]. The potential applications of monitoring systems have been discussed in the scientific literature. Sitompul et.al [14] have integrated electronic components into a limited number of field monitoring systems and then further improved them by connecting a variety of sensors to a microcontroller to increase overall performance in a variety of different applications [15]. Sihombing [16] developed a detector system that is capable of sending its output to a smartphone user. Later, the authors built a mobile monitoring device that works in real time [17]. Sensors that can detect soil qualities have been introduced in a variety of forms and applications. Admachuk et al. [18] integrated a pH meter and a flat electrode mounted on a shaft into the autonomous soil sampling system. Mirrell and Hummel [19] developed a device for real-time soil analysis based on the technology known as the ion selective field effect transistor (ISFET). The hydrogen potential is defined by the pH value, which is important for determining the acidity of the soil. The negative logarithm of the hydrogen ion concentration in a given soil is referred to as the pH value [20]. In view of the incidents that have occurred, it is abundantly clear that a warning system is needed to monitor leaks in underground pipelines. Consequently, a device can be installed to detect leaks and provide an early warning system to the user.

Although some work has been done to develop a monitoring system, few efforts have been made to demonstrate the applicability of a system that can detect leaks in underground pipelines and record the pH values in a database. The fundamental objective of this work is to create an early warning system for underground pipelines system that is driven by the Internet of Things (IoT). This prototype will be able to detect changes in the pH value that measure the acid soil that is found near the pipelines with mobile or web applications to provide a real-time monitoring system. This system also enables to examine the pH value of the soil by offline and online mode to determine its current condition. The following is how this paper is structured. Section 2 provides the research method including system design. Section 3 presents the results and evaluation of the proposed system. Finally, section 4 concludes the research findings and the outcome.

2. Research Method

Figure 1 illustrates the proposed framework, which includes a detection system, internet interconnectivity, a warning system using the Blynk mobile application, and the Thingspeak website platform as a monitoring system database.

To solve the problem, a method of detecting the pH of the soil has been developed to provide early warning when a certain threshold is reached, in this case the presence of acid soil. The sensor element, namely the SENO 161 pH probe, which has a comparable design, is significantly less expensive, and uses the same calibration procedure as Atlas Scientific's industrial pH probe. The pH sensor is connected to a microcontroller, called an Arduino UNO R3, which then processes the data and transmits them to a Wi-Fi module (NodeMCU ESP8266). The Blynk application used by the microcontroller to send leak detection signals to other devices. Internet of Things (IoT) technology is used for remote monitoring and automated management of recorded pH parameters for the underground pipelines.

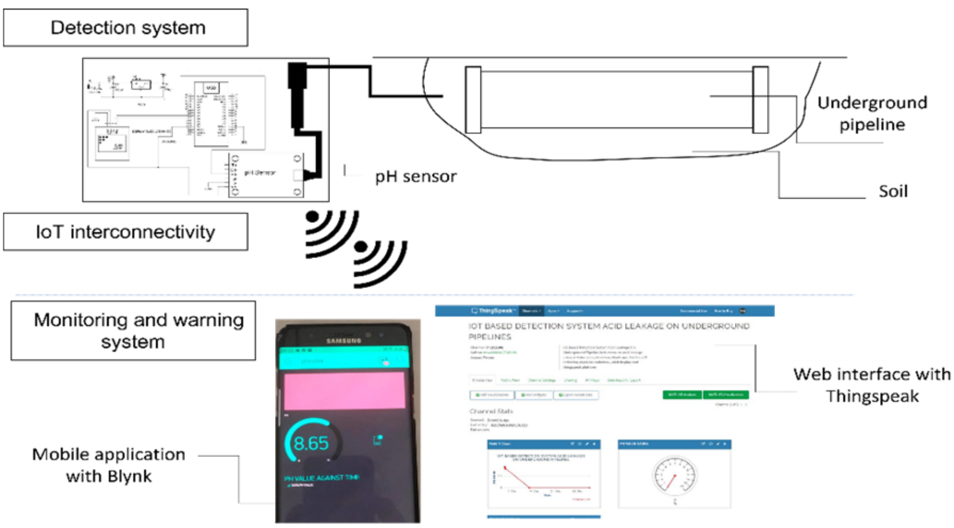

Figure 1. Overall system framework

The developed prototype is tested in a laboratory-sized environment as a final proof of concept. This system supports simultaneous offline and online mode of operation. Moreover, the notification system is equipped with three colours of LED indicators, each showing the offline, online and signal detection status. The pH sensor continues to read and save the value on the microcontroller even when it is operating in offline mode, which is the case when there is no internet connection. The current pH value is shown on the display so that the user can monitor it in applications where this is required. When the router switches to online mode, it establishes a permanent connection to the Internet. The Blynk application enables monitoring on mobile devices. When a certain threshold is reached, an accompanying graph and message are displayed without any intervention from the user. In this work, all pH data are uploaded to the Thingspeak website so that the user can monitor the pH value of the underground pipelines with a computer. This technique not only is more efficient, but also records the pH value in a database at the same time so that the data can be analysed at a later date.

