© AUG 2025 | IRE Journals | Volume 9 Issue 2 | ISSN: 2456-8880

Design and Simulation of High-Performance Temperature Control System for Glass Annealing Oven

GIDDEL INNY-MFON JOSHUA[1], L. O. UZOECHI[2], M. OLUBIWE[3], AGOHA STEPHEN CHUKWUMA[4], C. K. OGUZIE[5]

[1]*Department of Electronic Engineering, School of Electrical System Engineering and Technology, Federal University of Technology Owerri (FUTO) Owerri, Nigeria*

[2]*Department of Electronic Engineering, School of Electrical System Engineering and Technology, Federal University of Technology Owerri (FUTO) Owerri, Nigeria*

[3]*Department of Electrical Engineering, School of Electrical System Engineering and Technology, Federal University of Technology Owerri (FUTO) Owerri, Nigeria*

[4]*Department of Electronic Engineering, School of Electrical System Engineering and Technology, Federal University of Technology Owerri (FUTO) Owerri, Nigeria*

[5]*Department of Polymer Engineering, School of Engineering and Engineering and Technology, Federal University of Technology Owerri (FUTO) Owerri, Nigeria*

Abstract- This research presents a comprehensive study focused on the design and simulation of an advanced temperature control system designed for an oven for bottle production. The main issue addressed pertains to the desperate need for precise temperature regulation within the manufacturing process to ensure consistent product quality and operational efficiency. The study employs closed loop control systems, recognized for their adeptness in maintaining predefined temperature levels, as the core research method. A blend of experimental and simulation-based approaches is harnessed to craft and integrate the advanced temperature control system. The research details the annealing process, enhancing bottle ductility and hardness. Employing a closed loop mechanism, fortified with a proportional-integral-derivative (PID) controller to ensure meticulous temperature maintenance. The ZieglerNichols method refines the PID controller calibration, and the process reaction technique determines the PID parameters. The study establishes the integrated system's prowess in enhancing product quality and efficiency, attributing its success to the precise maintenance of the desired temperature range, concomitantly reducing subpar bottle production. The culmination of this research is the highlighting of the study's recommendation for closed-loop control systems, paired with PID controllers, as the optimal approach for temperature management in annealing oven and similar processes, resonating with significant manufacturing, particularly in developing contexts necessitating heightened quality and implications for efficiency. The result showed that PID controller was used to achieve the desired goal and objective because it was able to control the temperature sensors to keep the temperature at the desired range of 500 – 5500C. The research work was able to achieve its set objectives.

Indexed Terms— Simulation, PID, Ziegler-Nichols method, Temperature.

I. INTRODUCTION

Temperature control that is very effective is essential for a wide variety of procedures used in industry and research. The use of controllers that enable the value of the temperature to be maintained at a specified level is most often how the control is accomplished. Some examples of such industrial operations are the burning of coal in the furnaces of power stations, the melting of glass, the operation of nuclear reactors, and the operation of automated heating systems. Control system with an open loop as well as ones with a closed loop may be found in the fore mentioned applications. On the other hand, the latter option is recommended in order to provide accurate temperature control that also has adequate dynamic behavior and resilience against disruptions from the outside. For the process of heat treatment, furnaces are used in the manufacturing of bottles. Annealing is a kind of heat treatment in which molten glass is first subjected to high heat and then subjected to rapid cooling. The procedure's goal is to make the bottle more ductile while simultaneously increasing its level of hardness. The temperature profile that is maintained during the annealing process is what determines the qualities of the glass. Even little shift in temperature, have the potential to render a whole batch of goods useless, which would result in significant financial losses. In the event that this occurs in excessive number of times, it may cause clients to lose trust in the company and begin to look for alternative options. Because of the difficult circumstances that the bottle business is going through at the moment, it is more crucial than it has ever been to have procedures that are both cost effective and profitable.

Revolutionary advancements in glass manufacturing technology have been limited due to the conservative nature of the industry. Processes used currently are only slight variations of those pioneered over 100 years (Wikipedia, 2015). Design improvements which increase efficiency and production of smaller ovens must be made for small companies to survive in the future. The cyclic loading of glassware in smaller ovens creates thermal stresses that can cause cracking and failure of the glassware containers.

Strategies for improving productivity which include (Holladay & Holladay, 2005):

- Increasing the amount of product per unit time
- Decreasing breakage and waste/scrap
- Decreasing energy per ton of product
- Decrease labor needed per ton of product
- Increase oven lifespan
- Many of these objectives can be addressed via two synergistic paths
- Improved oven structural design
- Improved control of temperature and rate of combustion in the oven

The current issue at hand pertains to the distribution of temperature within the furnace. In certain areas of the furnace, the temperature exceeds the desired level despite the burners being in an inactive state.

Annealing is a thermal treatment in which a material is subjected to, such as glass bottles, to a specific temperature range to achieve desired material properties. The material is then rapidly cooled to preserve these properties. The afore mentioned process is widely recognized and frequently utilized in the production of glass items. The attainment of a specific reference temperature by the furnace is crucial as it determines the resultant properties of the material, as dictated by its temperature profile. An excessive temperature if differential has the potential to result in the complete loss of a batch of processed material. The glass will be propelled through the temperature zones by means of a moving beam. The employment of a moving beam is associated with the act of opening and closing doors for the insertion and removal of glass bottles from the oven.

APPLICATION

This thesis is based on the acknowledgement of a widespread industry requirement for energy preservation, driven by the dual objectives of environmental conservation and corporate profitability. The escalating cost of energy poses a significant challenge to the sustainability of small-scale glass manufacturing enterprises. Consequently, there exists a pressing demand for a cost-effective and energy-efficient furnace design that caters to the specific needs of small glass production facilities. Heat control of the sensors to a desired temperature range will adequately improve and boost the end product with a very good minimum loss.

II. LITERATURE REVIEW

2.1 Review of Glass Production Process

The glass production process can be separated into four phases – batch mixing, furnace charging, melting, and forming.

2.1.1 Batch Mixing

Batch mixing, also called "batching," includes the creation of a mixture of raw materials designed to produce the desired end product. Raw materials used in batching can be divided into groups based on their function in the melting process. (Shelby 1997) separates batch materials into five groups – glass-formers, fluxes, property modifiers, colorants, and fining agents. Although formulae for batch mixtures vary greatly among producers, the majority of batch material used in a mixture is always a glass-former. Glass-formers are the compounds that create the structural basis of the glass. The most common glass formers are silica, (SiO_2), boric oxide, (B_2O_3), and phosphoric oxide, (P_2O_5). Pure silica has a melting temperature over 2100°C. Adding a flux to the batch mixture can lower the melting temperature by over 500°C (Shelby 1997). The most common fluxes are soda ash (sodium oxide (Na_2O) mixed with sodium carbonate (Na_2CO_3)), limestone ($CaCO_3$), and potassium carbonate (potash, K_2CO_3). Lead oxide, (PbO), the compound used to make crystal glass, is also an effective fluxing agent, but usage is decreasing due to environmental regulations concerning heavy metals.

Adding property modifiers, such as alumina (AlO_3), will increase the durability of the chemical structure. Batch recipes are designed to balance the effects of the flux and the property modifier in a manner that suits the desired purpose of the finished product. Colorants are chemical compounds added to the batch mixture to create a desired tint in the finished glass. Most colorants are transition metals including iron, manganese, cobalt, copper, chromium and tungsten. Transition metals have valence electrons (the electrons that combine with other elements) in more than one shell or level. Since each level of the transition metal absorbs light of a different frequency, the visible colors are a result of electron transmission between valence levels in the ion. Other colorants, including Sulfur and selenium, replace some of the oxygen in the glass and form new compounds with different absorption characteristics than the batch compounds (Tooley 1984).

Fining agents help remove bubbles from the molten glass. Bubbles can be caused by chemical reactions during the melting process, breakdown of the refractory lining of the furnace or by gasses trapped between batch particles. These bubbles must be removed to improve the quality of the glass. Compounds including arsenic and antimony oxides (AS_2O_5, Sb_2O_5), potassium and sodium nitrates (KNO_3, $NaNO_3$), salt, (NaCl), sulfate (SO_3), and several fluorides (CaF_2, NaF, $NaAlF_6$) can be added separately or in combination for the fining portion of glass production. Small bubbles in the molten glass are carried to the surface with larger bubbles formed by chemical reactions induced by the addition of the fining agents (Shelby 1997).

2.1.2 Furnace Charging

Furnace charging is the process by which the raw materials are fed into the furnace. Materials are added to the furnaces either continuously or in batches. Continuous batch feeding is accomplished with the use of either a screw, blanket or pusher type charger. All three types of chargers push the batch material into the furnace at a steady rate. A screw charger is a large helical auger that moves the batch toward the furnace as it rotates. Blanket chargers push horizontal lines of batch towards the furnace with a long bar. And pusher chargers feed small amounts of batch into the center of the melter by means of a rocking mechanism. 2 Batch charging is used on small furnaces with capacities of less than 10 tons per day. Batch charging is a manual procedure; employees use shovels to load batch materials into a furnace. Some operations require small amounts of batch to be added to the furnace 2-3 times per hour, while other operations only load batch once per day.

2.1.3 Melting Process

The melting process converts raw materials to molten glass. This process can be divided into 4 stages: melting, fining, homogenizing and heat conditioning. These stages are not completely sequential from the charging end of the furnace to the forming end. Instead, the stages overlap as the materials progress towards the outlet of the furnace. For a batch furnace the position of the stages along the length of the furnace can be equated to the time from loading the batch to the removal of glass. Figure 2.5 shows the overlap of stages.

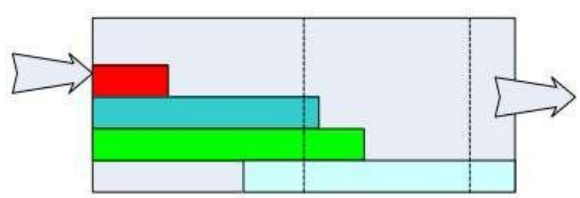


Fig 2.1: Stages of Melting (Tooley 1981)

2.1.4 Melting

Melting begins upon introduction of the batch material to the charging end of the furnace. As heat is added to the furnace, water in the batch evaporates and chemical compounds break down and begin to transition to a liquid stage. The evaporation of water decreases the volume of the melt and increases the energy consumption of the furnace, compounds in batch materials are hygroscopic and will absorb water from the atmosphere. Also, raw materials are often sprayed with water to decrease dust during mixing and transportation. As the chemical compounds break down, and become liquid, several gasses, including CO2, SO2, and SO3, are formed. The formation of these gasses produces bubbles which must be removed before the forming process.

