DESIGN AND SIMULATION OF A TEMPERATURE CONTROLLER FOR EFFECTIVE PETROLEUM PRODUCT STORAGE.

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CERTIFICATION

This is to certify that this thesis entitled **"DESIGN AND SIMULATION OF A TEMPERATURE CONTROLLER FOR EFFECTIVE PETROLEUM PRODUCT STORAGE"** was carried out by **ENE-NTE NSAN-AWAJI PETERSON (Reg. No. 20184138648)**. In partial fulfillment of the requirements for the award of the degree **Master of Engineering (M.Eng.) in Control System Engineering** in the department of Electrical and Electronic Engineering, School of Electrical Systems Engineering and Technology of the Federal University of Technology Owerri, Imo State, Nigeria.

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DEDICATION

This thesis is dedicated to the Almighty God for giving me the grace, patience, courage, and strength to overcome all challenges I encountered. It is also dedicated to my family for their support and love towards me.

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ABBREVIATIONS

Occupational Safety and Hazard Administration	-	OSHA
National Fire Protection Association	-	NFPA
Dangerous Substances and Explosive Atmospheres Regulations	-	DSEAR
Emergency Shutdown Valves	-	ESV
Premium Motor Spirit	-	PMS
Resistance Temperature Detectors	-	RTD
Surface Acoustic Wave	-	SAW
Mass Flow Controllers	-	MFC
Gas Chromatography	-	GC
Pounds per Square Inch	-	PSI
Pounds per Square Inch Gauge	-	PSIG
Parts Per Billion	-	PPB
High Performance Liquid Chromatography	-	HPLC
Mass Spectroscopy	-	MS
Predictive Emissions Monitoring Systems	-	PEMS
Hazard Identification	-	HAZID
Hazard Analysis and Operability	-	HAZOP
Fault Tree Analysis	-	FTA
Event Tree Analysis	-	ETA
Oil and Gas Operations	-	OGP
Health and Safety Environment	-	HSE
Internal Model Control	-	IMC
Silicon-Controlled Rectifier	-	SCR
Distributed Control System	-	DCS
Proportional Derivative	-	PD
Proportional Integral	-	PI
Proportional Integral Derivative	-	PID

ABSTRACT

The growing demand of petroleum product has brought a significant increase in risk to human and its environment. Temperature controller of a petroleum product storage tank are specifically designed for the purpose of controlling the enormous temperature characteristics of the petroleum product during weather variations in critical industries such as the oil and gas, process, and other related smaller industries. In this work, a temperature controller and a cooling system for the petroleum product storage tank was designed using proportional derivative, proportional integral and proportional integral derivative controllers to obtain the response of the product temperature on the atmospheric variations. The simulation results were carried out on uncontrolled temperature deviation from set point, controlled temperature error deviation, pressure effect on temperature error deviation, gasoline, kerosene, diesel temperature error deviation using the proportional derivative, proportional integral and proportional integral derivative controller to ensure excellent control measure in the stability of the temperature characteristics of the storage tank. The temperature stability with the Proportional Integral Derivative controller provides an insight into the control performance of the Proportional Integral Derivative controller, whose essence is to ensure that error correction takes place without time delay.

Keywords: Temperature Controller, Petroleum Product, Stability, Storage Tank and PID Controllers.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

According to (Ibrahim and Syed, 2018), several fatal accidents in process facilities happen during storage processes. These unfortunate events in the past have caused huge economic losses, injuries and even death to workers with accompanying environmental pollution. The use of adequate sensors as well as controllers in temperature measurement may not only be essential in weather and environmental observations but important in the various industrial processes. Process industries require efficient system of storage and safety of the equipment, environment and personnel as major changes are taking place in the process industries. In developing countries like Nigeria, quest for technological advancement is increasing day by day and with issue of local content, many Nigerians are now eager to become entrepreneurs in oil and gas sector. Also, the successive inflation, oil crises, changing world economic conditions and increased competition from developing countries have altered the profitability of many traditional products and processes, whilst new technology and changes in society have created new opportunities and new markets. There is of course a continuing large-scale demand for many of the traditional staple products, but with the intense competition in these areas, the producers will have to make their processes more efficient with adequate storage systems. Sources of raw materials will be more varied and market demand more uncertain, creating the need for more flexible tank storage that is capable of storing economically all the process end products. Tighter environmental constraints and tighter requirements for hygiene, health and safety on the plant mean that processes must be more closely monitored.

To meet the demands of higher control performance under much more variable conditions, flexibility and robustness have become important issues in both design and control (Joshi, 2012). Temperature can be said to be an average energy of microscopic motions in the system of a single particle per degree of freedom. Temperature control and measurement performs a crucial purpose in home applications and industries, example, in boilers (Narong et al, 2011), it also plays key role in greenhouses (Saudagar et al, 2012), ovens, rooms (Theophilus and Bhudi, 2012), geothermal power plants (Aman and Debashish, 2013), LEP2 Superconducting RF cavities (Brun et al, 2005), turbo gas units (Salvador et al, 2003) and weather monitoring (Kamarul, 2006). Sensor are peripheral device commonly used to adequately sense temperature, it transforms the measured physical quantity into a signal that is readable by an observer with the help of an instrument. For instance, the mercury thermometer is a device that converts a temperature measured into a contraction and expansion of liquid that can be interpreted with the help of a calibrated glass tube (Doc, 1997).

The recording of temperature for a specific period is referred to as temperature monitoring, in earliest technology the observation of temperature was made easy using data loggers. Through the analog instruments, manual measurements were carried out which forms the development of data loggers. Regrettably these data loggers can no longer satisfy the postulated sequence of possible present events due to a function of lack of time and correctness. An advancement of data logging occurs in the 1990s in which the PC based data logging systems were designed by researchers (Goswami et al, 2009), the 8051 microcontrollers were observed to be an efficient and reliable controller in its application of embedded system design in the advance development of data logging. Although in severe weather or environmental conditions these microcontrollers may not be put to use as well as the difficulties associated in programming them (Ljubivoj and Zeljiko, 2008).

To ensure stability and safety of the petroleum product the numerous methods that can be applied in measurement and control of temperature in the storage systems of a process products were analyzed. Stability can be referred to two main issues for fuels: stability at elevated temperature and pressure of the recirculation of fuel in an engine system and aging or long-term storage stability. In petroleum products, Stability of fuel temperature at elevated fuel system is referred to as Thermal stability while Oxidative stability as the long-term storage stability.

The principles which help in identifying combustible, flammable and storage conditions in order to ensure the highest level of stability are:

i. Fluids must be stored in a separate storage system away from the storage of metals like lead, zinc, brass bronze, tin, copper, and iron to reduce a high means of sedimentation and its degradation processes.
ii. With the use of a nitrogen blanket on storage tanks, tank with minimal headspace and storage of fuel in a well-sealed drum. Oxidation of fuel which is the removal of oxygen from the fuel can be achieved and storage life can be prolonged.
iii. The increase in the unsaturation level from monounsaturated to polyunsaturated causes the stability of the fuel to exponentially decrease since the fluids oxidize most likely at a higher level of unsaturation as saturated fatty acid esters are fairly stable. The reaction of oxygen at the point of unsaturation of the fuel molecules can form peroxides which breaks down into gums, acids and sediments.
iv. Sunlight and heat can significantly facilitate these processes.
v. Antioxidants either incorporated as additives or natural can greatly increase the stability of fluids as well as its storage life.

Temperature sensors are highly essential devices in the storage of products that greatly rely on temperature control and maintenance to function appropriately such as thermostats. The control of temperature plays an important role in control and process engineering, examples which include the maintenance of a chemical reactor at an ideal set-point temperature, monitoring the temperature to guarantee the safety of the personnel in the event of a runaway reaction. To reduce harmful environmental impact, temperature of the streams to be released into the environment should be maintained and monitoring of temperature of fluids in tank farms. While temperature is generally sensed by humans as “hot”, “neutral”, or “cold”, control engineering requires precise, quantitative measurement of temperature to accurately control a process, this is accomplished with the aid of a temperature sensor and the signal receive from the sensor is being process by the temperature regulator. As heat is added to a system, molecular motion increases which result in the system experiencing an increase in temperature. Temperature changes as a function of the average energy of a molecular movement from a thermodynamics perspective, the measurement of the energy of a molecular movement is not an easy function as temperature sensors are mainly designed to measure the change of a property in response to temperature. The calibration of the device is done using a standard in accordance to the traditional temperature scale (i.e., the boiling point of water at known pressure).

1.1.1 Storage System

Although the storage of local gases is difficult, most at times the use of caverns or salt deposit and underground mines can be used in storing these gases. Oil and gas are directly piped to a tank terminal to be stored in an onboard storage tank on most production sites without a pipeline to be transported by a shuttle tanker. These petroleum products are stored on concrete platforms in tanks, on floating units and cells around the shafts, a separate storage tanker is used on some floaters. When oil volume differs, ballast handling is highly essential to balance its buoyancy in both cases. The crude oil is stored in a fixed roof tanks while the floating roof tanks are used for condensate in an onshore platform, the use of special tank gauging systems like level radars, pressure or float in moderating the level of storage caves, cells and tanks is utilized. Depending on the tank geometry, its level measurement is converted into appropriate volume via tank strapping tables and compensated for temperature to provide standard volume. The float gauge calculates for density and as such mass can be ascertained.

A typical maximum capacity of different volume of tank comprises of 25 – 85 tanks in the area of 5 – 55 million barrels in a tank farm. About three weeks of oil production is usually stored in the storage tanker, one week is scheduled for a proper cycle while the other extra weeks for expected delays which can amount to millions of barrels. Documentation of accurate volume of what is received and dispatched are kept. The record of stock movement and logistics operations are kept in the tank farm management system, various product and quality blending must surely be handled for installation that serve multiple production sites.

The plate 1.1 shows a typical process facility and storage tank of the oil refining industry.

Plate 1.1: Typical Process Facility and Storage Tanks (Devold, 2013).

1.2 Problem Statement

Petroleum and chemical products are essential resources of our time and are considered as one of the important basic building blocks for sustainable development. The increase in demand of hazardous chemicals has brought significant risk to man and its environment. Hazardous chemicals have intrinsic hazards for the environment, which may result in destruction of humans and properties within the accident zone. The Occupational Safety and Hazard Administration (OSHA) has defined a hazardous chemical as any chemical, which has a physical hazard such as (acute or chronic effects) health hazard (Ministry of Environment and Forests, 2010) or (fire and explosion). The historical analysis of major accidents in the chemical industries have shown that 17% of the accidents were during storage processes (Vilchez et al, 1995). According to the National Fire Protection Association (NFPA) 2009 report, 13% of the worldwide fire accidents took place in storage tank farm (Badger, 2010).

The factors enumerated above, could happen if the temperature of the tank is not properly control and regulated for effective storage purposes.

1.3 Objective of the Study

The main objective of the study is to Design and Simulate a Temperature Controller for Effective Petroleum Product Storage.

The specific objectives are as follows:

i. To design the controller for the temperature.
ii. To design the cooling system.
iii. To simulate the designed systems using MATLAB software.
iv. Validation of the research work.

1.4 Justification of the Study

The different processes and chemical reaction of the oil refining industry makes it a complex chemical industry, although it has a great economic value, it also comes with huge environmental impact worldwide. Petroleum and chemical products are considered as one of the most valuable basic building blocks for sustainable advancement. The growing demands of hazardous chemicals has brought a significant accretion in risk to human and its environment. Below are factors which have caused fire accidents in the tank farms and other storage facilities of process industries.

A. **More pressure inside the storage tank:** This is caused by.

i. Tank exposed to an external heat source.
ii. Outlet pipe of the storage tank blocked during transfer.
iii. Failure of the automatic pressure control system.
iv. Poor ventilation.
v. Thermal expansion of oil in the storage tank due to strong sunlight.
vi. Failure of the pressure relief valve.

B. **More level in the storage tank:** This is caused by.

i. The level indicator fails.
ii. The alarm doesn't work properly.
iii. The wrong valve opened.
iv. Tank top unattended.
v. Expansion of oil due to exposure to higher temperature.

The fire accidents that occurred in many parts of the world in process industries took place in storage tank farms, causing injury or death for workers, millions of dollars losses, and huge environmental pollution. Many catastrophic casualties occurred in history such as the Bhopal disaster of 1984, which caused thousands of fatalities and thousands of people were injured (Lees, 2005). The possible hazards are a function of both the intrinsic nature and the involved volume of the chemical and irregular temperature rise. Therefore, it is essential to design a good temperature controller for petroleum tank storage.

Fire or explosion preventive measures at production sites, workplaces, storage or the use of flammable liquids can be guaranteed by complying with the Dangerous Substance and Explosive Atmosphere Regulations 2002 (DSEAR). The main essence of the DSEAR is to ensure the safety of personnel and as many who may be at risk as a function of the disastrous substances that can cause explosion, fire and similar energy releasing event such as a runaway exothermic reaction. Also, the increase demand for local content in the oil industries is a practical motivation for indigenous entrepreneurs to explore the opportunities available in the country. Besides, every developing country is striving to ensure that there is technological advancement in their country like Nigeria. Realizing the objective of this study will certainly create wealth, improve productivity, save time in manufacturing processes and above all create employment opportunity.

1.5 Scope of the Study

The scope of the study will be designing, modeling and simulation of temperature controller for a petroleum product tank storage system. The study will not look at the processes involved in seismic, drilling, refining, or modeling of the tank. The petroleum product is emphatically crude oil. The study will carry out research on the flash points of crude oil and its characteristics during storage. The study will also research on how a cooling system could be incorporated into the controller so that when the liquid reaches the flash point, a cooling liquid could be showered on the vessel automatically to reduce the temperature.

CHAPTER TWO

LITERATURE REVIEW

2.1 Review of Fundamental Concepts

In this section we review all the various approaches, techniques and fundamental concepts of the literature related to our research work.

2.1.1 Temperature Measurement

The evaluation of the temperature of a product is a sine-qua-non in a tank gauging system for input to the standard volume and mass calculation. In the past (also to some extent today), storage tanks usually have one temperature sensor mounted on the bottom section of the tank wall. This type of configuration will not show a representative value of the overall product temperature, since all storage tanks will show a significant temperature gradient from top to bottom. This to some extent can be minimized by agitation of the product, although agitation in most cases is unwanted since it will increase evaporation in or from the tank (American Petroleum Institute, 2012).

The plate 2.1 shows a temperature transmitter for a storage tank.

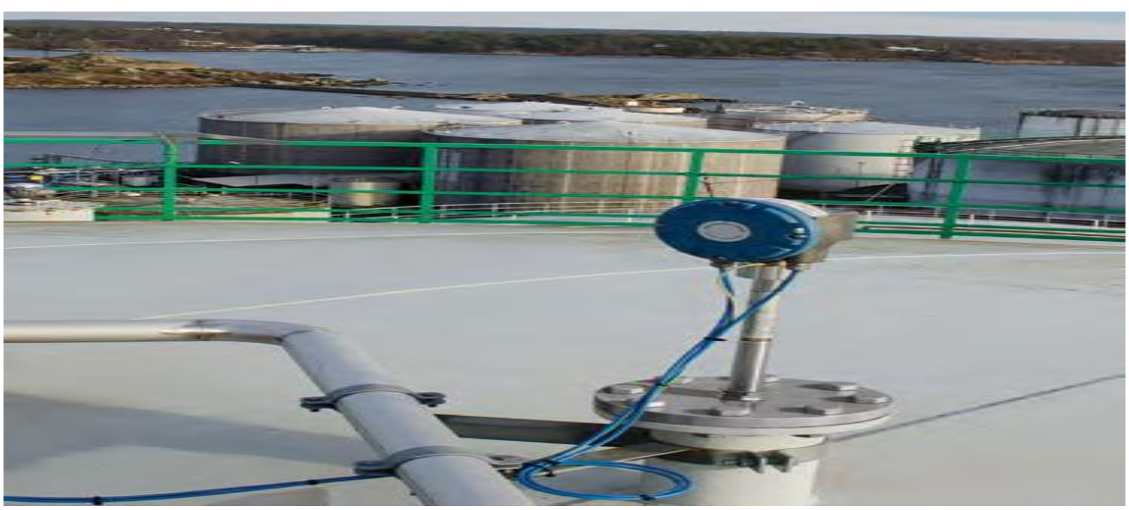

Plate 2.1: Top mounted temperature transmitter for up to 16 spot temperature elements (Devold, 2013).

In a normal cylindrical tank, the temperature difference expected to be settled is in the range of 1 - 4 °C in a vertical direction. As a result of higher density, cold products will end up at the bottom of the tank. The temperature gradient in a horizontal direction has often been debated, but under normal circumstance American Petroleum Institute (API) documents state that the horizontal temperature difference in a storage tank is less than 0.5 °C (The Engineer's Guide to Tank Gauging**,** 2021).

2.1.2 Influence of API Tables

The restraint in the temperature evaluation related to the API tables and the Volume Correction Factor (VCF) calculation has to be put into consideration. The API tables before 2004 had a resolution of 0.25 °C (0.5 °F), which made temperature measurement accuracy better than 0.25 °C meaningless. The type of sensor used is a 3-wire Pt100 elements, where the error due to the difference in resistance of the three wires in most cases should be able to get below 0.25 °C. Hence, if the temperature precision is only as good as 0.25 °C, the resultant level error in the tank is in the range of several millimeters, and on massive crude tanks the figure can be a lot larger. A recent level gauge has an intrinsic accuracy of 0.5 mm (0.02 in.) and when applying certain tank corrections, the installed accuracy could be in the range of 2 mm (0.08 in.) or even better. As a result of the introduction of the new higher resolution 2004 of API tables, using these high accuracies is now highly recommended (American Petroleum Institute, 2012). The 2004 tables do not use the tabulated VCF value from the API table but the result from the algorithm behind the table. Operators today no longer use the table values instead a computer program which has the algorithm implemented to aid the computer in making the calculations. However, the computer should be able to round off the temperature value to the nearest 0.25 °C to achieve the same result as in the printed table. This is different in the 2004 table, where the rounding up should be to the nearest 0.1 °C. For an average liquid temperature of 18.37 °C, the value of 18.4 °C should be used in the algorithm and not 18.25 °C as with the old tables. The new API tables open up achievable volume of estimation through more precise temperature evaluation (The Engineer's Guide to Tank Gauging**,** 2021).

A 4-wire Pt100 sensor will fully compensate for the resistance difference in a 3-wire Pt100 system from conversion electronics to the Pt100 element, hence the resistance difference is not critical anymore. It requires a resistance to temperature conversion unit that is designed for 4-wire connections, and the conversion electronics should have sufficient accuracy and ambient temperature stability.

The plate 2.2 shows a 4-wire Pt100 sensor which is made up of two different segments.

Right Segment - Complete temperature measuring assembly with transmitter, sensor, optional water level sensor and anchor weight.

Left Segment - Multi-spot temperature sensor with Pt100 elements and corrosion resistant metallic sheath.

Plate 2.2: The 4-wire element Pt100 sensor (Devold**,** 2013).

The Pt100 sensor elements are in various accuracy classes and in general 4-wire elements use the degree of accuracy classes. While some manufacturers issue a calibration sheet alongside each element, this calibration sheet can be used for entering corrections of the sensor element and thereby improving the accuracy even more. In doing this automatic calibration, a corresponding function must be available in the temperature measuring system.

2.1.3 Additional Usage of Temperature Measurement in Tank Gauging

The use of the standard volume calculation for temperature measuring system is highly essential in the industry and its most useful in the correction of tank height.

Correction of tank height

Most level gauges measure the interval from the liquid surface down to their mounting position (ullage measurement) and the level is calculated by subtracting the reference height from the ullage measured (distance of the datum plate to the level gauge mounting point).

There will be an error in the calculation if the distance is not constant, i.e., the level varies with change in the reference height. The thermal expansion/contraction of the tank wall or the still-pipe cannot be easily compensated. An average temperature value of either the tank wall or the still-pipe can be estimated with the installation of a multi spot temperature sensor from the top of tank down to the bottom. For the average temperature calculations, all individual temperature elements are used and a correction can be applied on the reference height based on thermal expansion of carbon steel (10-12 ppm/ °C). The various media involved in the correction of a tank wall ought to be put into considerations. The liquid content of the tank and its surrounding air, the thermal influence is quite different for liquid, air and the API standard for calculating the temperature of the tank wall in each measuring point is given as:

$$T_{\text{tankwall}} = \frac{1}{8}\, T_{\text{ambient}} + \frac{7}{8}\, T_{\text{liquid}} \tag{2.1}$$

Due to the radiation effects from sun and the temperature sensor actual position on the tank there is difficulty in measuring the ambient temperature. An accurate ambient temperature would certainly need an advanced metrological station on each tank and in reality, most users will not make this investment since the influence is quite small. Hence, the accuracy of the temperature measuring system is not critical for this correction. (API, 1983).

2.2 Fire Safety

Fire is described as a very fast chemical reaction of oxidant with fuel which is accompanied by the release of energy and indicated by flame or incandescence.

2.2.1 Classification of Fire

Fires are classified into the following, based on the category in which the fuel involve belongs.

i. *Class A Fires* — these are referred to as the solid combustible materials of organic nature such as paper, rubber, plastics, textile, and wood.
ii. *Class B Fires* — the type of fire which involves flammable liquids.
iii. *Class C Fires* — the flammable gases under intense pressure e.g., liquefied gases.
iv. *Class D Fires* — combustible metals, such as potassium, magnesium, sodium etc.

2.2.2 Heat Transfer

Heat transfer occurs during a fire by.

i. *Convection* - transfer of heat by the physical movement of hot masses of air.
ii. *Conduction* - transfer of heat which occurs within the material itself.
iii. *Radiation* - the emission of heat in the form of electromagnetic waves.

2.2.3 Combustion Characteristics

The combinations of the following essential elements in their right proportion at the same time are necessary for the occurrence of fire.

i. Fuel or combustible material.
ii. Oxidizer to maintain combustion.
iii. Heat to activate ignition temperature.

The combine effect of these essential element in their right proportion resolves into a chemical chain reaction that initiates a fire. Hence, the removal of any of these elements douses out the fire.

The plate 2.3 shows a fire tetrahedron.

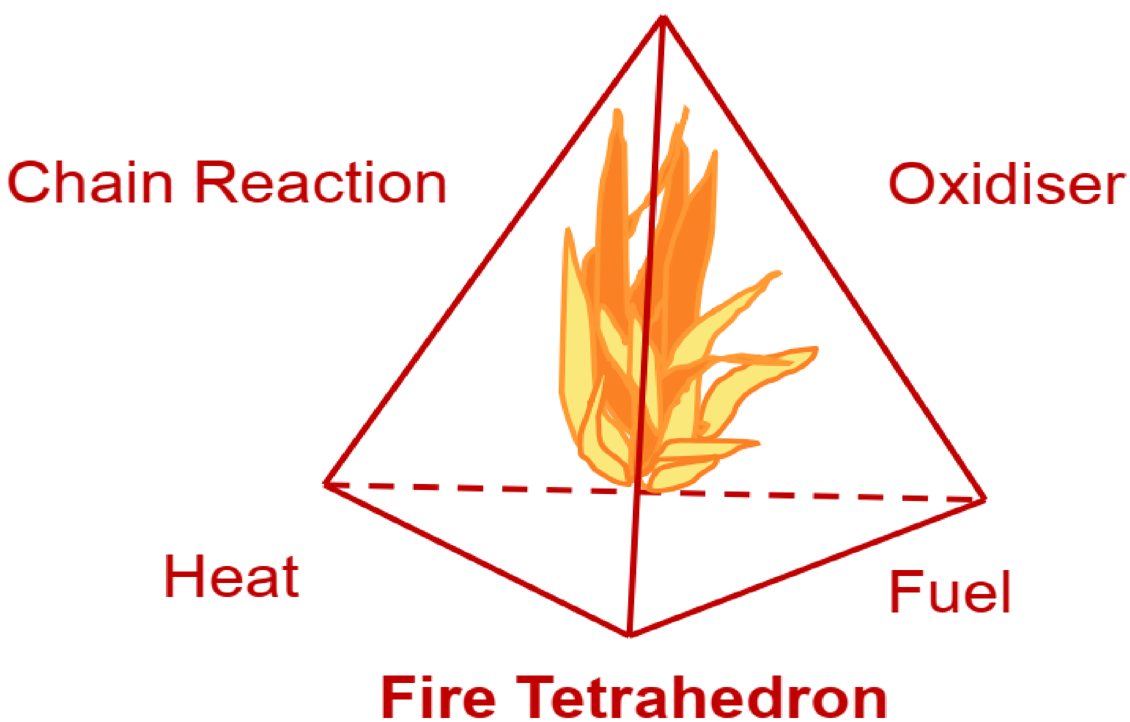

Plate 2.3: Fire Tetrahedron (API, 1983).

2.2.4 Dousing Fire

Fire can be douse by the application of the following three major means.

i. Fire can be douse by releasing the water hydrant; Cooling the fuel by reducing the effect of radiant heat.