3. Experimental Test Results

A total of three tests were conducted as part of this study. The following sub-topic explains the specifics of results that were discovered.

3.1. Monitoring of Alert Signals (Notifications)

In order to configure this experiment, the mobile application development platform called Blynk was included. This experiment was conducted in such a way that the user would be notified about leakage of underground pipelines. A number of different indicators, such as the display, gauge and graph status, can be organised, analysed and monitored on the device. An alarm can be triggered that plays a pop-up sound, vibrates the mobile phone and sends it to the user's phone when the hazards caused by the leaking acid on the underground pipeline exceed the threshold. The first warning level provided by Blynk takes the form of a pop-up warning message. The second warning level consists of the yellow light that is turned on when there is a leak in the system.

The notification appears in Figure 2 when the pH value drops below 6.5 and continues until the system is reset to its set point, which is greater than 6.7. This value is displayed until the system is reset to its original state. The user receives information about the previous warning system. The yellow LEDs will only light up when the pH value is below 4.5, indicating a sign that the pipeline is in a very dangerous state. This message also appears if the user does not react to it when it first appears. In the case that the pH is normally higher than the set point, the device will not send a notification due to this condition. The user receives a notification via the graph display whenever the pH value shifts from an acidic to a neutral state. When there is no longer any danger, the yellow LED automatically switches off due to this action.

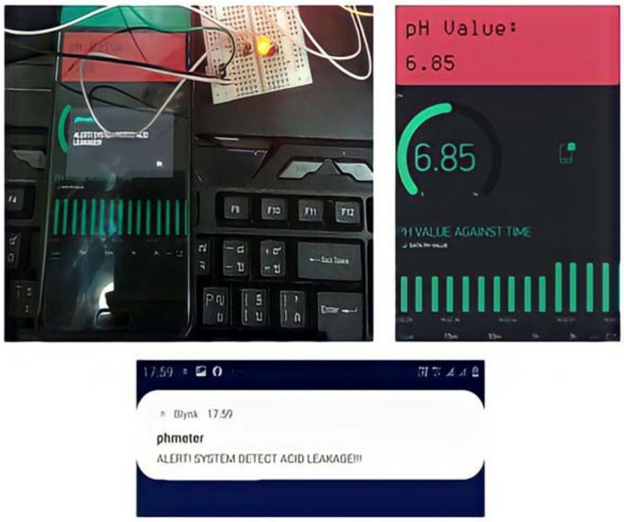

Figure 2. Blynk application for alert signal (notification)

3.2. pH Value Reaction to Precipitation in the Underground

The purpose of this experiment is to demonstrate how the natural environment might influence leaks in underground pipelines caused by precipitation. The purpose of this experiment is to establish whether the precipitation that falls around this underground pipeline is polluted. The fact that acid can harm the subsurface pipelines is critical for the user. Although it will take longer to leak due to corrosive rains, the pipelines will eventually degrade. The amount of precipitation collected as a sample should be measured as soon as possible after it has been collected.

The result can be seen in Figure 3, which was generated after the samples were collected and the pH values were instantly monitored on the Thingspeak website, that is, thingspeak.com. The ultimate value is determined when the pH value is stable. It is possible to draw the conclusion that the examined area is not polluted based on the data obtained, as the pH values are between 7 and 8. It may be distilled water or seawater, but either way, its pH value is neutral.

The acidification of the soil was mostly caused by the features of the soil, with just a few natural causes, like acidic precipitation, contributing to the process. The regional distribution pattern of soil pH, which was predominantly acidic, varied less throughout the duration of the study. The pH of the soil went from 5.70 to 5.50 on average, which indicates that the soil has become more acidic. The pH transition is a very slow process, and it frequently takes an extremely long time to change one unit. Soil pH is a comprehensive representation of many chemical properties of soil and is mainly regulated by influences on soil formation.

