

SMART PIPELINE MONITORING: USE OF PIGGING SYSTEM.



BY

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CERTIFICATION

We undersigned that this work was carried out by the above named student of the Department of Mechatronic Engineering, Faculty of Engineering, University of Benin, Benin City and in partial fulfillment of the requirement for the award of Bachelor of Engineering.

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DEDICATION

We have unanimously agreed that this project work should be dedicated to God Almighty only.

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First and foremost, we would like to express our sincere gratitude to God Almighty, for the successful completion of this research project.

We equally wish to appreciate our supervisor, **Prof. G.O Ariavie**, for his excellent guidance and constructive feedback throughout this study. Without his encouragement, we would not have finished this research project write-up, also we would love to appreciate our profound lecturers **Engr. Linus G.S and Engr. Olagbegi P.O.**

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ABSTRACT

The integrity and efficient operation of pipelines are critical for the safe transportation of oil, gas, and other fluids. Traditional pipeline monitoring methods often fall short in providing comprehensive and real-time data essential for proactive maintenance and risk management. This project explores the integration of smart technologies in pipeline pigging systems to enhance pipeline monitoring and management. Smart pigging involves the use of intelligent inspection tools that traverse the pipeline, collecting high-resolution data on internal conditions, including corrosion, cracks, and other anomalies.

By leveraging advanced sensors, data analytics, and real-time communication technologies, smart pigging systems offer unprecedented insights into pipeline health, enabling predictive maintenance and timely interventions. The implementation of these systems can significantly reduce the risk of leaks and ruptures, thereby ensuring environmental safety and operational efficiency. This study reviews the latest advancements in smart pigging technology, examines case studies of successful implementations, and discusses the challenges and future directions in the field of smart pipeline monitoring.

In summary, the implementation of smart pipeline monitoring using pigging systems has delivered substantial benefits in terms of anomaly detection, maintenance optimization, operational efficiency, safety, and environmental protection. The device

was fully tested and proven to perform optimally by taking temperature readings of the pipeline and converted it to pressure through the use of a programmable microcontroller. Pipeline leaks and failures can easily be detected by this prototype model when there is an increase and decrease in the flow rate of the fluid.

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CHAPTER ONE

INTRODUCTION

1.1 Background study

The concept of monitoring pipeline integrity has been around for decades, but it gained importance in the 1980s after a series of pipeline failures. In the wake of these incidents, regulatory bodies around the world began to focus on ways to improve the safety of pipelines. Since then, there have been significant advances in the technology used for pipeline integrity monitoring. In the early days of pipeline integrity monitoring, the main focus was on using in-line inspection tools to detect and characterize corrosion. These tools, sometimes called "smart pigs," were pulled through pipelines using the flow of the material inside them. They used a variety of technologies, such as magnetic flux leakage and ultrasonic testing, to detect corrosion. Over time, other technologies were developed, such as distributed acoustic sensing, which uses fiber optic cables to detect changes in the pipeline. In recent years, the focus has shifted to using data analytics and machine learning to detect patterns in the data collected from the various sensors. This allows for the early detection of potential failures, as well as the prediction of when a failure might occur. The data is also used to optimize the maintenance of pipelines, which helps to prevent failures and increase the lifespan of the pipelines. Another important

aspect of pipeline integrity monitoring is the development of risk-based inspection programs. These programs consider factors such as the age of the pipeline, the type of material it's made from, and the environment it's in, to prioritize inspections and maintenance. This helps to ensure that the most critical pipelines are inspected and maintained regularly. The use of risk-based inspection programs has become a key part of pipeline integrity management systems. In addition, data sharing is another field of pipeline integrity monitoring. In recent years, there has been a push for the sharing of data between pipeline operators, regulators, and other stakeholders. This is done through the use of centralized databases and open-source platforms. This allows for the sharing of information, which leads to better insights and improved pipeline integrity management. Awesome! There's one more important thing I should mention, which is the role of human expertise. Even with the best technology and data, it's still important to have experienced inspectors and engineers who can make decisions based on their knowledge and experience. Humans are still the most important part of the pipeline integrity management process.

1.2 Statement of the problem

There are a few problems that led to the development of the concept of pipeline integrity monitoring. One of the most significant was a series of pipeline failures in the 1970s and 1980s. These failures often resulted in the release of hazardous materials, leading to significant environmental and economic damage. In

addition, there were also issues with the quality of construction and maintenance of pipelines. There was a major pipeline explosion in Nigeria in 1998 that was known as the Jesse pipeline fire. This incident involved a gas pipeline that ran through the town of Jesse in Delta State, Nigeria. The explosion occurred when a team of welders accidentally ignited gas that had been released from a leak in the pipeline. The resulting fire spread to the surrounding area, causing significant damage and over 1,000 deaths. This incident highlighted the need for better safety procedures and the importance of community engagement in pipeline projects. There's another important incident that took place in Nigeria in 2012, which is known as the Brass pipeline explosion. In this incident, a pipeline transporting oil to a processing facility in Brass, Bayelsa State, exploded after being struck by lightning. The resulting fire caused 10 deaths and forced hundreds of people to evacuate from the surrounding area. This incident also highlighted the need for improved safety procedures and risk management. There are a few common themes across these incidents, such as the need for better inspection and maintenance practices, the importance of safety training for workers, and the need for improved community engagement. In addition, these incidents have also highlighted the need for better emergency response procedures and coordination between government agencies and local communities.

1.3 Aims & Objectives

The aims of this project is streamlined to five key areas which include:

- i) Minimizing the risk of pipeline failures and their associated costs
- ii) Enhancing public safety by protecting people and property from pipeline incidents
- iii) Maintaining a high level of operational reliability
- iv) Supporting the safe and efficient operation of the pipeline
- v) Maintaining public confidence in the safety of pipelines.

Minimizing the risk of pipeline failures and their associated costs: Pipeline failures can be very costly, both in terms of direct costs such as repairs and cleanup, and indirect costs such as reputational damage and loss of public confidence. By proactively identifying and addressing potential issues, pipeline integrity monitoring can help to reduce the risk of failures and their associated costs.

Enhancing public safety by protecting people and property from pipeline incidents: One of the primary goals of pipeline integrity monitoring is to protect people and property from the dangers of pipeline incidents.

Maintaining a high level of operational reliability: Operational reliability is essential for the safe and efficient operation of a pipeline. By identifying potential issues early and taking action to address them, pipeline integrity monitoring can help to ensure that a pipeline remains reliable and able to operate as intended. This is important for both safety and economic reasons.

Supporting the safe and efficient operation of the pipeline: In addition to reducing the risk of failures, pipeline integrity monitoring can also help to ensure that a pipeline operates safely and efficiently.

Maintaining public confidence in the safety of pipelines: One of the key goals of pipeline integrity monitoring is to maintain public confidence in the safety of pipelines. By proactively addressing potential issues and communicating transparently about the safety of the pipeline, pipeline operators can help to ensure that the public has confidence in the safety of the pipeline.

All of these aims and objectives are interconnected and work together to promote the overall safety and reliability of pipelines.

1.4 Scope of study

Pipeline integrity monitoring is a multi-disciplinary area of study, and as such the project applied knowledge from different fields/expertise. These included engineering, data science, risk management, and safety. Engineers use their knowledge of materials and structures to design pipelines and to identify potential weaknesses. Data scientists use their skills to analyze data from the pipeline and to develop predictive models. Risk managers use their knowledge to assess the risks associated with pipeline operations and to develop risk mitigation strategies. Safety experts play a vital role in ensuring that the pipeline operates safely and in

compliance with regulations. All of these areas work together to ensure that pipeline integrity monitoring is effective.

1.5 Relevance of study

The relevance of pipeline integrity monitoring is linked to the need for the safety and reliability of pipelines. Without pipeline integrity monitoring, there would be a greater risk of pipeline failures, which could lead to serious consequences, such as loss of life, environmental damage, and economic losses. By reducing the risk of failures, pipeline integrity monitoring helps to protect people, the environment, and the economy. It also helps to ensure that pipelines operate efficiently and without disruption. All of this contributes to the smooth functioning of our society. In the past, there have been a number of pipeline failures that have had serious consequences. For example, in 2010, a pipeline ruptured in San Bruno, California, causing an explosion that killed eight people and destroyed dozens of homes. In 2013, a pipeline in Mayflower, Arkansas ruptured, spilling over 200,000 gallons of oil and contaminating a local waterway. In 2015, a pipeline ruptured in the Yellowstone River, releasing over 50,000 gallons of crude oil into the river. These are just a few examples of the serious impacts that pipeline failures can have, hence the relevance of this project.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Sensor

In simple terms, sensors are devices that detect and respond to a specific type of input, like light, heat, sound, pressure, or motion. There are many different types of sensors, each designed to detect and respond to a specific input. For example, a light sensor detects and responds to light, while a pressure sensor detects and responds to changes in pressure. Sensors are used in many different applications, from consumer electronics to industrial automation.