2.1.5 Fining

The removal of bubbles in the melt occurs in the fining stage. Bubble behavior in the melt can be described by Stokes' Law:

$$\overrightarrow{V_s} = \frac{2g(p_s - p_l)r^2}{9\eta_v} \quad (2.3)$$

Where

$\overrightarrow{V_s}$= Velocity of a solid sphere of a known density,
G = acceleration of gravity
(p_s- p_l)= difference in the density of the sphere and the surrounding fluid
r = radius of the sphere
η_v= viscosity of the fluid

Which states that the velocity of a solid sphere is proportional to the square of the radius of the sphere. A variation of Equation (2.3) is used by (Shelby,1997) to describe the behavior of a gas filled bubble in a viscous liquid.

$$\overrightarrow{V_b} = \frac{3}{2}\overrightarrow{V_s} \quad (2.4)$$

Where $\overrightarrow{V_b}$is the velocity ofthe bubble.

Because bubble velocity is dependent upon size, larger bubbles will quickly rise to the top of the melt. Small bubbles move so slowly that time required to reach the surface can cause delays in production. The presence of fining agents in the batch material aids in the removal small bubbles by creating larger bubbles that will carry the small bubbles to the surface.

Creating an upward flow within the melt can help increase the rate of bubble rise. Mechanical stirring, or compressed air forced through nozzles located in the bottom of a tank, can be used to produce the necessary current. The creation of hotter and cooler sections of a furnace by localized heating can induce convective currents that promote fining and the geometric design of the bottom of the furnace can also produce the desired upward flow (Shelby 1997).

2.1.6 Homogenizing

The homogenizing phase of melting begins with the initial melting and ends when the material in the furnace reaches the point at which the melt is free of batch material and of relatively uniform consistency. The degree of homogeneity required is based on the desired properties of the formed product. The homogenizing phase includes the entire melting and fining phases because the compounds in the melt are continually reacting to form the final product. Factors that affect the time required for a melt to homogenize include: particle size of the batch materials, combination of batch materials, temperature, and mixing patterns from either mechanical or convective currents (Tooley 1984).

2.1.7 Heat Conditioning

The heat conditioning phase is the time period in which the melt is brought to the temperature required for the intended forming process. Heat conditioning creates a uniform temperature in the portion of glass at the forming end of the furnace. The time required for heat conditioning is dependent upon the volume of the glass in the forming end, the desired forming temperature, and the flow rate of glass to the forming process.

2.1.8 Forming

Forming is the process that is applied to the molten glass as it leaves the furnace. Forming includes molding, hand blowing, floating, and glass fiber production. Although the various forming methods are not the focus of this thesis, the quality issues affecting the usability of the glass for each method are directly related to the melting process (Tooley 1984).

2.1.9 Furnace Design

Smaller furnaces, those with a production of less than 10 tons/day, are usually classified as one of two basic types – pot furnaces and tank furnaces. The fundamental difference in these two types is how the portion of the furnace that holds the glass is constructed. In pot furnaces, the container that holds the glass is constructed of ceramic clay and looks like a large, sometimes covered, crucible. The bottom and sides are usually formed in pieces and then pressed together to form the body of the pot; although, some monolithic designs exist, which are molded as a single unit. Plate 2.1 is a picture of the type of ceramic pot used in a pot furnace.

Fig. 2.3: Ceramic Pot Used in Pot Furnace (Kokomo Glass co.,)

Tank furnaces are constructed of refractory as in bricks. The bricks are stacked together without mortar to form a tank to hold the molten glass. The bricks are stabilized by an exterior frame usually made of steel. Molten glass seeps through cracks between the refractory bricks until it reaches the point where it cools enough to solidify. A picture of a tank furnace is included as plate 2.2

Fig. 2.2: Tank Furnace (Falorni Glass Furnaces)

Pot furnaces and smaller tank furnaces, called day tanks, are both used in the same manner. Raw materials are loaded into the pot or tank, the material is melted and held at a desired temperature, then the molten glass is taken out for production purposes. Most furnaces with a production rate of less than 5 tons per day are batch fed pot or day tanks. These furnaces are not recharged until the molten glass in the pot or tank has been depleted. The production of glass from pot and day tanks happens in cycles because of the time required to bring the large number of raw materials to the desired temperature. Some batch fed tank furnaces that produce over 3 tons of glass per day operate with more frequent batch charging (2-3 times per hour). The molten glass in these furnaces is maintained at a relatively constant level and production for these furnaces is usually continuous (Tooley, 1984).

2.1.10 Annealing

The annealing lehr refers to a sizeable insulated enclosure that facilitates the controlled passage of a flat glass ribbon at a predetermined speed, as illustrated in the schematic figure2.6. The enclosure is equipped with air ducts that facilitate the flow of air from a plenum, with a regulated initial temperature and flowrate. The objective of this arrangement is to expose the ribbon to an appropriate temperature profile, resulting in a desirable residual stress distribution upon reaching ambient temperature.

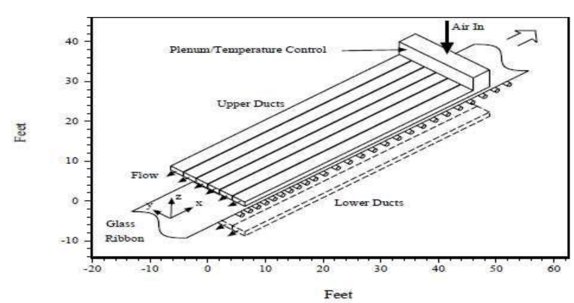


Fig 2.4: The annealing lehr

The glass ribbon is transported by means of supporting rollers and introduced into the lehr while in a fluid state, with a temperature of approximately 1050 degrees Fahrenheit. Upon exiting, the glass has undergone a transition to a temperature below its glass transition temperature as shown in figure 2.5.

Fig 2.5: lehr glass ribbon

The process of annealing occurs within a lengthy furnace, commonly referred to as a lehr. The lehr facilitates a regulated thermal processing regimen that effectively reduces the hardness of the glass, thereby eliminating the residual strains that are inherent in the glass during the shaping process. It is imperative that the temperature cycle for annealing is sufficiently low to prevent any loss of strength or alteration in shape of the glass. After the elimination of stresses, it is imperative to gradually cool the glass to avoid their reoccurrence. The lehr, which is responsible for achieving these outcomes at Glass producing facility, measures approximately 180 feet in length. The thermal distribution within the lehr is established through the utilization of heated gas generated by burners located in close proximity to the front end of the lehr. This gas is subsequently directed downwards through ducts situated beneath a steel mesh belt which serves to convey the glass. The quantity of hot gas introduced into the sections of the lehr is regulated by dampers situated along the duct.

The lehr chamber is supplied with hot gas through a set of apertures that are strategically placed to avoid direct contact between the gas and the glass. Subsequently, the heated gas is circulated back through the burner mechanism located at the anterior section of the lehr as shown in figure 2.6.

Fig 2.6: Lehr oven burner attached to the body of the lehr.

The regulation of the temperature of the incoming gas flow is achieved through the utilization of two thermocouples located within the lehr, specifically one in close proximity to the front and another positioned approximately 60 feet inward. In general, defects in a product that are a result of other processing stages become apparent once the glass has exited the lehr as shown in figure 2.7.

Fig 2.7: output bottles.

Once the glass has undergone the cooling process, it is possible for defects to arise. In such instances, it is customary for a professional in the field to be consulted in other to know the root cause of the issue. The services of the expert are often required in situations where modifications to the lehr are necessary due to alterations in product attributes or when the lehr is reactivated following a period of dormancy. In order to attain a specific temperature profile during the lehr process, the specialist has a variety of controls at their disposal that can be adjusted as shown in figure 2.8.

Fig 2.8: Lehr temperature controller for crown

Thermocouples.

Thermocouples have the capability to be adjusted in a manner similar to that of a standard residential thermostat. It a situation that the temperature at the probe decreases below the predetermined temperature, the temperature of the gas generated by the burners is elevated until the temperature is restored to the desired setting. Dampers are utilized in the lehr control to regulate the direction of hot air. The equitable distribution of heat throughout the lehr can be achieved by fully opening all the dampers as shown in figure 2.11. The obstruction of heat to all sections beyond a particular damper is achieved through its closure.

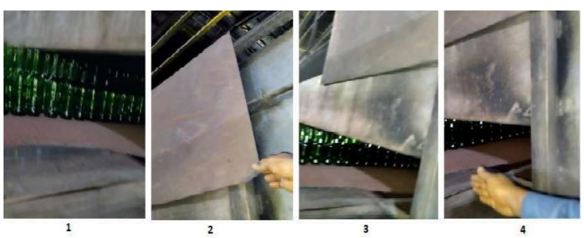


Fig 2.9: A suspended plate affixed to the lehr for regulating temperature.

Traditionally, individuals would commonly regulate the temperature by utilizing a suspended plate affixed to the lehr. Consequently, in situations where the temperature inside the lehr oven needs to be increased, the operator proceeds to lower the plate handling mechanism that is in contact with the oven and subsequently covers the exposed region of the oven. The temperature generation process in a lehr oven is symmetrical on both sides and ends, and the removal of plates is a gradual process to achieve the desired temperature level. Nonetheless, this process poses a significant risk to the operator's well-being and safety due to the exposure to exceedingly high temperatures. The automation of temperature monitoring and control in the glass-making oven is deemed necessary.

It is possible to partially close dampers. The lehr incorporates ports and louvers that function as air vents, facilitating the release of hot air and subsequently reducing the temperature within the lehr. The challenging aspect involves utilizing the various controls to elevate the temperature in specific regions of the lehr, while concurrently reducing it in other areas. Typically, a skilled professional is capable of effectively adjusting the process after two or three iterations. The objective of this project is to shift the responsibility of aiding operators in the adjustment of lehr firing and airflow systems from its human experts to a computer system.

2.2 REVIEW OF RELATED WORKS

Automatic temperature control system is one of the most popular feature which is rapidly gaining its popularity due to its importance to certain applications such temperature control (Ahmed,2009). This is an actual fact because of its innovative feature in changing temperatures automatically. According to Zairi et al (2013).