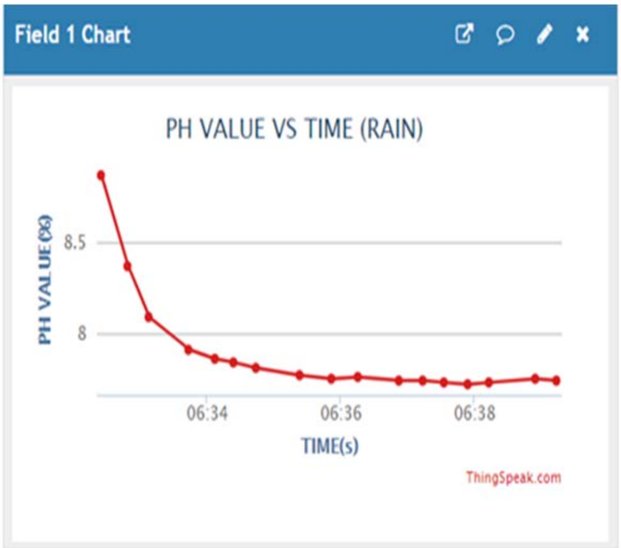

Figure 3. PH value for precipitation in the underground

3.3. Leaking Reaction Testing in the Underground for Real-time Monitoring

The testing of the leak reaction was separated into two conditions: slow and fast. This experiment demonstrates a gradual reaction established between the two distinct pH value ranges. This experiment is crucial for the underground pipelines since it will take longer for a leak to occur as the pipelines ages. The first experimental setup includes 250 milliliters of distilled water and two drops of acid solution. Once the pH has reached a stable value, it is recorded. The experiment was subsequently repeated using alkaline solutions and then the maximum pH value was measured and recorded.

Figure 4 shows a decrease proportional to the number of drops of distilled water added to the set point. To obtain accurate data, an average of ten data points were recorded at each point to achieve the best outcome. This experiment was replicated using an alkaline solution. The results have been recorded in the database, from which users can retrieve them for use in future studies.

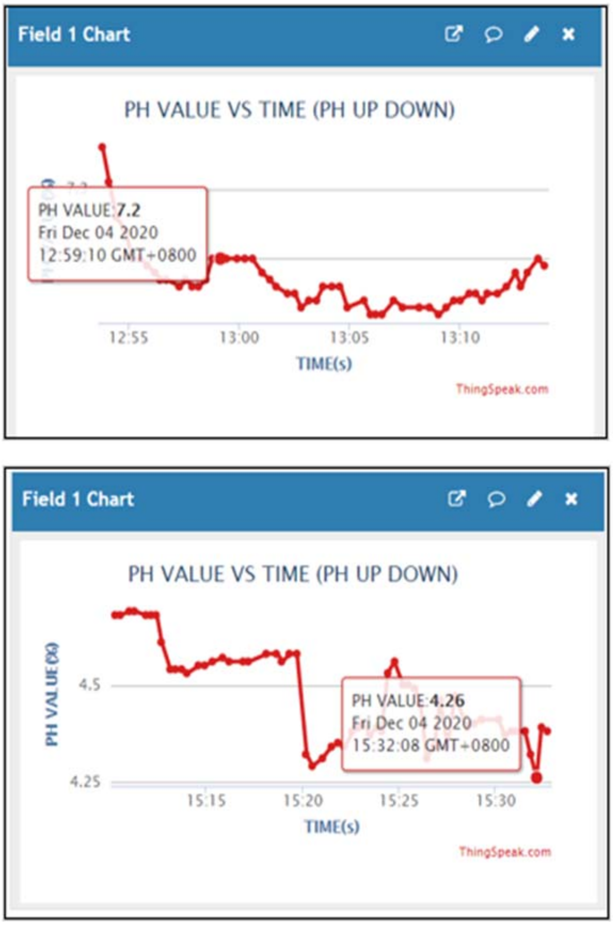

Figure 4. Slow condition for leaking reaction

This experiment demonstrates a rapid reaction between two pH value ranges. This experiment is particularly important for underground pipelines in the event of a sudden explosion or rupture, as it is dependent on the pressure and temperature connected to the process. When the pH value has stabilised, the pH value is monitored and the amount of time necessary is logged on the IoT platform. The initial setup consists of a pH-neutral buffer solution with a pH of 6.86 and pH-acidic buffer solution with a pH of 4.01. The experiment was repeated with the same offset, but an alkaline solution with a pH of 9.01 was used this time. Figure 5 shows fast condition experiments in which the neutral pH value is derived from buffering acidic or alkaline solutions. It is essential to allow the neutral pH value to stabilise before recording the result. The results further highlight the value of the acid buffer solution when the pH remains constant. This experiment was repeated, however this time an alkaline buffer solution was utilised.