The plate 2.4 shows the dousing of fire by water.

Plate 2.4: Dousing of fire by water (API, 2012).

ii. Fire can be douse by smothering the fire; occupying the air space thereby removing the supply of oxygen (e.g., by applying foam or carbon dioxide).

The Plate 2.5 shows the dousing of fire by cutting off oxygen.

Plate 2.5: Dousing of fire by cutting off oxygen (API, 2012).

iii. Fire can be douse by depriving the fire; the removal of fuel. (e.g., stopping gas flow in a pipeline) and restraining the chain reaction from occurring. (e.g., applying dry chemical powder).

The Plate 2.6 shows the dousing of fire by starving the fire of fuel.

Plate 2.6: Dousing of fire by starving the fire of fuel (API, 2012).

2.2.5 Ignition Point

Ignition is the process of actuating a self-sustained combustion. The ignition temperature of a volatile material is the lowest temperature wherein a combustible or flammable liquid produces sufficient amount of vapour which forms a sustained ignitable mixture with air.

Ignition can occur by:

i. Chemical reaction between incompatible chemicals.
ii. Sparks from welding operations.
iii. Smoking.
iv. Batteries.
v. Open flame.

vi. Hot surfaces.

vii. Electrically powered equipment - Loose electrical connections or damaged wiring, over heating of cables due to excess loads, arcing, heat from electric bulbs etc.

2.2.6 Flash Points and Auto-ignition Temperature of some Hydrocarbon Liquids

The Flash point is referred to as the minimum temperature at which the vapour produce from the flammable liquid is enough to form an ignitable mixture. The released of vapour from the surface of the liquid deflagrate into a flammable liquid fire. A volatile material flash point is the lowest temperature at which its vapour can ignite when given an external source of ignition, hence the lowest temperature in which this vapour continues to burn with the support of an ignition source is referred to as the fire point. As the flammable liquid drops beyond its flash point, there is a greater increase in hazard.

The autoignition temperature which is the temperature that result in spontaneous ignition is most times confused with the flash point temperature, since the ignition source temperature is far higher than the fire point and flash point, neither either of them depends directly on the source of ignition temperature. The specific vapour pressure of a liquid is the function of the temperature of that liquid and is subject to Boyle's Law, the increase in temperature results in a corresponding increase in the vapour pressure and the concentration of vapour of a combustible or flammable liquid in the air increases. Hence, the concentration of vapor of the flammable liquid in the air is determined by temperature.

A certain concentration of a flammable or combustible vapour is necessary to sustain combustion in air, the lower flammable limit and that concentration is specific to each flammable or combustible liquid.

The table 2.1 shows flash point and autoignition temperature of some hydrocarbon liquids.

Table 2.1 Flash Point and Autoignition Temperature of some Hydrocarbon Liquids (Fuels, 2014).

S/N	TYPES OF LIQUIDS	FLASH POINTS	AUTOIGNITION TEMPERATURE
1	Gasoline	-42.78 °C (-45 °F)	280 °C (536 °F)
2	Diesel (2-D)	> 52 °C (126 °F)	210 °C (410 °F)
3	Jet fuel (A/A-1)	> 38 °C (100 °F)	210 °C (410 °F)
4	Kerosene	> 38–72 °C (100–162 °F)	220 °C (428 °F)
5	Ethanol (70%)	16.6 °C (61.9 °F)	363 °C (685 °F)
6	Coleman fuel (White Gas)	-4 °C (25 °F)	215 °C (419 °F)
7	Vegetable Oil	372 °C (621 °F)	424 °C (795 °F)

2.3 Handling of Flammable Materials

The flammable materials are easily self-excited volatile substances that are very common in most production sites in the three main states of solid, liquid and gas states. Main examples of these flammable materials are as follows;

Gases — The flammable gases are normally referred to as gases having an explosive limit which is less than 14 percent in air as well as having a flammable range of at least 11 percent in air, these includes the natural gas, carbon monoxide, hydrogen sulphide, propane, butane. For instance, carbon monoxide has an upper explosive limit of 74 percent in air, a lower explosive limit of 13 percent and flammable over a percentage range of 61 and butane is having a 20 percent as its lowest explosive limit in air.

Liquids — Flammable liquids mainly has its flashpoint below 37.80 °C (100.04 F). Gasoline are major solvents such as acetone, adhesives, cleaners, waxes, degreasers and polishes, paints and paint thinners, alcohols and toluene.

Solids — This includes the various types of coal, gunpowder, matches, solid wastes such as rags and paper that get soaked with flammable liquid and pyrophoric metals such as potassium and sodium which goes up in flame when in contact with water or air.

Flammable materials present a health hazard in addition to the danger of fire, this occurs drastically below the air concentration that is required to initiate a fire hazard. Hydrogen sulphide and carbon monoxide are flammable gases that are toxic at a very low concentration. The lowest explosive limit in air for acetone is 2.5 percent (which is about 25,000 parts per million), notwithstanding at concentrations of about 1,000 parts per million personnel mostly experience health hazard like intoxication and irritation. Vapour from most flammable liquids is heavier than air, when there is deficiency in the amount of oxygen, they displace the air and cause a hazard of asphyxiation (suffocation) as a result of been accumulated near the ground.

The burning of flammable material’s produces vapour and toxic gases. Combustion products can include chemicals such as hydrogen cyanide, nitrogen oxides and carbon monoxide. If the materials burnt contains chlorine, then other irritating and toxic chemicals such as hydrogen chloride and acrolein can be produced.

2.3.1 Storage of Flammable Materials

Generally, flammable materials must be kept separately from a potential ignition source in a well-ventilated storage room and these materials should not be stored anywhere close to electrical or heating equipment’s and exits. A flammable material must be placed back into an appropriate container should it be removed from its original container.

Storage tanks and rooms: Flammable materials used in production sites should be stored in large containers (tanks or drums), there may be an excluded storage room for these specific materials as they are mostly in large volumes as well as available in different types and sizes hence the need for a proper storage. (The Alberta Fire Code, 2007) outlines the specific obligation for most overhead and underground storage tanks and rooms. Facilities, pipelines and well sites licensed are approved by the Alberta Energy and Utilities Board for production, processing, exploration, handling, treatment, recovery, disposal or transmission of hydrocarbons are covered by (*Guide 55: Storage Requirements for the Upstream Petroleum Industry*).

In general:

i. Compressed gases must not be stored beside flammable material containers.
ii. Flammable material storage areas are highly restricted for smokers.
iii. Storage rooms ventilation systems must be properly designed and maintained on a regular basis.
iv. Ignition sources such as open flames, sparks and heat should be located away from bulk storage containers.
v. Other chemicals are to be kept away from the flammable materials bulk storage rooms and containers.
vi. Bulk storage rooms and areas are to be equipped with spill protection having appropriate signage or placarding.
vii. The use of large containers in blocking access or being kept near exits of the flammable material storage rooms should be completely avoided.

2.3.2 Incompatible Materials

Incompatibility involves the combination of two or more undesirable and unplanned chemical reactions. The occurrence of incompatibility reactions produces hazard such as:

fire or explosion, violent reaction, toxic dusts, heat or pressure, mists and flammable fumes or gases.

Chemicals are normally grouped into five main categories; flammable/combustible, acid, alkaline or basic, oxidizer and reactive. These groups lack compatibility as such should be stored separately from each other.

Table 2.2 clearly shows some incompatible materials that will results in fire and/or explosive hazard when stored or mixed together.

Table 2.2 Incompatibility of Materials (Alberta Fire Code, 2007).

S/N	E +	N =	P
1	Acids or Bases (Corrosives)	Reactive metals such as • aluminum • beryllium • calcium • lithium • potassium • magnesium • sodium • zinc powder	Fire
2	Cyanide and Sulphur Gases	Acids	Fire
3	Solvent or Reactive organic materials such as • Alcohols • Aldehydes • Nitrated Hydrocarbons	• Acids • Bases • Reactive Metals	Explosion
4	Flammable Liquids	• Acids • Bases • Oxidizers Poisons	Fire Explosion or Violent Reaction

TABLE 2.2 CONTINUES.	E +	N =	P
5	Oxidizers such as • Chlorates • Chlorine • Chlorites • Chromic acid • Hypochlorite’s • Nitrates • Perchlorates • Permanganates • Peroxides	• Flammable Liquid • Flammable Solids • Flammable Wastes • Combustible Wastes	Explosion
6	Flammable Compressed Gases	Oxidizers	Fire Explosion or Violent Reaction

2.3.3 Static Electricity

Static electricity is an electric charge in its stable state and is created when two materials or objects previously in contact are separated from each other. The surface electricity charges try to maintain balance with each other while the objects are in contact. Separating the objects in contact causes them to become electrically charged since either of them are left with shortage or excess of electrons. The charges continue on the increase if static electricity is not eliminated immediately. Hence, the charges become static and unable to move if they do not have a path to the ground until it finally develops sufficient energy enough to jump as a spark to any less highly charged nearby object. In a flammable or highly explosive atmosphere, the spark is capable of setting off a fire or explosion. The danger is greater when flammable liquids are being spilled.

Static electricity can therefore be produced by;

i. The movement of dry powdered material through the conveyors.

ii. The non-conductive drive belts movement.
iii. Filling tanks and movement between materials.
iv. Appliances plugged into an electrical outlet.
v. Flipping a light switch on or off.
vi. The flowing of hydrocarbon liquid through a hose or pipe.
vii. Spraying and blending.

The control of static electricity can be achieved by;

i. Static collectors.
ii. Humidification.
iii. Additives.
iv. Bonding and grounding.

2.3.4 Metering and Storage of Crude Oil

The management and monitoring of the natural gas and oil to be exported from the production facilities is carried out by operators through the metering station, with the aid of a specialized meter, the measurement of flow is done without hindering its flow rate through the pipeline. Custody transfer metering is an exchange of ownership between the produce metered volume from a producer to a customer or within different department of the same company and forms the invoice for the sold product. The metering station comprises of a cluster of meters functioning in a dependent way, as such a meter is in dual communication with other installed meters in other to be able to handle the full capacity range associated with the prover loops. Governmental authorities are responsible for setting the exactitude requirements, testing and calibration of meter accuracy is done at regular time intervals. Crude oil storage in an offshore facility lacking a direct pipeline completely rely on the base or hull of the facility for storage, wherein a shuttle tanker is use in offloading the crude about once a week. With a larger production storage, there is an associated tank farm terminal which aid in the storage of different segment of the crude oil to counter the high rise in demand and transportation delays.

The plate 2.7 shows the crude oil storage tank in the oil refining industry.

Plate 2.7: Crude Oil Storage Tank (Devold, 2013).

2.4 Control System Instrumentation

Modern instrumented control systems are generally electrical, electronic, or programmable electronic system (E/E/PES). These engineered systems are individually and collectively described as control systems, and may be independent, or share elements such as the human interface, plant interface, logic, utilities, environment, and management systems. These functions are normally provided by alarm, protection (trip, interlocks, and emergency shutdown), and process control systems.

2.4.1 Transmitters and Transducers

The operation of complex industrial plants would be difficult, if not impossible, without the measurement and control of critical process variables. Large plants typically have hundreds or thousands of process variables that are repetitively measured on-line every few seconds or minutes. In addition, important product properties are measured in quality control labs less frequently - e.g., once per hour, once an eight-hour shift, or daily. Consequently, the design and maintenance of accurate, reliable measurement systems is a critical aspect of process control. The lack of an authentic, cost-effectual, on-line sensor can be a major setback on the efficiency and effectiveness of a process control system. A physical variable is measured by a sensor which produces a physical response (e.g., mechanical or electrical) in relation to the value of the process variable. For example, in the stirred-tank heating system in Fig. 2.7, as the temperature of the liquid increases the thermocouple generates a millivolt electrically increasing signal. However, for the measurement of temperature in the control calculations to be used, the millivolt level signal must be converted to an appropriate current or voltage signal in a standardize input range for the controller. This conversion is done by a transmitter.

The figure 2.1 shows the controller / process interface. Where M, C and A are Measuring device, Controller and Actuator respectively.

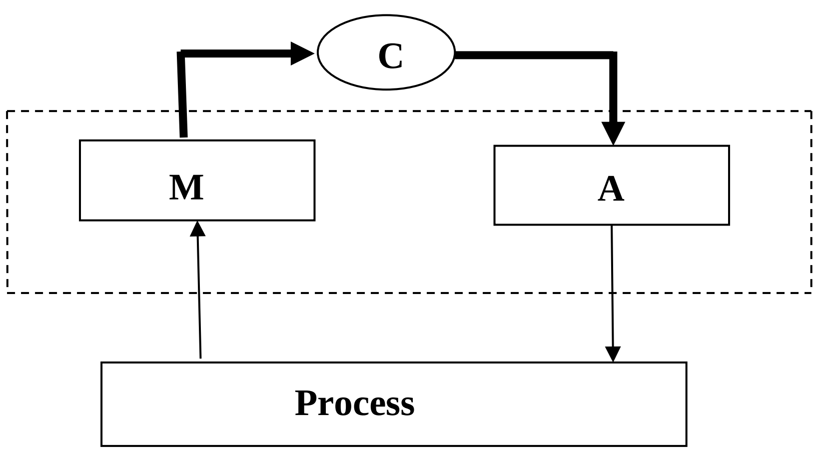

Figure 2.1: Controller / Process Interface.

In the process control literature, the terms transmitter, sensor-transmitter, sensor and transducers are used less or more interchangeably. It is essential to convert an instrumentation signal from one state to another, an electronic device that converts a physical force into an electrical signal so that it can be easily handled and transmitted for measurement is referred to as a transducer. To determine the exact magnitude of physical forces such as temperature and pressure is difficult. But if these physical forces are converted into an electrical signal, then their values can be easily determined using a meter. The required conversion is performed by a current-to-pressure (I/P) transducer, voltage-to-pressure (E/P) transducers are also quite common, one common application is when the controller output signal is a current signal, and the final control element is a pneumatic control valve.

2.4.2 Standard Instrumentation for Signal Levels

In earliest 1945, instrumentation utilizes pneumatic (air pressure) signals to transmit measurement and control information exclusively in the process industries. These devices make use of mechanical force balance elements to generate signals in the range of 3 to 15 psig, an industrial standard. Since about 1950, electronic instrumentation has become predominant. The standardize signal ranges for analog instruments are 4 to 20 mA and 1 to 5 V, direct current (VDC).

Selection Criteria: The following factors should be considered in the selection of a device for measurement;

i. *Materials of construction*; The instrument may need to withstand high temperatures, high pressures, corrosive and abrasive environments as seals or purges may be essential for some applications.

ii. *Electrical classification*; If the sensors are not inherently harmonious with affirmable exposure to hazards, suitable enclosures should be included in the installation costs.
iii. *Prior use*; Purchases of spare parts and training of maintenance personnel is highly essential, especially for the first-time installation of a measuring device at office.
iv. *Reliability*; Manufacturers provide baseline conditions where in previous experiences with the device for measurement is very important.
v. *Measurement range (span)*; The range of performance of the instrument determines the required measurement range for the process variable.
vi. *Performance*; Based on the type of application involved, accuracy, repeatability, or some other measure of performance is appropriate.
vii. *Invasive or non-invasive*; The insertion of a probe (invasive) can cause fouling, which leads to lack of accuracy in measurements. To minimize fouling and improving accuracy in measurements, the location of probe should be carefully selected.
viii. *Potential for releasing process materials to the environment*; Sterility in bioprocesses must be maintained. For maintenance personnel, it is highly important to prevent exposure to fugitive emissions when the process fluid is toxic or corrosive.

2.5 Process Control and Measurement

Continuously changing variable data and control methods are often required in process control. Process variables such as temperature, pressure, flow, and level are sensed, transmitted, and converted for continuous or batch processing by a wide variety of instrumentation.

Some of the most common variables used for process control are temperature sensor, differential pressure, flow rate, liquid level, and chemical composition.

2.5.1 Temperature Sensors

The most common type of temperature sensors are resistance temperature detectors (RTDs), filled systems, pyrometers, and thermocouples. Measurement principles are respectively based on the measurement of volumetric expansion, resistance as a function of temperature, electromotive force generated by two unlike metals and wavelength of radiated energy. Thermocouples and RTDs can be used up to 1000 °C, although RTDs are much more accurate. Pyrometry is typically used above 900 °C (e.g., in high temperature applications such as combustion). Fewer options include surface acoustic wave (SAW), which measures attenuation and frequency shift as a function of temperature on a solid surface and semiconductors whose resistance varies with temperature.

2.5.2 Differential Pressure

For pneumatic instrumentation, pressure sensing is quite straight forward. A bourdon tube, bellows or diaphragm isolates process gas or liquid from the instrument at the time of furnishing a deflection to a force-balance element that generates a proportional signal in the range of 3 to 15 psig. For electronic instrumentation, strain gauges are often used in converting pressure into an elongation of resistance wires which changes a millivolt-level emf. This signal is therefore amplified to an appropriate current or voltage range. A pressure difference can be measured similarly by placing the two process pressure connections on either side of a diaphragm. Electronic measurements typically use a strain gauge to convert the diaphragm deflection in differential pressure instruments in the same way as in pressure measurement instruments.

For many processes, the liquid or gas streams cannot be brought into direct contact with the sensing element (diaphragm) because of high temperature or corrosion considerations. In these cases, an inert fluid, usually an inert gas, is used to isolate the sensing element.

More recently, fiber-optic sensors have been developed to measure pressure in high temperature environments (Krohn, 2000).

The Plate 2.2 shows a Multivariable transmitter used in measuring several process variables.

Plate 2.2: A multivariable pressure transmitter that measures absolute pressure, differential pressure, and temperature (Devold, 2013).

2.5.3 Liquid or Gas Flow Rate

For a flow transmitter selection, the following factors must be put into consideration; the nature of the material in flow (liquid /solid /gas), volume vs mass measurement, nature of the signal, accuracy and cost, space availability, corrosiveness, and necessary maintenance.

With the use of the pressure drop across a venturi or orifice as the input signal to a conventional differential pressure instrumentation, flow rate can be measured. Therefore, the volumetric flow rate is directly proportional to the square root of the pressure drop. Normally the orifice plate is sized to provide a pressure drop in the range of 20 to 200in of water, but this approach is not very accurate (±5%) compared to venturi meters (±2%). Volumetric flow rates can also be measured using turbine flow meters. The pulse output signal can be modulated to give an electronic signal which can be totalized in a counter and sent periodically to a controller.

Deflection of a vane inserted in the pipe or channel also can be used as a flow sensor, such as in a target meter or a vortex shedding meter. Magnetic flow meters are used to measure volumetric flow rates of conducting fluids. Mass flow meters that are independent of changes in viscosity, pressure, temperature and density including the Coriolis meter and the thermal mass meter. Thermal mass meters are widely used in semiconductor manufacturing and in bioprocessing for control of low flow rates called mass flow controllers, or MFCs. MFCs measure the heat loss from a heated element which varies with the flow rate, with an accuracy of ±1%: Coriolis meters uses a vibrating flow loop that undergoes a twisting action due to the Coriolis effect.

The amplitude of the deflection angle is converted to a voltage that is nearly proportional to the liquid mass flow rate, with an accuracy of ±0.5%. Sufficient space must be available to accommodate the flow loop and pressure losses of 10psi should be allowable. Capacitance probes measure the dielectric constant of the fluid and are useful for flow measurements of slurries and other two-phase flows. The accuracy of ultrasonic meters has been improved during recent years owing to better sensors and software for analysis of the wave patterns, they are attractive because of their noninvasive nature and the absence of moving parts that can wear out.

2.5.4 Liquid Level

The position of a free float or the buoyancy effects on a fixed float can be detected and converted to level if the liquid density is known. The difference in pressure between the vapour above the liquid and the bottom of the liquid can be similarly used. Pressure taps (tubes connected from the transmitter to the appropriate process locations) can be kept from plugging by maintaining very low flows of inert gas through the taps to the process. The attenuation of high-energy radiation (e.g., from nuclear sources) by the liquid also can be used when solid material or gas streams cannot be in contact with process liquids.

2.5.5 Chemical Composition

Chemical composition is generally the most challenging on-line measurement. Before the era of on-line analyzers, technologist was required to deliver samples to the laboratory for analysis and results were returned to the control room. The duration of time involved in analyzing the samples prevent process adjustment from being carried out in good time and quality of product is being affected. The on-line analyzers development has automated this approach reducing the delay in analysis time. However, where few instruments are commercially available, manual sampling is still frequently employed, especially in the specialty chemical industry. Since a chemical composition analysis system is usually too expensive, it is essential to assess the returns on investment vs. the cost of manual sampling. Potential quality improvements become an important consideration. Measurement of a specific concentration involves the use of a unique physical or chemical attribute, specific instruments must be chosen depending on the nature of the species to be analyzed, in order to obtain quantitative composition measurements. In infrared (IR) spectroscopy, the vibrational frequency of specific molecules like CO and CO_2 can be probed by absorbing electromagnetic radiation.

Ultraviolet radiation analyzers operate similarly to infrared analyzers in that the degree of absorption for specific compounds occurs at specific frequencies and can be measured. Turbidity, an indicator of cell mass in a bioreactor can be measured by absorbance in a spectrophotometer. Magnetic resonance analysis uses magnetic moments to discern molecular structure and concentrations for both chemical and biochemical systems. Significant advances have occurred during the past decade to obtain lower cost measurements in some cases, miniaturizing the size of the measurement system in order to make on-line analysis feasible and reducing the time delays that often are present in analyzers. Recently, chemical sensors have been placed on microchips, even those requiring multiple, physical, chemical, and biochemical steps (such as electrophoresis) in the analysis. These devices have been called lab-on-a-chip. The measurements of chemical composition can be direct or indirect, the latter case referring to applications where some property of the process stream is measured (such as refractive index) and then related to composition of a particular component.

In gas chromatography (GC), the thermal conductivity is used to measure concentration. The GC can measure many components in a mixture at the same time whereas most other analyzers can only detect one component. Hence, GC is widely employed. A gas sample (or a vaporized liquid sample) is carried through the GC by an inert gas and components of the sample are separated by a packed bed. Because each component has a different affinity for the column packing, it passes through the column at a different time during the sample analysis, allowing individual concentrations to be measured. Typically, all components can be analyzed in a five to ten-minute time period (although miniaturized GCs are faster). The GC can measure concentrations ranging from parts per billion (PPB) to tens of percent, depending on the compound. High-performance liquid chromatography (HPLC) can be used to measure dissolved solute levels, including proteins. Mass spectroscopy (MS) determines the partial pressures of gases in a mixture by directing ionized gases into a detector under a vacuum (10 - 6 torr), and the gas phase composition is then monitored more or less continuously based on the molecular weight of the species. Sometimes GC is combined with MS in order to obtain a higher level of discrimination of the components present. As an example, complete analysis of a combustion gas requires multiple on-line analyzers as shown in the table 2.3.

Table 2.3 Combustion Gas with Multiple On-line Analyzers (Steven et al, 2015).

S/N	COMBUSTION GAS	FORMULAR	ANALYZER
1	Ozone	O_3	UV Potentiometer
2	Sulphur dioxide	SO_2	UV fluorescence
3	Nitroxide	NO	Chemiluminescence
4	Carbon monoxide	CO	Infrared
5	Carbon dioxide	CO_2	Infrared
6	Trace hydrocarbons	CH_4	GC/MS

Fiber-optic sensors are alternative options (but more expensive) for acquiring measurements in harsh environments such as high temperature or pressure. The transducing technique used by these sensors is optical and does not involve electrical signals, so they are immune to electromagnetic interference. Raman spectroscopy uses fiber-optics and involves pulsed light scattering by molecules. It has a wide variety of applications in process control. Many composition measurements are both difficult and expensive to obtain. Indirect means of measuring concentrations are often less expensive and faster for example, relating the mole or mass fraction of a liquid component to pH or conductivity or the concentration of one component in a vapor stream to its IR or UV absorption. Often an indirect measure is used to infer composition; for example, the liquid temperature on a plate near the top of a distillation column might be used to indicate composition of the distillate stream.

A related approach is to use a process model as a soft sensor to estimate process variables that cannot be measured in real time. For example, Predictive Emissions Monitoring Systems (PEMS) relate trace pollutant concentrations to operating conditions such as temperature, pressure, and excess air.

2.6 Calibration of Temperature Instrument

Temperature devices in process manufacturing environments provide measurements to the process plants' control systems. The performance of these temperature instruments is often critical to optimize operation of the process manufacturing plant or proper functioning of the plant's safety systems. Process temperature instruments are often installed in harsh operating environments, causing their performance and the performance of their sensors to shift or change over time. Keeping these devices measuring temperature within expected limits requires periodic verification, maintenance, and adjustments.