2.1.1 Types of Sensors in Pipeline Monitoring

The most common sensors deployed in pipeline monitoring system include:

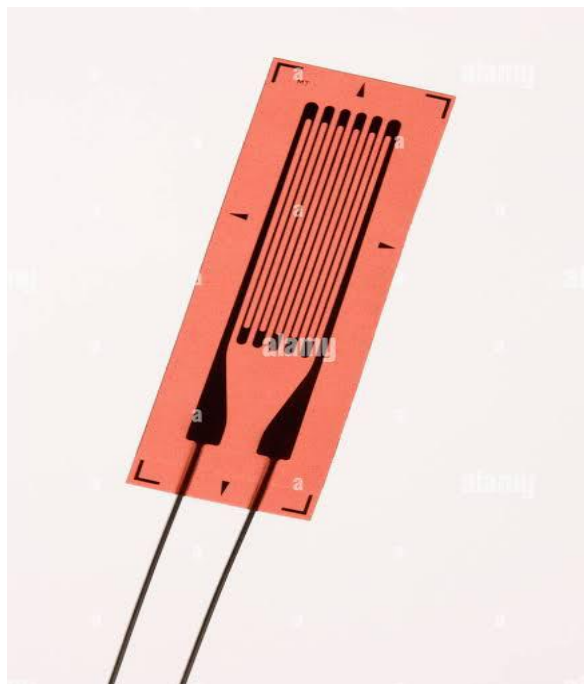
- i) Strain Gauge Sensor
- ii) Acoustic Emission Sensor
- iii) Fibre Optics Sensor
- iv) Ultrasonic Sensor

Strain Gauge Sensors:

This is a type of sensor that measures strain or deformation in a material. They work by using a resistive element that changes its resistance when it is stretched or

compressed. The change in resistance is proportional to the amount of strain experienced by the material. Strain gauge sensors are often used in pipelines to detect the amount of strain or deformation in the pipeline, which can be an indicator of potential problems like leaks or cracks.

There are various types of strain gauge sensors that are used in pipeline monitoring, depending on the specific application. The most common type is the foil strain gauge, which is a thin, flexible sensor that can be attached directly to the surface of the pipeline. There are also other types, such as semiconductor strain gauges, which are made of semiconductor materials, and fiber optic strain gauges, which use optical fibers to detect strain. Each type of strain gauge has its own advantages and disadvantages, but they all serve the same purpose of measuring strain in the pipeline.



Acoustic Emission Sensors:

Acoustic emission sensors or AE sensors, are a type of sensor that detects the presence of acoustic emissions, or high-frequency sound waves, in the pipeline. These emissions are caused by a variety of factors, including corrosion, leaks, and other types of damage. The sensor is able to detect these emissions and convert them into an electrical signal that can be analyzed. This analysis can yield precise information about the severity of damage to the pipeline.



Fiber Optics Sensors:

Fiber optic sensors are another type of sensor that is used in pipeline monitoring. They work by sending light pulses through the pipeline and measuring the amount of light that is reflected back. Any changes in the fiber optic cable, such as damage or cracks, will cause a change in the amount of light that is reflected back. The basic idea of fiber optic sensors is that they use a fiber optic cable, which a thin, flexible cable is made of glass or plastic. Light is sent through the fiber optic cable and is reflected back, which is measured by a device called an interrogator. Any changes in the fiber optic cable will cause a change in the amount of light that is reflected back.

This change can be detected and analyzed to determine what kind of damage has occurred to the pipeline. However, they are usually very expensive to install and maintain.



Ultrasonic Sensors:

Ultrasonic sensors are another type of sensor that is used in pipeline monitoring. They work by sending sound waves through the pipeline and measuring the time it takes for the sound waves to be reflected back. Any changes in the amount of time it takes for the sound waves to be reflected back can indicate a problem with the pipeline, such as a crack or leak. An important consideration with ultrasonic sensors is the size of the sound waves that are used. The smaller the sound waves, the more accurate the sensor will be. However, this also means that the sensor will be more susceptible to background noise and vibrations. Another consideration is the frequency of the sound waves. Different frequencies will be better at detecting different types of damage, so it is important to choose the right frequency for the specific application.



2.2 Evolution of Pipeline Monitoring

As pipeline networks grew after World War II and governmental agencies developed to ensure public and environmental safety surrounding hazardous fluid transport, pipeline leak detection and testing became a field of its own. Until acoustic and electric current pigs were developed, the dominant method of leak detection was hydrostatic pressure testing whereby a line must be taken out of service for testing. Although still in use today, this process is time consuming and inefficient, particularly in light of the extensive mileage in play currently. In the late 1960s and throughout the 1970s, acoustic pigs began gaining traction as a reliable in-line leak detection technique (**Riemsdijk and Bosselaar, 1967; Fluornoy and Schroeder, 1978**).

2.2.1 In Real-time Oil and Gas Control

One of the biggest advances in this field is the development of supervisory control and data acquisition (SCADA) systems. These systems allow for real-time monitoring and control of pipelines, as well as the collection and analysis of data from sensors. This data can then be used to optimize the operation of the pipeline and to detect any potential problems. Another important advancement is the use of cloud computing and big data analytics, which allow for the processing of large amounts of data from sensors in a timely and efficient manner. (**Khan, N., Yaqoob,**

I., Hashem, I. A. T., Inayat, Z., Ali, M., Kamaleldin, W. M., ... & Gani, A. (2014). Big data: survey, technologies, opportunities, and challenges. *The Scientific World Journal*, 2014. doi:10.1155/2014/712826)

SCADA systems are made up of several components. There's the hardware component, which includes sensors and other devices that are installed along the pipeline. Then there's the software component, which includes the software that is used to collect and analyze the data from the sensors. And finally, there's the communication component, which includes the networks and protocols that are used to transmit data between the sensors and the central control system. A major benefit of SCADA systems in pipeline monitoring is that they allow for real-time monitoring and control, which means that any problems can be detected and addressed quickly. They also provide a centralized view of the pipeline, which makes it easier to identify and solve problems. And finally, they can be used to optimize the operation of the pipeline, which can lead to cost savings and increased efficiency. A major challenge to SCADA is the cost of implementing and maintaining these systems. They can also be vulnerable to cyberattacks, which is a major concern for critical infrastructure like pipelines. Despite these challenges, SCADA systems are considered to be essential for modern pipeline monitoring and control. (Clarke, G., & Reynders, D. (2004). *Practical modern SCADA protocols: DNP3, 60870.5 and related systems*. Newnes.)

2.2.2 Pressure Point Analysis

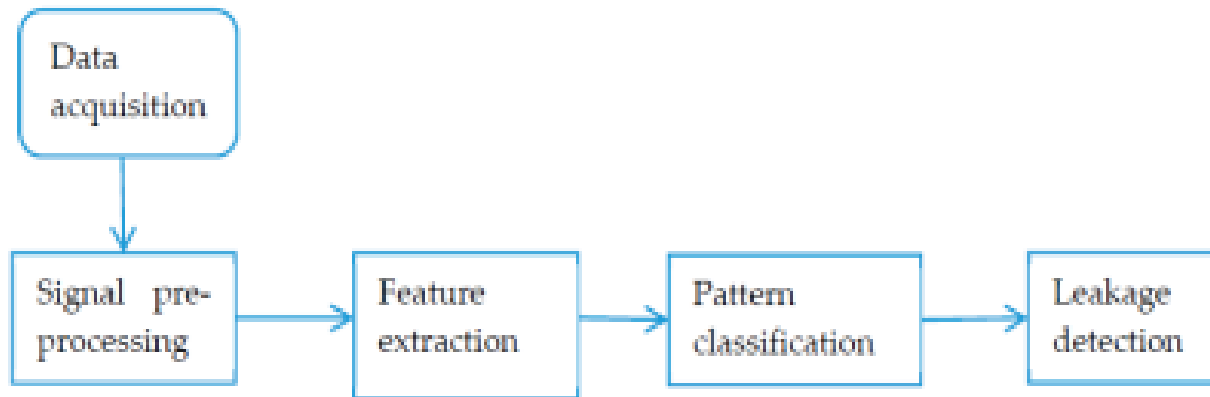
Pressure point analysis is a method adopted based on the pressure values at different points of pipeline. Based on this a pressure profile is created¹¹. Any leak, if it occurs, changes the pressure profile. Threshold values are set at different points and if the monitored pressure drop exceeds the set threshold values then it triggers an alarm indicating leak¹².

2.2.3 Statistical Systems

Statistical methods are used to examine the pressure, temperature calculation of a pipeline. It is particularly suitable for difficult pipe line structure since it can monitor any change occurring in the flow or pressure instruments and deduct the result by using hypothesis method¹⁵. Generally two hypotheses are taken one is for no leak condition (Hypothesis H0) and the other for leak condition (Hypothesis H1). Depending on the measured values, statistical variable can either be H0 or H1. If it is a part of leak an alarm is triggered¹⁶.

2.2.4 Signal Processing

Digital signal processing (DSP) is yet another scheme employed for leak detection. In this method, a known alteration in flow is introduced in the system and the system response is studied. Based on this, DSP is carried out to detect the deviations from the standard system response¹⁷.



2.3 PIGGING SYSTEM TECHNOLOGY

Pigging is a technique that uses a tool called a "pig" to clean, inspect, and maintain the inside of a pipeline. One of the main benefits of combining these two technologies is that it allows for more accurate and reliable monitoring of the pipeline. In particular, the use of pigs in conjunction with smart monitoring systems has been shown to improve the detection of small leaks, which can be very difficult to detect using traditional methods. This has important implications for safety and efficiency in pipeline operations. **(Williamson, T. D. (n.d.). *Guide to pigging.*)**

Another benefit of combining these technologies is that it allows for more efficient and effective cleaning and maintenance of pipelines. Pigs can be used to remove debris, inspect the condition of pipelines as pigs can be equipped with a variety of sensors such as cameras, to provide detailed information about the condition of the pipeline. Furthermore, combining these technologies it permits for more energy saving, time saving and accurate monitoring of the flow rate and pressure in the

pipeline. This information is essential for ensuring the safe and efficient operation of the pipeline, as well as for detecting any potential problems. For instance, by monitoring changes in flow rate and pressure over a period of time, it is possible to detect blockages or leaks before they become primary issues. Moreover, this data can be utilized in optimizing the operation of the pipeline, resulting in cost savings and improved efficiency. (Sun, Z., Wang, P., Vuran, M. C., Al-Rodhaan, M. A., Al-Dhelaan, A. M., & Akyildiz, I. F. (2011). MISE-PIPE: Magnetic induction-based wireless sensor networks for underground pipeline monitoring. *Ad Hoc Networks Journal*.)

