Design, Simulation and Hardware Implementation of Automatic Industrial Temperature Controller On Embedded Platform

A Dissertation Submitted to the
Delhi Technological University, Delhi, in partial
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MASTER OF TECHNOLOGY
IN
INSTRUMENTATION AND CONTROL

Submitted By

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2K12 / C&I / 026
M Tech (C&I) – Part Time

Under The Guidance of

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Department Of Electrical Engineering

Certificate

This is to certify that the Dissertation entitled — Design, Simulation and Hardware Implementation of Automatic Industrial Temperature Controller on Embedded Platform,

Submitted by – **Rakesh Goswami**
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is a bonafide work carried out by him in this department in the partial fulfillment of the award of the Degree of Master Of Technology (Control And Instrumentation) of the Delhi Technological University, Bawana Road, New Delhi, in the session 2012-15 under my supervision and upto my satisfaction.

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Abstract

Automatic industrial temperature controller is an integral and one of the critical components of an Industrial Process heating. One such industrial process is food sterilization process[25] where it is required to Heat the process fluid at specific sterilization temperature, maintain this temperature for the process duration, on completion of process; the process fluid is to be cooled down. In such industrial process heating system, the controller maintains the temperature of fluid under consideration at a specified value during the entire process duration. If the current temperature of the fluid falls below the specified value an Electric heating element is required to be switched ON, so that the current temperature can be brought within specified limit. After the sterilization process is over it is desired to cool the process fluid, for this a cooling arrangement is required to be switched ON so that the current temperature can again be brought down to new specified limit i.e. new desired temperature. Thus the intended purpose of automatic industrial temperature controller for sterilization process of food product is achieved by a combination of heating system in conjunction with a cooling arrangement.

This Dissertation proposes to design, simulate and physically implement a microcontroller based Industrial Process temperature control system which will control and optimize the power input to heating system when the temperature deviates below the set temperature. If the desired temperature requirement falls below the present level, the same controller will control and optimize the power input to a variable speed DC motor based cooling system, which will cool the process fluid till the new desired temperature is achieved. The proposed controller will switch, optimize and control the power to two in no heating element based on temperature requirement if needed, the **Pulse-Width Modulation** based speed controller will be implemented so that cooling pressure depending on the quantum of temperature variation is achieved The average value of power fed to the cooling pump motor is controlled by duty cycle of the PWM signal, this is achieved by a solid-state switching circuit. The longer the switch is on compared to the off periods, the higher the power supplied to the load i.e. higher the cooling.

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CHAPTER - 1

INTRODUCTION

Chapter – 1

Introduction

The process industry is a typical example of integrated system where a large no of Electrical and Non- Electrical parameters are to be measured, analyzed, maintained and controlled. The basic need of a process system is accurate measurement and control of such parameters. Hence, Instrumentation system and Control system is the back-bone of process industry. Instrumentation system is considered to be the senses of the process industry, and control system is like a watchdog always alert and vigilant to prevent the process parameters from going off the track. In much application, it is reliability which is of more concern, therefore the best system is one, which offers simplicity, flexibility, and reliability [1]. These characteristics are inherent in embedded system.

1.1 Need of Temperature Control

Temperature control technique is one of the most sought and the integral critical requirement of an Industrial Process heating. The heating curve of a typical sterilization process of Meat is shown in fig. 1.1, from this heating curve [25] it is observed that, for food sterilization system, there are three main requirements:

- Heating the process fluid up-to sterilization temperature.
- Maintain the sterilization temperature for process duration.
- Cooling the process fluid on sterilization.