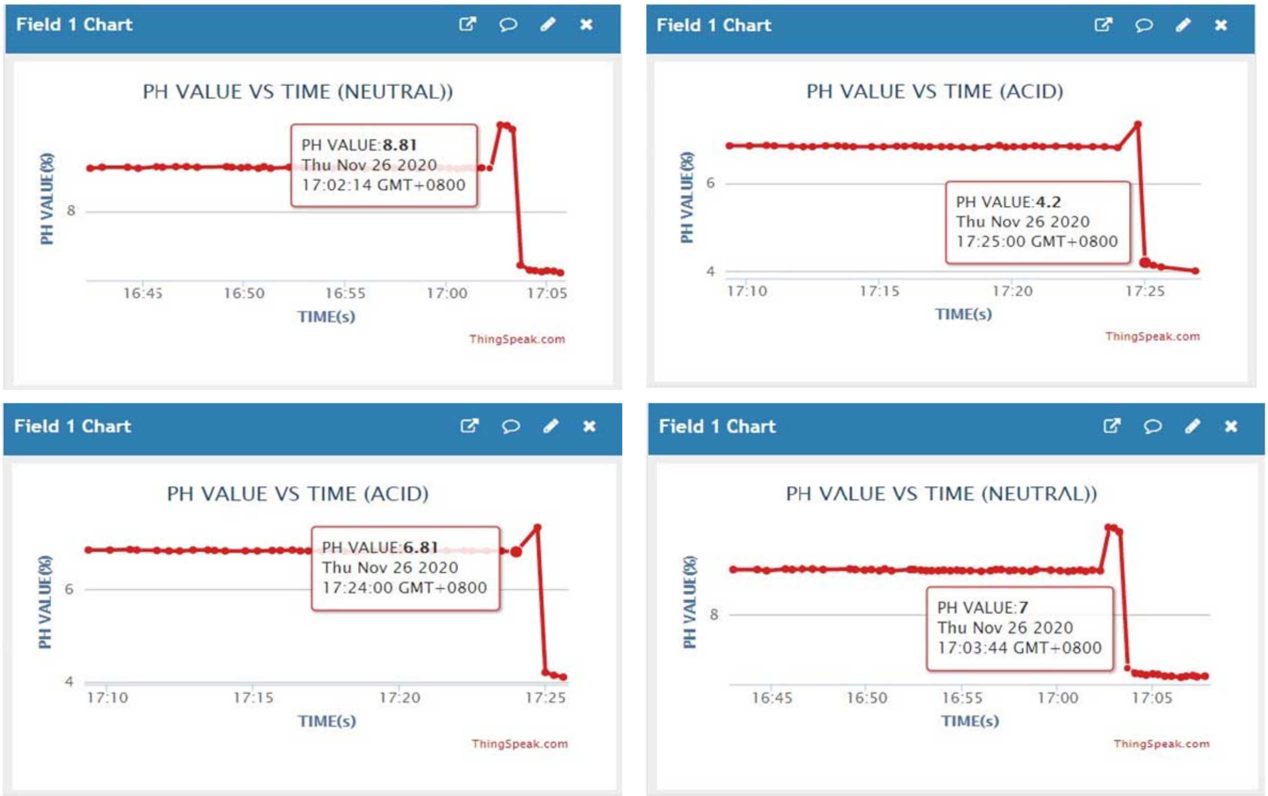

Figure 3. Fast condition for leaking reaction

4. Conclusion

This work aims to detect acid leaks and develop an early warning system for the safety of underground pipelines leaking using the Internet of Things (IoT). The system can be applied to the collection of data, as well as to test and develop a real-time monitoring system utilising of mobile or web applications. This research has led to the development of a prototype that is safer for the user and has the potential to reduce industrial incidents. It used a straightforward circuit layout, and its components are suitable for installation near underground pipelines. The novelty of the developed system is that it can help detect leaks early and safely, as well as reduce production waste. This technique also has a quick response time because it enables real-time and database analysis, allowing for continuous pH monitoring. Therefore, the project is advantageous to industry because it is cost-effective, dependable, and automated. For future recommendations, a pH sensor of an industrial type can be used to improve the accuracy and durability of real-world field tests.

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