2.3.1 Components of a Pigging System

The components of this application is made up of the pig itself, the sensors and other devices that are accessories to the pig, and the data processing and analysis system. The pig is a cylindrical device that is designed to travel throughout the pipeline, while carrying the sensors and other devices that are used to gather data about the condition of the pipeline. These sensors can include cameras, ultrasonic transducers, and other devices that measure the flow rate, pressure, and temperature level of the pipeline.

Once the data has been gathered, it is sent to the data processing and analysis system. The data processing and analysis system is responsible for analyzing the data

collected by the sensors and devices on the pig. This can include a variety of tasks, such as comparing the data to historical data, looking for anomalies or trends, and using advanced algorithms to detect any forthcoming issues. This information is then used to generate reports and alerts, which can be used by operators to take action, such as repairing a leak or cleaning a section of the pipeline.

A most crucial aspect of the data processing and analysis system is the algorithms that are used to analyze the data. These algorithms are often centered on machine learning or artificial intelligence, which enables the system to learn from the data and improve its accuracy over time. In addition, many systems use predictive analytics, which can be used to predict potential problems or trends in the pipeline. This encourages operators to take proactive measures to prevent issues from occurring, rather than waiting until they become major problems. Key components of a pigging system includes:

- i) Pipeline Pig
- ii) Pig Detection System (or Pig Detectors)
- iii) Pigging Control Systems and Software (For automatic pigging solutions) and HMI screens
- iv) Receive and Launch Station
- v) Pig Housing
- vi) Various Valves, Supports and Fittings

vii) Pipework plus more

One of the most common algorithms used in this type of system is called **supervised learning**.

This algorithm uses a set of labeled data (e.g., data that is labeled as normal or abnormal) to train a model that can then be used to predict whether new data is normal or abnormal. For example, the system could be trained using data from previous pipeline inspections that were labeled as normal or abnormal. Once the model is trained, it can be used to predict whether new data from the pipeline is normal or abnormal.

2.4 Benefits of Pigging System

1. Predictive Maintenance: One of the benefits of condition monitoring using the IoT and pigging systems is the ability to perform predictive maintenance. Predictive maintenance is a process of using data to predict when equipment will need maintenance or repairs, rather than waiting for something to break down. This is particularly important for pipelines, as unexpected shutdowns can be very costly and disruptive. By using data to predict when maintenance is needed, it is possible to schedule it at a time that is convenient and minimize downtime.

2. Anomaly Detection: Anomaly detection is a means of using data to identify any unusual or unforeseen patterns in the pipeline. For instance, an anomaly could be a

sudden drop in pressure or an unexpected change in flow rate. By identifying these anomalies, it is possible to investigate them further and take action to prevent any potential problems. In some cases, the anomalies may be false alarms, but it is important to investigate them to be sure. Anomaly detection is a powerful tool for pipeline monitoring, as it can help to identify potential problems before they cause serious issues.

3. Asset Health: Asset health monitoring is the process of using data to monitor or track the condition of individual assets within the pipeline system. For example, an asset could be a valve or a pump. By tracking the condition of these individual assets, it is possible to identify any potential problems and take action to prevent them. This is particularly useful for assets that are critical to the operation of the pipeline, as any issues with them could cause major disruptions. Asset health monitoring is an important part of a comprehensive pipeline monitoring system.

4. Big Data Utilization in Pigging System.

Big data refers to the large amounts of data that can be collected from sensors, machines, and other sources. In the context of pipeline monitoring, big data can be used to analyze trends and patterns over time, and to make predictions about future events. For example, it may be possible to use big data to predict when a certain part of the pipeline is likely to fail, or when demand for the pipeline's output is likely to

increase. This information can be used to plan for future events and to make decisions about the pipeline's safety. When it comes to pigging systems, big data can be used to optimize the cleaning and inspection process. For example, the data can be used to determine the best speed and frequency for the pigging process, based on factors such as the type of pipeline, the materials it carries, and the environmental conditions.

This information can help to ensure that the pigging process is as efficient and effective as possible. Additionally, big data can be used to monitor the condition of the pigging system itself, and to predict when maintenance or repairs may be needed.

System can learn from the data collected by the sensors and use this information to improve the accuracy of future measurements. This can help to ensure that any anomalies or problems in the pipeline are detected as early as possible.

Additionally, machine learning can be used to detect anomalies in the data itself, which could indicate a problem with the sensors or the pigging system itself.

CHAPTER THREE

DESIGN AND ANALYSIS

3.1 BLOCK DIAGRAM

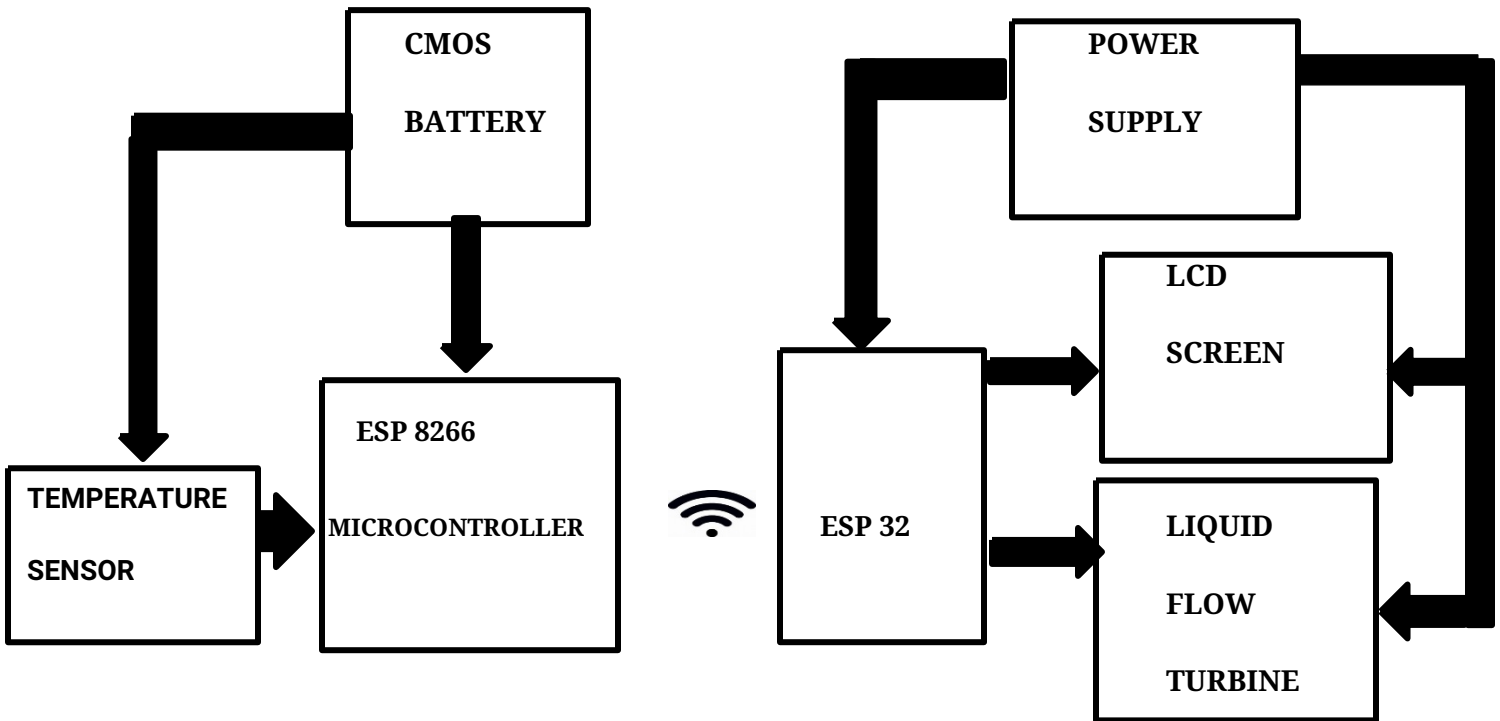


FIGURE 3.1: BLOCK DIAGRAM OF THE SYSTEM

3.1.1 THE MICRO-CONTROLLER UNIT (ESP 8266 AND ESP 32)

3.1.1A THE MICRO-CONTROLLER ESP 8266

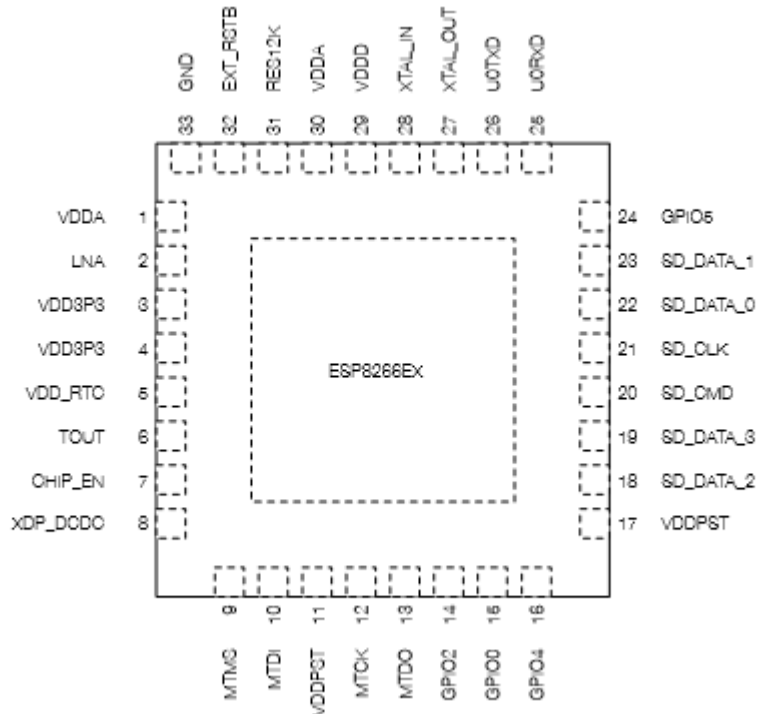


FIGURE 3.2A: THE ESP 8266 MICROCONTROLLER WITH PIN POSITIONS

The ESP 8266 is designed to meet users demand in terms of compact design, efficient power usage and an efficient performance in the Internet of Things (IOT).