Calibrating and Testing of RTD sensors

Typically, RTDs are checked while calibrating the connected device, such as a panel meter or temperature transmitter. However, if a problem is suspected with a temperature sensor, sensor calibrations can be performed separately from the calibration of process electronics. Field checks of temperature sensors can be easily performed with a dry-block or Micro-Bath. For best results, a full calibration of a temperature sensor is performed at the bench. Here are a few tips to consider before getting started:

i. Dry wells have inserts that are interchangeable and have a variety of hole patterns to accommodate various probe sizes. Avoid placing fluids in a dry well if fluids are required use a Micro-Bath instead.
ii. To achieve published performance levels, the insert's hole size should be no more than a few hundredths of an inch larger than the probe being calibrated.

2.7 Review of Related Literatures

We present a brief review of all the similar research works, various approaches and techniques used by previous researchers in the field of control systems relatively in existence to our work.

2.7.1 Hazard Analysis of Crude Oil Storage Tank Farm (Ibrahim and Syed, 2018).

Ibrahim and Syed, (2018) in their paper entitled, "Hazard Analysis of Crude Oil Storage Tank Farm." Observed the historical analysis of accident which shows that 17% of industrial major accidents were during storage processes. The NFPA report of 2009 infer that 13% of fire accidents that took place in the USA occurred in storage farms, leading to injury or death for staffs, millions of dollars losses and huge environmental pollution.

The Bhopal disaster in 1984 causes thousands of fatalities and injuries. The possible hazards are a function of the quantity involved and inherent nature of the chemical, thus they found it necessary to conduct a sound and competent hazard analysis of the oil storage facility to figure out the possible damages to life and property in order to make it easier for the decision makers to be satisfied with the safety levels in the storage tank farm.

Hazard Analysis is an important process and plays an effective role in the studies related to hazardous chemical handling. Hazard Identification (HAZID) is the first step in any hazard analysis process and involves the finding of all potential accidents in the facility. The Hazard and Operability (HAZOP) study is a systematic review of the design and operation of the system to predict the possible accidental leaks of hazardous material (Mistry, 2012).

They inferred that the defined hazards can be analyzed using tools such as fault tree analysis (FTA) and event tree analysis (ETA). FTA is a deductive and systematic approach that concentrates on hazardous outcomes and investigates the basic causes that result to such undesirable outcomes (Zhao-mei, 2011). FTA is therefore used widely in hazard analysis of the several storage facilities. ETA is an inductive and graphical tool that presents all the final consequences resulting from a specific initiating event while considering the states (failure/ success) of the installed safety measures.

They further suggest that the frequent accidents can be evaluated by using ETA if the data of events are known. Otherwise, it can be obtained from databases such as (OGP) oil and gas operations (OGP, 2010) or (HSE) health and safety environment (HSE Manual, 2006).

The major goals of their studies are.

i. To provide all preventive measures which assist in adverting injuries and accidents in the storage tank farm.
ii. To guarantee protection for staffs, equipment as well as maintain safety at workplace.

The conclusion of their study was summarized as follows.

i. Hazard analysis study of crude oil storage tank farm was successfully carried out.
ii. HAZOP study has established all potential deviations in parameters from design of pressure, flow and level which could lead to oil leakage therefore result in unsuitable events such as explosion and fire.
iii. Fault Tree Analysis of crude oil storage tank explosion and fire has been drawn. The quantitative and qualitative evaluations were conducted.
iv. Maximum attention must be given to the identified causes to minimize possibilities to lighten the severity of accidents.
v. Using ETA, the analysis for a crude oil leakage was frequently carried out. The results indicates that there is a high frequency in pool fire than any other accidents.

2.7.2 Flammability of Emulsions on Hot Surfaces (Deleanu et al, 2015).

Deleanu et al, (2015) in their paper entitled, ''Flammability of Emulsions on hot Surfaces.'' Discovered that the combine effect of temperature and pressure result in high risk of fire therefore, one must be extremely careful in designing these systems and fluids-based selection should be on the basis of a fire tests. The resultant effect of explosion caused by these fluids which includes fuels and lubricants are too severe with regards to human and financial resources of the economics of an organization (Yuan, 2006).

The high enthusiasm in fire test systematization is on the increase because of several applications, grades of fluids and innovative design solutions requiring advance parameters in exploitation, including temperature and pressure (Prista, 2011). They also emphasized the need of minimizing this flammability risk when utilizing industrial fluids particularly in explosive environment. But their prerequisite does not expressed recommendations for specific design solutions and fluids.

Hence, suggest that the interest in testing fluids on hot surfaces is sustained by the following;

i. There is definitely a possibility of leakage when using fluid; adequate maintenance as well as design solution may minimize the risk of such events, but may not completely eradicate it.
ii. Accidental ignition of fluids on hot surface produces huge losses which affect the performance of the organization by reducing supply and transport processes thereby pose a threat to the health and life of human resources.
iii. Recent design solution involves a minimize volume of the machine; thus, there could be an increase rate in hot surfaces. Although with the previous design solution especially with regards to load, speed and pressure this increase could be higher with a lower working parameter.

iv. Hot surfaces are mostly ignition sources; they are either intentionally generated as a result of the process or accidentally because of insufficiency in lubrication, malfunctioning of the electric system or, human errors in controlling the system.

Modern research work has shown that emulsions play an important role in minimizing the flammability risk, particularly in hazardous environments such as mining exploitations and in heavy industries. Likewise, the risk of fire exists in all other fields of activities, as thermal treatment of metal alloys, cold rolling (Dubey et al, 2005) and metal cutting.

In their conclusion, they observed that unlike the auto-ignition temperature and flash points which are considered as a well-defined fire feature (Zink, 2005), the flammability features on hot surface are not significant properties of the fluid and are strongly related to the part of factors involved in tests: the means through which the fluid reaches the surface (spray, droplets, stream etc.), material and size, surface shape, local air flow and the fluid quantity (Hu et al., 2010).

Using the test processes described in SR EN ISO 20823:2004 data derived have to be carefully integrated in choosing fluids and designing systems for minimizing the fire risk stimulated by the possibility of having locally high temperature surfaces and a fluid flow on them (Kadota et al., 2007).

2.7.3 Development of Microcontroller Based Temperature and Lighting Control System in Smart Home (Tharaphe and Aung, 2014).

Tharaphe and Aung, (2014) in their paper captioned, ‘‘Development of Microcontroller Based Temperature and Lighting Control System in Smart Home.’’ The paper describes the use of microcontroller in temperature control application. In order to reduce costs and optimize production, in many applications it is necessary to control the change.

In their paper, integrated-circuit temperature sensors were used as the input sensor, analog signal was used as the type of output, ON/OFF control as the control algorithm and heating and cooling system as two outputs are selected to control the temperature condition.

The main essence of their study was to develop the room temperature controller using PIC. To drives the external equipment's while keeping the rooms temperature at the preset temperature, this device utilizes the use of four different temperature sensors. In other to reduce the high cost of electricity, the heating system is used to adjust the temperature of the room automatically as to avoid the constant use of an air conditioner. The result indicates the efficiency and effectiveness of the control scheme developed as it ensures energy saving in the smart home for high tariff consumption home appliances when compare with the existing ordinary home systems, since energy saving is an important issue nowadays.

The microcontroller program determines the lights to switch on/off and the cooling/heating setting. Temperature control system depends upon a controller responsible in sending signals from the temperature sensors such as a thermistor, thermocouple or Resistive Temperature Detector (RTD) and embedded circuit sensor to specifically control the temperature of a process without the involvement of an external operative and equates the actual temperature with the desired set point or controlled temperature and supply the output to a control element.

The PIC microcontroller is used in controlling the heating and cooling system operational environment and to observe the temperature data both inside and outside of a building in order to drive the external heating and cooling system. They also observed that the material properties of buildings such as walls, floor, roof and windows have central thermal conductivity which allow circulation of warm or cold air in the house which influence the thermal performance and their energy consumption patterns.

The energy consumption rate solely depends on the house characteristics, specifically on its geometry. Therefore, the house geometry is defined by the numbers of rooms assumed to be from 1 to 6, using the average height, width and length of walls, doors and windows to determine the size of the house. The sensors are assumed to be placed in master bedroom, secondary bedroom, living room and kitchen room. The use of the LM35 temperature sensor was deploy in the temperature system in taking the reading of the temperature value, the LM35 sensor takes care of non-linear effects and has an integrated circuit that outputs a voltage proportional to the temperature value in degree Celsius hence referred to as the easiest of the temperature sensors. The microcontroller PIC18F4550 which is directly connected to the LM35 temperature sensor reads the signal as a variable analog value from the sensor and process a heating or cooling signal to the temperature system.

The smart home technology ensured flexibility and absolute functionality that is far better than the conventional installation of environmental control systems, the control of the temperature system as well as the lighting and security system was the main essence of their paper as a smart home will certainly guarantee an automated, fully secured and efficient energy system.

2.7.4 Temperature and Level Control of a Multivariable Water Tank Process (Vassilios and Matthew, 2013).

Vassilios and Matthew, (2013) in their research a Multivariable Water Tank Process uses a metal tank of 39gallon capacity in storing water, several instruments were used to achieve full control of the water level and temperature. A general-purpose Echo pod Dl14 sensor was used on measuring the water level with a 4 – 20 mA signal output, the level transmitter is connected to the input card of the distributed control system (DCS) and calibrated to read up to a maximum of 25 inches. The water tank is having a fixed cross-sectional area while having the inflow and outflow rate of the water greatly affecting its height, the inflow rate of the tank can be manually altered as to arouse a process disturbance since it cannot be accessible for control purposes, the supplied power to the pump can be manipulated to enable the control of the tank's water level upon which the outflow of water depends. By adjusting the electrical power, a heating element ensures that the amount of energy needed to set the temperature of the water is maintained. The system control essence is to sustain the measured temperature by the TT transmitter and the preset value of the water level measured by the LT transmitter with the aid of the closed loop feedback control strategies utilizing the (LC and TC) PI controllers respectively on a Delta-V distributed control system.

The control system measure used in this project is Emerson Delta-V Distributed Control System which uses an I/O module to control numbers of control loops and a standard PC hardware for the user interface paired with the proprietary controllers, the distribution of the hardware can be done throughout the process plant connected through a foundation field bus module. A thermocouple card, analog input and output card were used for the process, the implementation of the temperature and level control were strategically carried out with the aid of two PI controllers.

The user interface section of the implemented system was configured to enable the user supervise the control actions of the tank process, with the aid of these faceplates the user will be able to interchange the mode of the controllers from manual to automatic and adjust the set point of the controllers in automatic mode while improving the effectiveness of the controller by determining the values for the integral time and proportional gain to be reset in Delta-V terminology.

They concluded with the design of two feedback, single input and output control interface to control an interactive, multivariable and experimental process. The tank water level and temperature are the controlled variables, modeling results using analytical step test based, empirical step-test based and first principles-based method approach were presented. There was a close understanding between the empirical and analytical models. For improved closed loop performance, calibration of the proportional-integral-derivative (PID) controllers was carried out with the aid of the internal model control (IMC) tuning method.

2.7.5 Temperature Control of Liquid Filled Tank System Using Advance State Feedback Controller (Kunal et al, 2015).

Kunal et al, (2015) in their project entitled, ‘‘Temperature Control of Liquid Filled Tank System Using Advance State Feedback Controller.’’ Presented that the measurement of temperature of a tank’s liquid can be controlled by advance and classical control algorithm. Hence, consider the non-interacting system comprising of a three tank and observe how the dynamic behaviour of tank 1 affecting that of tank 2, consequently the dynamic behaviour of tank 2 affects that of tank 3 and vice versa since the flow rate is a function of the difference in the liquid level h1 and liquid level h2 (Ang et al, 2005). The temperature and the liquid level in the tank are greatly affected by any change in the inlet flow rate which result in a thermal process using the various types of thermistors, temperature sensor RTD and T/C (Considine, 1974).

In their project a mathematical model for the three tanks method resulted in a third order differential equation in which a mercury thermometer was deployed as the temperature sensor and a transfer function of the first order system is obtained from each of the tanks, which makes it easier in confirming that the requisite result was actually given to a particular algorithm (Bently, 1995). Several works were carried out in the stabilization of a temperature control system as well as in controlling the temperature measuring system response, the method was utilized in investigating the designed controller’s global properties (Brian, 2008).

Their system consists of a mercury-in-glass thermometer placed in a liquid tank which is used in measuring the liquids temperature when heated by a steam through a coil system, the liquid temperature Ta varies with time and the mercury temperature of the thermometer in the well is represented by T (Bela, 1999).

The transfer function in relation to the variation of the thermometer T for a change in the liquid temperature Ta can be determine with the following assumptions.

i. The contraction or expansion of the glass walled well containing mercury is negligible.
ii. The only resistance to the heat transfer is the liquid surrounding the bulb.
iii. The isothermal condition was assumed by the mercury.

In their conclusion, they inferred that the three-tank temperature measuring system modelling shows instability in the system for a given range. Hence, the need to design a conventional controller strategy process in other to be able to maximize the settling time while reducing the steady state error and propose the use of genetic algorithm in designing the controller for their future works.

2.7.6 Design and Implementation of Microcontroller Based Programmable Smart Industrial Temperature Control System (Ruhul et al, 2018).

Ruhul et al, (2018) in their paper entitled, "Design and Implementation of Microcontroller Based Programmable Smart Industrial Temperature Control System." Observed that several heating and cooling function exist in almost every industry for example textile miles, pharmaceuticals, power station and so on. Smart control of temperature is an important task for smooth running of industries. Each part of industry has particular temperature requirement which is to be acquired during production hour. It is highly important to observe and control the precise temperature of a process in an industry and this was earlier carried out manually with the aid of the manometer and thermometer. To effectively and efficiently monitor and control temperature a progress in data logger which had earlier existed took place in the 1990 as researchers began to develop PC based data logging system. The temperature controller with a single chip is designed and programmed in a single programmable system on chip with mixed array logic consisting of an analog and digital communication block within it.

The compressed design through its computer-generated instrument program enables the selection of any type of control function by the user, this design could be connected straight to the PCs. An embedded system is used as a field processing unit with the application mode of B/S, the web based distributed control and measurement with programmable single-wire digital temperature sensor DS18B20, a remote temperature control and measurement system is designed by embedded functionality. In case of variable temperature requirement, manufacturing operator can also select multiple options for controlling temperature with displaying necessary information in the display. Number control applications have been already developed in electrical engineering for controlling the automatic system. Microcontroller can also be used to control light smoothly. In their paper, PIC 16F876A microcontroller was used to design temperature control system for casting process. For selection of proper temperature, a variable resistance with LM35 sensor is used. From the concept of Temperature Control Proficiency, to increase the production of an industry smooth control of temperature is the key function. Various industry has its precise required temperature for different roles. Conventionally, the temperature instrument thermometer is used in measuring the industrial temperature. After careful observation of temperature reading, operator manually controls the temperature. Most at times controlling is not appropriate since it requires sufficient timing of human operated control of cooling and heating device. Hence, efficiency of temperature control is not achieved and production is hindered in industries. While, thermostat is used in selecting efficient-less temperature because of erosion of metal and degradation in strength of metal for subsequent utilization. Consequently, analog system loses linearity function since it is a mechanically designed temperature control device. Therefore, temperature can be controlled efficiently using the interface between microcontroller which takes response fraction of millisecond to response and temperature sensors LM35 which produce linear voltage signal with rising temperature. Microcontroller takes signal from temperature sensor and compare with pre-set value of temperature then take decision when heating device or cooling device would be turned on and the duration of maintained temperature in system.

They concluded that microcontroller-based temperature measurement and controlling system which contains few basic elements having couple of lines control code using Micro-C has been designed. The system measures temperature using LM35 temperature sensor device and compares the results with standardize industrial thermometer value having negligible deviation. It also keeps maintenance of laboratory temperature at constant level. The hardware validation shows that the temperature can be maintained between 39 ^{0}C to 41 ^{0}C which is displayed in LCD. In addition, a control knob has been used to set temperature according to application having a range of selection choice.

2.7.7 Microcontroller Based Temperature Monitoring and Closed Loop Control to Study the Reaction of Controlled Variable with Respect to Load Changes (Reetam and Sagarika, 2013).

Reetam and Sagarika, (2013) in their paper entitled, "Microcontroller Based Temperature Monitoring and Closed Loop Control to Study the Reaction of Controlled Variable with Respect to Load Changes." Says that Chemical and Physical reactions are erogenous to temperature so therefore, temperature control is essential in various industrial processes. Temperature controllers using digital computers as a central unit have by merit of their computing power features such as programmability, adaptability and high accuracy.

The output produce by the temperature sensor is in a current or voltage form, a high precision A/D converter is needed for interfacing the sensing device with the microcontroller or the computer. Many innovative temperature control techniques have been developed in recent times. (Kaliyugavaradan S, 1997), designed a microcontroller based programmable temperature controller using RTD as temperature sensor and was able to implement a PID algorithm to control the firing angle of silicon-controlled rectifier (SCR) in controlling the applied power of the heater. (Diamond, 1971) presented a triode for alternating current (TRIAC) phase control circuit in response to the amplitude of a sine wave signal of line-frequency. The optically assembled TRIAC driver circuit operating on the normal range of 115 V ac line concise specification is given by (O'Neil et al, 1978). The device ensures optical isolation of the line TRIAC from the logic trigger signal and performs the logic necessary to guarantee TRIAC triggering only at zero crossing of the AC line voltage.

The Temperature control system consists of a process tank containing a microcontroller along with 8255 programmable peripheral interfaces, 220 V 3A 50 Hz Heater, RTD Temperature Sensor, Signal Conditioning Circuit, ADC circuit, zero crossing detector for zero reference and TRIAC Opto-isolator which gives an output pulse depending on the temperature of the process tank. The process tank or heating chamber used in the design houses a resistive heater, a holder which is capable of holding both the temperature sensor or RTD and the Liquid-in-glass thermometer used in reading the temperature attained.

In their conclusion, A temperature control system technique using an RTD as the temperature sensor was ascertained. The effectiveness of the design method of the temperature control system has the advantages of human-computer interface friendliness, convenience and versatility, low cost and simple hardware, high temperature control precision, etc. The RTD signal conditioning circuit which consist of RTD in one of the arms of the Wheatstone bridge was designed effectively using OPAMPs and resistors. The bridge output is fed to the Signal Conditioning Circuit, which consists of Summing Amplifier, Instrumentation Amplifier and an Inverter to produce the output with a correct sign.

The variation of the RTD resistance with an up rise in temperature of the process tank is almost linear. Since an offset error is obtained with Proportional-control, Proportional-Integral control algorithm can be implemented to eliminate this offset. The performance of the system can also be improved by choosing microcontroller chip, which performs better than 8051 chips and the detailed comparative analysis of the control algorithm adopted based on their repeatability, accuracy and cost may constitute the future scope of work.

2.7.8 Large-Scale Wireless Temperature Monitoring System for Liquefied Petroleum Gas Storage Tanks (Guangwen et al, 2015).

Guangwen et al, (2015), in their paper captioned “Large – Scale Wireless Temperature Monitoring System for Liquefied Petroleum Gas Storage Tanks”. They said that over the decades in China there has been a sharp increase in demand for energy resources, it was estimated in 2014 that 20% of the global energy consumption rate occurred in China ranking them the first in the world (Yuan et al, 2015). The rate of growth in energy consumption will sustain an average speed of 4.5% in the next 30 years and will result in the consumption of 82 billion tons of coal, 12 billion tons of crude oil, and 5.8 trillion of natural gas (Xie et al, 2015). They also discovered that of all the various kinds of energy resources, the Liquefied Petroleum Gas (LPG) is recognized for its environmental friendliness, convenience and efficiency. It is these specific features that makes the LPG a perfect choice for refrigeration, motor fuel, rural heating, and cooking. Although the LPG is a dangerous chemical with a very high rate of flammability and explosiveness (Yun P, 2013). Accidents related to LPG storage tanks result in tremendous destruction of properties and life on a yearly basis (Jian et al, 2012). Since the LPG storage tank explosion accidents generally threaten lives, through monitoring technology the safe operation of the LPG storage tanks can be ascertained.

They inferred that among various monitoring parameters such as pressure, refractive index, temperature, displacement, strain, vibration, etc., temperature is the most crucial factors to guarantee the safe status of the LPG storage tanks (Chen et al, 2004); (Fei et al, 2012), designed a real-time distributed measurement system that is based on the field bus technology for large-scale oil tanks. The system utilized optical fiber sensors to collect the oil tank's data, Ethernet to achieve long-distance data transmission by RS-485 and using a computer to analyze the data collected, monitoring and management of oil tanks is intelligently actualized. (Lei et al, 2014), proposed a multi-point temperature monitoring system based on infrared thermal imagers for the Liquefied Nature Gas (LNG) storage tank monitoring. (Liu et al, 2011), proposed to use of fiber Bragg grating sensors to conduct real-time measurements of the pressure and temperature of the gas tanks.

To solve the numerous challenges affecting the existing temperature monitoring systems, (Guangwen et al, 2015) designed an integrated monitoring system which combines a large-scale sensor network, fiber optical high-temperature sensors, wireless temperature sensors, and a management software to sense, collect, store, display, and manage the monitored data.

The main conclusions of their study are outlined below in the following points.

i. The monitoring system hardware which includes wireless temperature sensors, onsite monitoring system, fiber optic high temperature sensors and the remote access system was developed which allows multi-parameter monitoring, local and remote access, wireless sensing and harsh environmental adaptation.
ii. Software for the monitoring system was developed which automatically calculates the maximum history temperature, its changing rate and configure the sensors and diagnose the health of the sensor, data acquisition interval and display the monitoring parameters both in history curves and 3D vision.

iii. The developed system feasibility was validated, and it can be applied in the monitoring of the LPG storage tanks, other chemical storage tanks which will greatly improve the reliability and safety management of these essential facilities.

2.8 Literary Criticism of the Reviewed Literatures and Gap Obtained.

With a vast number of approaches, the practice of literary criticism has created a space and context for we to create works of literature that push boundaries and break new creative ground in the reviewed related literature in existence to our research work.

2.8.1 Summary of the Reviewed Literatures

Ruhul et al, (2018) in their assertion, observed that Smart control of temperature is an important task for smooth running of industries. to increase the production of an industry, smooth control of temperature is the key function. Various industry has its precise required temperature for different roles. After careful observation of temperature reading, operator manually controls the temperature. Most at times controlling is not appropriate since it requires sufficient timing of human operated control of cooling and heating device. Thus, a microcontroller-based temperature measurement and controlling system which contains few basic elements with couple of lines control code using Micro-C was designed. They measured the system temperature using LM35 temperature sensor device and compares the results with standardize industrial thermometer value having negligible deviation.

Ibrahim and Syed, (2018) observed that the historical analysis of accident which shows that 17% of industrial major accidents were during storage processes and found it necessary to conduct a sound and competent hazard analysis of the oil storage facility to identify the possible damages to life and properties to make it easier for the management to be satisfied with the safety levels in the storage tank farm. They inferred that the defined hazards can be analyzed with the help of analyzing tools such as fault tree analysis (FTA) and event tree analysis (ETA).

Guangwen et al, (2015), discovered that of all the various kinds of energy resources, the Liquefied Petroleum Gas (LPG) is recognized for its environmental friendliness, convenience, and efficiency. It is these specific features that makes the LPG a perfect choice for refrigeration, motor fuel, rural heating, and cooking. Although the LPG is a dangerous chemical with a very high rate of flammability and explosiveness. Accidents related to LPG storage tanks result in tremendous destruction of properties and life on a yearly basis. Since the LPG storage tank explosion accidents generally threaten lives, through monitoring technology the safe operation of the LPG storage tanks can be ascertained.

Kunal et al, (2015) Presented that the measurement of temperature of a tank's liquid can be controlled by advance and classical control algorithm. Hence, considered the non-interacting system comprising of a three tank and observe how the dynamic behaviour of tank 1 affecting that of tank 2, consequently the dynamic behaviour of tank 2 affects that of tank 3 and vice versa. In their conclusion, they inferred that the three-tank temperature measuring system modelling shows instability in the system for a given range. Hence, the need to design a conventional controller strategy process in other to be able to maximize the settling time while reducing the steady state error and propose the use of genetic algorithm in designing the controller for their future works.

Lorena Deleanu, (2015) discovered that the high enthusiasm in fire test systematization is on the increase because of several applications, grades of fluids and innovative design solutions required advance parameters in exploitation since the combine effect of temperature and pressure result in high risk of fire The resultant effect of explosion caused by these fluids which includes fuels and lubricants are too severe with regards to human and financial resources of the economics of an organization, they also emphasized the need of minimizing this flammability risk when utilizing industrial fluids particularly in explosive environment.

Tharaphe and Aung, (2014) they concluded that the main essence of their paper is to control the temperature system, security system and lighting system. Smart homes will certainly guarantee an automated, fully secured and efficient energy system while ensuring flexibility and absolute functionality that is far better than the conventional installation of environmental control systems. The result indicates the efficiency and effectiveness of the control scheme developed as it ensures energy saving in the smart home for high tariff consumption home appliances when compare with the existing ordinary home systems, since energy saving is an important issue in recent time.