Rajkanna et al., 2012 in their work observed the various method of temperature control in forging and rolling industries. They noticed the temperature of most furnaces is controlled by supplying air-fuel combination, flow of electron, inflow of coal etc, depending on the type of furnace. The temperature is measured by using pyrometer type sensors or any contact type sensors. For fully automated furnace, temperature is measured and transmitted to control room through a wired connection. In wired network, transmission between control room and furnace and vice versa needs lengthy and confusing wire connections with high installation cost. Different types of furnaces like oil furnace, gas furnace and electric furnace are available in industrial applications, its classification is based on the method of heating the materials. Induction furnaces will not pollute the environment as that of other furnaces. In this method electric current is supplied to the induction coil. Current flow creates magnetic field in the coil, it induces eddy current in the work piece. This supplies heat to the work piece without any contact of an induction coil (Snaran et al., 1982). Transmitting and receiving of measuring and control variables are wired. In the occurrence of fault in wires, it's difficult to identify. The furnaces used in small scale industries are not fully automated. So, it's dangerous and insecure to use and also consumes more energy when it operates. They inferred that for such situations Resistance Temperature Detector (RTD) is used to measure temperature. Some advantages of using RTD are easy recalibration and providing accurate and stable output.

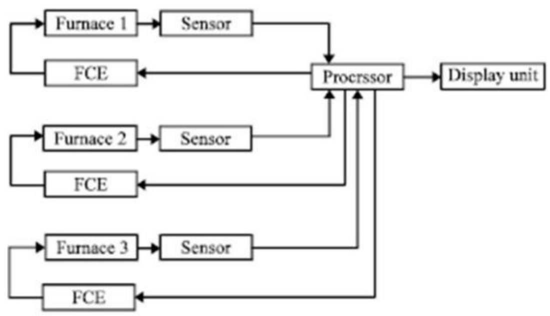


Fig. 2.10: Block diagram of a multiple furnace control system.

Important features of the RTD are quick response to temperature change and linear for a wide range of temperature (Singh, 2009). They follow positive temperature co-efficient principle, in which resistance value is increased whenever temperature is increased. Their temperature measuring range is from -200 to 650°C. Using RTD Tin, Cadmium and Aluminium-Bronze melting temperature can be measured. After the measurement, temperature is transmitted to the controller unit through the wireless medium. In this work, (Shu-Guang, 2011) ZigBee technology is used to replace Digital wireless telemetry circuit temperature system (Shengyong and Changzan, 2011). Depending on the received value from measuring unit, the control action is performed on the furnace by the controller. All these data transfer actions are performed by wireless network. For wireless transmission XBee is used which is a low cost and low power communicating device. It transmits the data at the speed of 250 kb sec-1 and the operating frequency is about 2.4 GHz. It's operating voltage also very less of about 3.3 V. In processing unit LPC2148 is used to control the process. It is a 64 pin IC which has inbuilt ADC module, PWM, RTC, DAC etc.It follows RISC architecture and performs faster (Sloss et al., 2004).

Final Control Element (FCE) has a direct influence on the process. It converts the electrical signal into mechanical action. So, that energy/mass goes in or out of the process is adjusted from the command given from the control unit. Common energy resources of FCE are pneumatic, electric and hydraulic (Johnson, 2003). For this process stepper motor (Austin,2009; Kant, 2008) is considered actionable as FCE (Patranabis, 2006) which is controlled by LPC2148. The stepper motor is coupled with the potentiometer which is either linear or circular type. Rotation of stepper motor adjusts the resistance value; this resists the flow of electrons in inductive coils. This reduces eddy current flow in the surface of the materials; thus, the temperature of the furnace is maintained.

In their research, the entire process is divided into three units, they are Measurement unit, Control Unit and FCE unit. The measurement unit consists of sensors, Signal Conditioning Unit (SCU), LPC2148 and XBee. Furnace temperature is calculated from the sensor and transmitted it to control unit through XBee. Figure 2.13 indicates the general block diagram of Measurement unit. Control unit receives data from measurement unit and displays the value locally. The display unit may be of LCD or PC. Here PC is configured as a display unit. The controller also generates code depending upon the furnace temperature. Generated value is transmitted to the FCE unit through XBee. Figure 2.14 indicates the general block diagram of a control unit. FCE receives the value through XBee and rotate stepper motor according to it.

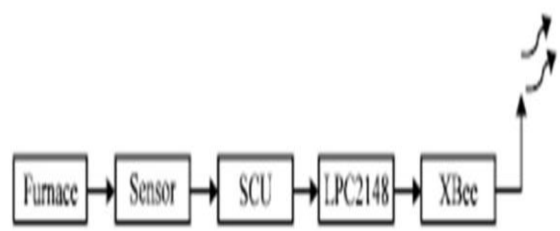


Fig. 2.11: Temperature measuring unit

Fig 2.12: Controller unit the conclusion of their study is summarized as follows:

The system is easy to monitor and control the temperature of the furnace. This can also be implemented in small scale boilers too. It avoids separate control room and air conditioning unit and with the least amount of wire and power it can be implemented. Fault occurrence can be easily detected. This system suits for any type of sensors like Thermocouple, LM35 and Pyrometer etc.

The conclusion of their research was as follows:

It gives an easy and less expensive way to implement an incubator System with a wireless status monitoring and set the required reference values.

This system uses the cheapest and efficient Tensilica ESP 8266 processor. By using this processor and the DHT 11 sensor the current status of the temperature and humidity inside an incubator is monitored and controlled precisely. So, this efficient smart incubator system that automatically adjust the values of temperature and humidity according to the optimum values.

In their research, presented a technique for the linear fuzzy controller designed to limit temperature in injection-mold machine. Initial, time-delay system is presented as temperature control system. A fuzzy-controller system is made up of controller (heater transfer function) & decision maker. All two decision makers & controller are outlined by utilizing fuzzy circuit, and it is simulated in MATLAB.

Their objective was to introduce the fuzzy logic controller to improve the performance of the system. They changed the fuzzy logic rules for the design system so that they can achieve the constant temperature and stable setting point. Fuzzy Logic Controller for Setting Point Control Fuzzy logic controller is used to control the setting point of the system. Seven membership functions were used for controlling the error.

The conclusion of their research shows that fuzzy logic has low setting time and overshoot is reduced up to 1 with stable temperature of injection molding machine.

According to Ahmad Faris (2009), his work is designed to monitor the temperature inside a server room. A server room is a room that houses mainly computer servers. In server room, the temperature is always high and unstable and human will not able to control the temperature manually. The automatic system required to control the temperature within the server room is measured by using a temperature sensor. When the current temperature is below the lower limit of the desired temperature or in the upper limit that is 25°C to 40°C, the server room is cooled using a fan. When the current temperature is within the desired range, no control action is needed. The current temperature of the room must be continuously displayed on the LCD. In addition, the controller should use LEDs to indicate the current state of temperature in the server room. General recommendations suggest that temperature range in server room should not go below 10°C (50°F) or above 28°C (82°F). Although this seems a wide range these are the extremes and it is far more common to keep the ambient temperature around 20-21°C (68-71°F). For a variety of reasons this can sometimes be a tall order (Faris, 2009).

The project used PIC16F876A to control NPN power transistor (BD135) to further drive DC brushless fans, LEDs and buzzer when the certain temperature was detected. The value of temperature always displayed on a LCD screen. The project used two temperature sensors that placed at different area. This means that temperature can be measured at different place. The project also used PIC16F877A, LCD screen and keypad to develop a password door security system. The system activates the relay and buzzer if the password is inserted. The relay controls the door while the buzzer as indicator for incorrect password. The door used is magnetic door which is automatically open and close depends to the relay. The result shows that the temperature controller was able to detect the change in temperature by increasing the rate at which fan blows to counter the increasing rate of temperature. More so the security was able to detect if the password entered is right or wrong.

Regarding an Automatic Room Temperature control for temperate regions, Nor Mazlu. B.N. (2009), in his work, proposed an automatic room temperature controller, which uses the difference between the outside and inside room temperature. The difference is assumed to affect the compressor speed in order to achieve the desired set point. The frequency of the speed compressor is also taken into account. The project involves finding the mathematical model of an air conditioning system, designing a controller and performing a simulation to analyze the performance of the designed controller using Matlab/Simulink. The controller is based on adaptive fuzzy to control the room temperature. The result shows that the controller is able to follow the input reference and the output response of adaptive fuzzy control has better tracking performance. The developed system is hoped to address the issue of high-cost electricity.

In Kumar et al (2013) work, they proposed a control scheme for a static room based on the continuous monitoring of the thermal variables. Their aim was to maintain the temperature and the humidity of room close to the targeted values, and lessen the electrical energy intake of the compressor/Fan while using all available assets in the most efficient manner. In this work, the indoor temperature control loop has been implemented using a conventional PID algorithm & fuzzy logic. Since Fuzzy logic technique is an innovative technology used in designing solutions for multi-parameter and non-linear control models for the definition of a control strategy. As a result, it delivers solutions faster than the conventional control design techniques. A practical application of a fuzzy control system & PID for a static room was carried out and the simulation results are presented using Simulink / MATLAB trying to deal mainly with the issue of maintaining the desired indoor temperature in spite of the change in outdoor temperature simultaneously reducing the temperature oscillations and energy consumption.

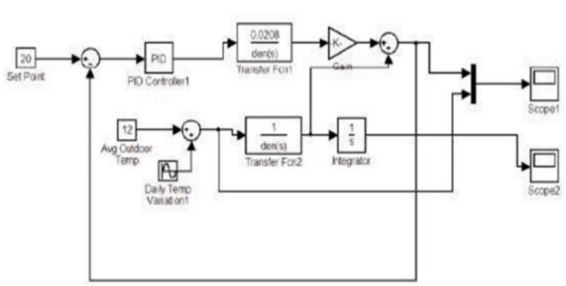


Fig. 2.13: Simulink Model Using PID Controller (Kumar et al, 2013)

Akpado et al (2013), still on the use of fuzzy logic and PID controller simulating it with Simulink/Matlab, they focused on the performance evaluation of PID controllers implemented with a clear objective to control the temperature of a ventilation system, Mathematical models of plant (chamber) and actuator were developed. Controller design based on the models was also developed using Simulink. The models were validated through simulation using Matlab/Simulink and the Zeigler-Nichol tuning method was adopted as the tuning technique for varying the parameters of the PID controller in order to achieve a desirable transient response of the system when subjected to a unit step input. A schematic model of the system was also captured using proteus and the animated simulation was carried out to validate the system's performance to varying temperature conditions within the chamber. After several assumptions and simulations, a set of optimal parameters was obtained that exhibited a commendable improvement in the overshoot, rise time, peak time and settling time thus improving the robustness and stability of the system.