Chosen because of its ability to be interfaced with external sensors and its Wi-Fi networking capabilities, the ESP 8266 compact design integrates the following

components thereby reducing external circuitries and minimizing PCB size. Power Amplifier, RF balun, filters, low noise receiver amplifiers and power management modules,

Besides its inbuilt functionalities, this microcontroller also integrates an enhanced version of Tensilica's L106 diamond series 32-bit processor and on-chip SRAM.

This microcontroller integrates memory controller in addition to the SROM and ROM.

3.1.1.1A WI-FI KEY FEATURES OF THE ESP 8266

- i)** 802.11 n support (2.4Ghz), up to 72.2 Mbps
- ii)** Defragmentation
- iii)** 2 x virtual Wi-Fi interface
- iv)** Automatic beacon monitoring
- v)** 802.11 b/g/h support

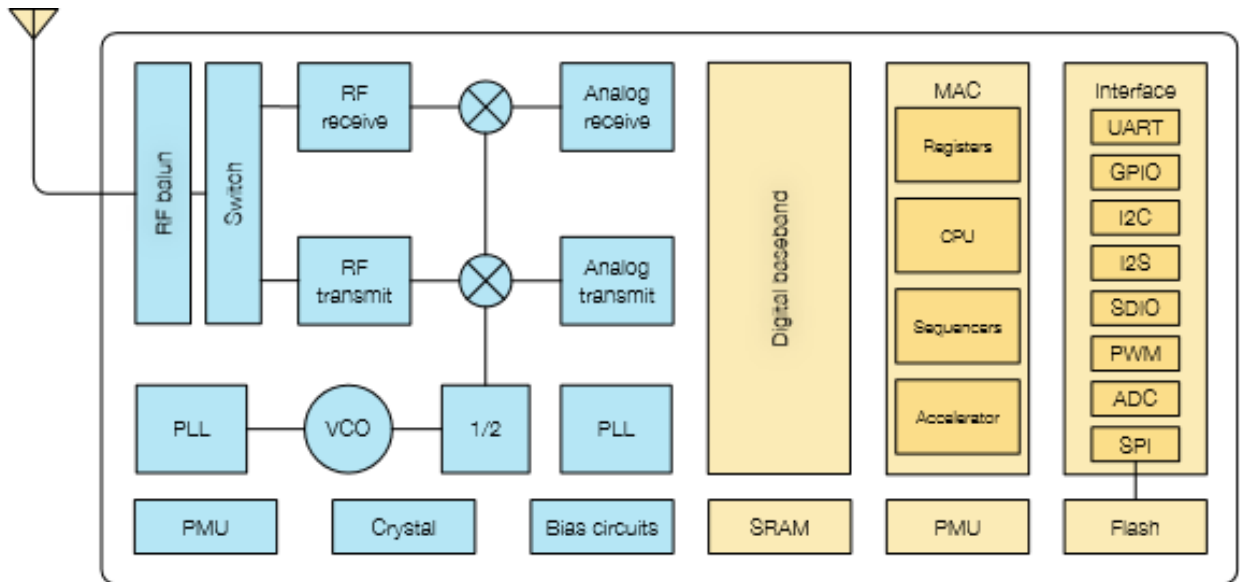


FIGURE 3.2B: FUNCTIONAL BLOCK DIAGRAM OF ESP8266

3.1.1B THE MICRO-CONTROLLER ESP 32

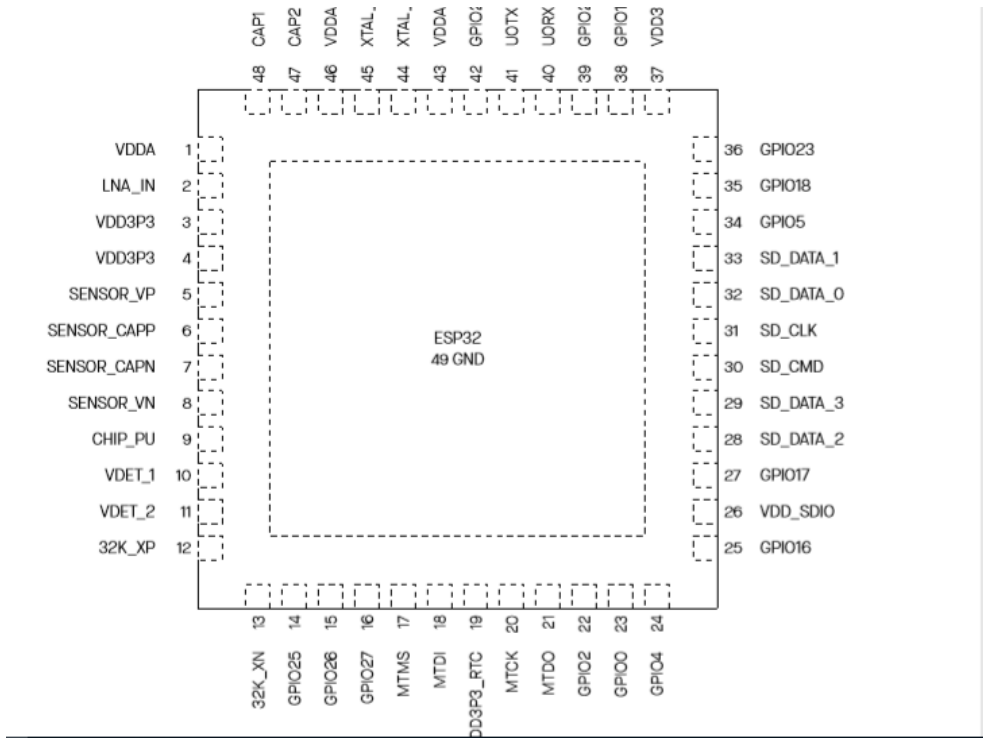


FIGURE 3.3A: ESP 32 PIN CONNECTIONS

FIGURE 3.3B: ESP 32 FUNCTIONAL BLOCK DIAGRAM

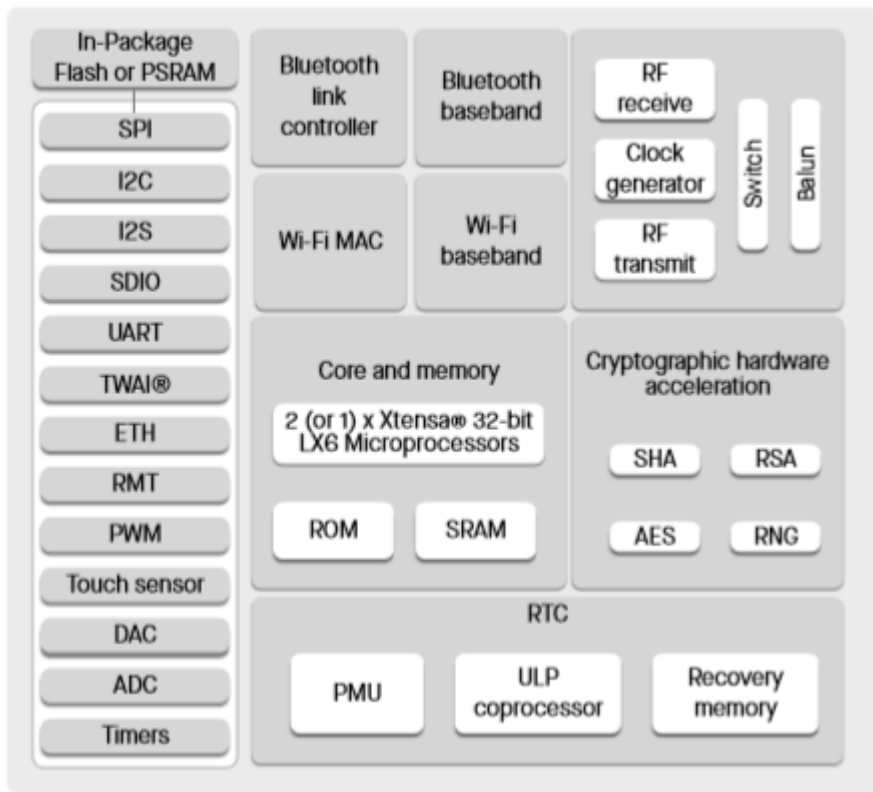


FIGURE 3.3B: ESP 32 FUNCTIONAL BLOCK DIAGRAM

Chosen because of its wide range of applications and effective RF performance, the ESP 32 is designed to achieve reliability, robustness, and versatility in operations.

This ESP32 Microcontroller is a single 2.4Ghz Wi-Fi Bluetooth combo chip designed with the TSMC low power 40nm technology which enables it achieve best power and RF performance. It contains one or two low power 32-bit LX6 microprocessors with a single or dual CPU interface.

The ESP 32 supports multiple external QSPI flash and external RAM chips. This flash and SRAM chips can be accessed through high speed caches.

3.1.1.1B WI-FI FEATURES (ESP 32)

- i) 802.11 b/g/n
- ii) 802.11n (2.4Ghz), up to 150Mbps
- iii) Defragmentation
- iv) Immediate Block ACK
- v) Antenna Diversity

3.1.1.2B BLUETOOTH FEATURES (ESP 32)

- i) Enhanced Power Control
- ii) Bluetooth Piconet and Scatternet
- iii) Adaptive Frequency Hopping
- iv) +9 dBm transmitting power
- v) High speed UART Hcl, up to 4 Mbps
- vi) CVSD and SBC for audio codec.