Vassilios and Matthew, (2013) The Emerson Delta-V Distributed Control System is the control system measure deployed which uses an I/O module to control numbers of control loops and a standard PC hardware for the user interface paired with the proprietary controllers. The tank water level and temperature are the controlled variables, modelling results using analytical step test based, empirical step-test based and first principles-based methods approaches were presented. There was a close understanding between the empirical and analytical models. Calibration of the proportional-integral-derivative (PID) controllers was carried out with the aid of the internal model control (IMC) tuning method.

Reetam and Sagarika, (2013) affirms that the Chemical and Physical reactions are erogenous to temperature so therefore, temperature control is essential in various industrial processes. Temperature controllers using digital computers as a central unit have by merit of their computing power features such as programmability, adaptability and high accuracy. In their conclusion, A temperature control system technique using an RTD as the temperature sensor was ascertained and the effectiveness of the design method having the advantages of human-computer interface friendliness, convenience and versatility, low cost and simple hardware, high temperature control precision, etc. was designed. The variation of the RTD resistance with an up rise in temperature of the process tank is almost linear Since, an offset error is obtained with Proportional-control, Proportional-Integral control algorithm can be implemented to eliminate this offset.

2.8.2 Gap Obtained from the Reviewed Literature

From the reviewed literatures, we obtained a temperature controller that detects maximum temperature attained and trigger on a cooling system that cools the storage tank with processed product thereby preventing fire outbreak and accident in the tank farm. From the reviewed literatures of the concept of temperature control technique, to increase the productivity of oil and gas industry, smooth control of temperature remains the key function as it was observed that different industries have its own individual temperature requirement for specific role. To correct the abnormalities that usually result to fire outbreak, a new method of control system is proposed which will involve designing of a controller, that will control a temperature monitoring system and a cooling system will be incorporated into the controller so that when a petroleum product reaches its flash point, a cooling liquid will be showered on the vessel (tanks) automatically and continuously to reduce the temperature as quickly as possible. Since the essence of temperature control in the storage systems of process products is to ensure stability and safety.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

ASUS Laptop Computer was used in documenting the project work.

MATLAB / SIMULINK software version 7.9 R2009b was used for simulation of results.

Microsoft Visio Software was used in designing the cooling system.

Mendeley Desktop Research Package was used for reference.

3.2 Methods

Using the direct synthetic method, the steps taken in achieving the objective of the study and simulation of the designed system using MATLAB was presented in this section.

The figure 3.1 shows the block diagram of the storage tank control system.

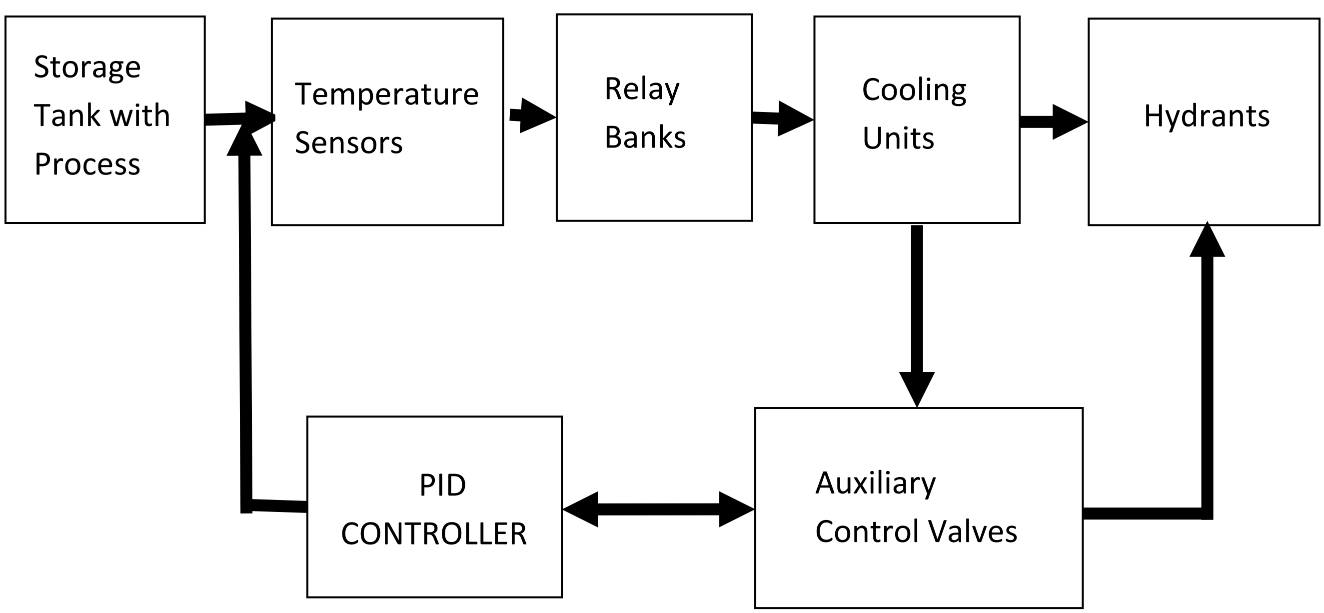

Fig. 3.1: Block diagram of the Storage Tank Control System.

A system is an arrangement of different components that act together as a collective unit to perform a certain task. The physical system is defined as the collective action of physical objects in a system to perform an objective. A control system is the interconnection of various physical elements connected in a way to regulate or direct itself or the other system.

The portion of the system that is to be controlled or regulated is known as plant of the process often referred to as a transfer function which specifies the relationship between the input and output of the system without feedback. The sensors are used to measure the plant's output while actuators drive the plants input. The controller is the element of the system that controls the plant or process. The controller in the control system is a mechanism that reduces the difference between the actual value and desired value of the system.

The reference input in a control system acts as the basis for error-controlled regulation using negative feedback for error control. The inputs are excited into the system and the outputs are the processes results of that inputs. Disturbances are a type of signal which adversely affects the output value of the control system, it can be internal or external. The internal disturbances that arise in the system itself and the external disturbances are generated outside of the system.

Algorithm of Methodology

i. Determine the Temperature Range.
ii. Design and Modeling of the Controller.
iii. Design and Modeling of the Cooling Unit.
iv. Coupling of the Temperature Controller and Cooling Unit.
v. Simulation of the Coupled System.
vi. Validation of the Research.

3.2.1 Temperature Range of the Storage System

Theoretical models of process control are based on conservation laws such as the conservation of mass and energy. Thus,

Rate of mass accumulation = Rate of mass in – Rate of mass out (3.1)

Also,

$$E_A = E_{INC} - E_{OC} + H_{AD} + W \tag{3.2}$$

Where;

E_A = Rate of energy accumulation. E_{INC} = Rate of energy in by convection.

E_{OC} = Rate of energy out by convection.

H_{AD} = Net rate of heat addition to the system from the surroundings.

W = Net rate of work performed on the system by the surroundings.

The total energy of a thermodynamic system, E_A, is the sum of its internal energy, kinetic energy, and potential energy:

$$E_A = E_{in} + E_{ke} + E_{pe} \tag{3.3}$$

Assumptions.

i. Changes in potential energy and kinetic energy can be neglected because they are small in comparison with changes in internal energy.
ii. The net rate of work can be neglected, because it is small compared to the rates of heat transfer and convection.

From equation 3.2, the energy balance can be written as:

Total Energy Input = Rate of Energy Accumulation + Rate of Energy in by Convention

$E_{IN} = E_A + E_{INC}$ (3.3a) ; $E_{IN} = H_{AD} + W$ (3.3b)

From energy balance in thermodynamics, we define eqn. 3.3b as thus,

$$H_{AD} = \Delta\,(WH)\,(t) \tag{3.3c}$$

$$W = (Q + q)\,(t) \tag{3.3d}$$

Where; Q = rate of heat transformed from the system.

q = Reaction of the system to the surrounding which can be neglected.

Combining equations 3.3c and 3.3d we obtained.

$$E_{IN} = -\Delta\big(w\widehat{H}\big) + (Q + q)\,t \tag{3.3e}$$

$$\frac{dE_{in}}{dt} = -\Delta\big(w\widehat{H}\big) + Q \tag{3.4}$$

Where;

E_{in}	= the internal energy of the system.	H	= the enthalpy per unit mass.
Q	= the rate of heat transfer to the system.	w	= the mass flow rate.

The Δ operator denotes the difference between outlet conditions and inlet conditions of the liquid. Consequently, the $-\Delta(wH)$ term represents the enthalpy of the inlet liquid minus the enthalpy of the outlet liquid.

3.2.1.1 Resistance Temperature Detector (RTDs)

This is used in areas where high precision is needed and where narrow temperature span are required. Because the electrical resistance of a conductor changes as its temperature varies. The magnitude of the change with respect to 1°C changes in temperature is its temperature coefficient of resistance (Lei et al, 2014). Platinum = 0.00392 ohm/^{0}C over a range of 0°C to 100°C. It has a linear characteristic. Resistivity of platinum = 10 ohm – cm at 20°C

$$R_t = R_{rt}(1 + \alpha T) \tag{3.5}$$

$$\frac{dRt}{dT} = \alpha R_{rt} \tag{3.6a}$$

Where;

R_t = resistance in ohms, at temperature T. α = temperature coefficient of resistance.

R_{rt} = resistance in ohms at a reference temperature (often 0°C).

$$R = R_{rt}(1 + T + T^2 + T^3 + \cdots + T^n) \tag{3.6b}$$

To project the appropriate value of temperature greater than 1000°C or less than – 500°C.

We also calculate,

$$R = R_{rt}(1 + \alpha T + \beta T^2 + \gamma T^3 + \cdots) \tag{3.7}$$

Where;

β = imperial obtained from the manufacturer. Resistance value = 10 to 500 Ohms.

γ = temperature coefficient of the metal conductor.

Conductor diameter = 0.002 (standard from literature).

A piece of alloy can be connected in series or shunt connected internally to raise or lower overall resistance to standardize RTDs for interchangeability. The figure 3.2 shows the Wheatstone Bridge.

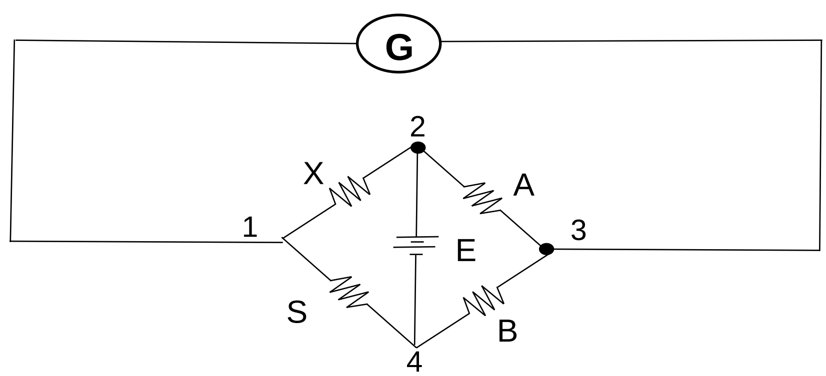

Fig. 3.2: Wheatstone Bridge, the basic circuit for the readout device.

Figure 3.2 can be adapted to give an indication analogous to temperature.

The resistance X represents RTD. The Galvanometer G (a sensitive DC current meter with zero center scale) can be calibrated to deflect accordingly. L which is the lead resistance as shown in figure 3.2 becomes a part of the X - terminal of the bridge circuit.

Since,

$$E = V_{21} + V_{14} = V_{23} + V_{14} \tag{3.8}$$

i.e., when the voltage at node 1 equals the voltage at node 2, galvanometer G will experience null (zero) indication.

Therefore, the ratio of the bridge components.

$$^{A}/_{(X+2L)} = {}^{B}/_{S} \tag{3.9}$$

Or

$$X = S\left(\frac{A}{B}\right) - 2L \tag{3.10}$$

The figure 3.3 shows a two-conductor circuit with a lead resistance.

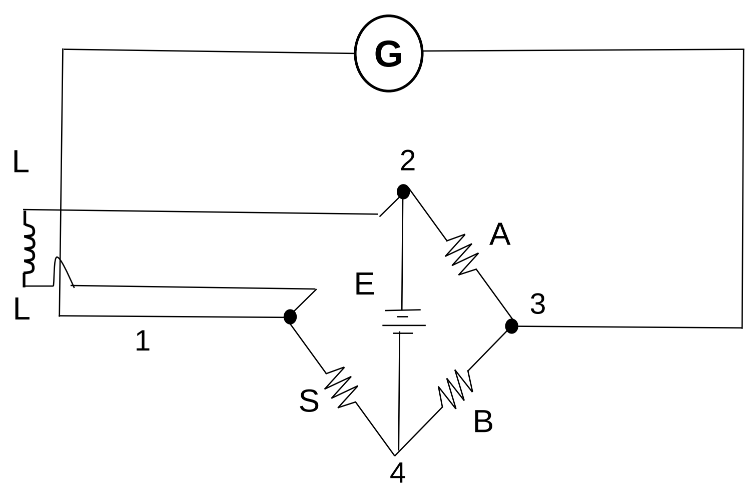

Fig. 3.3: Lead Resistance becomes a part of the measurement in a two-conductor circuit**.**

3.2.1.2 Deflection Reading

By adding the resistance L to both terminals of the bridge circuit as shown in figure 3.4 for meter null, deflection in bridge is calculated by a galvanometer based on the law of conservation of charge. It shows zero readings when there is no voltage between the ends. The following ratio applies, the opposite resistance is equal to another side ratio between the opposite resistance. Hence, the combination must be accurate.

$$\frac{A+L}{X+L}\,G = \frac{B}{S}\,C \qquad (3.11)$$

Note, the addition of variable resistance C provides the adjustment of the galvanometer G to some convenient point. For the value of X, G can be calibrated to read temperature directly. When zero current passes through the galvanometer then the bridge is said to be in balanced condition and mainly used for determining the medium resistance.

$$X = S\,C\left(\frac{A+L}{B}\right) - G\,L \qquad (3.12)$$

The figure 3.4 shows the elimination of the effect of lead resistance.

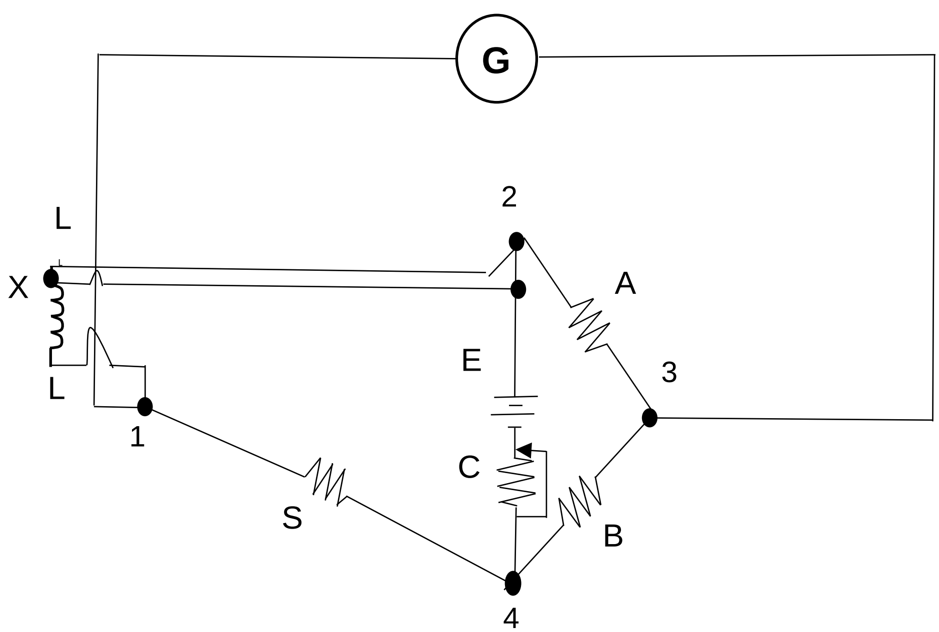

Fig 3.4: Eliminating the effect of Lead Resistance by adding resistance in another terminal of the bridge circuit using a three-wire system to cancel out the lead resistance.

3.2.1.3 Null Direct Reading

Resistance A could be replaced by a highly accurate adjustable resistance which is calibrated to correspond to the temperature which X measures. The ratio of their resistances is equal and no current flows through the circuit. Under normal conditions, the bridge is in an unbalanced condition where current flows through the galvanometer. For each new reading, Galvanometer G is set to null electronically by means of resistance A as shown in figure 3.5.

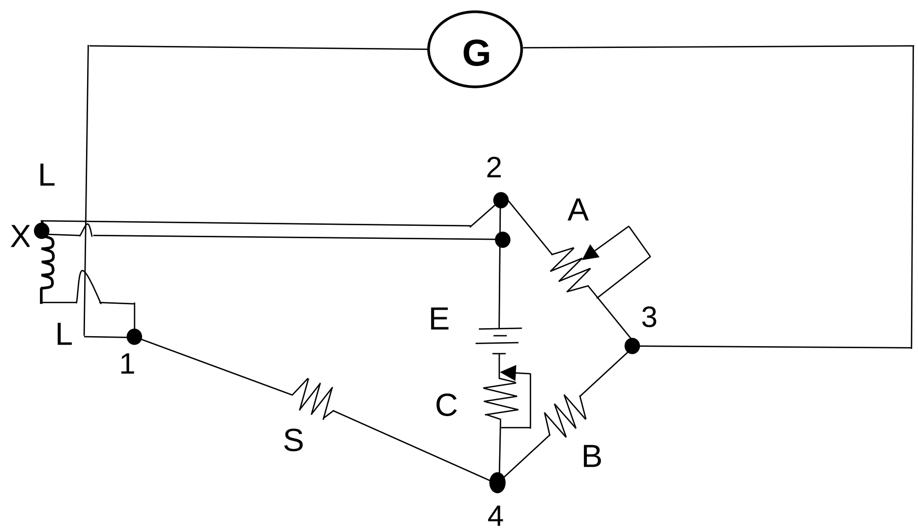

Fig. 3.5: Temperature made analogous to potentiometer setting which nulls the meter in a null - direct reading bridge.

Also, by placing sliding contacts in both the galvanometer and battery circuit loops as shown in figure 3.5, the effects of contact resistance are eliminated. Resistances A is gauged so that percentage of span K is equal. For high resistance measurement presented by the bridge is so large that the galvanometer is insensitive to imbalance and low resistance measurement, the resistance of the leads and contacts becomes significant.

Null measurement techniques achieve greater accuracy by balancing a circuit so that no current flows through the measuring device. Therefore, with galvanometer at null, the equation becomes.

$$\frac{X}{A + KE} = \frac{S + D\,(1 - K)}{B + KD + E\,(1 - K)} \tag{3.13}$$

$$X = \frac{S + D\,(1 - K)\,(A + KE)}{B + KD + \ E\,(1{-}K)} \tag{3.13a}$$

$$X = \frac{AS + AD\,(1{-}K) + KES + KED\,(1{-}K)}{B + KD + E - EK} \tag{3.13b}$$

$$X = \frac{A\,(S{+}D) + (ED + ES - A)\,K - EDK^2}{(B + E) + (D - E)\,K} \tag{3.14}$$

The voltage source E can be replaced by an alternate current source (normally f - 1000 Hz) and resistance A and B can be replaced by capacitor creating an AC bridge. Thus;

$$\frac{I_S}{Z_A} = \frac{Z_S}{Z_B} \tag{3.15}$$

The upper range of the bridge can be increased with the help of the applied emf, and the lower range is limited. Hence, the circuit gives inaccurate readings if it is unbalanced.

$$\frac{X}{\frac{1}{2fCA}} = \frac{S}{\frac{1}{2fCB}} \tag{3.16}$$

The controlled variables are those variables that must be maintained at a precise value. Their sensitivity decreases when their ratio is less than unity and accuracy is reduced.

$$X = \frac{C_B}{C_A} S \tag{3.17}$$

3.2.1.4 Operation of the Resistant Temperature Detector (RTD) Sensor

Because of the peculiar nature of petroleum products, most RTDs are made of platinum which is linear over a greater range of temperatures, resistant to corrosion and based its operation upon a linear relationship between temperature and resistance, since the resistance increases with temperature. However, in determining a resistor material the following factors such as temperature sensitivity, temperature range, durability and response time must be duly put into consideration. For each of these characteristics, different types of materials have different range. The principle of the RTDs is based upon the Callendar – Van Dusen equation, which relates the electrical resistance to the temperature above 0 °C up to the melting point of aluminum which is ~660 °C. Based upon an experimental data from the specific RTD, the equation normally takes on a linear form since it is merely a generic polynomial and the coefficients of the higher - order variable is relatively small (a_2, a_3, etc.).

The figure 3.6 shows the schematic diagram of the RTD sensor.

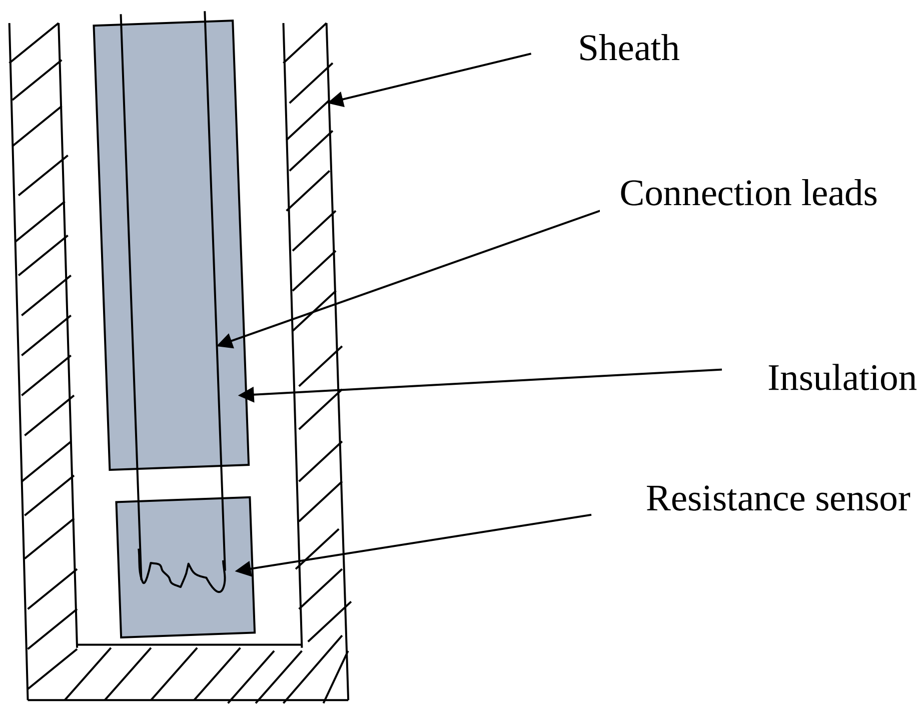

Fig. 3.6: Schematic diagram of Resistance Temperature Detector (RTD).

The RTD is made up of an outer sheath material which is composed to efficiently conduct heat to the resistor, resist degradation from heat and prevent it from the surrounding medium contaminations. The resistance sensor is mostly composed of metals, such as nickel, copper or platinum and responsible for the temperature measurement. The choice of material for the sensor strongly determines the range of temperatures wherein the RTD can be utilized. The most common type of resistor, platinum sensor has a range of approximately -200°C – 800°C. The two insulated connection leads are connected to the resistor, these leads continue to complete the resistor circuit.

There are 4 main classes of RTD sensors, they are the wire-wound thermometers, coil elements, film thermometers and 187 carbon resistors.

The 187 Carbon Resistors are accurate for low temperatures, less expensive, are not affected by strain gauge effects or hysteresis, hence the most used type of RTD sensors by researchers.

Film thermometers are often made of platinum with a very thin layer of metal on a plate, on the micrometer scale this layer is very small. Based on the composition of the metal and plate, the thermometers have different strain gauge effect and the type of components used determines its stability problem,

In wire-wound thermometers the coil gives stability to the measurement. Although a larger diameter of the coil gives more stability, it also increases the amount in which the wire can expand which in turn increases strain and drift. Hence, they have very good accuracy over a large temperature range.

The coil elements have generally replaced the wire-wound thermometers in all industrial applications because of their similarity features. The coil is allowed to expand over large temperature ranges while decreasing the drift and giving support.

3.2.2 Design of a Proportional Integral Derivative (PID) Controller Capable of Regulating the Temperature of the Storage Tank

The storage tank with the flow rate of pure component S, W_2 as the manipulated variable. The control objective is to regulate the tank composition X, by adjusting the mass flow rate W_2. The primary disturbance variable is assumed to be set point temperature X_1. The tank temperature is measured by a sensor/transmitter whose output signal X_m is sent to an electronic controller. Because a pneumatic control valve is used, the controller output (an electrical signal in the range of 4 to 20 mA) must be converted to an equivalent pneumatic signal P_t (3 to 15 psig) by a current-to-pressure transducer. The transducer output signal is then used to adjust the valve. Next, we develop a transfer function for each of the five elements in the feedback control loop. For the sake of simplicity, flow rate W_1 is assumed to be constant, and the system is initially operating at the nominal steady rate. Later, we extend this analysis to more general situations.