III. MATERIAL AND METHODOLOGY

3.1 MATERIALS

In order to bring the device to life, certain tool/ components were used for its design and implementation. There are both software tools and hardware components.

3.1.1 Software Tools

- Mathlab and Simulink soft wares
- Visio Software
- Protus Software

3.1.2 Hardware Component

- Laptop

3.2 METHODS

An annealing furnace works by heating an annealing furnace above its re -crystallization temperature and then cooling, once the sample has been maintained at this temperature for a suitable amount of time.

An oven with an exothermic reaction requires a more elaborate system model, because its outputs are temperature oriented. Furthermore, the system is nonlinear, which enable promptness to make a linear approximation to solve it. The closed loop will show how automatic control can stabilize an inherently unstable process.

The process product which is the output of the chemical reactor is stored in the first heating facility. The first heating facility supplies the product to the oven system

using a pump and a non-returning valve. The burner heats up the oven to a desired set point using super-heated firing at 500-550°C supplied from the oven burner. The super-heated steam comes from the burner and flows through the tubes of the oven,

We assume the following:

Exchanger response to steam flow gain is 50◦C/kgsec-1, time constant is 30 sec, Exchanger response to variation of process fluid flow gain 1◦C/kgsec-1, Exchanger response to variation of process temperature gain 3◦C/◦C, capacity of control

3.2.1 Dynamic model of the Temperature Control System of the Glass Annealing Oven - Oven

With two output variables, we face two balances, as well as several supporting relationships. The mole balance on the reactant A is indicated in equation (3.1).

$$V\frac{dC_A}{dt} = FC_{Ai} - FC_A - V(-r_a) \qquad (3.1)$$

Where:

A = Area
CA = Velocity of the area in the heat exchanger
F = Fluid
C_{Ai} = Initial velocity of the area in the heat exchanger
V = Volume of the fluid
rA= Radius expansion ratio, compression ratio

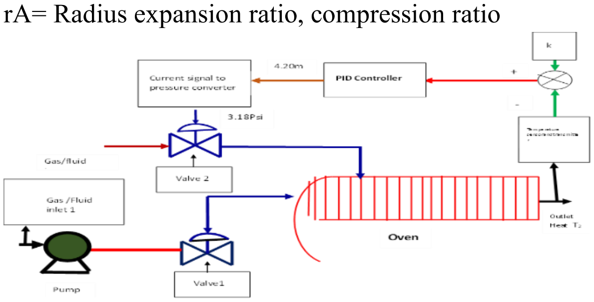


Fig. 3.1: Diagram of the Processes of the Gas Annealing Oven Control

The mole balance in equation (1) above, requires a second-order kinetic rate expression for the rate of disappearance of A,

Thus

$$-r_A = \left(-\frac{1}{V}\frac{dN_A}{dt}\right) = KC_A^2 = K_0 e^{\frac{-E}{RT}} C_A^2 \qquad (3.2)$$

Where:

NA= Rotational speed
K = Gain
e = Base of natural logarithm
R = Thermal resistance, gas constant, expansion ratio,
T = Absolute temperature
Accounting for the reaction and heat transfer, we have

$$V_\rho C_P \frac{dT}{dt} = F_\rho C_P(T_1 - T_{rf}) - F_\rho C_P(T - T_{rf}) - \Delta H_R V(-r_A) - Q \qquad (3.3)$$

Where:

V_ρ = Volume at Absolute pressure
C_P = Molar heat at constant pressur
F_ρ = Fluid pressure
T_{rf} = Reference Temperature
ΔH_R = Heat reaction
Q = Rate of heat transfer

Note that Q is equal to:

$$Q = U_0 A_0 \frac{(T - T_{C1}) - (T - T_{C0})}{ln\frac{T - T_{C1}}{T - T_{C0}}} \qquad (3.4)$$

Where

U_0 = Overall heat transfer coefficient or internal energy
A_0 = Initial area
T_{C1} = Temperature of the specific heat at time inflow of fluid to the oven
T_{co} = Temperature of the specific heat at time the initial action takes place

The overall energy transfer depends on the inner and outer surfaces of the heat transfer disturbance.

$$U_0 = \left(\frac{1}{h_0} + \frac{A_0}{A_1 h_1}\right)^{-1} \qquad (3.5)$$

Where:

A1 = Area occupied by the heat or fluid for annealing
h0 = Initial specific enthalpy heat transfer coefficient
h1= Specific enthalpy heat transfer coefficient when there is observable temperature difference in the oven during annealing for the inner coefficient.

Inner coefficient hi, depends on the flow of coolant. Invoking typical internal flow characteristics. Thus

$$\frac{h_1 D_1}{K_1} = Re^n Pt^m \qquad (3.6)$$

Where:

D = Bore daimeter

en = Logarithmic index in the number of moles

P = Power

tm = Mass temperature

flow dependence of h1 becomes

$$h_1 = h_{1r}\left(\frac{F_C}{F_{cr}}\right)^n \qquad (3.7)$$

Energy balance on the coolant becomes

$$V_C P_c C_{pc}\frac{d(T_c)}{dt} = F_c P_C C_{\rho C}\left(T_{c1} - T_{rf}\right) - F_c P_C C_{\rho C}\left(T_{co} - T_{rf}\right) + Q \qquad (3.8)$$

Where:

Vc = Constant volume
Pc = Constant pressure
Cpc= Molar heat at constant pressure
Tc1 /= Inicate constant temperature
Trf = Reference temperature
Using the first order lag equation,

$$\tau_T \frac{dT}{dt} + T = \frac{\tau_T}{\tau_R}T_1 + K_{TC}C_A + K_{hT}F_c, \qquad T(0) = 0 \qquad (3.9)$$

Where:

τ_T = Thermal time constant
K_{TC} =Gain for composition
K_{hT} = Gain for heat transfer disturbances
F_c = Fluid specific
For Mole balance equation, we have

$$\tau_C = \frac{dC_A}{dt} + C_A = \frac{\tau_C}{\tau_R}C_{A1} + K_{CT}T, \qquad C_A(0) = 0 \qquad (3.10)$$

Where:

$$\tau_R = \frac{VV}{F} = \tau_C = \frac{\tau_R}{1+2\tau_R K_T C_{AT}}$$

$$K_{CT} = -\tau_C \frac{E}{RT^2} K_r C_{Ar}^2$$

Where r is:
R =Radius expansion ratio, compression ratio.

3.2.1.2 Laplace transforming and deriving the transfer Functions for the energy balance and mole balance equation of (3.9) and (3.10).

This becomes:

$$(\tau_C S + 1)C_A(s) = \frac{T_C}{T_R}C_{A1}(s) = \frac{\tau_C}{\tau_R}C_{A1}(s) + K_{CT}T(s) \qquad (3.11)$$

$$(\tau_C(s) + 1)C_A(s) = \frac{T_C}{T_R}C_{A1}(s) = \frac{\tau_C}{\tau_R}C_{A1}(s) + K_{CT}T(s) \qquad (3.12)$$

3.2.2 Modelling of the PID Controller for the Annealing Oven

3.2.2.1 Modelling of the PID Controller

In modelling and designing the PID controller, it will be necessary and convenient to express a control system with a block diagram. To ascertain the relationships between each part of the control system. We consider the diagram below

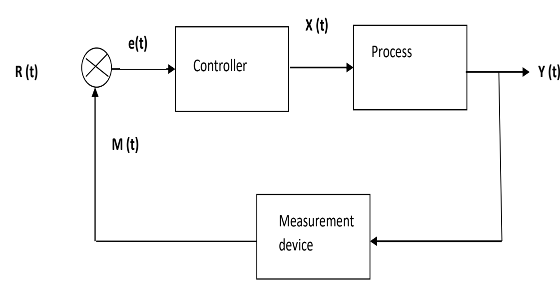


Fig. 3.2: Block diagram representing a control system

Where:

e(t) = process error or comparator

M(t) = measurement variable

Y(t) = output variable

X(t) = process variable

R(t) = set point

The figure 3.2 shown above is a closed-loop system or a feedback system because the measured value of the controlled variable is "fed back" to the comparator. In the comparator the controlled variable is compared with the desired value or set point. If there is any difference between the measured variable and the set point, an error is generated. This error enters a controller, which in turns adjusts the final control element to return the controlled variable to the set point.

From the above figure,

Process: $Y(t) = \dot{G}_p X(t)$ (3.14)

Controller: $X(t) = \dot{G}_C \in (t)$ (3.15)

Comparator: $e(t) = R(t) - M(t)$ (3.16)

Measurement delay: $M(t) = \dot{G}_m Y(t)$ (3.17)

Where:

$\dot{G}_C$ = Controller operator

$\dot{G}_P$ = Process operator

$\dot{G}_m$ = Measurement delay operator

$$\epsilon(t) = R(t) - \dot{G}_m Y(t) \quad (3.18)$$

Also, the equation above can be substituted in the controller equation and this becomes

$$X(t) = G_C\left[R(t) \dot{-} \dot{G}_m Y(t)\right] \quad (3.19)$$

Also, the equation for *Y(t)* can be obtained by putting the above equation into the equation for the process. Thus

$$Y(t) = \dot{G}_P \dot{G}_C\left[R(t) - \dot{G}_m Y(t)\right] \quad (3.20)$$

The differential equation for *X*(*t*) in terms of derivatives of *Y*(*t*) becomes

$$X(t) = G_P^{\dot{-}1} Y(t) \quad (3.21)$$

Which can be shown in the form of general equation as

$$G_P^{\dot{-}1} Y(t) = \dot{G}_C\left[R(t) - \dot{G}_m Y(t)\right] \quad (3.22)$$

From the equations above,

$$Y(t) = \dot{G}_P X(t) \quad (3.23)$$

$$X(t) = G_C \dot{\epsilon}(t) \quad (3.24)$$

$$\epsilon(t) = R(t) - M(t) \quad (3.25)$$

$$M(t) = \dot{G}_m Y(t) \quad (3.26)$$

Assume no lag in measurement

$$\dot{G}_m = 1 \quad (3.27)$$

$$G_P^{\dot{-}1} = \frac{1}{K_p}\left(\tau_p \frac{d}{dt} + 1\right) \quad (3.28)$$