3.1.2 POWER SUPPLY UNIT

This unit consists of two power source. The first comes from a CMOS battery and is used to power the system while the other comes from a Lithium Ion battery.

3.1.2A THE CMOS BATTERY

CMOS stands for Complementary Metal Oxide Semiconductor and is usually powered by a coin sized CR-2032 cell battery, referred to as the CMOS battery. Reduction of power makes a device more reliable. The need for devices that consume minimal amount of power was one of driving force for the creation of the CMOS battery. This battery powers the ESP 8266 microcontroller in the pigging system.

3.1.2B THE LITHIUM ION BATTERY

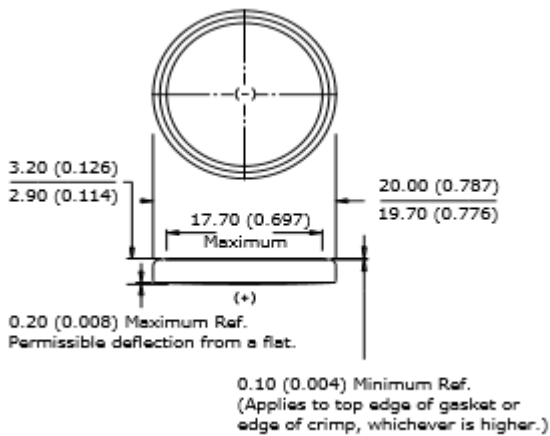


FIGURE 3.5A INDUSTRIAL STANDARD DIMENSIONS OF THE LITHIUM BATTERY

Lithium Ion batteries are secondary batteries that power the ESP 32 microcontroller in the system. The battery consists of an anode of Lithium, dissolved as ions into a carbon. The cathode material is made from Lithium liberating compounds.

For the Lithium Ion batteries, during the charge and discharge stages, lithium ions are removed from the interstitial space between atomic layers within the active material of the battery.

The operation of Lithium ion batteries is based on the intercalation mechanism. This mechanism entails the insertion of lithium ions into the crystalline lattice of the host electrode without changing its crystal structure.

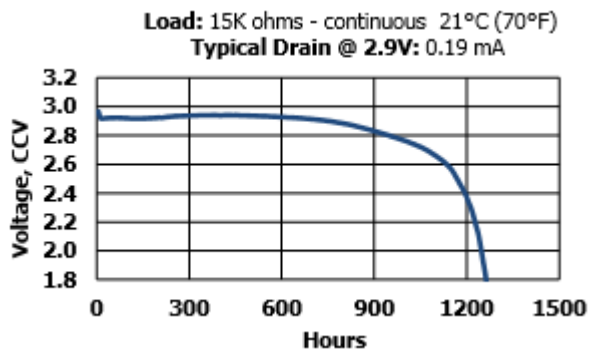
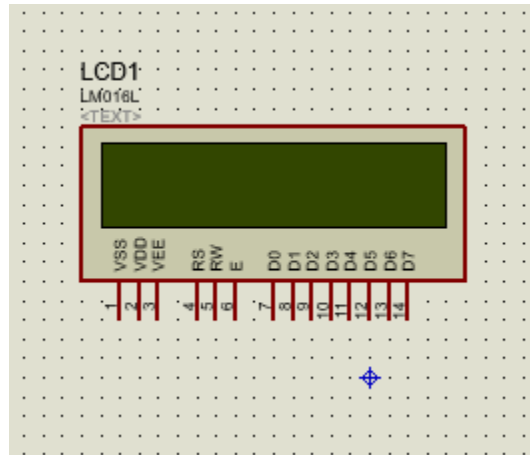


FIGURE 3.5B: CONTINUOUS DISCHARGE CHARACTERISTICS OF THE BATTERY

3.1.3 DISPLAY UNIT (LM1602)



The display unit consists of an LCD screen. This LCD screen has a 16 by 2 screen resolution with 14 pin positions. It was chosen because of its effectiveness in displaying the status of the system.

3.1.4 TEMPERATURE SENSING UNIT

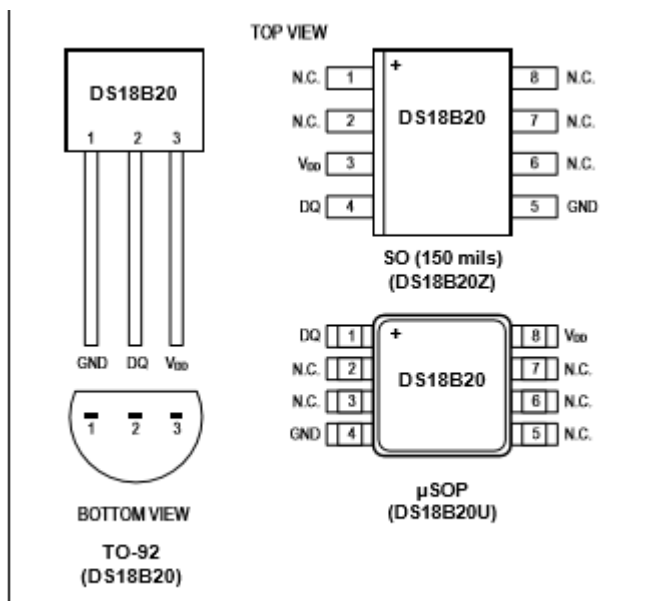


FIGURE 3.6: THE DS18B20 AND ITS PIN POSITIONS

This unit consists of the temperature sensor connected to the ESP 8266 microcontroller. It was chosen because of its many advantageous characteristics, one being that it gives a precise and accurate temperature reading.

The DS18B20 is a digital thermometer that provides 9 bit to 12 bit celcius temperature measurements. It communicates over a one wire bus that requires one data line for communication with a microprocessor.

3.1.5 LIQUID FLOW TURBINE UNIT

This consists of the rotor blade attached to a rod. It is able to spin at an angle, through the use of bearings.

We can calculate the flow rate through a turbine using the formula:

$$Q = A * V$$

Where Q is the flow rate in Cm/s,

A is the cross-sectional area of the turbine represented in M²,

V is the velocity of the fluid in m/s. 3

As turbine is in operation, it reduces the flow rate.

Therefore,

From Bernoulli's equation,

$$g*hl = v^2 / 2 + g*ht$$

hl is the water level and hk is the head loss produced by the turbine.

We also know;

$$P = p*Q*g*ht$$

$$ht = P/(p*A*v*g)$$

This yields,

$$g*hl = v^2/2 + P/(p*A*v)$$

This can be written as:

$$0.5*p*A*v^3 - p*A*hl*g*v + P = 0$$

This formula can also be used to calculate for flowrate and iterate the water level hl.

3.2 DESIGN CONSIDERATIONS

The following considerations and assumptions were made when designing the system:

- ✓ Microcontrollers with Wi-Fi modules were considered over other microcontrollers because of the need for network communication in building the system. As a result of this, the ESP 8266 and ESP 32 were chosen.
- ✓ In the design of the system, a CMOS battery and a Lithium battery were used to supply the entire system with power.
- ✓ In choosing the pressure sensor, we considered the capacity of different sensors to allow for more specialized predictive maintenance strategy and their ability to read real time data before picking the most efficient to be used.
- ✓ Also, some gas laws were taken into consideration when building the system. They are:

Boyle's law and Charles's law.

3.2.1 BOYLE'S LAW

This law states that at constant temperature, the pressure of a fixed mass of gas is inversely proportional to its volume. It is an important thermodynamic principle that describe the relationship between those three parameters.

Mathematically,

$$P_1V_1 = P_2V_2$$

Where P and V represents Pressure and Volume respectively.

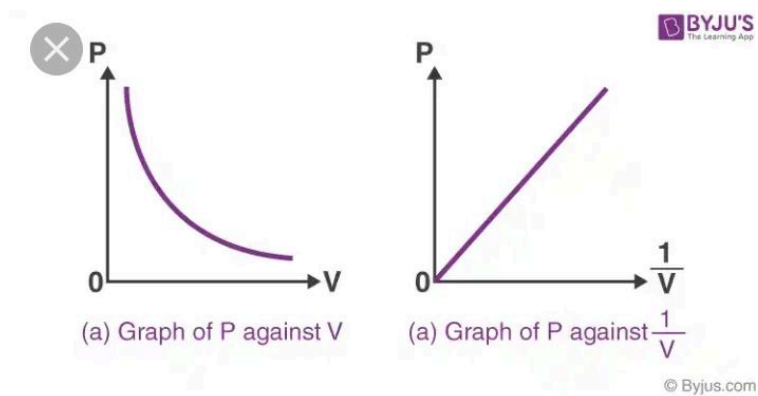


FIGURE 3.7 : GRAPH REPRESENTING BOYLE'S LAW

3.2.2 CHARLE'S LAW

This law states that provided pressure is kept constant, the volume of a given mass of gas is directly proportional to the temperature in kelvin. This law is named after the chemist Robert Charles and is important in several fields of science.

Mathematically,

$$V_1T_1 = V_2T_2$$

Where V and T represents volume and temperature respectively.