3.2.2.1 Effect of Temperature Change Due to Process Characteristics in the Storage Tank

The dynamic model of a storage - tank system is:

$$X'(s) = \left(\frac{K_1}{\tau s+1}\right) X_1'(s) + \left(\frac{K_2}{\tau s+1}\right) W_2'(s) \tag{3.18}$$

Where;

$$\tau = \frac{V\rho}{w}, \tag{3.19}$$

$$K_1 = \frac{\overline{W_1}}{W'} \tag{3.20}$$

$$K_2 = \frac{1-\bar{x}}{w} \tag{3.21}$$

Note that:

$$X'(s) = \mathcal{L}[\mathrm{x}'(\mathrm{t})] \tag{3.22}$$

$$X_1'(s) = \mathcal{L}[\mathrm{x}_1'(\mathrm{t})] \tag{3.23}$$

The block diagram of figure 3.7 shows the detail information of equations (3.18) and (3.19 - 3.21). In the diagram, the deviation variable $X_d(s)$, denotes the change in outflow composition due to a change in the inflow composition X'(s) (the disturbance). Similarly,

X'_u(s) is a deviation variable that denotes the change in X'(s) due to a change in the manipulated variable {the flow rate of pure A, W'_2(s)}. The effects of these changes are additive because X'(s) = X'_d(s) + X_u(s) as a direct consequence of the Superposition Principle for linear systems. Also, we know that this transfer function representation is valid only for linear systems and for nonlinear systems that have been linearized, as is the case for the process model for storage. The figure 3.7 shows the block diagram of the storage process.

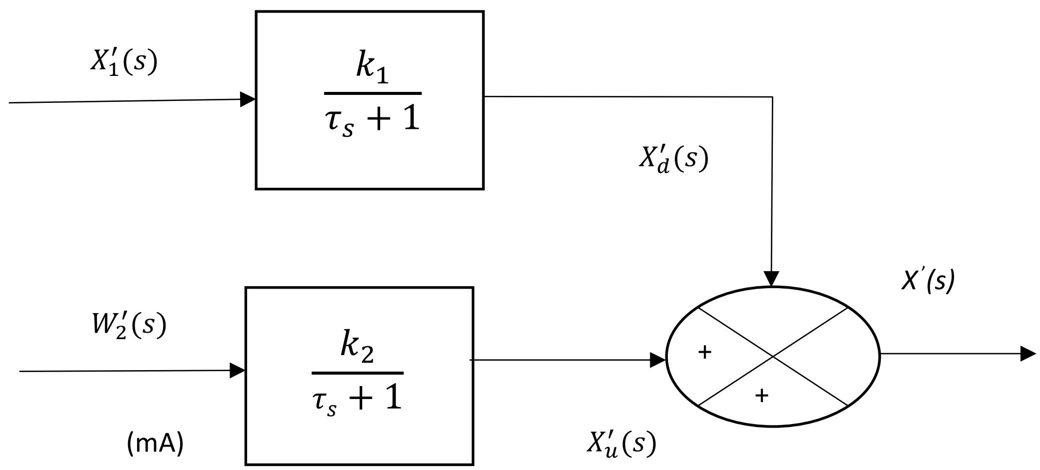

Fig. 3.7: Block diagram of Storage Process.

3.2.2.2 Composition of the Temperature Sensor (Analyzer)

For several applications in control and safety value monitoring, a profound knowledge of the dynamic behaviour of process temperature sensors is of great importance. We assume that the dynamic behavior of the temperature sensor can be approximated by a first order transfer function: For a change in the input, the measured temperature *x: n(t)* rapidly follows the true position *x'(t),* even while *x'(t)* is slowly changing with time constant τ. There has been a change in the sensor temperature in response to a dynamic change in the input temperature signal. Hence, the dynamic error associated with the measurement can be neglected. A useful approximation is to set $\tau_m = 0$ as heat can be transferred from the environment to the sensor. In general, we reasoned that the temperature sensor performs some mathematical operation on the input signal and outputs the results. Measurement system operation on an input signal $x'(s)$, provides the output signal $X'_m(s)$, the measurement system is modeled using an equation that describes the relationship between the input signal and the output signal.

$$\frac{X'_m(s)}{X'(s)} = \frac{K_m}{\tau_m s+1} \tag{3.24}$$

The steady-state gain K_m depends on the input and output ranges of the composition sensor combination. The block diagram for the sensor-transmitter is shown in figure 3.8.

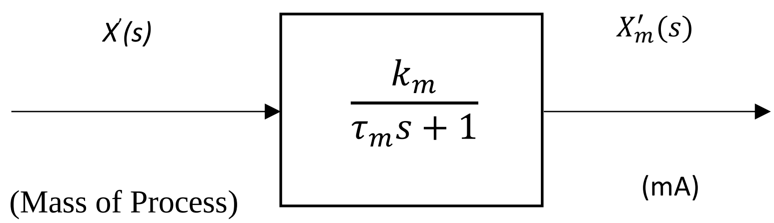

Fig. 3.8: Block diagram of the Temperature Sensor for the Storage Tank (analyser).

3.2.2.3 Proportional Integral Derivative Controller Design (PID)

The transfer function for PID controller is:

$$\frac{P'(S)}{E(s)} = K_c\left(1 + \frac{1}{\tau_1 s}\right) \tag{3.25}$$

where P'(s) and E(s) are the Laplace transforms of the controller output p'(t) and the error signal e(t). Note that p' and e are electrical signals that have units of mA, while K_c is dimensionless.

The error signal is expressed as:

$$e(t) = \widetilde{x'_{sp}}(t) - x'_m(t) \tag{3.26}$$

From laplace transformation,

$$E(s) = \widetilde{X'_{sp}}(s) - X'_m(s) \tag{3.27}$$

The symbol $\widetilde{x'_{sp}}(t)$ denotes the internal set-point composition expressed as an equivalent electrical current signal. This signal is used internally by the controller. $\widetilde{x'_{sp}}(t)$ is related to the actual composition set point $x'_{sp}(t)$ by the sensor gain K_m.

$$\widetilde{x'_{sp}}(t) = K_m x'_{sp}(t) \tag{3.28}$$

This means that,

$$\frac{\widetilde{X'_{sp}}(s)}{X'_{sp}(s)} = K_m \tag{3.29}$$

The block diagram representing equations (3.25 - 3.29) is shown in figure 3.9.

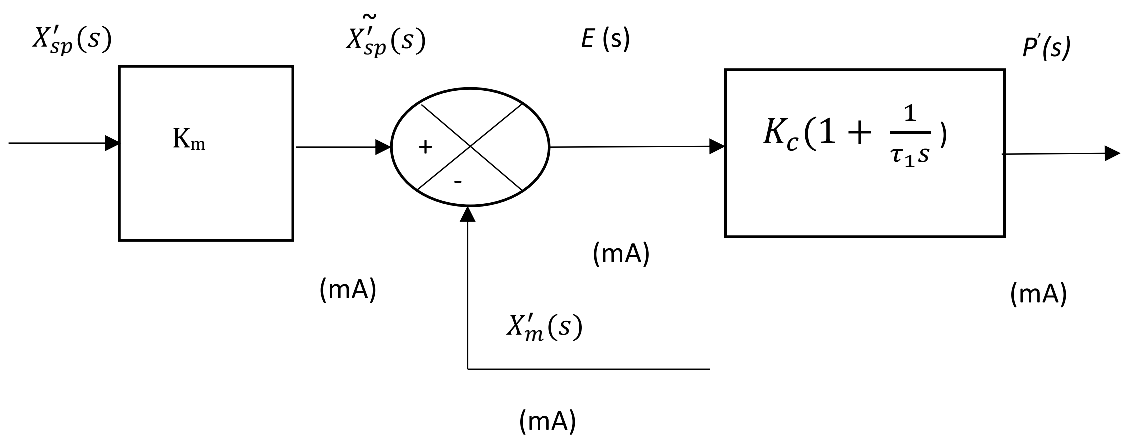

Fig.3.9: Block diagram of the Proportional Integral Derivative Controller.

3.2.2.4 Control Valve

The control valve is thus designed for the flow rate through the valve to be nearly a linear function of the signal to the valve actuator. Therefore, a first-order transfer function provides an adequate model for operation of an installed valve in the vicinity of a nominal steady state. Thus, we assume that the control valve can be modeled as shown in figure 3.10:

$$\frac{W_2'(s)}{p_1'(s)} = \frac{K_v}{\tau_{v1}s+1} \tag{3.30}$$

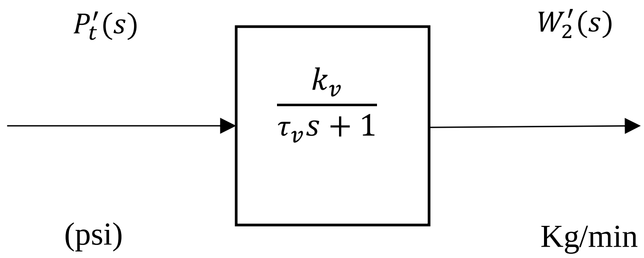

Fig. 3.10: Block diagram for the Control Valve.

Now that transfer functions and block diagrams in Figures. 3.7 to 3.10 have been developed for the individual components of the feedback control system, we now combine this information to obtain the composite block diagram of the controlled system as shown in Figure 3.11.

The figure 3.11 shows the block diagram of the temperature control system of the storage tank.

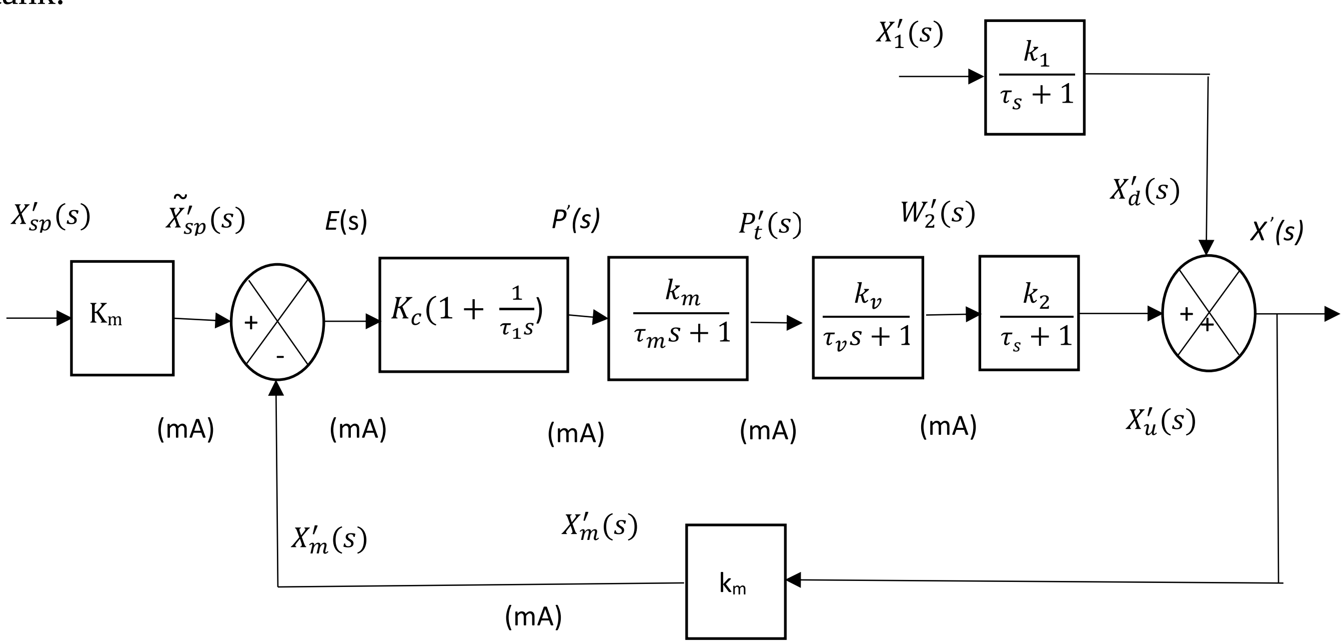

Fig 3.11: Block diagram for the entire Temperature Control System for Storage Tank.

3.2.2.5 Determination of the Close Loop Transfer Function

The block diagrams have been developed for the storage-tank system with its temperature sensor and cooling systems. Figure 3.11 can now be further developed with the standardize notations of a feedback control system. This is shown in figure 3.12.

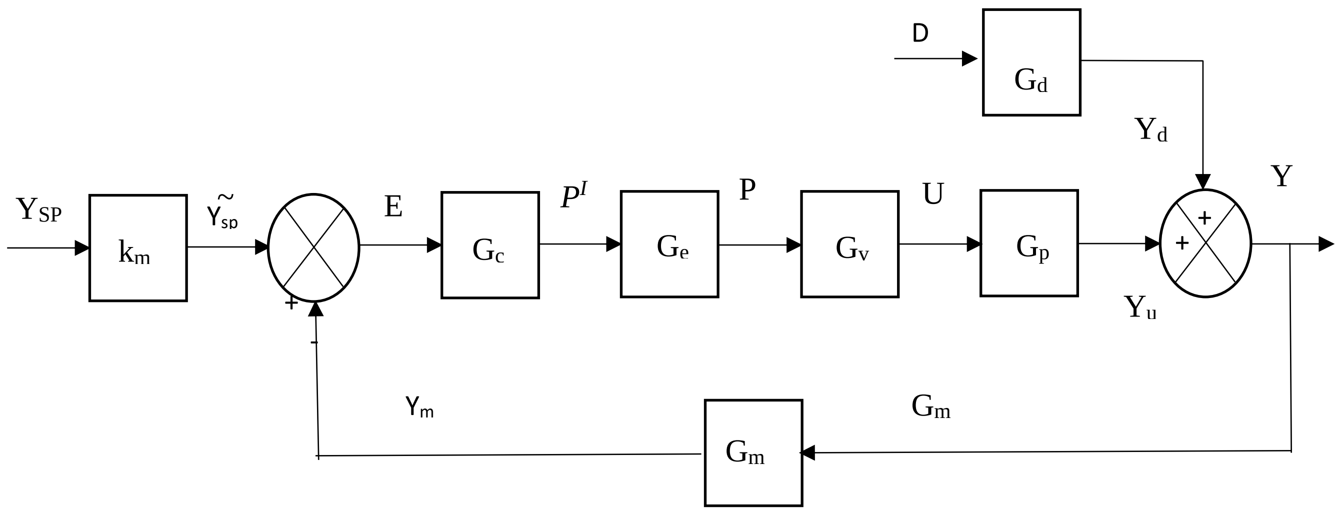

Fig. 3.12: Standardized Notation of a feedback Control System of figure 3.11.

Where;

Y_{sp} = Set point of Y.

$\widetilde{Y_{sp}}$ = Internal set point (used by the controller).

K_m = Steady-state gain for G_m.

E = Error signal.

P = Controller output.

G_c = Controller transfer function.

G_v = Transfer function for the final control element.

G_P = Process transfer function.

G_d = Disturbance transfer function.

D = Disturbance variable (also referred to as the load variable).

Y = Controlled variable.

Y_u = Change in Y due to U.

U = Manipulated variable.

Y_d = Change in Y due to D.

Y_m = Measured value of Y.

G_m = Transfer function for sensor add transmitter.

In Figure 3.12, each variable is the Laplace transform of a deviation variable. To simplify the notation, the primes and s dependence have been omitted; thus, Y is used rather than Y'(s). Because the final control element is often a control valve, its transfer function is denoted by G_v. Note that the process transfer function G_p indicates the effect of the manipulated variable on the controlled variable. The disturbance transfer function G_d represents the effect of the disturbance variable on the controlled variable. For the storage-tank system, G_d and G_P are given in Equation (3.18). In Figure 3.12, the signal path from E to Y through blocks G_c, G_v, and G_P is referred to as the forward path. The path from Y to the comparator through G_m is called the feedback path.

3.2.2.6 Using Direct Synthesis (DS) Method

In the Direct Synthesis (DS) method, the controller design is based on a process model and a desired closed loop transfer function. The DS approach provides valuable insight into the relationship between the process model and the resulting controller. For the analysis, consider the block diagram of a feedback control system of figure 3.12, the closed loop transfer function becomes.

$$\frac{Y}{Y_{sp}} = \frac{K_m G_c G_d G_e G_v G_p}{1 + G_c G_d G_e G_v G_P G_m} \tag{3.31}$$

Let $G = G_d G_e G_v G_P G_m$

We also assume that,

$G_m = K_m$, this implies that,

$$\frac{Y}{Y_{sp}} = \frac{G_C G}{1 + G_C G} \tag{3.32}$$

Rearranging and solving for G_c gives an expression for the PID feedback controller:

$$G_c = \frac{1}{G}\left(\frac{\frac{Y}{Y_{sp}}}{1 - \frac{Y}{Y_{sp}}}\right) \tag{3.33}$$

Distinguishing between the actual process G and the model $\breve{G}$, that provide an approximation of the tank process behavior. A practical design equation can be derived by replacing the unknown G by $\breve{G}$ and $\frac{Y}{Y_{sp}}$ by a desired closed loop transfer function $\left(\frac{Y}{Y_{sp}}\right)_d$

$$G_c = \frac{1}{\breve{G}}\left(\frac{\left(\frac{Y}{Y_{sp}}\right)_d}{1 + \left(\frac{Y}{Y_{sp}}\right)_d}\right) \tag{3.34}$$

For processes without time delay, like the storage tank, the first order model in equation (3.34) is a more realistic choice. Thus,

$$\left(\frac{Y}{Y_{sp}}\right)_d = \frac{1}{\tau_c s + 1} \tag{3.35}$$

Where, τ_c is the desired closed loop time constant.

This model has a settling time of $5\tau_c$.

3.2.3 Design of the Water-Cooling System (Medium Velocity Spray System)

Automatic operation of the water spray system can be initiated by separate water filled detection piping when regular sprinkler heads are used as shown in the Figure 3.14. In this arrangement, detector sprinklers are fixed to a water charged pipe arrangement. A water tapping from below the lower isolating valve is connected through a restricted orifice valve to the array of sprinkler detectors and also to the deluge valve diaphragm. In the event of fire when one or more sprinkler detectors are activated, water from the tapping below the deluge valve through the restricted orifice cannot make up the flow discharging from the actuated detector sprinklers and thus the water pressure is released from the deluge valve diaphragm allowing the valve to open. Local manual release is provided by a valve on the sprinkler detection line and a pressure switch provides alarm indication. Sometimes a bypass valve is provided to enable local operation.

Within an automatic sprinkler installation, the type of sprinklers used are thermo sensitive, which are designed to react at predetermined temperatures and to function independently from one another. A mechanism is designed to open a valve and a stream of water is sprinkled over a given predetermined area once the preset temperature has been reached. The sprinklers head are placed at constant intervals away from one another and through a specially designed pipe system, the water travels to the sprinklers which are ordinarily over-headed. There are varieties of factors that should be put into consideration during the design of any sprinkler system. The operating temperature, speed of operation and the area which the spray umbrella will be covered are major factors of the design. The size of the sprinkler's orifice is used in determining the amount of water to be discharged as well as the pressure through which the water flows.

In designing the water-cooling system, dependent and independent variables have to be considered. Thus,

3.2.3.1 Dependent and Independent Variables

The independent variables used are L (length), H (height), and W (width). The dependent variables solved for are the velocities of the gas and liquid phases in the space directions when there is fire v_1, v_2, and u_l, u_2. The pressure **p,** which is assumed to be the same for both phases, the gas and liquid volume fractions $\mathbf{R_1}$ and $\mathbf{R_2}$ as well as the "shadow" volume fraction $\mathbf{R_s}$. i.e., the volume fraction in the absence of evaporation, all other conditions being those evaluated with evaporation, the turbulence kinetic energy and its dissipation rate for the gaseous phase **k** and **E** and the concentration of water vapor C_l. The "shadow" volume fraction technique allows us to evaluate the diminishing droplet size during evaporation. Turbulence in the liquid phase is neglected.

The differential equations applied becomes:

3.2.3.2 The Mass Conservation Equation

$$div(\rho_i R_i V_i) = S_i \tag{3.36}$$

$$R_g + R_l = I \tag{3.37}$$

Where;

I = Refers to the phase in question

g = For gas

l = Liquid

The volume fractions R_g and R_l need to satisfy the volume sharing condition.

$\mathbf{S}_i$ is the rate of evaporation for the gaseous phase and the liquid phase

3.2.3.3 The Conservation Equation for the General Variable $\boldsymbol{\delta}$

The general source - balance equation for δ is,

$$div(\rho_i R_i V_i \delta_i - R_i \gamma_\delta grad\delta) = S_\delta \tag{3.38}$$

Where δ stands for the general dependent variables and γ is assumed constant from liquid phase to gaseous phase.

3.2.3.4 Inter Phase Friction Coefficient

The two phases, gas and liquid slip with respect to each other resulting in the inter phase-friction force, as stated in equation (3.39).

$$F = D_C \rho B_P V_{slip} \tag{3.39}$$

Where; ρ = Density of the gas phase.

D_c = Drag coefficient.

V_{slip} = The resultant slip velocity.

B_P = The total projected droplet area in the cell given by.

$$B_P = \left(1.5\frac{V}{d}\right) R_e \tag{3.40}$$

Where; d = the droplet diameter,

V = the volume of the cell,

R_e = the particle Reynolds number given by

$$R_e = d\,\frac{V_{SLIP}}{\alpha_i} \tag{3.41}$$

Where; α_i is the laminar viscosity of the gas.

The drag coefficient Dc is evaluated as follows;

$$D_c = max\left[0.42\frac{24}{R_e}(1 + 0.15R_e^{0.68}) + \frac{0.42}{1+(4.25\times10^4)R_e^{-1.16}}\right] \tag{3.42}$$

3.2.3.5 Inter Phase Mass Transfer Coefficient

As cooling of heated areas deals with evaporating water droplets, the loss of mass of the droplets needs to be calculated, see S_i in equation (3.36).

$$\dot{M} = \frac{A\sigma}{C_p D} ln\left(1 + C_p \frac{T_g - T_s}{L}\right) \tag{3.43}$$

Where;

C_p = The specific heat, which is assumed to be constant for both phases.

D = The initial droplet diameter.

σ = The thermal conductivity of the water droplets.

L = The latent heat of evaporation.

T_g = The temperature of the gas.

T_s = The temperature at the surface of the droplet.

A = The interface surface area per cell given by.

$$A = \frac{6R_2V}{d} \tag{3.44}$$

Where;

R_2 = the liquid volume fraction.

V = the cell volume.

d = the droplet diameter.

In the event of fire protection, adequate knowhow of the optimal droplet size is necessary to maximize the effectiveness of firefighting and improve the efficiency of the sprinklers. The major functionality of a sprinkler system is to douse out a fire as quickly as possible or to control its effect in the best possible way, it is also essential to use as few sprinkler heads as possible. Nevertheless, the discharge water droplet optimum size is dependent on specific criteria and requirements that should be put in place before installation. Some of these criteria are as follows:

i. To prevent an excessive number of sprinklers from opening under the ceiling, cooling of the combustion products and ambient atmosphere is necessary.
ii. Wet and cool the walls subjected to direct exposure to fire and surrounding combustibles immediately.
iii. In order to extinguish the burning surface, the rising fire plume needs to be penetrated.

Therefore, large orifice sprinklers should be used, if greater penetrability of the drops through the plume is required.

3.2.3.6 Rate of Air Entrainment

An approximated description of the whole air entrained by the sprays is given by the mono-dimensional models considering a finite element *dz* of the barrier:

$$\frac{da_1}{dz} = k_c 2 l \rho_a v \tag{3.45}$$

Where;

a_1 = Total mass flow rate of air entrained by the nozzle.

ρ_a = Air density in Kgm^{-3}

L = Width of curtain tunnel.

k_c = Entrainment constant.

z = Curtain axial coordinate.

v = Fluid velocity at distance z from the nozzle MS^{-1}

$$\frac{d}{dz}[(a_1 + s)v_1] = \frac{s}{v}g \tag{3.46}$$

Where;

s = mass flow rate of sprays kgs^{-1}

g = acceleration due to gravity.

Equation (3.45) defines the global air entrainment. The balance of vertical momentum, Equation (3.46) is based on the assumptions that drops and entrained air are characterized by the same velocity, uniformly distributed on each horizontal section of the curtain. In particular, the right-hand side represents the force per unit length acting on the volume element dV ≅ b·l·dz of the curtain, being dF_{oS} the force acting on dV_1. Note that;

F_{oS} = Mass force acting on the curtain, N.