If we assume first-order system,

$$G_c^{-1} = K_c + \frac{K_c}{\tau_I}\int_0^t dt \quad (3.29)$$

Where

K = Gain

τ = Temperature coefficient

For PI controller,

$$\frac{1}{K_p}\left(\tau_p \frac{d}{dt} + 1\right) Y(t) = \left(K_c + \frac{K_c}{\tau_I}\int_0^t dt\right)\epsilon(t) = \left(K_c + \frac{K_c}{\tau_I}\int_0^t dt\right)\left(R(t) - Y(t)\right) \quad (3.30)$$

solving further

$$\tau_P Y'(t) + Y(t) = K_C\left(R(t) - Y(t)\right) + \frac{K_c}{\tau_I}\left(R(t) - Y(t)\right) \quad (3.31)$$

Differentiating the above equation gives

$$\tau_P Y''(t) + Y'(t) = K_C R'(t) - K_C Y'(t) + \frac{K_c}{\tau_I} R(t) - \frac{K_c}{\tau_I} Y(t) \quad (3.32)$$

Rearranging the above equation, we have

$$\tau_P Y''(t) + (1 + K_C) Y'(t) + \frac{K_c}{\tau_I} Y(t) = K_C R'(t) + \frac{K_c}{\tau_I} R(t) \quad (3.33)$$

If we multiply the above equation by $\frac{\tau_I}{K_c}$ for us to eliminate the coefficient of $Y'(t)$, this implies that:

$$\frac{\tau_I \tau_p}{K_c} Y''(t) + \tau_I \frac{1+K_c}{K_c} Y'(t) + Y(t) = \tau_I R'(t) + R(t) \quad (3.34)$$

3.2.2.2 PID CORELATION

Controllers vary in the way they connect the controller input (error) to the controller output (actuating signal). Proportional- integral-derivative (PID) controllers are commonly used. PID controllers relate the error to the actuating signal either in a proportional (P), integral (I), or derivative (D) manner. PID controllers can also relate the error to the actuating signal using a combination of these controls.

3.2.2.3 Proportional (P)Controller

Proportional control has a feedback control. It is the simplest form of continuous control that can be used in a closed-looped system. P-only control minimizes the shift in the process variable, but does not always bring the system to the desired value. As the system becomes more complex, the response time difference could accumulate, letting the P-controller to possibly respond even a few minutes faster. Although the P only controller does offer the advantage of faster response time, it produces deviation from the set point. This deviation is known as the offset, and it is usually not desired in a process. The offset can be minimized by combining P-only control with another form of control, such as I- or D- control. It is important to note, however, that it is impossible to completely eliminate the offset, which is implicitly included within each equation. This P-control characteristic is mathematically illustrated as

$c(t)=K_c e(t)+b$ (3.35)

Where:
c(t) = Controller output
K_c= Controller gain
e(t)=Error
b = Bias

This could be rewritten as:
$u(t) = K_1 e(t)$
(3.36)

From figure 3.3 below, we can develop the transfer function as

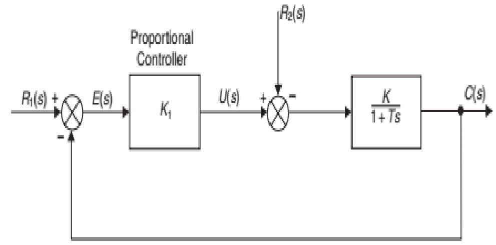


Fig. 3.3: Proportional control of a first order plant

$$(U(s) - R_2(s)) \left(\frac{K}{1+T_s}\right) = C(s) \quad (3.37)$$

The proportional control law from equation 3.46 becomes

$$U(s) = K_1(R_1(s) - C(s)) \quad (3.38)$$

Substituting equation 3.37 in equation 3.38, we have the below equation

$$C(s) = \frac{\{K_1(R_1(s) - C(s) - R_2(s))\}K}{1+T(s)} \quad (3.39)$$

This becomes:

$$[(1 + K_1 K) + T(s)]C(s) = K_1 K R_1(s) - K K_2(s)$$
(3.40)

T= Time constant
Now rearranging, this becomes,

$$C(s) = \frac{\left(\frac{K_1 K}{1+K_1 K}\right) R_1(s) - \left(\frac{K}{1+(K_1 K)}\right) R_2(S)}{\left[1 + \left(\frac{1}{1+K_1 K}\right) s\right]} \quad (3.41)$$

Using final value theorem which is

$$f(x) = \lim_{t \to \infty} [f(t)] = \lim_{s \to 0} \{sF(s)\} \quad (3.42)$$

If we assume $r_1(t)$ is a unit step, and $r_2(t)$is zero, the final value theorem gives the steady state response.

$$c(t) = \left(\frac{K_1 K}{1+K_1 K}\right) \quad as\ t \to \infty \quad (3.43)$$

If we also assume $r_2(t)$ to be a unit step, and $r_1(t)$ is zero, the final value theorem gives the steady state response as shown below.

$$c(t) = -\left(\frac{K}{1+K_1 K}\right) \quad as\ t \to x \quad (3.44)$$

For the system to have zero steady-state error, the terms in equation 3.44, have to be $\frac{K_1 K}{1+K_1 K} = 1$

$$\frac{K}{1+K_1 K} = 0 \qquad (3.45)$$

3.2.2.4 Proportional plus Integra Controller

Adding an integral term into proportional equation for the plant, so that the steady state error could be removed add an improvement to the expected solution. Thus

$$u(t) = K_1 e(t) + K_2 \int edt \qquad (3.46)$$

Taking laplace transforms, it becomes

$$U(s) = \left[K_1 + \frac{K_2}{s}\right] E(s) \qquad (3.47)$$

$$=K_1\left(1 + \frac{K_2}{K_{1s}}\right) E(s) \qquad (3.48)$$

$$=K_1\left(1 + \frac{1}{T_{1s}}\right) E(s) \qquad (3.49)$$

In equation 3.49, T_1 is called the integral action time defined as the time interval in which part of the control signal due to integral action increases by an amount equal to the part of the control signal due to proportional action when the error is unchanging.

$$C(s) = \frac{\left(K_1\left(1+\frac{1}{T_1 s}\right)(R_1(s)-C(s))-R_2(s)\right)K}{1+Ts} \qquad (3.50)$$

Which can also be rewritten as

$$\{T_1 Ts^2 + T_1(1 + K_1 K) + K_1 K\}C(s) = K_1 K(1 + T_1 s)R_1(s) - K_1 K T_1 s R_2(s) \qquad (3.51)$$

Rearranging, this gives

$$C(s) = \frac{(1+T_1 s)R_1(s) - T_1 s R_2(s)}{\left(\frac{T_1 T}{K_1 K}\right)s^2 + T_1\left(1+\frac{1}{K_1 K}\right)s+1} \qquad (3.52)$$

If we use the final value condition, the steady state becomes

$$C(t) = [1 + 0]r_1(t) - (0)r_2(t) \quad as\ t \to x \qquad (3.53)$$

3.2.3 PID Controller Design

3.2.3.1 PID Controller Design for the Annealing Oven

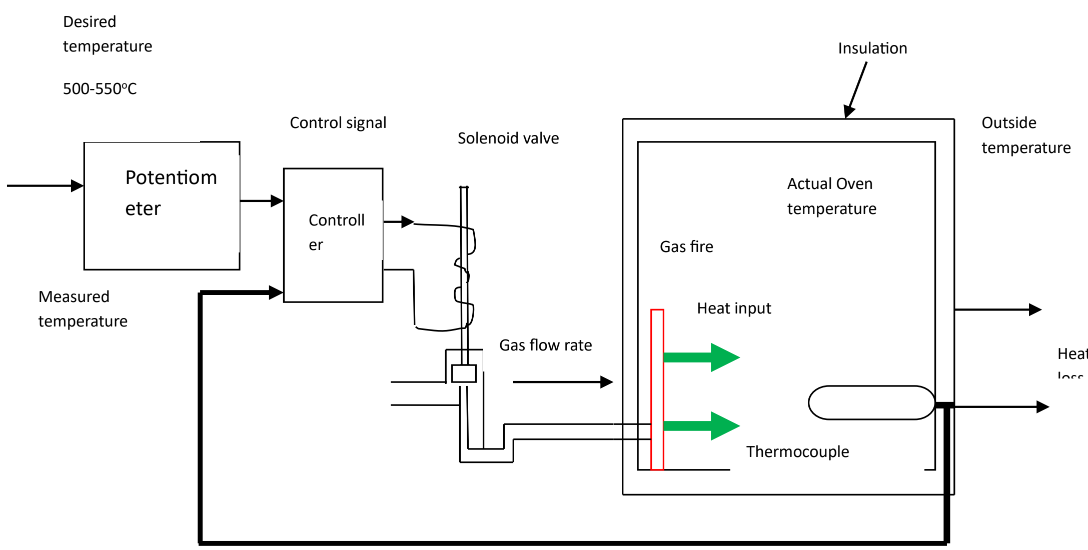


Fig. 3.4: Oven temperature control system

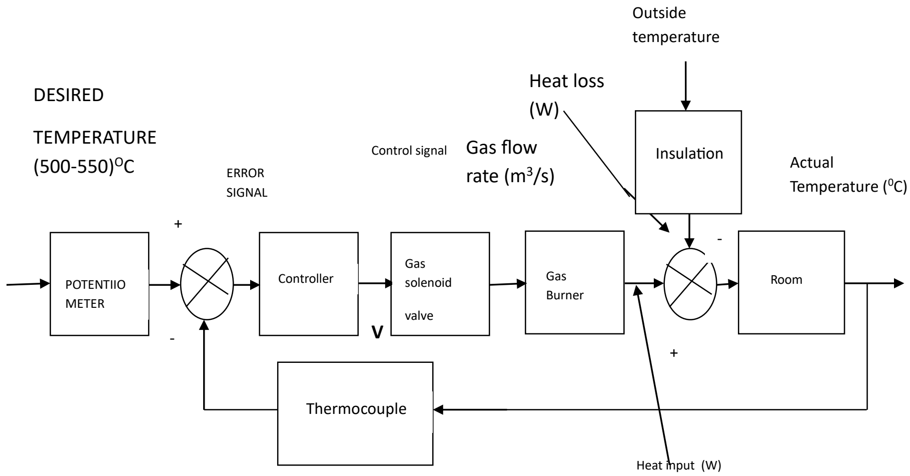


Fig. 3.5: Oven block diagram of temperature control system of the annealing oven

The PID controller measures both the primary and secondary loops and adjusts the power level affecting the heat of the secondary element so that it will in turn heats the primary element to the setpoint.