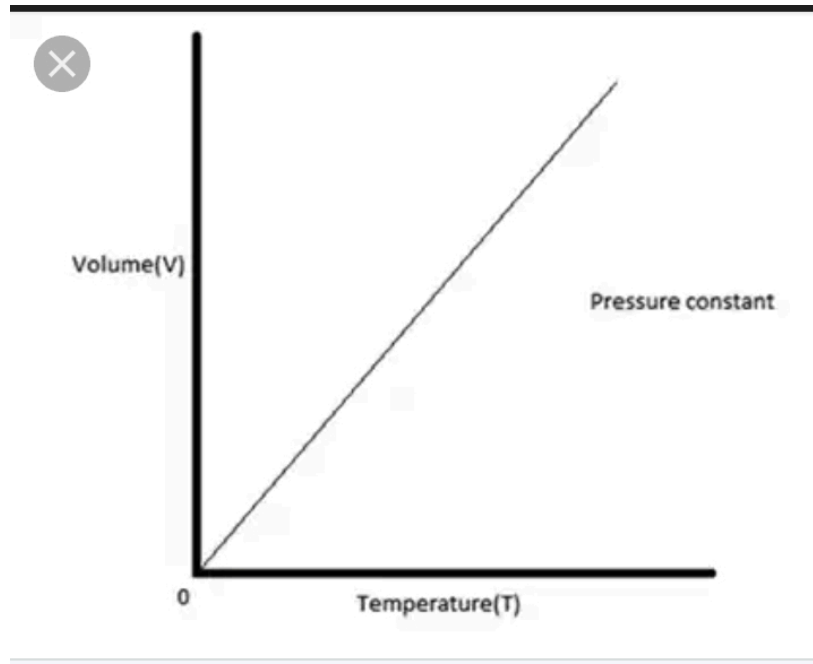


FIGURE 3.8: GRAPH OF CHARLES LAW

3.3 DESIGN COMPONENTS

The components combined to give the system are as follows:

- i) Power source: CMOS and Lithium Ion batteries
- ii) LCD Screen
- iii) Temperature sensor (DS18B20)
- iv) Microcontrollers ESP 8266 and ESP 32
- v) Two plastic bowls representing tank A and tank B containing the liquid
- vi) Pigging device

3.3.1 DESIGN OF THE POWER SUPPLY UNIT

The power supply unit comprises the CMOS and LITHIUM ION batteries. They have different functions but work simultaneously in the design of our experiment. While one power source receives the external data, the other supplies power for processing the internal data.

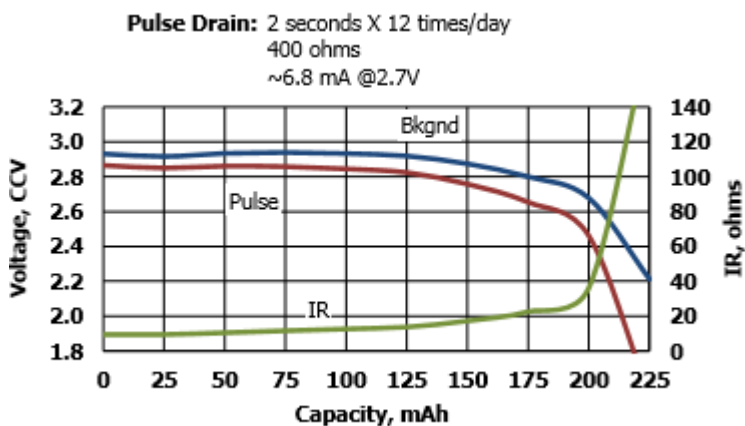


FIGURE 3.9: PULSE DISCHARGE CHARACTERISTICS FOR THE LITHIUM ION BATTERY

3.3.1.1 POWER CONSUMPTION CALCULATION FOR THE CMOS

The leakage current along with the supply voltage causes static power consumption in the CMOS. This static power consumption is defined as quiescent or P_S and can be calculated using equation 1 below.

$$P_s = V_{CC} \times I_{CC} \dots \dots \dots (1)$$

Where:

V_{CC} = supply voltage

I_{CC} = current

Therefore, the transient power consumption can be calculated using equation 2 below.

$$P_T = C_{pd} \times V_{CC}^2 \times f \times N_{SW}$$

Where;

F = input frequency and N_{SW} = number of bits switching

From these equations, we can then calculate for the dynamic power consumption.

3.3.2 DESIGN OF THE DISPLAY UNIT

This unit consists of an LCD screen connected to the Microcontroller ESP 32. It displays the pressure of the system and other necessary information. This LCD screen consists of 16 pin positions connected to their correct terminals on the ESP 32 microcontroller.

3.3.3 DESIGN OF THE TEMPERATURE SENSING UNIT

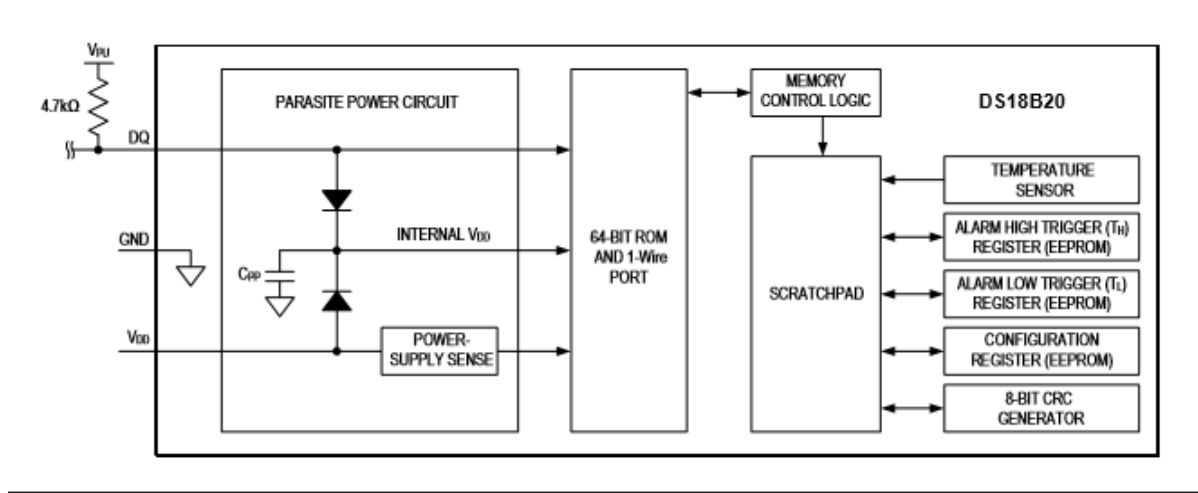


FIGURE 4.0: FUNCTIONAL BLOCK DIAGRAM OF THE DS18B20 TEMPERATURE SENSOR

DS18B20 has a unique 64-bit serial code which allows multiple DS18B20'S to function on the same 1-wire bus. Thus, it is simple to use one microprocessor to control many DS18B20 sensors distributed over a large area. This benefits HVAC environmental controls and temperature monitoring systems inside buildings, equipment or machinery.

This temperature sensor has a 64-bit memory that contains the 2 byte temperature register that stores the digital output from the temperature sensor. It also uses Maxim's exclusive 1-wire bus protocol that implements bus communication using one control signal. The control line requires a weak pullup resistor since all devices are linked to the bus via a 3 state or open drain port.

TABLE 3.3.3.1 : DC ELECTRICAL CHARACTERISTICS OF THE TEMPERATURE SENSOR (DSB18B20)

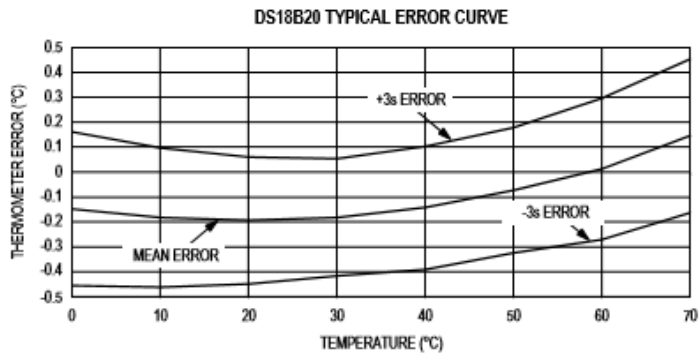
(-55°C to +125°C; V_{DD} = 3.0V to 5.5V)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage	V _{DD}	Local power (Note 1)	+3.0		+5.5	V
Pullup Supply Voltage	V _{PU}	Parasite power	+3.0		+5.5	V
		Local power			V _{DD}	
Thermometer Error	t _{ERR}	-10°C to +85°C			±0.5	°C
		-30°C to +100°C			±1	
		-55°C to +125°C			±2	
Input Logic-Low	V _{IL}	(Notes 1, 4, 5)	-0.3		+0.8	V
Input Logic-High	V _{IH}	Local power	+2.2		The lower of 5.5 or V _{DD} + 0.3	V
		Parasite power				
Sink Current	I _L	V _{I/O} = 0.4V	4.0			mA
Standby Current	I _{DDs}	(Notes 7, 8)		750	1000	nA
Active Current	I _{DD}	V _{DD} = 5V (Note 9)		1	1.5	mA
DQ Input Current	I _{DQ}	(Note 10)		5		µA
Drift		(Note 11)		±0.2		°C