ρ_2 = Density of the sprayed solution, Kg m^{-3}

b = Curtain width at distance z from the nozzle, m.

$$dF = (\rho_c - \rho_a)gdv_1 = \left\{\frac{a_1+s}{\frac{a_1}{\rho_a}+\frac{s}{\rho_2}} - \rho_a\right\}gdv = \frac{s\left(1-\frac{\rho_a}{\rho_2}\right)}{\frac{a_1}{\rho_a}+\frac{s}{\rho_2}} \equiv \frac{s}{blv}gbldz = \frac{sg}{v}dz \tag{3.47}$$

Combining equations (3.45) and (3.46), we have.

$$\frac{dv}{dz} = \frac{sg-2k_cl\rho_a v^3}{v(a_1+s)} \tag{3.48}$$

Also if we combine equation (3.45) and (3.48), we have;

$$\frac{da_1}{a_1+s} = \frac{v^2 dv}{v_2^3 - v^3} \tag{3.49}$$

Where v_2 is defined as,

$$v_2 = \left[\frac{sg}{2k_c l \rho_a}\right]^{1/3} \tag{3.50}$$

represents the value of v which makes up the drag and gravitational forces acting on the curtain.

$$2k_c \rho_a l v^2 = \frac{sg}{v} \tag{3.51}$$

Therefore, integrating equation (3.49), on the assumption that $a_1(v_4) = 0$ then we have;

$$a_1 = s\left[\left(\frac{v_4^3 - v_2^3}{v^3 - v_2^3}\right)^{\frac{1}{3}} - 1\right] \tag{3.52}$$

V_4 = Liquid velocity at the nozzle exit ms^{-1}

Substituting equation (3.52) in (3.48) gives,

$$\frac{dv}{dz} = -\frac{g}{v_2^3 (v_4^3 - v_2^3)^{\frac{1}{3}}} \frac{(v^3 - v_2^3)^{4/3}}{v} \tag{3.53}$$

3.2.4 Simulation of the Designed Scheme

Let's consider the Simulink of the transfer functions and block diagrams for the individual components of the feedback control system that has been developed from Figure 3.7 to Figure 3.10.

We now combine this information to obtain the composite Simulink design of the controlled scheme developed for the storage-tank system with its temperature sensor and cooling systems as shown in figure 3.13.

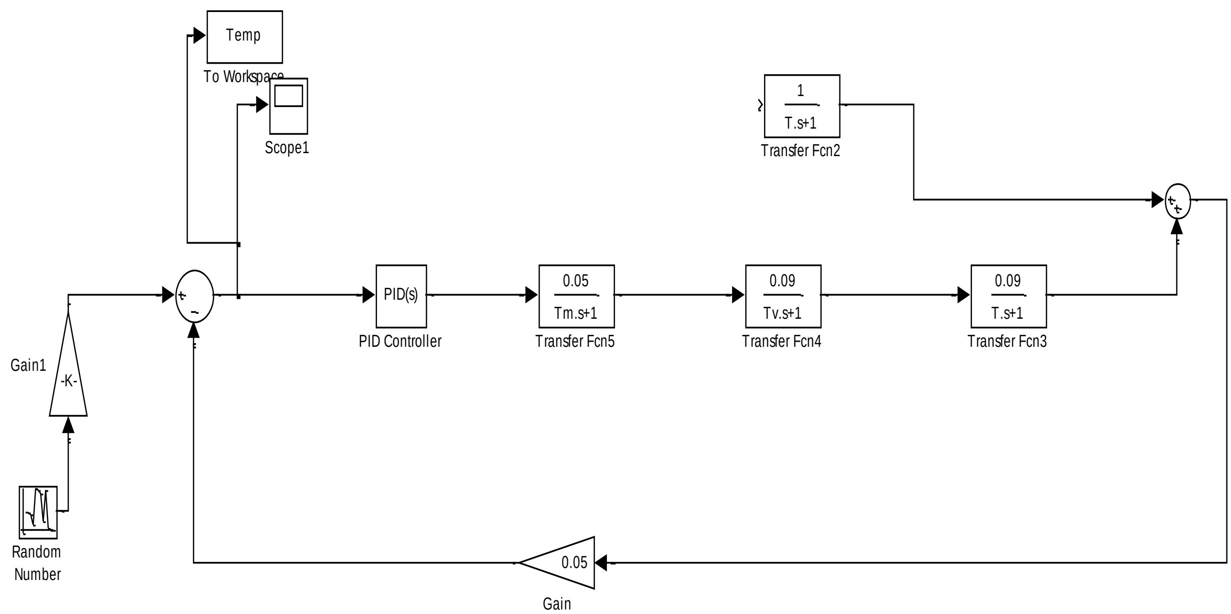

Fig. 3.13: **The Simulink of the Designed System**.

The schematic diagram of the storage tank cooling system is shown in figure 3.14.

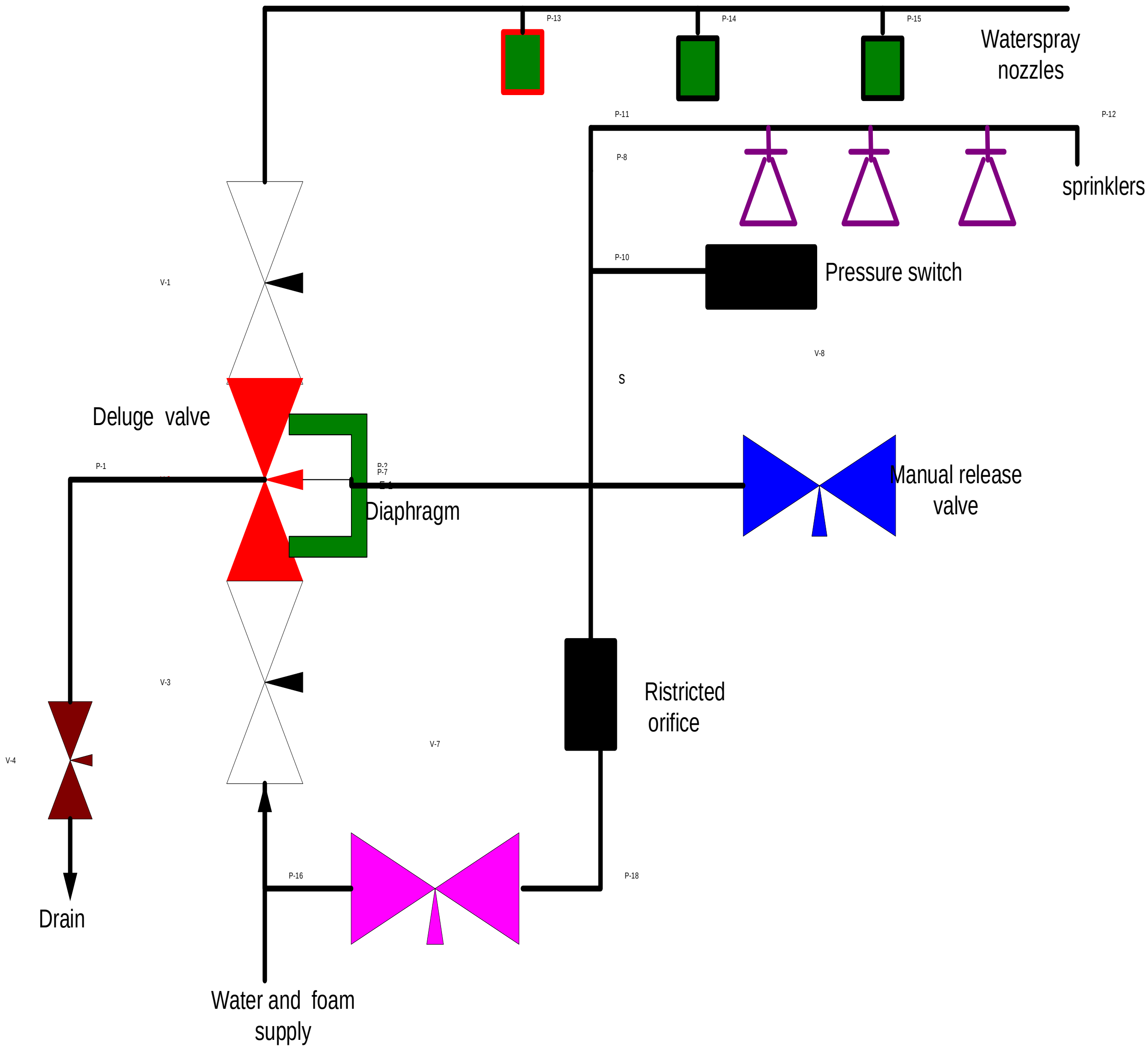

Fig. 3.14: **Storage Tank Cooling System**.

The flow chart of the processes is shown in figure 3.15.

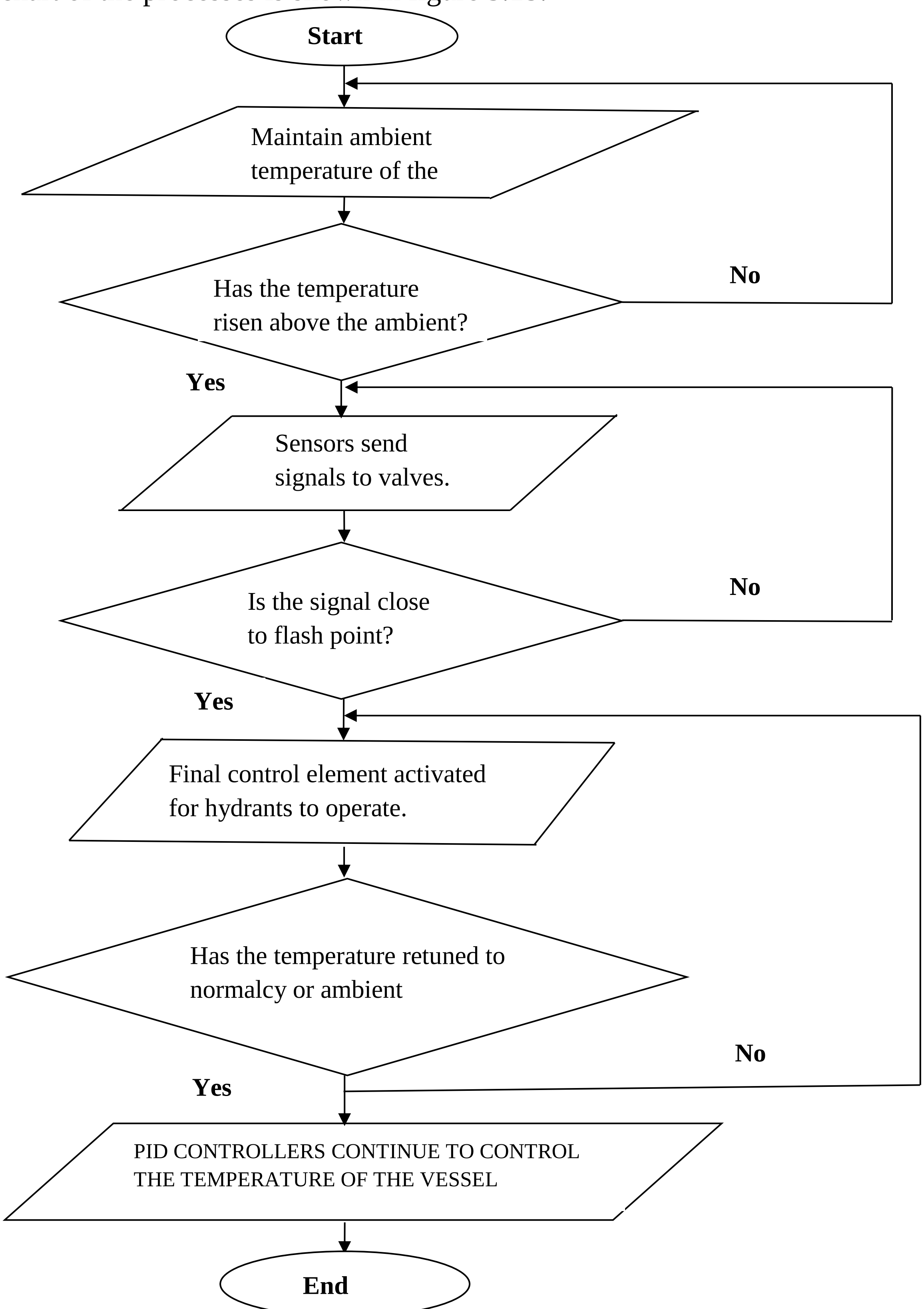

Fig. 3.15: Flow Chart of the Temperature Control System of the Storage Tank.

The table 3.1 shows the list of expenditures made because of this study.

Table 3.1: Cost Estimation of the Study.

S/N	DESCRIPTION	QUANTITY	UNIT PRICE (#)	COST (#)
1	HP Laptop	1	155,000.00	155,000.00
2	MATLAB Software	1	26,000.00	26,000.00
3	Microsoft Visio Software	1	16,000.00	16,000.00
4	Microsoft Office 2016	1	10,000.00	10,000.00
5	Enterprises Antivirus 2012	1	3,000.00	3,000.00
6	Printing of Thesis	4	6,500.00	26,000.00
7	Transportations	Lump Sum	17,000.00	17,000.00
8	Miscellaneous	Lump Sum	45,000.00	45,000.00
9	**Total**			**298,000.00**

The overall estimation cost of the implementation is N 298,000.00 (Two hundred and Ninety-Eight Thousand Naira Only).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

In this chapter, the simulated results of the model are shown as well as discussion on the activities of the model as obtained from the results.

4.1.1 Simulation Results on Temperature and Atmospheric Effects

The results obtained on the atmospheric effects on temperature are shown as follows.

The figure 4.1 shows the uncontrolled temperature deviation from set point.

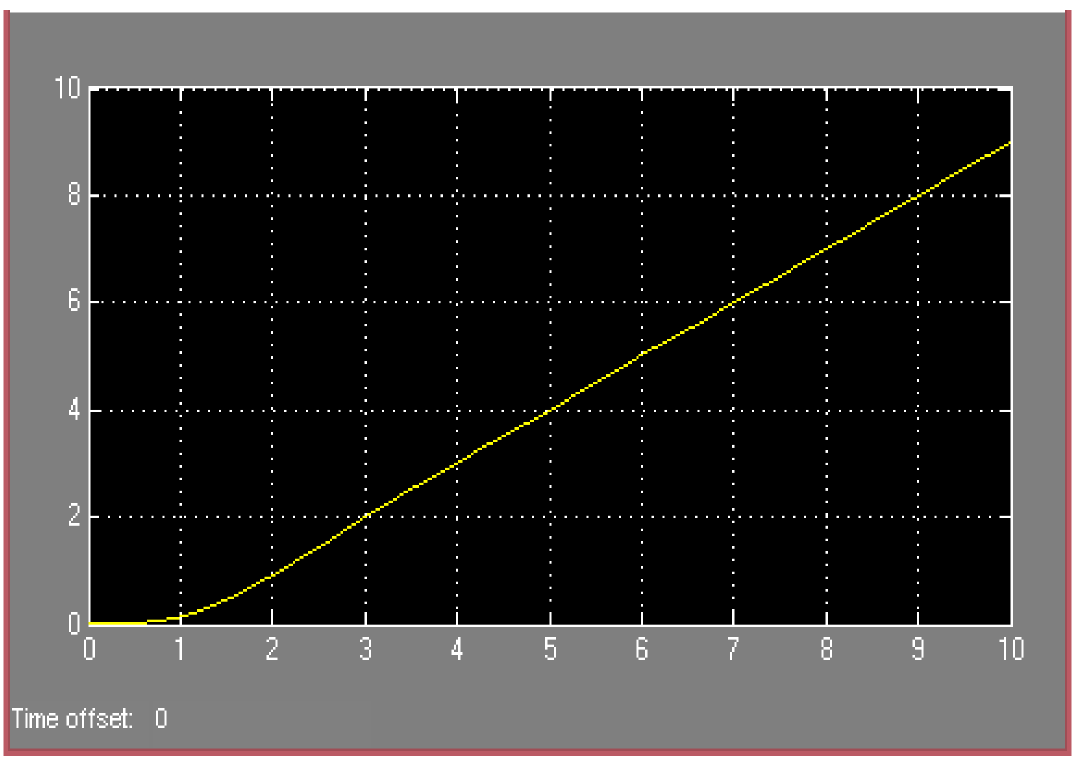

Fig. 4.1: Uncontrolled Temperature Deviation from set point (Temperature in degree centigrade vs Time).

The figure 4.2 shows the control of atmospheric effect on temperature using the PID controller.

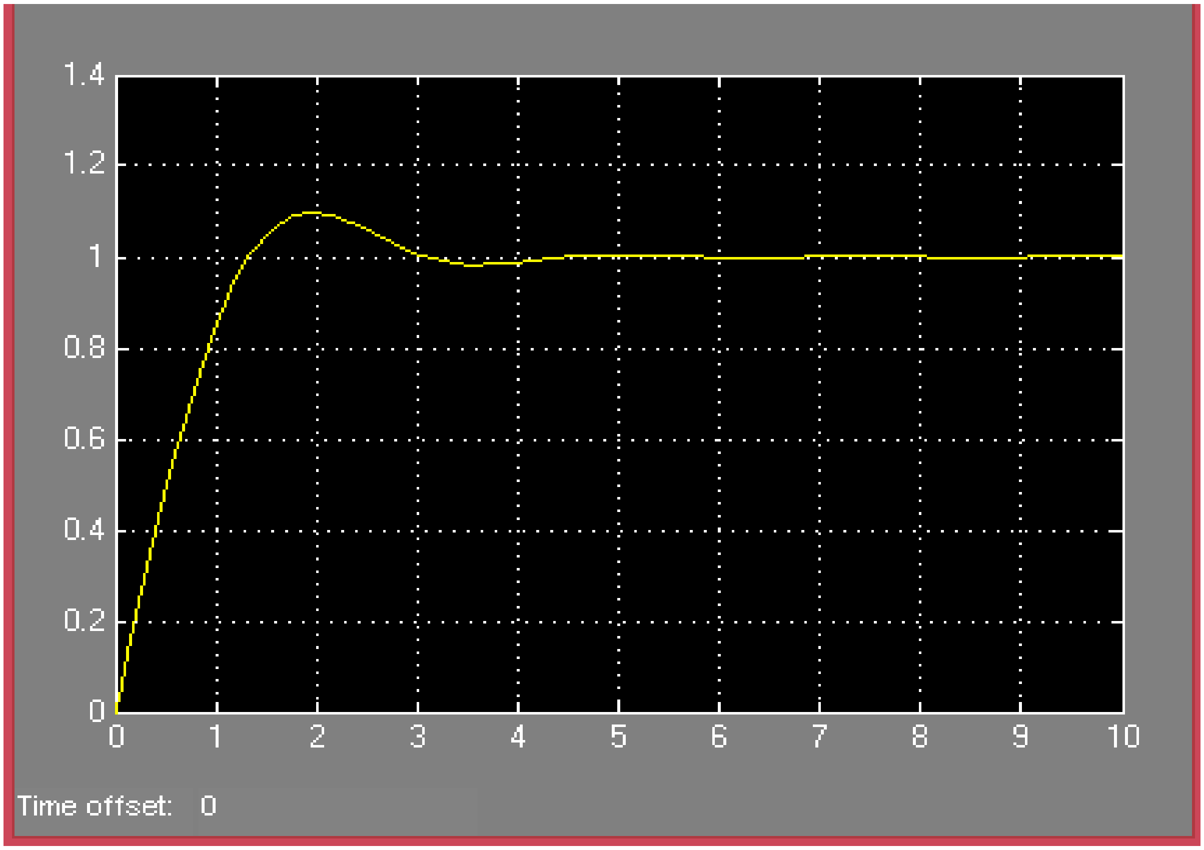

Fig. 4.2: Simulation result on the control of atmospheric effect on temperature using PID Controller (Temperature in degree centigrade vs Time).

4.1.2 Simulation Results on the Effect of Temperature Error Difference

The results obtained on the effect of temperature error difference using the PD, PI and PID controllers are shown as follows.

The figure 4.3 shows the control of temperature error deviation using the PD controller.

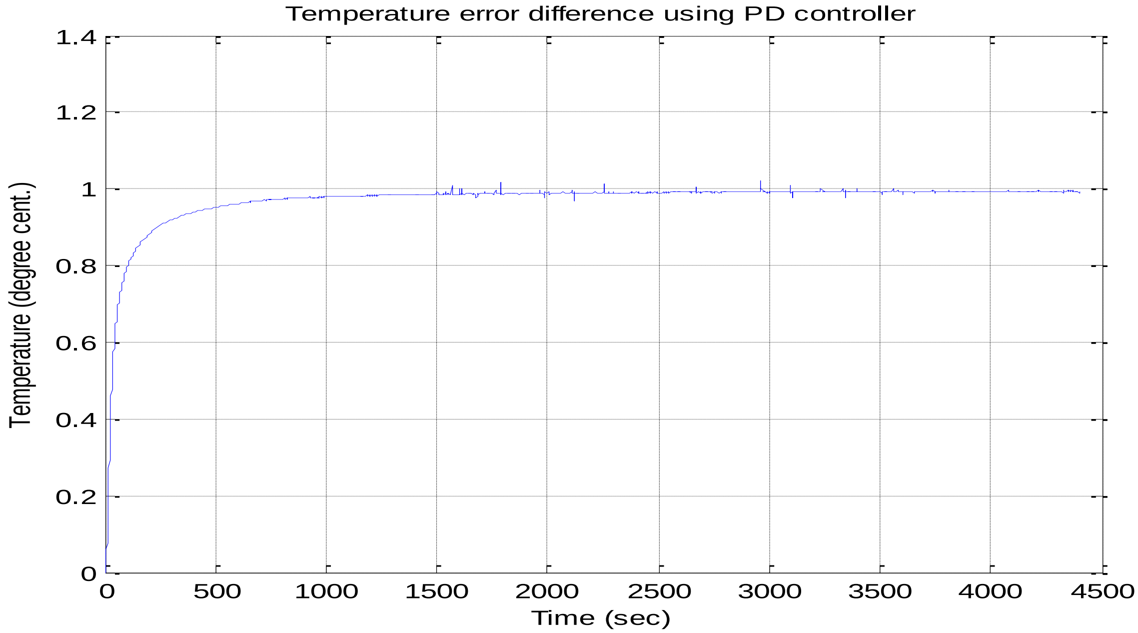

Fig. 4.3: Temperature Error Deviation using Proportional Derivative (PD) Controller.

The figure 4.4 shows the control of temperature error deviation using the PI controller.

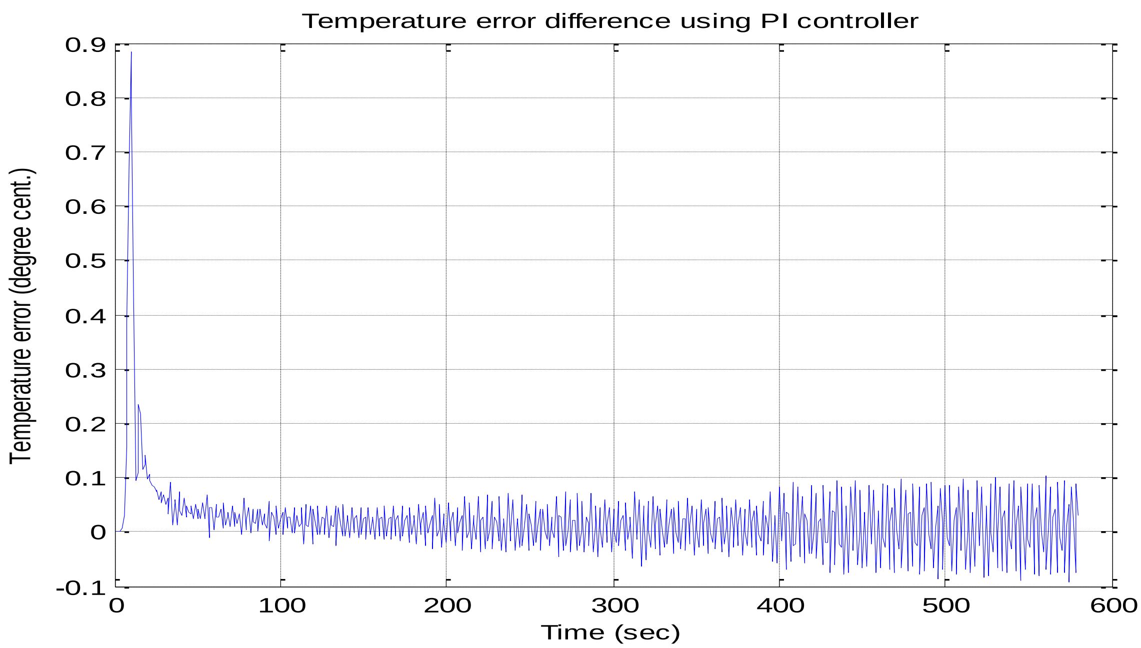

Fig. 4.4: Temperature Error Deviation from setpoint using Proportional Integral (PI) Controller.

The figure 4.5 shows the control of temperature error deviation using the PID controller.