Most commercial controllers provide full PID, which is also called three terms control action. Including a term that is a function of derivative of the error can, with high order plants provide a stable control solution.

Proportional plus Integral plus Derivative control action could be expressed as

$$u(t) = K_1 e(t) + K_2 \int edt + K_3 \frac{de}{dt} \qquad (3.54)$$

as general model

If we take Laplace transform of the equation 3.40, this becomes

$$U(s) = \left(K_1 + \frac{K_2}{s} + K_3 s\right) E(s) \quad = \quad K_1 \left(1 + \frac{K_2}{K_{1s}} + \frac{K_3}{K_1} s\right) E(s)$$

$$= K_1 \left(1 + \frac{1}{T_{1s}} + T_d s\right) E(s) \qquad (3.55)$$

In equation 3.41, T_d, is called the derivative action time and is defined as the time interval in which the part of control signal due to proportional action which increases by an amount equal to the part of the control signal due to derivative action when the error is changing at constant rate.

Also, equation 3 41 could be expressed as

$$U(s) = \frac{K_1 (T_1 T_d s^2 + T_1 s + 1) E(s)}{T_1 s} \qquad (3.56)$$

From figure 3.4 above, the oven PID controller can be designed as follows

Considered variables are

$\theta_d(t)$ = Set point temperature (^{0}C)

$\theta_m(t)$ = Measured temperature (V)

$\theta_s(t)$ = Ambient Temperature (^{0}C)

$\theta_0(t)$ = Actual temperature (^{0}C)

$u(t)$ = Control signal (^{v})

$v(t)$ = Gas flow rate (m^3/s)

$Q_1(t)$ = Heat flow into the Oven (J/s=W)

$Q_0(t)$ = Heat flow through walls of the Oven (W)

3.2.3.2 Designed processes are as follows:

(a) Controller: The control action is PID of the form given in equation (3.65)

$K_1\left(1+\frac{1}{T_{1s}}+T_d s\right)E(s)(\theta_d(s)-\theta_m(s))$ (3.57)

(b) Gas solenoid valve: we assume it to have first order dynamics equation like

$\frac{V}{U}(s)=\frac{k_2}{1+T_1 s}$ (3.58)

Where K_2 is the valve constant (m^3/s V)

(c) Gas burner: This converts gas flow rate v(t) into heat flow $Q_1(t)$. This implies

$Q_1(s)=k_3V(s)$ (3.59)

Where K_3 is the burner constant (Ws/m^3)

(d) Oven dynamics: The thermal dynamics of the oven are

$Q_1(t)-Q_0(t)=C_T\frac{d\theta_0}{dt}$ (3.60)

From equation (3.46) C_T is the thermal capacitance of the air in the oven

The heat flow through the walls of the oven is given as

$Q_0(t)=\frac{(\theta_0(t)-\theta_s(t))}{R_T}$ (3.61)

Where R_T is the thermal resistance of the walls of the oven. Substituting equation (3.72) into equation (3.46) becomes

$Q_1(t)-\frac{(\theta_0(t)-\theta_s(t))}{R_T}=C_T\frac{d\theta_0}{dt}$ (3.63)

Then multiplying through by R_T, this implies that

$R_TQ_i(t)+\theta_s(t)=\theta_0(t)+R_TC_T\frac{d\theta_0}{dt}$ (3.64)

Laplace transforming the above

$R_TQ_i(s)+\theta_s(s)=(1+R_TC_Ts)\theta_0(s)$ (3.65)

From the equation above, (3.75). It can be represented in block diagram as shown below in figure 3.6.

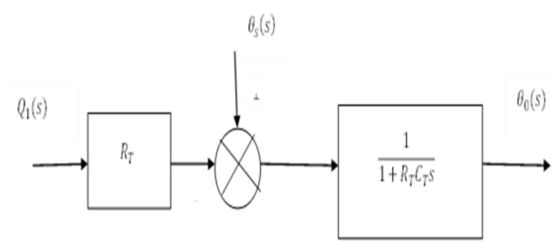


Fig. 3.6: Block diagram of thermal dynamics of the Oven

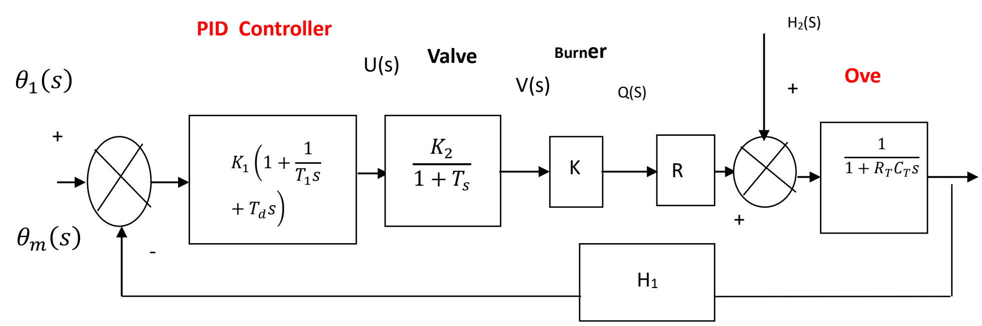


Fig. 3.7: Oven Temperature control system block diagram

3.2.3.3 The Thermocouple in the design:

The equation of the thermometer is given below.

$\theta_m(s)=H_1\theta_0(s)$ (3.66)

The overall block diagram of the PID control system for the Oven is shown in figure 3.6, from the figure,

$\frac{K_1K_2K_3R_T(T_iT_ds^2+T_1s+1)(\theta_d(s)-H_1\theta_0(s))}{T_1s(1+T_1s)}+\theta_s(s)=((1+R_TC_Ts)\theta_0(s))$ (3.67)

Equation (3.78) could be rearranged to become:

$\theta_0(s)=\frac{\frac{1}{H_1}(T_1T_dS^2|+T_1S+1)\theta_d(S)+\frac{T_1s(1+T_1s)}{K_1H_1}\theta_s(s)}{\left(\frac{T_1T_1T_2}{K_1H_1}\right)S^3+\left(\frac{T_1(T_1+T_2)}{K_1H_1}+T_1T_d\right)S^2+T_s\left(\frac{1}{K_1H_1}+1\right)s+1}$ (3.79)

The forward path gain K_F is

$K_F=K_1K_2K_3R_T$ (3.80)

If we assume system parameters as to determine the controller settings for K_1, T_1, and T_d
This is done using the Zeigler-Nicholes process reaction method.

3.2.3.4 Parameters of the System
K_2K_3= 100W/N
R_T= 0.1Ks/J
C_T= 120 J/K
H_1 = 1.0V/K
T_1= 10 seconds
Reaction Curve: This is obtained from forward –path transfer function as:

$$\frac{\theta_0}{U}(s) = \frac{K_2K_3R_T}{(1+T_1s)(1+R_TC_Ts)} \quad (3.81)$$

Substituting values in equation (3.55), we have

$$\frac{\theta_0}{U}(s) = \frac{100\times0.1}{(1+10s)(1+0.1\times120s)} \quad (3.82)$$

$$\frac{\theta_0}{U}(s) = \frac{10}{(1+10s)(1+12s)} \quad (3.83)$$

The close loop transfer function using equation (3.79) for the temperature control system becomes:

$$\frac{\theta_0}{\theta_d}(s) = \frac{[2.25s^2+3s+1]}{7.344s^3+5.004s^2+3.229s+1} \quad (3.84)$$

In furtherance for critical simulation and comparison, the heat exchanger system, actuator, valve, sensor are mathematically modeled as above but using the another experimental data. The experimental process data are summarized below

Time constant of control valve - 4 Sec
The range of temperature sensor – 50^0C to 1000^0C
Time constant of temperature sensor -15 Sec
From the experimental data, transfer functions and the gains are obtained as shown in fig. 3.7.

$$G(S) = \frac{0.3404s+0.0237}{s^2+0.07869s+0.006344} \quad (3.85)$$

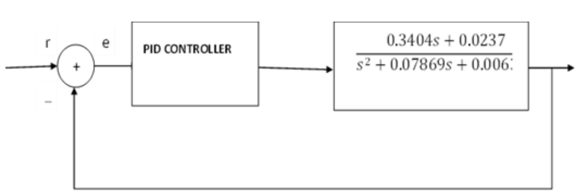


Fig. 3.8: Mathematical model of the heat exchanger for the oven for simulation and analysis.

3.2.4 Simulation of the Designed Control System
The simulations for the different control mechanism above were carried out in Simulink. Figure 3.8 represents the Simulink modeling of the shell and tube heat exchanger system with PID as a feedback controller.

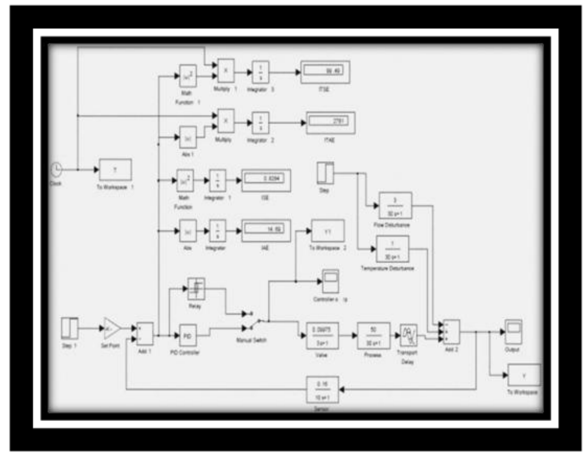


Fig.3.9: Simulink model of shell and tube heat exchanger system with feedback PID controller

As could be seen in figure 3.8, a relay block is connected in parallel with the PID controller with the help of a manual switch. When the auto-tune function is required, the manual switch is set to the relay block. The behavior obtained from auto tuning mode is very similar to the behavior obtained from Zeigler- Nichols closed loop cycling method. The result of the simulations is shown in chapter four under results and discussions.