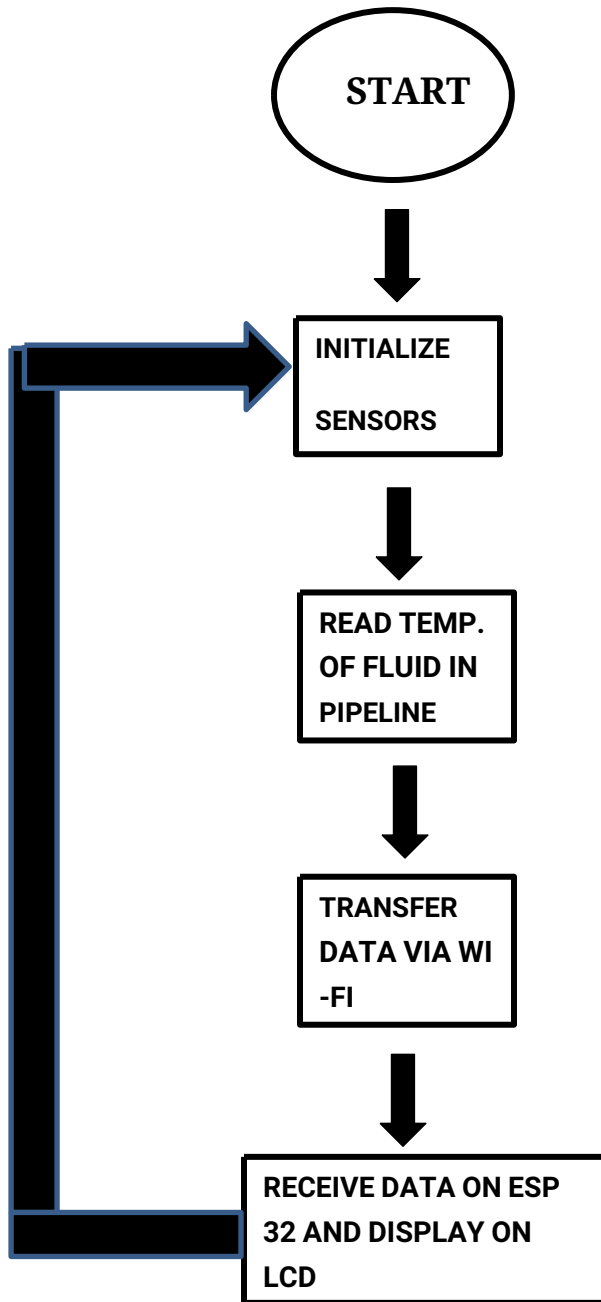
TABLE 3.3.3.2: AC ELECTRICAL CHARACTERISTICS OF DSB18B20

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Temperature Conversion Time	t_{CONV}	9-bit resolution	(Note 12)		93.75	ms
		10-bit resolution		187.5		
		11-bit resolution		375		
		12-bit resolution		750		
Time to Strong Pullup On	t_{SPON}	Start convert T command issued			10	μs
Time Slot	t_{SLOT}	(Note 12)	60		120	μs
Recovery Time	t_{REC}	(Note 12)	1			μs
Write 0 Low Time	t_{LOW0}	(Note 12)	60		120	μs
Write 1 Low Time	t_{LOW1}	(Note 12)	1		15	μs
Read Data Valid	t_{RDV}	(Note 12)			15	μs
Reset Time High	t_{RSTH}	(Note 12)	480			μs
Reset Time Low	t_{RSTL}	(Notes 12, 13)	480			μs
Presence-Detect High	t_{PDHIGH}	(Note 12)	15		60	μs
Presence-Detect Low	t_{PDLLOW}	(Note 12)	60		240	μs
Capacitance	$C_{IN/OUT}$				25	pF

3.3.3.1 PERFORMANCE CURVE OF THE DS18B20



3.4 SYSTEM FLOWCHART



3.5 WORKING PRINCIPLE OF THE SYSTEM

This pigging system has a short section of the pipeline attached between two liquid reservoir tanks with a turbine capable of moving liquid from one tank to the other present. Within the pipe system, the pigging device is embedded. The pigging device flows alongside the direction of the liquid flows, either from tank A to B or from tank B to A.

While the pigging device is inside the pipe, it picks out the temperature of the liquid and the temperature of the liquid along the pipe as it flows through. The temperature value is read by the DS18B20 temperature sensor and is sent to the ESP 8266 microcontroller module. This microcontroller has Wi-fi capabilities and as such, it transfer the real time temperature value wirelessly to another microcontroller system which in this case is the ESP32 module.

This module is a larger microcontroller than the ESP 8266 module. It supports the LCD connection, performs more tasks and has larger storage memory to hold the data. The ESP 32 stores the data that is being transferred by the ESP 8266 and also converts it by using the various gas laws and chemical laws to determine the gas pressure inside the pipeline.

The ESP 32 has the capacity to receive temperature sent by the ESP 8266 and also displays the pressure built up inside the pipeline. This real time information can

further be used to analyze the status of the pipe in case there is low pressure, high pressure or if the expected range of pressure depending on the type of fluid that is passing through is stable.

In this case oils like crude oil, petrol, diesel and so on emit gases. The gases in this case build up pressure and the concept of gas laws enables the system to analyze the state of the pipeline, thereby converting the temperature reading to pressure reading and we can determine areas of the pipeline that require attention while the pigging system is moving through the pipe.

The ESP 8266 inside the pipeline is powered by the CMOS battery while the ESP 32 is powered by Lithium Ion batteries connected in series. The ESP 8266 controls the turbine tanks that can determine the liquid flow from one tank to the other by turning on the turbine fans. .

CHAPTER FOUR

DESIGN AND CONSTRUCTION

4.1: CONSTRUCTION

Before the project was started, the materials had to be bought. Some of these materials were not readily available like the Vero board, the pigging device which contained one microcontroller and temperature sensor were not readily available.

The next procedure was putting all the components together in order to yield the desired hardware.

This was not entirely an easy process as it included different sections such as the soldering of other components on the Vero board. The Vero board served as the base for mounting other electronic components.

This had to be done carefully and firmly to ensure no two components were bridged. Program was then loaded into the micro controller and casing followed.

The process of construction is as follows;

- i) A continuous Vero board was chosen.
- ii) Components are soldered correctly following their right electric paths on the Vero board.

- iii) Hardware components are then assembled on a wooden board that serves as the base or support of the pigging system. For this, two tanks are needed. Tank A and Tank B are connected to the pipeline which contains the Pigging device.
- iv) The pigging device contains the ESP 8266 microcontroller and sensors like the temperature sensor. This microcontroller with the aid of the pigging device receives internal data and sends to the ESP 32 module.
- v) An adjustable box was attached to the base or support of the system. This box contained the Vero board. On the Vero board, various electronic components were soldered to avoid bridging.
- vi) An LCD screen is attached to the cut made on the surface of the adjustable box. On the LCD terminals, is attached an I²C module.
- vii) The LCD is then programmed using the C++ syntax and tested by simulation on Proteus.
- viii) Also, the temperature sensor, 16B20, is programmed and tested by simulation on Proteus.
- ix) Before coupling the hardware, the circuit had to be tested.
- x) The circuit then undergoes a number of tests for continuity, wireless communication test and data validation test.

Continuity test is one of the most important tests to be carried out. A Multi-meter was used for the continuity test. This test is very important as it shows where isolation is required, as a result of bridging which can destroy electronic components.

The wireless communication test is done to ensure that the two Wi-fi modules communicate effectively.

The data validation test confirms that the temperatures being transmitted are in line with actual data. It is done with the thermometer.

4.2: MOUNTING AND SOLDERING OF COMPONENTS

Components are mounted and soldered on the Vero board carefully to avoid bridging. Which could damage the system.



FIGURE 4,1 THE PIGGING DEVICE WHICH CONTAINS THE MICONTRROLLER(ESP 8266) AND THE SENSOR.

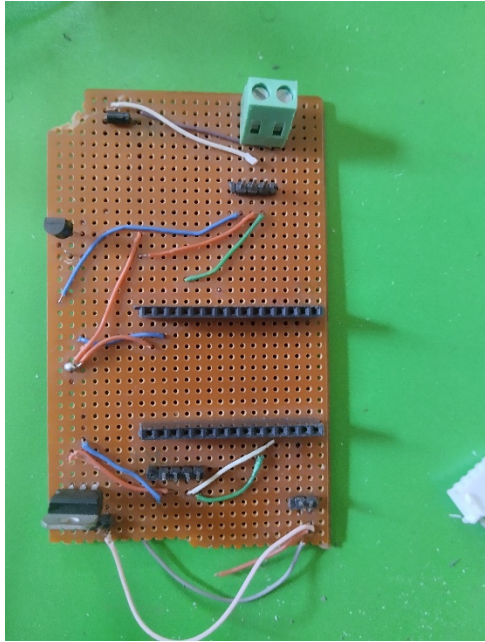


FIGURE 4.2 MOUNTING OF COMPONENTS ON THE VERO BOARD AND CONNECTING WITH JUMPER WIRES.