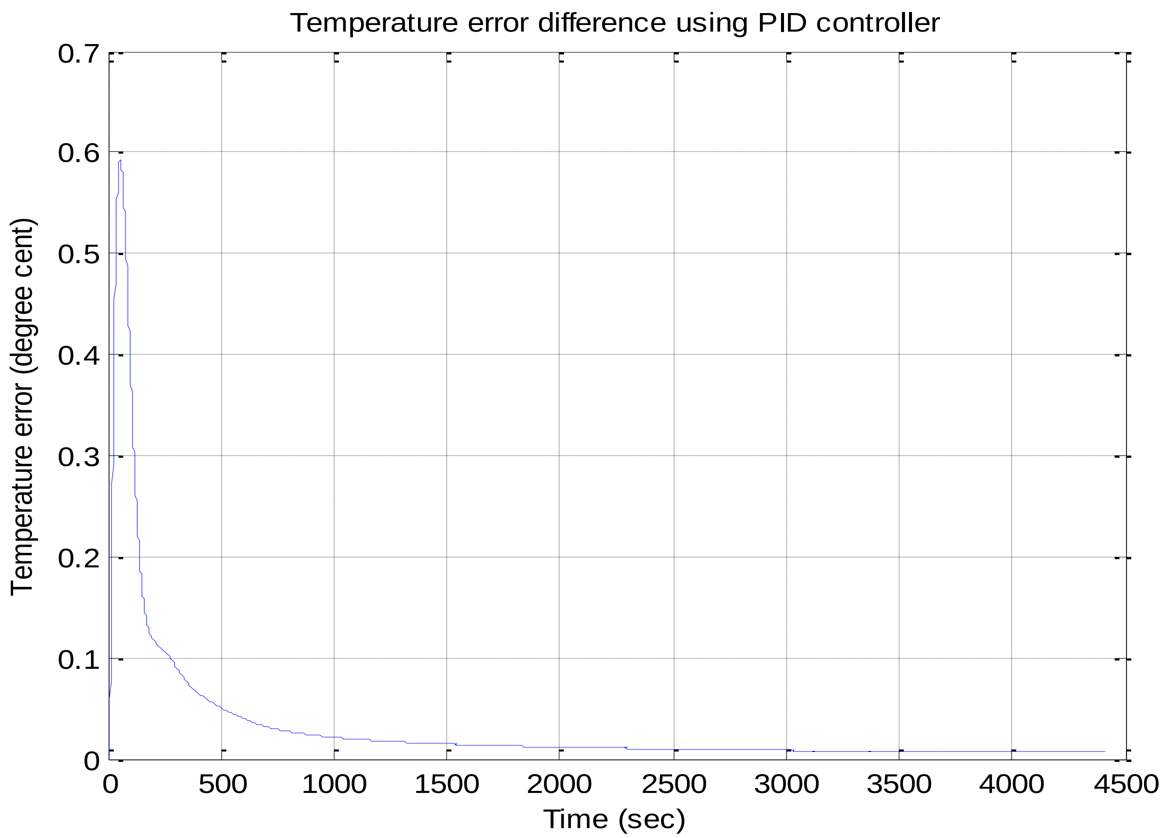

Fig. 4.5: Action of the PID Controller on the control of the Temperature Error Deviation from set point.

4.1.3 Simulation Results on the Effect of Pressure on Temperature

The results obtained on the effect of atmospheric pressure on temperature error deviation using the PD, PI and PID Controllers are shown as follows.

The figure 4.6 shows the atmospheric pressure effect on temperature error deviation using the PD controller.

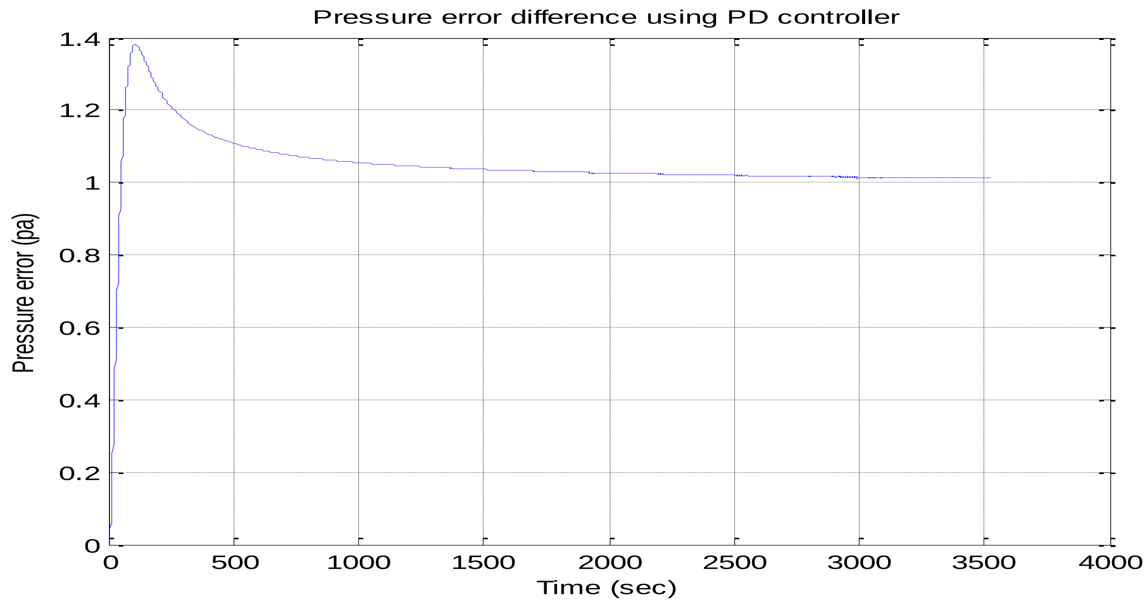

Fig. 4.6: The Pressure Effect on Temperature Error Deviation using PD Controller.

The figure 4.7 shows the atmospheric pressure effect on temperature error deviation using the PI controller.

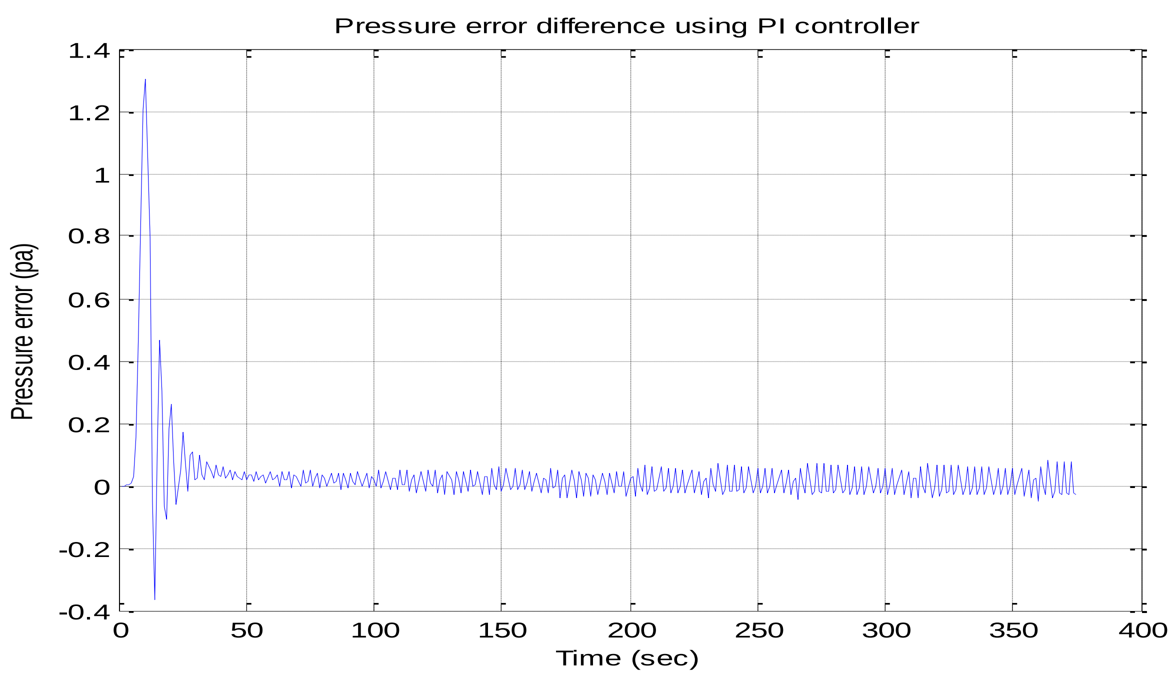

Fig. 4.7: Pressure Effect on Temperature Error Deviation using PI Controller.

The figure 4.8 shows the atmospheric pressure effect on temperature error deviation using the PID controller.

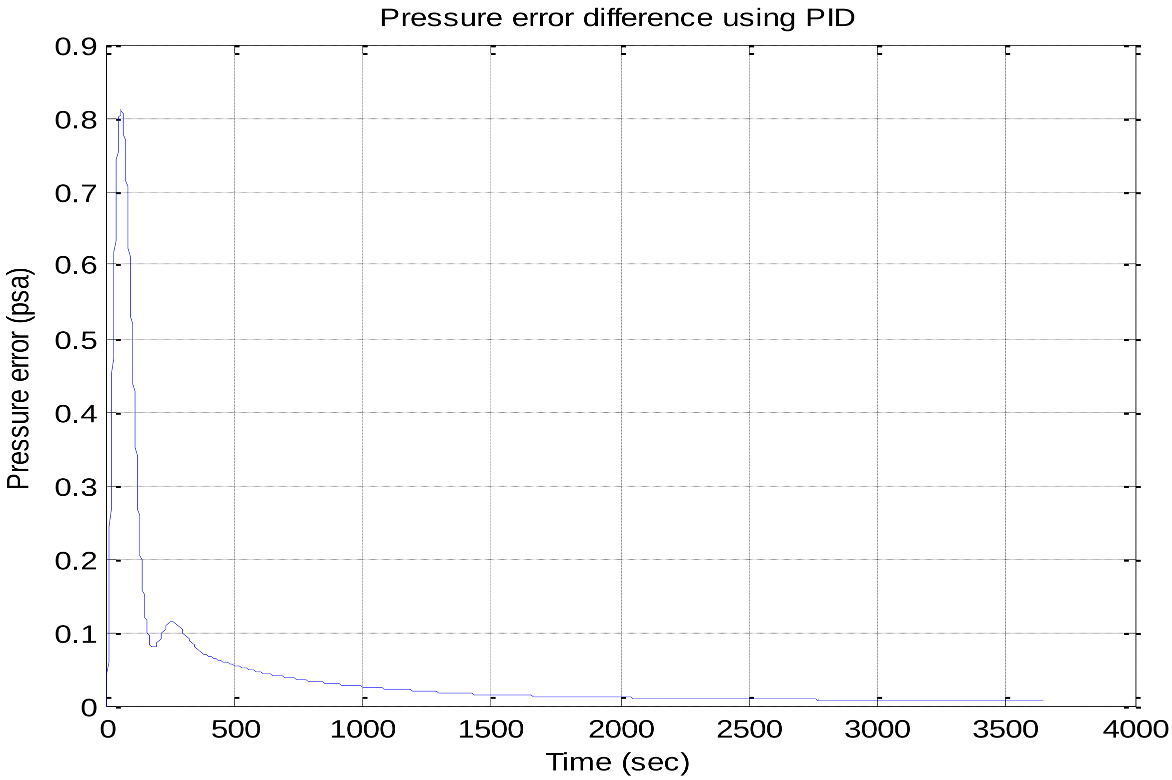

Fig. 4.8: The Control action of the PID Controller on Pressure Effect of Temperature Error Deviation.

4.1.4 Simulation Results on Gasoline (petrol) Temperature Error Deviation

The simulation results obtained on the temperature error deviation of Gasoline (petrol) using the PI, PD and PID controllers are shown as follows.

The figure 4.9 shows the Gasoline temperature error deviation using PI controller.

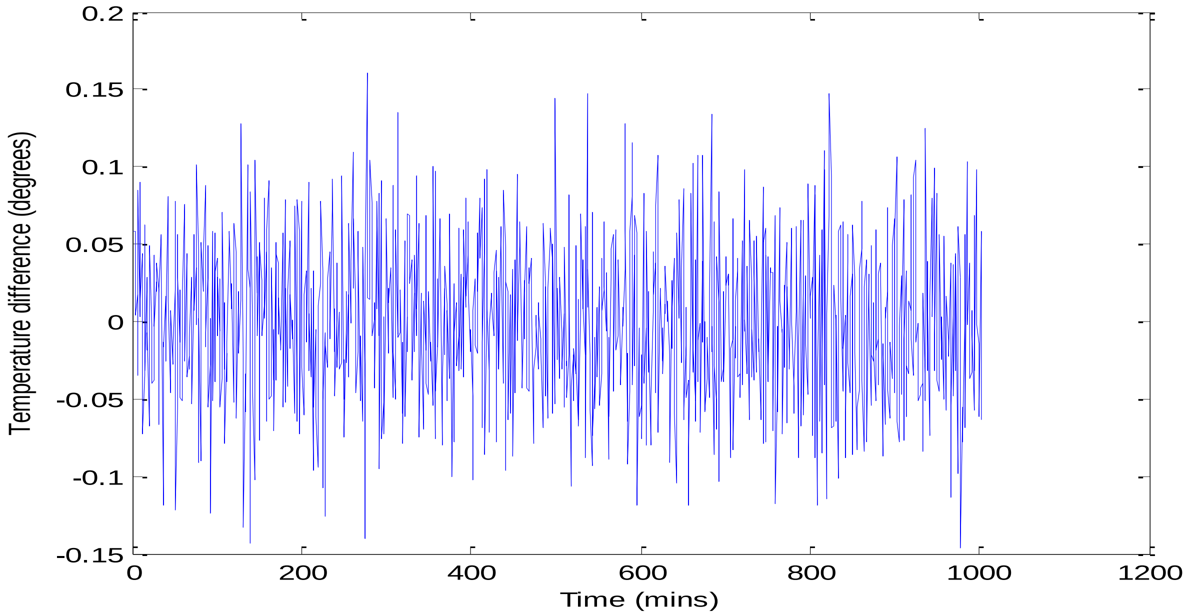

Fig. 4.9: The Control of Gasoline Temperature Error Deviation using PI Controller.

The Figure 4.10 shows the Gasoline temperature error deviation using PD controller.

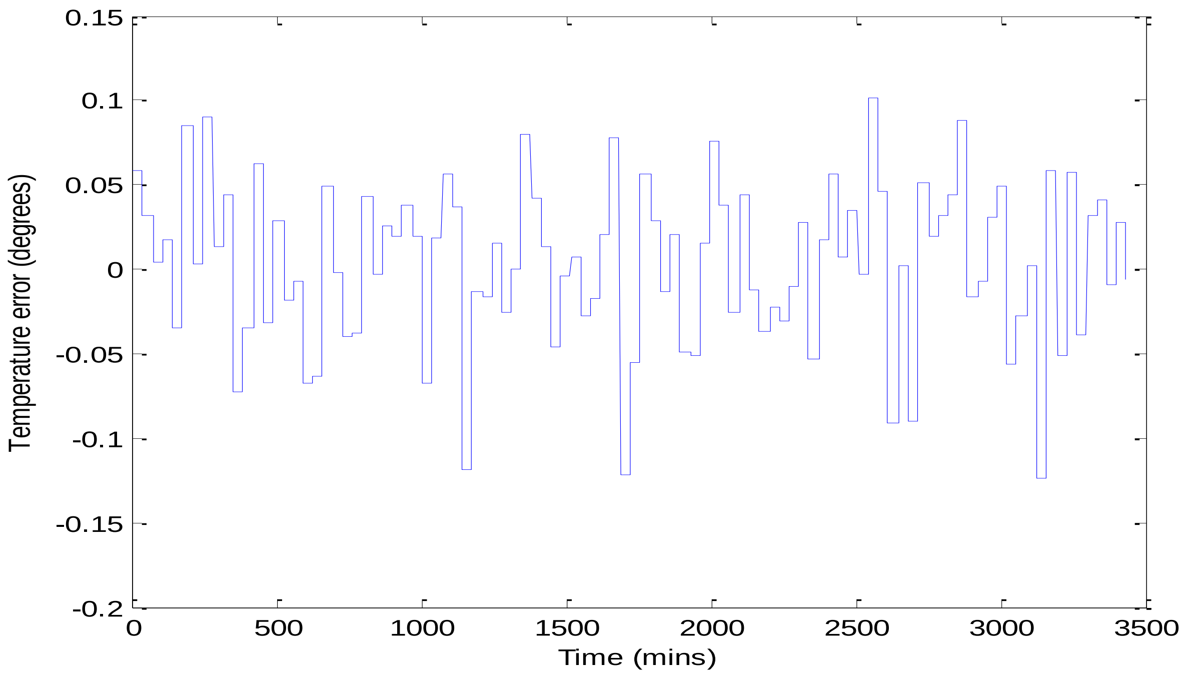

Fig. 4.10: The Control of Gasoline Temperature Error Deviation using PD Controller.

The Figure 4.11 shows the Gasoline temperature error deviation using PID controller.

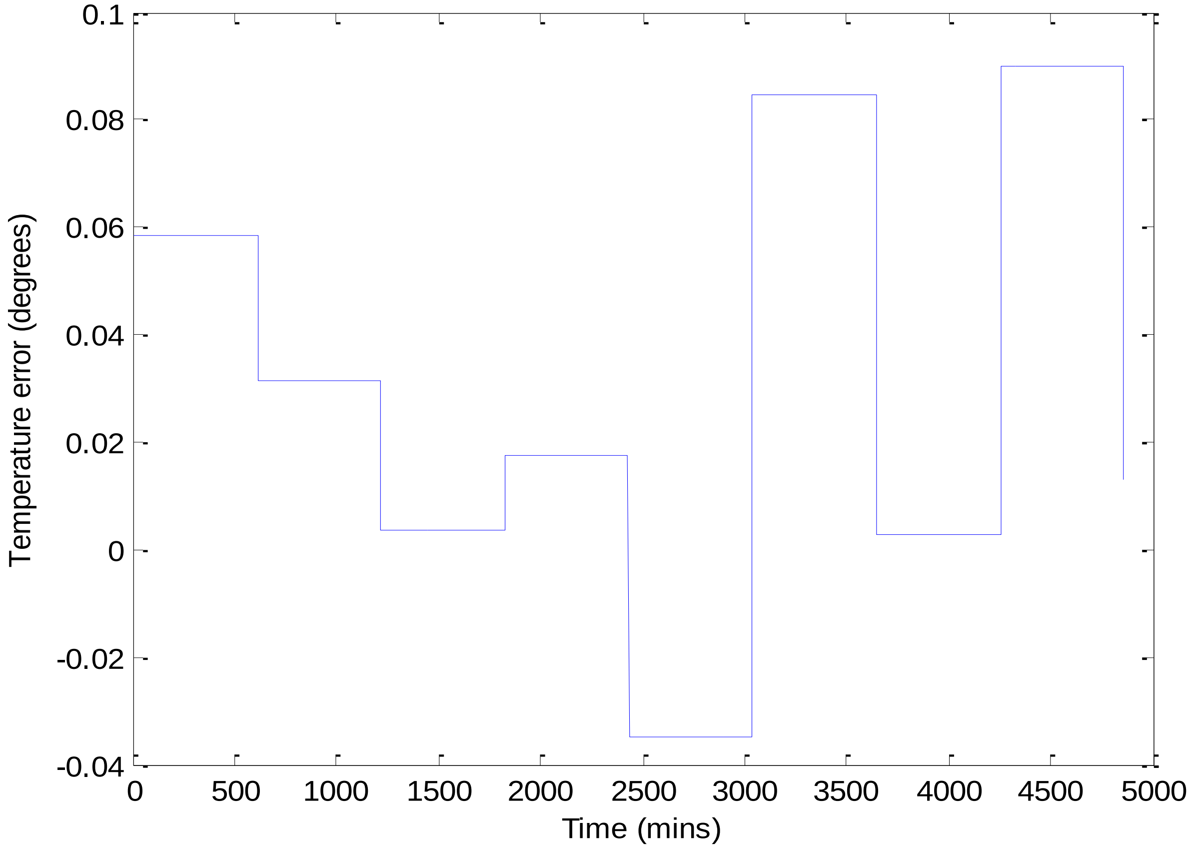

Fig. 4.11: The Control of Gasoline Temperature Error Deviation using PID Controller.

4.1.5 Simulation Results on Kerosene Temperature Error Deviation

The simulation results obtained on the temperature error deviation of Kerosene using the PI, PD and PID controllers are shown as follows.

The figure 4.12 shows the Kerosene temperature error deviation using PI controller

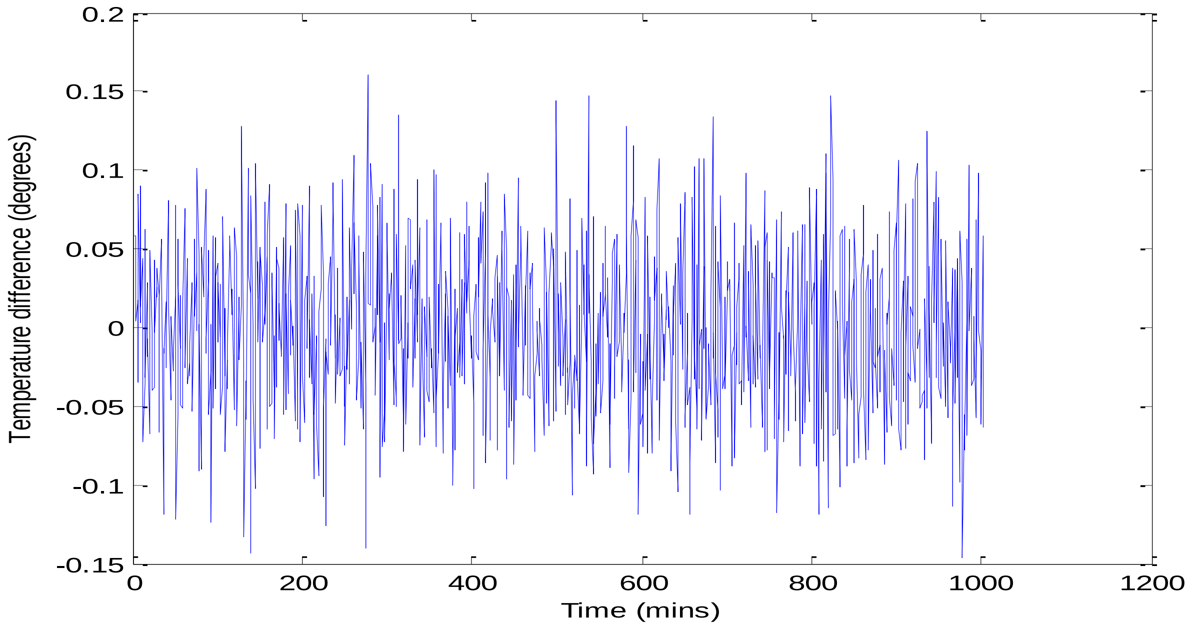

Fig. 4.12: The Control of Kerosene Temperature Error Deviation using PI Controller.

The Figure 4.13 shows the Kerosene temperature error deviation using PD controller.

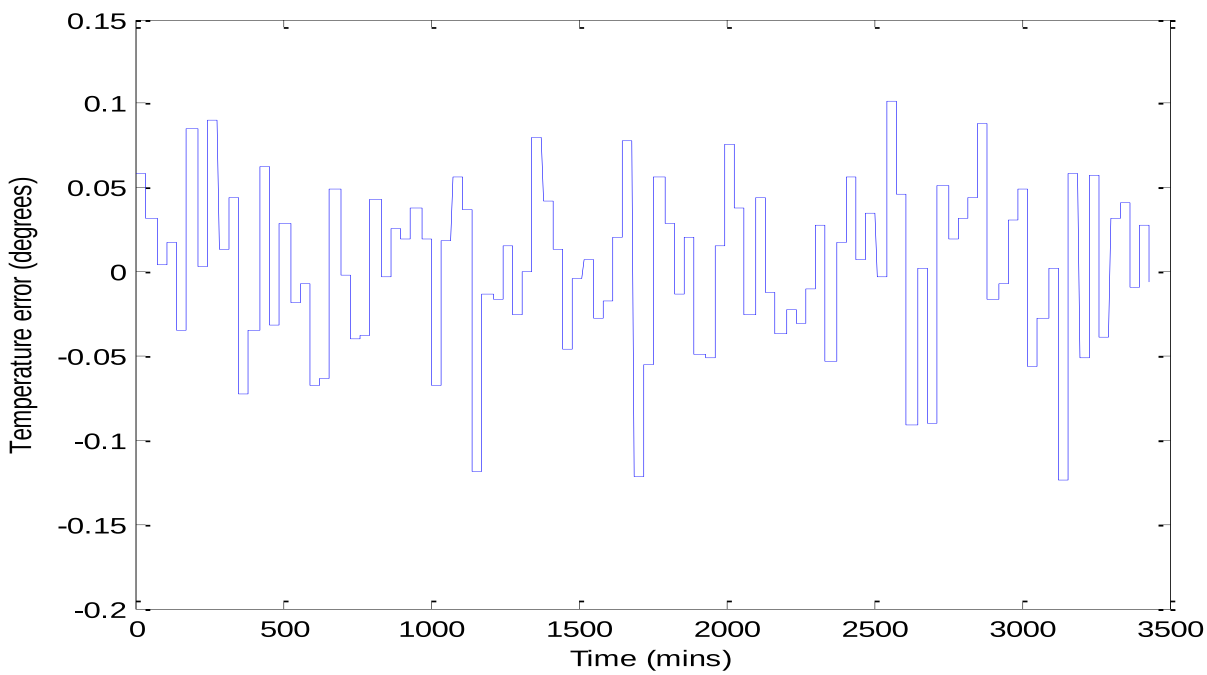

Fig. 4.13: The Control of Kerosene Temperature Error Deviation using PD Controller.