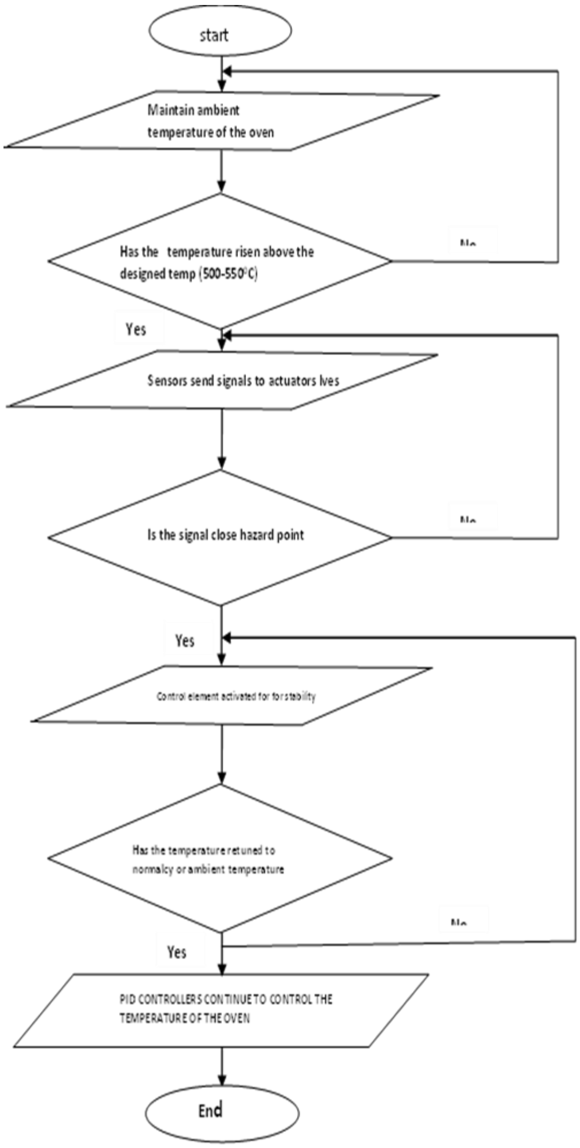


Figure 3.10 below shows the algorithm of the thesis

IV. RESULTS AND DISCUSSION

This chapter discusses the results of all the models, designs and simulation of chapter three. Below is the results and discussions.

4.1 RESULTS

Table 4.1: Ziegler Nichols PID parameters using process reaction method of tuning (Roland, 2001)

Controller type	K_1	T_1	T_d
P	1/RD	-	-
PI	0.9/RD	D/0.03	-
PID	1.2/RD	2D	0.5D

From R and D values obtained from the process reaction curve of figure 4.1 using Ziegler Nichols PID controllers settings given in Table 4.1 above, we have

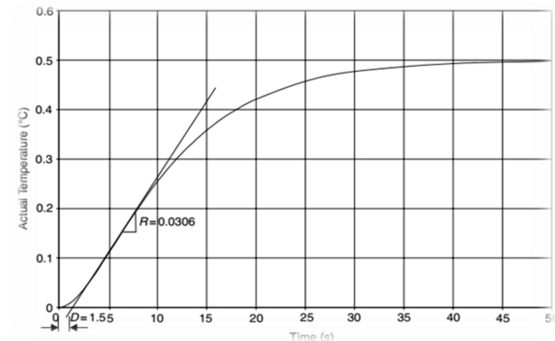


Fig 4.1: Process reaction curve for the temperature control system indicated in figure in figure 3.6.

From the curve,

R = 0.0306

D = 1.55

K_1= 1.2/RD = 25.301

T_1 = 2D = 3.10 seconds

T_d = 0.5D = 0.775 seconds

If we assume that the temperature of the surrounding $\theta_{s(t)}$is constant, then the response to the step change in the desired temperature of 0-550^{0}C for the closed loop transfer function given by equation (3.84) is shown in figure 4.2 below

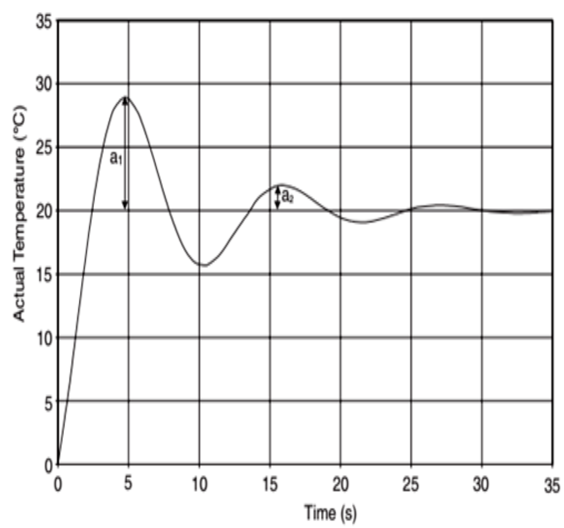
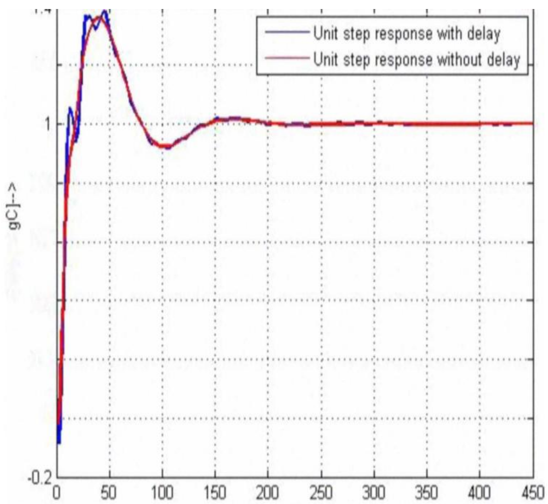
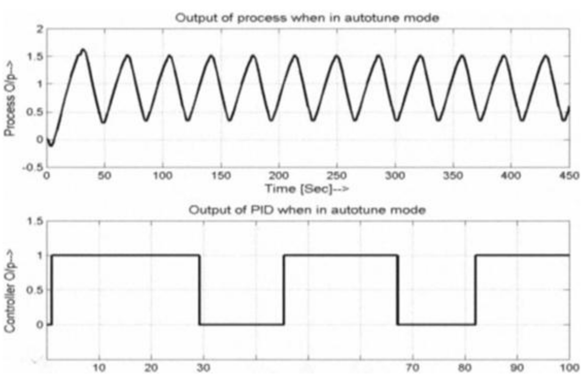


Fig:4.2: Close loop step response of temperature control system using PID controller tuned using Zeigler-Nichols reaction method

Figure 4.1 and 4.2 shows the rise time and settling time when the system is tuned to observe the rise time and the settling time when the system is operational at different temperature intervals in hundreds of degree centigrade



(a)



(b)

Fig. 4.3 (a) Unit step response of shell and tube heat exchanger system with feedback controller (b) Response of controller and shell and tube heat exchanger system in auto-tune mode (PI)

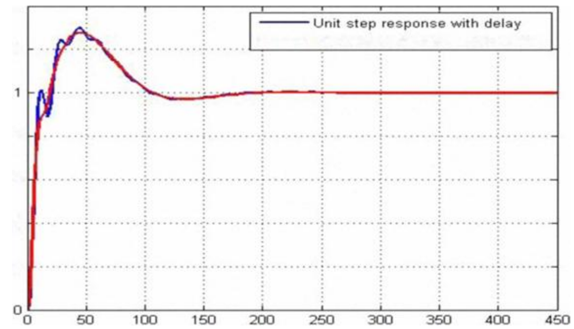


Fig. 4.4: Unit step response of shell and tube heat exchanger system with feedback and feed-forward controller

Figure 4.4 shows the unit step response of the shell and tube heat exchanger system with feedback and feed forward controller. The combined effect of feedback and feed forward controller reduces the overshoot and also decreases the settling time by18 %

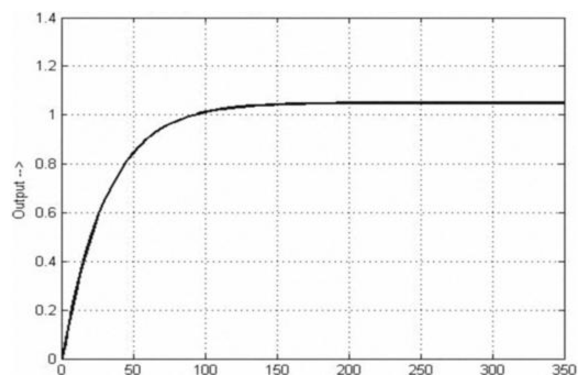
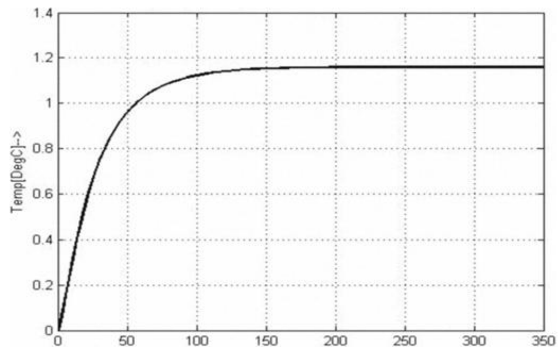


Fig. 4.5: Unit step response of process with internal model controller

Figure 4.6, shows the unit step response of shell and tube heat exchanger system when an internal model based PID controller is used to control the controlling variable. The maximum overshoot is only 5% and settling time is also reduced.