FIGURE 4.3A: THE LCD SCREEN EMBEDDED IN A 6 X 6 ADAPTAB;E BOX

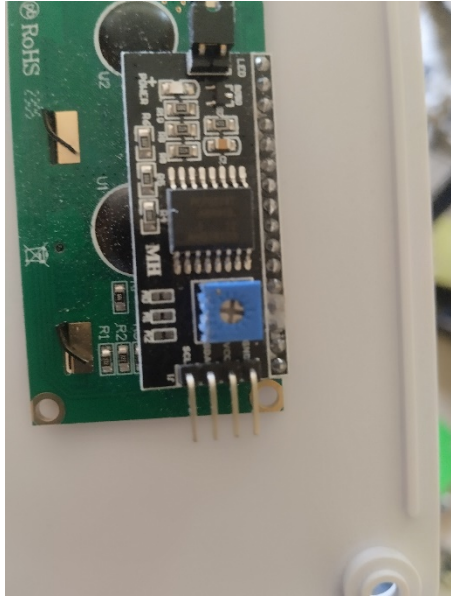


FIGURE 4.3B : THE LCD SCREEN AND I²C MODULE EMBEDDED IN A 6x6 ADAPTABLE BOX

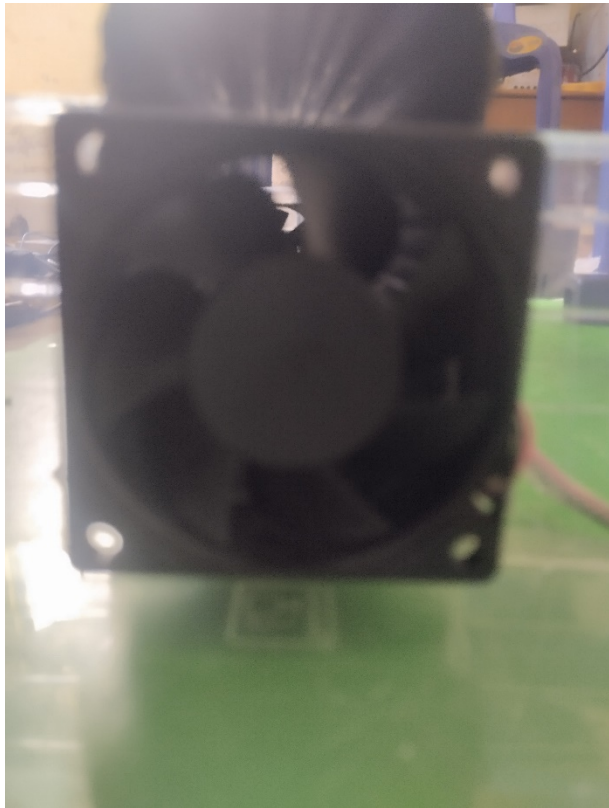


FIGURE 4.4A LIQUID FLOW TURBINE UNIT

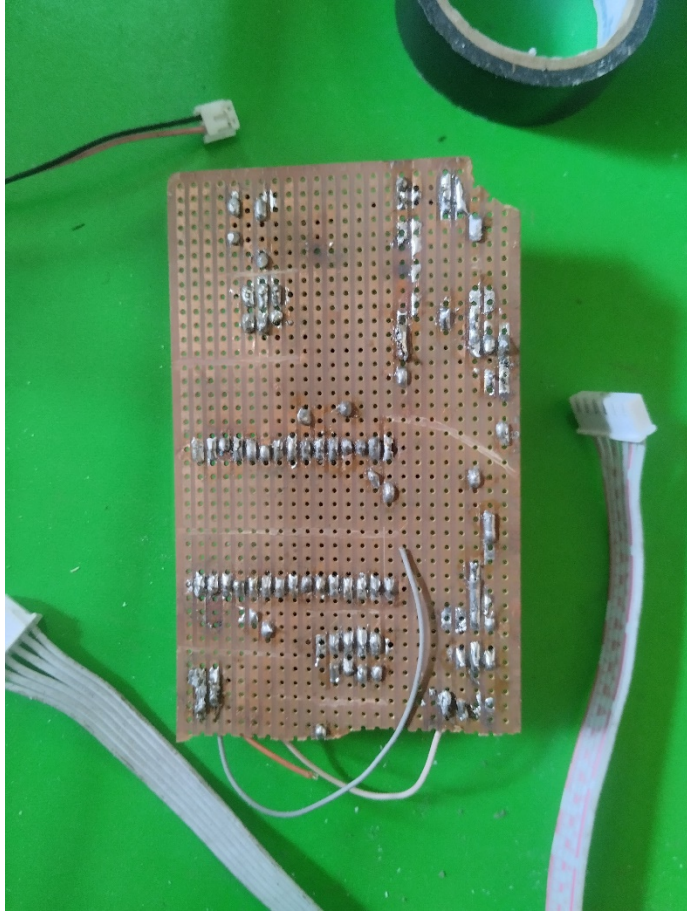
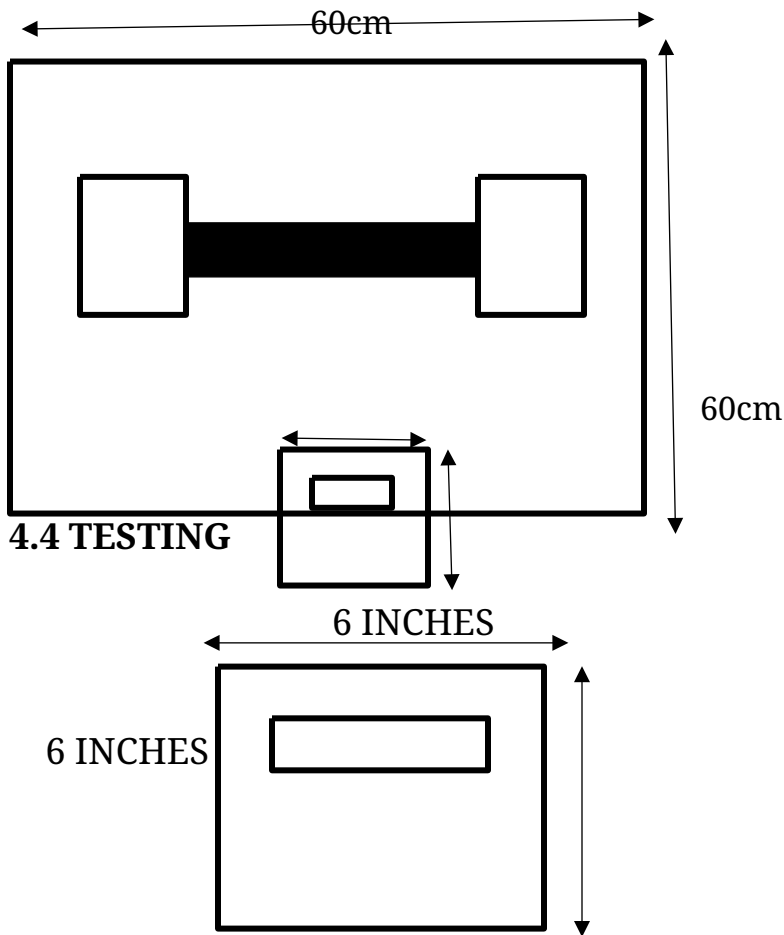


FIGURE 4.4B: SOLDERING OF COMPONENTS ON THE VERO BOARD

4.3 CASTING, LAYOUT AND DIMENSIONS

The wooden board which serves as the base of the system has a dimension of 60cm by 45cm. A 6 X 6 inches adaptable board is used to mount the LCD screen which supplies information about the system. Also, the liquid flow turbine is connected to two tanks, tank A and tank B.



FIGURES 4.5 DIMENSION AND LAYOUT OF THE SYSTEM AND DIMENSION OF THE ADJUSTABLE BOX

4.4 TESTING

As earlier stated, three tests were carried out on the system. They are;

1. Continuity test.
2. Data Validation test
3. Wireless Communication test

The continuity test is done to test if a circuit is open or closed. Only a closed and complete circuit has continuity. It is carried out by the use of a multimeter. A closed and operational switch has continuity.

During testing, a digital multimeter sends a small current through the circuit. This is done to measure the resistance in the circuit. The continuity tests determines the following:

1. If conductors are open or shorted.
2. If switches are operating properly.
3. If circuits paths are clear or bridged.

Wireless communication test is done between the two microcontrollers, ESP 8266 and ESP 32. Wireless communication entails the transfer of information between two or more devices without the use of an optical fibre or other physical means of communication like wires.

Data validation testing allows the operator to confirm if provided data is complete or correct. This enables the user to get data accuracy by validating data and databases successfully through needed data transformations. This test is an essential part of the Database and Data Quality Testing.

It takes and compares system data with needed data so as to validate the validity of the of data gotten from the system.

There are four types of data validation testing. They are:

1. Data type check: this confirms that the inputted data is of the correct type.
2. Code check: this checks and ensures that the selected field from a valid set of values follows certain formatting principles or protocols while ensuring correctness.
3. Range check: this type of data check ensures that the range of values ought to be gotten in real time is consistent with the pigging system output.
4. Format check

4.5 ESTIMATED BILL OF ENGINEERING MEASUREMENT AND EVALUATION

ITEM	AMOUNT	UNIT	PRICE PER UNIT	TOTAL
BLOW FAN	2	PIECES	2500	5000
ARDUINO NANO	1	PIECE	9000	9000
ESP 8266	1	PIECE	3500	3500
PRESSURE SENSOR	1	PIECE	4000	4000
CMOS BATTERY	10	PIECES	200	2000
ESP 32	1	PIECE	12000	12000
LCD	1	PIECE	7200	7200
RESISTORS	10	PIECES	200	2000
CAPACITORS	1	PIECE	2000	2000
LITHIUM BATTERY	3	PIECES	1000	3500
LIQUID PIPE	1	PIECE	3000	3000
LITHIUM CHARGER	3	PIECES	4500	4500
BOWLS	2	PIECES	1000	2000
CABLES	2	PIECES	1500	3000
BD 139 TRNSISTOR	1	PIECES	500	500
VEROBOARD	1	PIECE	500	500
SOLDERING LEAD	2	PIECES	1500	3000
BUCK CONVERTER	1	PIECE	3000	3000
SWITCH	1	PIECE	300	300

PACKAGES	2	PIECES	1400	2800
I2C MODULE	1	PIECE	2800	2800
ADHESIVE	1	PIECE	2500	2500
GLUESTICKS	2	PIECES	250	500
SUM TOTAL	-	-	-	79,600

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION(S)

5.1 CONCLUSION

The device was fully tested and proven to perform optimally. Pipeline leaks and failure which causes damage to the environment can easily be reduced by using this system which has proven to be effective for monitoring the pipeline.

However, this system can be upgraded or modified in various aspects. Some of these aspects are listed below.

5.2 RECOMMENDATIONS

- i) The automatic monitoring of this system can be applied in various aspects of the engineering industry like the gas pipeline sector where a more effective and accurate system of monitoring is required.
- ii) For better performance, it is advisable to test this prototype in a properly built physical system
- iii) Wireless network tests should be updated and upgraded as it helps companies and organizations verify and improve the security of existing wireless networks while ensuring rogue wireless access points do not infiltrate the system.
- iv) Being an automated system, a buzzer should be connected across the system so it gives out a warning sound when there is a detected fault. This serves as a form

of predictive and preventive maintenance from the overall breakdown of the system.

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