The Figure 4.14 shows the Kerosene temperature error deviation using PID controller.

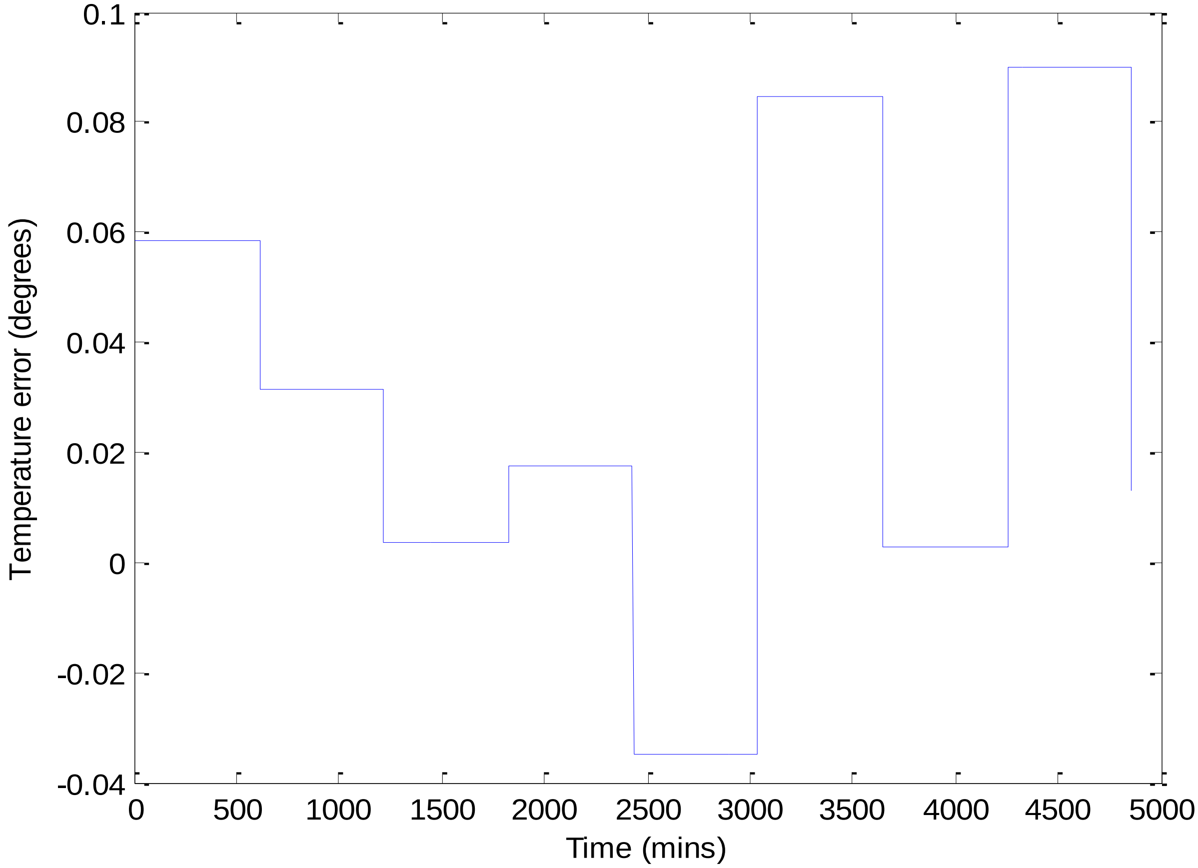

Fig. 4.14: The Control of Kerosene Temperature Error Deviation using PID Controller.

4.1.6 Simulation Results on Diesel Temperature Error Deviation

The simulation results obtained on the temperature error deviation of Kerosene using the PI, PD and PID controllers are shown as follows.

The figure 4.15 shows the Diesel temperature error deviation using PI controller

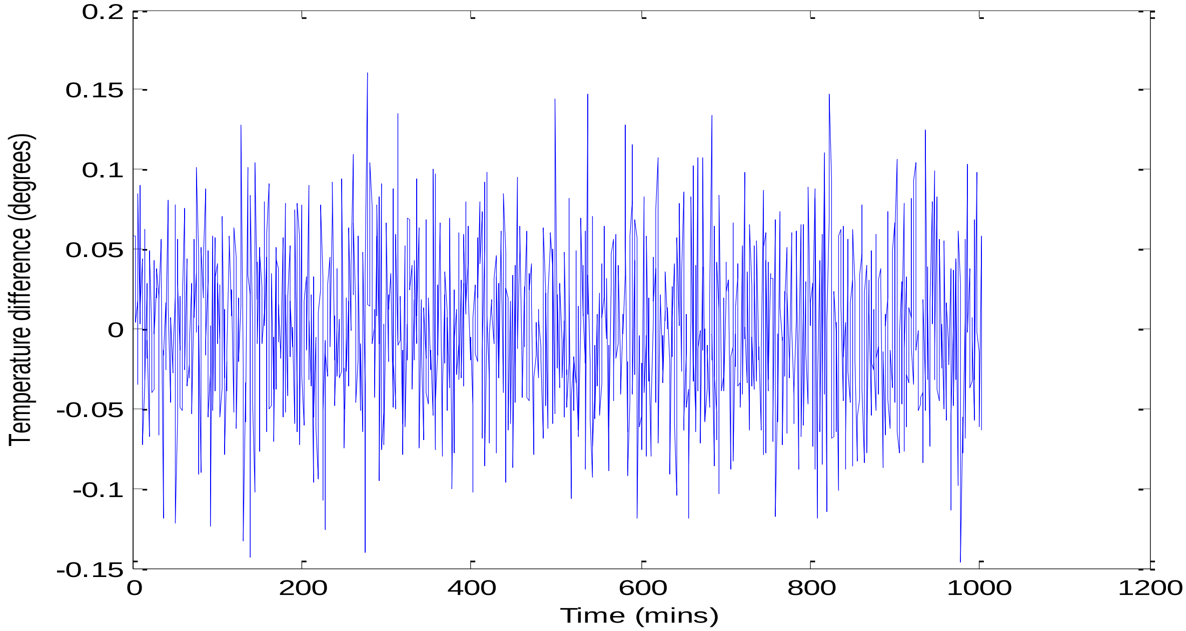

Fig. 4.15: The Control of Diesel Temperature Error Deviation using PI Controller.

The Figure 4.16 shows the Diesel temperature error deviation using PD controller.

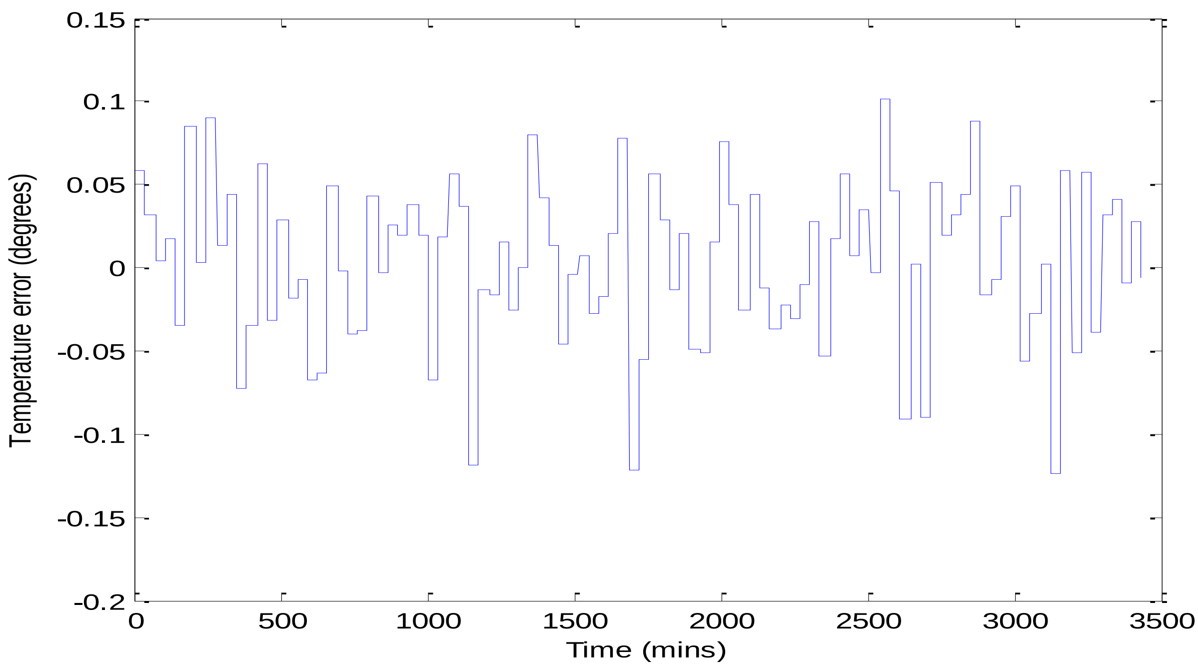

Fig. 4.16: The Control of Diesel Temperature Error Deviation using PD Controller.

The Figure 4.17 shows the Diesel temperature error deviation using PID controller.

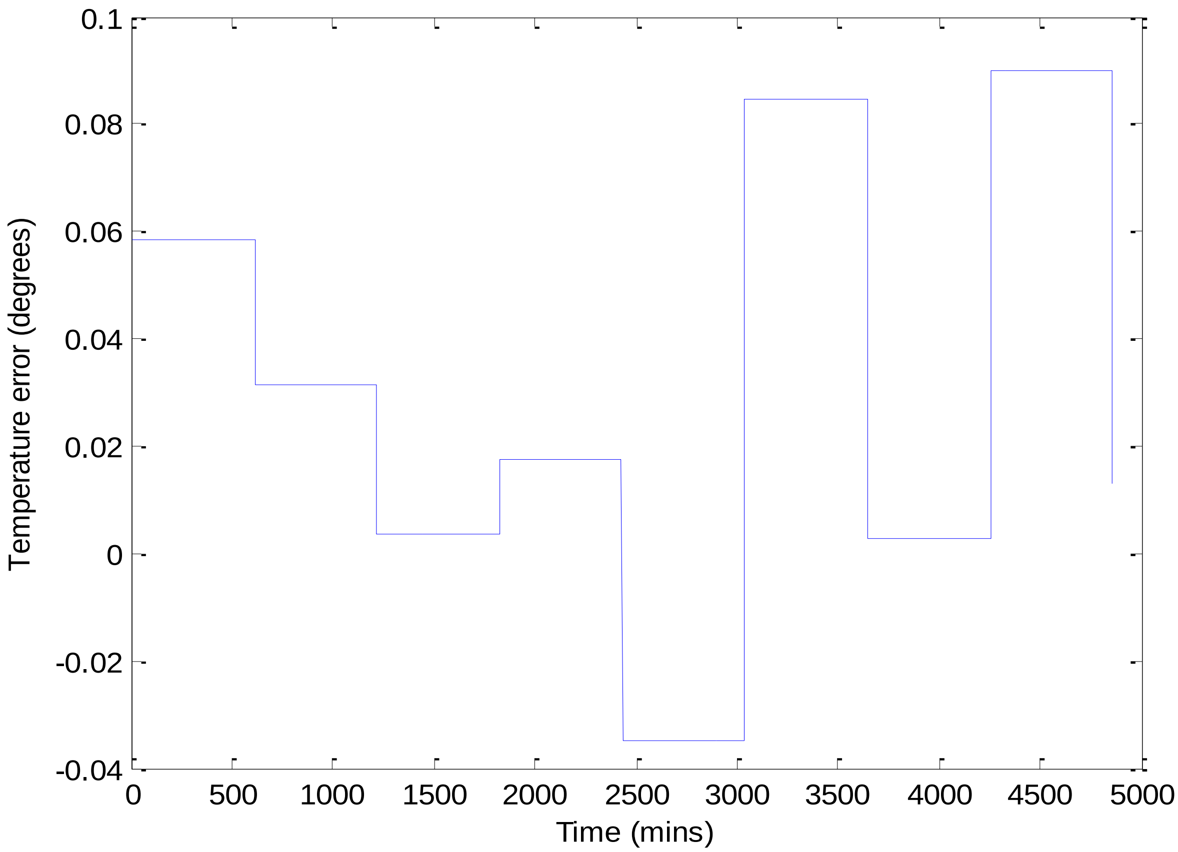

Fig. 4.17: The Control of Diesel Temperature Error Deviation using PID Controller.

4.2 DISCUSSIONS

The figure 4.1 is the simulated result of the uncontrolled characteristics of the thermal effect on the storage tank to be controlled. From the oscillogram, the simulation result indicate how atmospheric conditions and internal agitations of the molecules of the liquid in consideration affects the temperature of the system if not put under control system. It rises sharply deviating from the setpoint of the system. at this point, no control measure was taken. Table 4.1 shows how the temperature increases with time in seconds.

Table 4.1: Atmospheric Condition and Effect on Temperature Characteristics

TIME (SECONDS)	TEMPERATURE (°C)
1	0.2
2	1.0
3	2.0
4	3.0
5	4.0
6	5.0
7	6.0
8	7.0
9	8.0
10	9.0

The figure 4.2 shows how the temperature is controlled using PID controller to ensure that it does not get to the flash point of the material in the storage tank. The results proves that Proportion Integral Derivative is a good controller. As the temperature rises very high to dangerous level, the sensor will detect the sharp rise in the temperature and give command to the controller to trigger the switch for the hydrants to open and cool the storage tank thereby reducing the temperature to safe or normal range. Table 4.2 shows how the controlled temperature was evaluated with time. From the table, it can be seen that the temperature did not deviate from the setpoint when the system is under control unlike the system when is not under control.

Table 4.2: Temperature Controlled when PID is Applied to the Effect of Atmospheric Conditions

TIME (SECONDS)	TEMPERATURE (°C)
1	0.9
2	1,15
3	1.0
4	1.0
5	1.0
6	1.0
7	1.0
8	1.0
9	1.0

The figures 4.3, 4.4 and 4.5 and tables 4.3, 4.4 and 4.5 shows the simulated results of temperature error deviation when PD, PI, and PID controllers were used respectively.

The oscillogram of figure 4.3 shows the deviation of set point when Proportional Derivative (PD) controller is being used. The essence is to actually compare the performance of the PD controller with Proportional Integral Derivative (PID) controller. Table 4.3 shows temperature error deviation with time.

Table 4.3: Temperature Error Deviation Control with time using PD

TIME (SECONDS)	TEMPERATURE (°C)
500	0.95
1000	0.96
1500	0.97
2000	0.98
2500	0.99
3000	1.0
3500	1.0
4000	1.0
4500	1.0

The simulated result of figure 4.4 shows the control of temperature using proportional integral controller. The error is being manipulated by the controller to achieve a better result so that the temperature could be stable. It is used to compare the performance with Proportional Integral Derivative (PID) controller. Table 4.4 shows temperature error deviation with time.

The simulated result of figure 4.5 shows the control of temperature using Proportional Integral Derivative (PID) controller. The error is being manipulated by the controller to achieve the best result as to ensure that the temperature remains stable. It was discovered that PID controller gives an excellent control measure when compared with PI and PD controllers. Table 4.5 shows temperature error deviation with time.

Table 4.4: Response of Temperature control of the liquid in consideration Using PID as control element

TIME (SECONDS)	TEMPERATURE (°C)
50	0.89
100	0.09
200	-0.91
300	-0.93
400	-0.96
500	-0.99
600	-0.1

Table 4.5: The control of Temperature characteristics on the liquid to avoid temperature abnormal rise using PID control (Error deviation)

TIME (SECONDS)	TEMPERATURE (°C)
500	0.05
1000	0.04
1500	0.03
2000	0.02
2500	0.02
3000	0.02
3500	0.01
4000	0.01
4500	0.01

Having considered the atmospheric effect on the temperature, pressure effect was considered to actually know how it affects the temperature of the system. The system was simulated using PD, PI and PID controllers. Pressure is directly proportional to increase in temperature.

The figure 4.6 shows how pressure was controlled using PD controller. This is done to actually remove the impact of the pressure on the system because an increase in pressure will increase the temperature of the storage tank. All liquids have a specific vapor pressure, which is a function of that liquid's temperature and is subject to Boyle's Law. Table 4.6 shows pressure error deviation with time.

Table 4.6: Temperature and Pressure Relationships Showing Error Deviation with time using PD controller

TIME (SECONDS)	PRESSURE (PASCAL)
250	1.2
500	1.1
1000	1.05
1500	1.03
2000	1.02
2500	1.01
3000	1.01
3500	1.01
4000	1.01

Figure 4.7 also shows the simulation of the system when PI controller was used to control the pressure of the system. Normally, the relationship between the temperature and pressure is linear but the figure depicts the error correction as the sensors pick the deviation from the set points. Table 4.7 shows the error deviation of the pressure using PI as the controller.

Table 4.7: The Result of Pressure being Controlled using PI Controller

TIME (SECONDS)	PRESSURE (PASCAL)
25	0.18
50	0.05
100	0.05
150	0.06
200	0.06
250	0.08
300	0.08
350	0.1
400	0.1

The figure 4.8 shows the oscillograms of the PID controller when pressure effect is considered. It is obvious that PID gives the best control actions when compared with PI and PD controllers. As soon as the pressure rises to abnormal level, the temperature will also rise to abnormal level, The PID will initiate the control activities, the essence is to ensure that error correction takes place without time delay or time lags and figure 3.14 which is the storage tank cooling system will release the cooling fluid which may be mixture of water and detergents. Table 4.8 shows pressure error deviation with time.

Table 4.8: Control of Pressure Effect on the Liquid using PID Controller

TIME (SECONDS)	PRESSURE (PASCAL)
250	0.11
500	0.06
750	0.06
1000	0.04
1250	0.04
1500	0.03
1750	0.03
2000	0.02
2250	0.02
2500	0.01
2750	0.01
3000	0.01
3250	0.01
3500	0.01
4000	0.01

The figures 4.9, 4.10 and 4.11 and tables 4.9, 4.10 and 4.11 shows the simulated results of temperature error deviation carried out on Gasoline (also known as Petrol) with its flash point temperature as -43 °C using the PI, PD, and PID controllers respectively. It was observed that the PID controller gives a more stable result when compared with the PI and PD controller.

The figure 4.9 shows the simulated result on the control of temperature of the Gasoline using the Proportional Derivative Controller. The temperature error as seen is been manipulated by the controller in the best possible way as to achieved a minimal error in order to produce a desire result on the stability of the temperature. Table 4.9 shows temperature error deviation with time.

The figure 4.10 shows the simulated result on the control of temperature of the Gasoline using the Proportional Integral Controller. The temperature error as seen is been manipulated by the controller in the best possible way as to achieved a minimal error in order to produce a desire result on the stability of the temperature. Table 4.10 shows temperature error deviation with time.

The figure 4.11 shows the simulated result on the control of temperature of the Gasoline using the Proportional Integral Derivative Controller. The temperature error as seen is been manipulated by the controller in the best possible way as to achieved a minimal error in order to produce a desire result on the stability of the temperature. Table 4.11 shows temperature error deviation with time.

Table 4.9: The control of Temperature Error Deviation on Gasoline using PI controller

TIME (MINUTES)	TEMPERATURE (°C)
200	0.08
400	0.08
600	1.13
800	-0.09
1000	-0.1

Table 4.10: The control of Temperature Error Deviation on Gasoline using PD controller.

TIME (MINUTES)	TEMPERATURE (°C)
500	0.03
1000	0.04
1500	0.01
2000	0.08
2500	-0.06
3000	-0.05
3500	-0.02

Table 4.11: The control of Temperature Error Deviation on Gasoline using PID controller

TIME (MINNUTES)	TEMPERATURE (°C)
500	0.06
1000	0.03
1500	0.01
2000	0.02
2500	-0.03
3000	-0.03
3500	0.08
4000	0.02
4500	0.09

The figures 4.12, 4.13 and 4.14 shows the simulated results of temperature error deviation carried out on Kerosene with its flash point temperature ranging between 38 - 72 °C using the PI, PD, and PID controllers respectively. It was observed that the functionality of the three different types of controllers applied in controlling the temperature effect on Kerosene remains stable as that of the Gasoline irrespective of the flash point temperature difference that exist between the Kerosene and Gasoline. the PID controller gives a more stable result when compared with the PI and PD controller.

The figures 4.15, 4.16 and 4.17 shows the simulated results of temperature error deviation carried out on Diesel with its flash point temperature as 52 °C using the PI, PD, and PID controllers respectively. It was furthermore observed that the functionality of the three different types of controllers applied in controlling the temperature effect on Diesel remains stable as that of both the Gasoline and Kerosene irrespective of the flash point temperature difference that exist between both the Kerosene, Gasoline and that of the Diesel. likewise, the PID controller gives a more stable result when compared with the PI and PD controller.

The obtained results of figures (4.9, 4.10 & 4.11), figures (4.12, 4.13 & 4.14) and figures (4.15, 4.16 and 4.17) carried out on the temperature error deviation of Gasoline, Kerosene and Diesel further affirmed the effectiveness and efficiency of the designed control system. The PI, PD and PID controllers deployed in the designed scheme satisfactorily reduce the temperature error of the various petroleum product to a minimal level.

These results shows that the implemented control system will reduce some of the fire incidents that occurs in the oil facilities and most especially in the storage tank farms.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.I CONCLUSION

This thesis has presented a temperature controller and a cooling system for effective storage of the petroleum product. The research work is aimed at designing a temperature controller for regulating the temperature characteristics of a petroleum product in the storage tank. To achieve the objective of this thesis, mathematical modeling of the temperature controller was obtained in order to analyze the effect of high pressure on temperature characteristics of the petroleum product. Device modeling, analysis and simulation of the model were performed and transformed into their equivalent Simulink blocks. Resistance Temperature Detector (RTD) sensors, Proportional Derivative (PD), Proportional Integral (PI) and linear Proportional Integral Derivative (PID) controllers were designed to form the control loop representing the temperature control unit of the storage tank. Designing these controllers, Simulink block was used and the system modeled to meet design specifications. The PD, PI and PID were designed by selecting appropriate parameters to form the temperature controller. The designed controllers were integrated with a cooling system model dynamic to form the storage tank temperature control loop.

The parameters of simulation were modeled from the rated operational data of the considered proportional integral derivative (PID). The entire temperature control loop was implemented in MATLAB Simulink. The simulation results obtained showed that the PID gives the best control actions when compared with PD and PI controllers. As soon as the pressure rises to abnormal level, the temperature will also rise to abnormal level. The PID will immediately initiate the control activities which also activate the cooling system of the storage tank and triggers the release of the cooling fluid at which point the system is stabilized.

The designed temperature controller system ensures that the petroleum product of the storage tank can be operated without an abnormal increase in temperature, hence operational activities can be carried out over a long duration of time. Unlike the existing temperature control scheme in which an operator in the control room takes track record of the temperature characteristic of the petroleum product and immediately presses the fire alarm signal in the event of an increase in temperature. There is always an interval of time gap from the time of notification of the fire alarm because of the precautionary measures to be put in place by the safety and firefighters' personnel before their arrival at the storage facilities, it is this delay that often pave way for smoldering to take place and eventually result into a fire outbreak that could have been avoided with real time responses. Thus, a temperature controller for improving the temperature characteristics of a petroleum product in the storage tank has been developed with the help of the MATLAB software.

5.2 RECOMMENDATION FOR FUTURE WORKS

The storage tank farm as one of the main aspects of the process industries is economically critical. In this thesis, a temperature controller has been modeled and simulated to perform temperature control functions for effective storage of the petroleum product. Hence the following recommendation have been made.

i. This research work was developed to perform temperature control of the petroleum product in a storage tank. A robust pressure control system can be developed to further assured a safer activity in the storage tank farm.
ii. It is therefore recommended that an automated pressure and temperature control system be implemented as part of the control scheme in future work.

5.3 CONTRIBUTION TO KNOWLEDGE

The following are the contributions to knowledge drawn from the research work.

i. From standard flash points of different hydrocarbon liquids reference in the work, an effective and efficient temperature controller system has been designed for petroleum storage. The results obtained showed that this system was able to control the usually abnormal rise in temperature characteristics of petroleum product in locally available storage tanks.

ii. A temperature sensor detection system was designed to detect the sharp rise in temperature of the storage tanks and present a command to the controller to trigger the valve for the hydrants to open and a cooling fluid be showered on the storage tank of the petroleum product.

iii. An automated cooling system which sheds off the time delay of all human interfaces to enhance safety of equipment and personnel, in the event of an abnormal rise in temperature which most times lead to a fire outbreak was incorporated in the designed controller.

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