Fig,4.6: Unit step response of internal model based PID controller

Table 4.2: Comparison of Different Parameters in the Control System

S/ N	DESCRIPTION	OVERSHOOT IN PERCENTAGE	SETTLING TIME IN SECONDS
1	Feedback PID	35.40	113. 50
2	Feedback plus feed forward controller	26.70	90.21
3	Internal model controller	14.20	74.6
4	PID controller based Internal model	4.80	62.7

Table 4.3: Comparison of performance of the parameter with different controller and without controller

S/ N	VARIABLES	WITHOUT CONTROLLER	WITH PI CONTROLLER	WITH PID CONTROLLER
1	Rise Time in Seconds	1.43	1.89	0.92
2	Settling Time in Seconds	4.5	18.7	5.62
3	Overshoot in Percentage	2 0	15.6	8.5

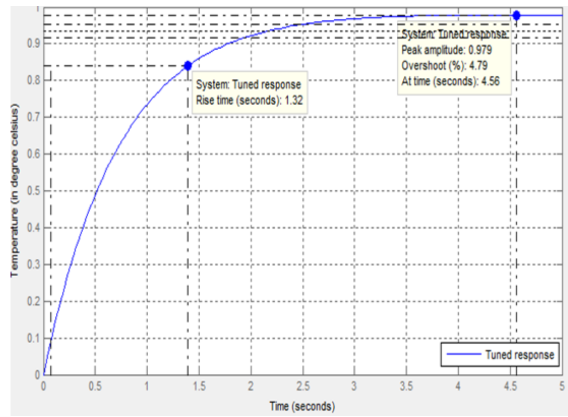


Fig. 4.7: Response of system using PI controller

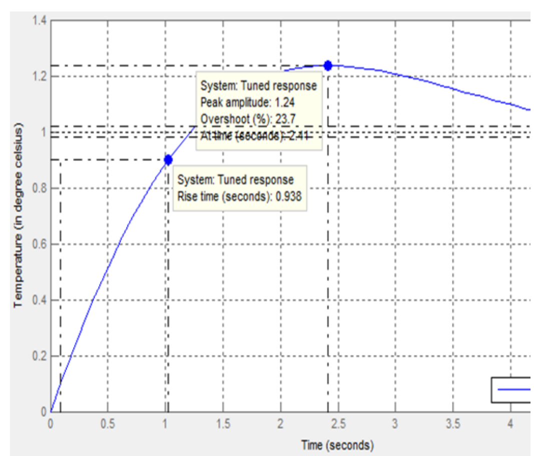


Fig. 4.8: Response of System using PID controller

4.2 DISCUSSIONS

In order to deduce the performance of the efficient way of controlling the temperature of the oven, the research has considered two vital parameters of the step response of the system. The first parameter is the maximum overshoot and the second parameter is the settling time. A comparative study of their performance has been shown in table 4.2 above.

Table 4.2 shows that feedback PID controller gives very high overshoot of 35.40%. To compensate, and reduce this kind of high overshoot a feed forward controller is added to the conventional PID in feedback loop and this is implemented. By implementing this method, the system overshoot was reduced to 26.70%, an improvement of almost 20%.

Though the overshoot has decreased, it could be further decreased by implementing internal model-based controller and internal model based PID controller. By implementing internal model-based controller and internal model based PID controller, the overshoot reduces to almost 14.20% and 4.80% respectively. In feedback controller the settling time was 113.5 sec where as in feed forward plus feedback controller the settling time decreases to 90.21 sec, an improvement of about 20.9%. By implementing internal model-based controller and internal model based PID controller the settling time decreases by 74.6 sec and 62.7 sec

In further simulation, of nth order where simulation was done with controller and without controller, we have the results of table 4.3 and the graphs of figure 4.6 and 4.7 above.

The values of KP, Kd, KI obtain from Ziegler Nichols tuning is applied to the controller transfer function and results obtained are given in graphs of figures 4.6 and 4.7 respectively. Values of KP=5.0301, Kd=0, KI=4.0153 these values were used for the second simulation.

Table 4.3 shows the comparisons of rise time, settling time and overshoot when the controller was used and when the control system was not applied to control the temperature of the annealing oven.

Annealing is a heat treatment process that is used to alter the chemical or physical properties of a metal to make it more ductile and reduce its hardness.

An annealing furnace works by heating an annealing furnace above its recrystallization temperature and then cooling once the sample has been maintained at this temperature for a suitable amount of time.

During the annealing process, the atoms within a sample diffuse in the crystal lattice and the number of dislocations reduce, changing the ductility and hardness properties of the sample.

Recrystallisation occurs as the sample cools down.
Heating the sample is what increases the rate of diffusion by providing the energy required to break bonds. Atom movement has the effect of redistributing and eradicating the dislocations in the sample.

V. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The aim of this thesis is to design an advanced, temperature controller that can perform more sophisticated operations than the single-loop controls commonly used in the industry. To achieve this, a simulation was conducted using a lumped-parameter model of the temperature in a small glass furnace. The utilization of a high-performance temperature control system-based methodology presents several benefits, such as the potential to develop an observer or state estimator for process parameters that may pose challenges in direct measurement.

At present, the predominant approach for small-scale glass furnaces involves assessing the temperature of the combustion gases located in the furnace crown, as opposed to directly gauging the temperature of the glass. The reason for this phenomenon is attributed to the high corrosiveness of molten glass, which leads to the rapid degradation of thermocouples upon immersion in the melt. The correlation between combustion gas temperature and glass temperature is widely recognized as being unreliable. Relying solely on TS measurements for the purpose of process control is unlikely to yield satisfactory outcomes. The aforementioned assertion is supported by the prevalent industrial methodology of approximating temperature through the evaluation of the viscosity of the molten substance. Non-contact infrared temperature sensors can be utilized to directly measure the glass temperature. Nevertheless, the aforementioned apparatus is delicate and comparatively costly. A novel methodology was devised in this study, wherein two supplementary temperature measurements were integrated with the conventional crown temperature measurement to construct a state estimator for the glass temperature.

Supplementary measurements may be conducted by utilizing conventional thermocouples positioned within the furnace refractory at both the crown and the bottom of the tank. The experiment addresses various control modes, namely on-off, P, PI, PD, and PID. The study entails conducting simulations through the utilization of a MATLAB/Simulink platform the incorporation of supplementary measurements facilitates the creation of a precise estimator that is resistant to sensor noise and disturbance inputs, and exhibits swift convergence properties. The utilization of an observer-based controller that relies on the estimated temperature of the glass exhibits superior temperature regulation and set point tracking. The implementation of this system can be achieved at a reasonable cost by utilizing readily available hardware and a moderate level of programming.

5.2 RECOMMENDATIONS

The utilization of microcontroller-based methodology for control purposes enables the implementation of advanced control modes that surpass the capabilities of contemporary technology. An instance of a profitable case is the formulation of "optimal" control methodologies for the melting, refining, and working processes. Optimization of time/temperature schedules can be achieved by minimizing melt times, minimizing energy melt cycles, or by striking a balance between these performance measures. A digital computer-based control system has the capability to establish several programs to cater to various product types, production schedules, or fuel cost scenarios. It is feasible to enhance the in formativeness and user-friendliness of operator interfaces beyond the capabilities of existing single-loop controllers. Ultimately, the production of a functional hardware prototype must be undertaken and subsequently exhibited in the context of a glass furnace.

In this research, a significant contribution to knowledge emerges from the development and validation of an advanced temperature control system tailored for small-scale glass furnaces. The primary innovation revolves around addressing the inherent challenges posed by molten glass's corrosiveness to sensors used for temperature measurement. To overcome this limitation, we propose a novel methodology that incorporates supplementary temperature measurements, captured through strategically positioned conventional thermocouples within the furnace refractory.

REFERENCES

[1] Ahmad Faris B.Z. Automatic Temperature Control with Security System. FY report (2009). Universiti Malaysia Pahang, Malaysia, May 2009.

[2] Akpado K.A, Ezeagwu C.O, Ejiofor.A, Nwokoko A.O. Design, Modelling and Simulation of a Microcontroller Based Temperature Control in a Ventilation System. IJAREEIE vol 2, issue 7, July 2013.

[3] Austin, H., 2009. Electric Motors and Drives: Fundamentals, Types and Application. 3rd Edn., Publisher Elsevier, India, ISBN: 8131206688, pp: 305-323.

[4] Dogan Ibrahim," Microcontroller Based Temperature" Newnes, 2002.

[5] Fiore, J.M., 1999. Operational Amplifiers and Linear Integrated Circuits: Theory and Application. 1st Edn.,Jaico Publishing House, USA., ISBN13: 9788172247782, pp: 133-138.

[6] Gregory_K._McMillan "Advanced_Temperature_Measure", International

[7] Habiballah, E., Mohammed, H., Abd, A., Suliman, A., Ghalib, A., Adam, O., &Babiker, U. G. (2017). Sudan University of Sciences and Technology College of Engineering Department of Electrical Engineering Industrial Temperature Control System Prepared By : Supervised By : October.

[8] James Ron Leigh, "Temperature measurement & control", Peter Peregrinus, London, 1988.

[9] Johnson, C.D., 2003. Process Control Instrumentation Technology. 7th Edn.,Prentile Hall of India Private Ltd., London, ISBN-10: 0130602485, pp: 321-360.

[10] Kant, K., 2008. Computer Based Industrial Control. 9th Edn., Prentice Hall of India Pvt. Ltd., New Delhi, pp: 259-262.

[11] Kumar.J, Kapoor.R, Brijebda, Hement, Jyoti. Comparative Analysis of Room Temperature Controller using Fuzzy Logic & PID. AEEE, volume 3, No 7:Pp 853- 858 (2013).

[12] Nilam Kumar.” Industrial temperature measurement “,RosemountInc ,Czech Republic,2013.

[13] Nor Mazlu. B.N.Automatic Room Temperature Control Sytem.FY report 2009, Universiti Malaysia Pahang, Malaysia, May 2009.

[14] Patranabis, D., 2006. Principles of Process Control. 2nd Edn., Tata McGraw Hill Publication Company Ltd., USA., pp: 242-246.

[15] Shengyong, Z. And S. Changzan, 2011. Digital wireless telemetry circuit temperature. Proceedings of the IEEE International Conference on Control, Automation and Systems Engineering, July 30-31, 2011, Singapore, pp: 1-3.

[16] Shu-Guang, M.A., 2011. Construction of wireless fire alarm system based on ZigBee technology. Procedia Eng., 11: 308-313.

[17] Singh, 2009. Industrial Instrumentation and Control. 3rd Edn., Tata McGraw Hill Publication Company Ltd., USA., ISBN: 0070262225, pp: 420-422.

[18] Sloss, A.N., D. Symes and C. Wright, 2004. Arm System Developers Guide: Designing and Optimizing System Software. Elsevier/ Morgan, USA., ISBN: 1558608745, Pages: 689.

[19] Snaran, R., S.N. Prasad and N.D. Saksena, 1982. Forging Die Design and Practice. Publisher Chand, UK.,pp: 183-188. Society of Automation, United States of America. 2011.

[20] Sundaresan K. R. And Krishnaswamy P. R. (1978), “Estimation of time delay, time constant parameters in time, frequency and Laplace domains”, Can. J. Chem Eng., 56, pp. 257.

[21] Taylor M.P. Taylor N. Depree, J. Sneyd. Development and validation of models for annealing furnace control from heat transfer fundamentals. Computers and Chemical Engineering, 34, 2010. Cited on page 2.