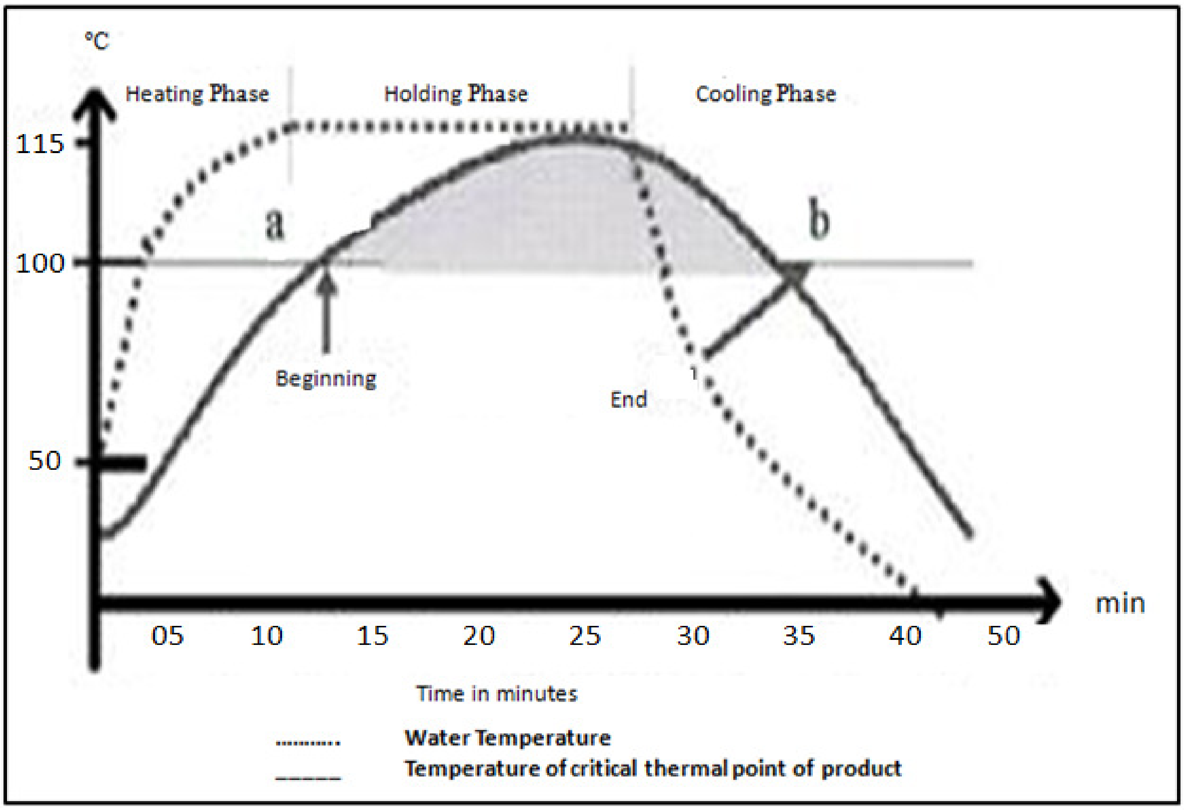


Fig 1.1 Heating curve for Sterilization Process of Meat

For this system, a controller is required to heat and then maintain the temperature of fluid under consideration at a specified value. If the present temperature of the fluid falls below the pre-set value a set of multiple element, electric heating elements is to be switched ON and OFF, so that the current temperature can be brought within pre-set specified limit. The moment the lower limit of the preset band value is achieved the controller will switch OFF the heating element. After the sterilization process is over the products need to be cooled down. For this a cooling arrangement is to be switched ON, so that the present temperature can again be brought within new set point band. Thus the intended purpose of automatic industrial temperature controller to maintain the present temperature within the pre-set value is achieved by a combination of heating system in combination with a cooling arrangement controlled by an AT89C51 microcontroller based Industrial Process temperature controller.

1.2 The Control System

The process control system is that means by which any quantity of interest in a process is maintained or altered in agreement with desired manner. Consider for example, the food sterilization system, the heating rate or cooling rate is the function of final temperature requirement. The closed loop interactive heating & cooling system constitute the control system loop. The heating system is a low speed system where as the cooling system is relatively faster system. This system is a combination of a fast and slow system to be controlled in this Industrial Process heating controller,this will control and optimize the power input to multiple element heating system when the temperature deviates below the set temperature. If the temperature exceeds above the desired value the same controller will control and optimize the power input to a variable speed DC motor based cooling system, which will cool the process fluid till the desired temperature is achieved. The proposed controller will switch, optimize and control the power to two in no heating element based on temperature requirement. If needed, the **Pulse-Width Modulation** (**PWM**)[26] based speed controller will be implemented so that cooling pressure depending on the quantum of temperature variation can be achieved. The average value of power fed to the cooling pump motor is controlled by turning the solid state switch between supply and motor, on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load i.e. higher the cooling.

1.3 Feedback Control loop

Control loop in this process temperature controller mainly consist of a Heating system control loop, and a cooling system control loop, the block diagram of basic control loop for the proposed controller is shown in fig .1.2.

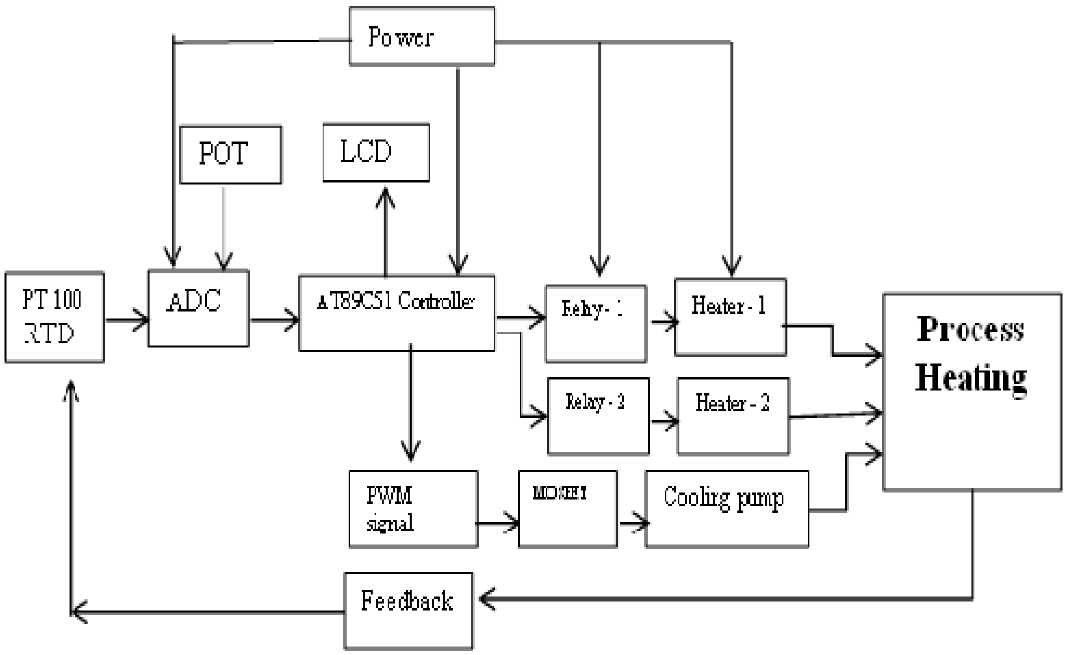


Fig 1.2 Block Diagram of the Control Loop

Let us compare the above block diagram of the above feedback control loop from the basic feedback control loop. The basic feedback control loop [14] is shown in fig. 1.3

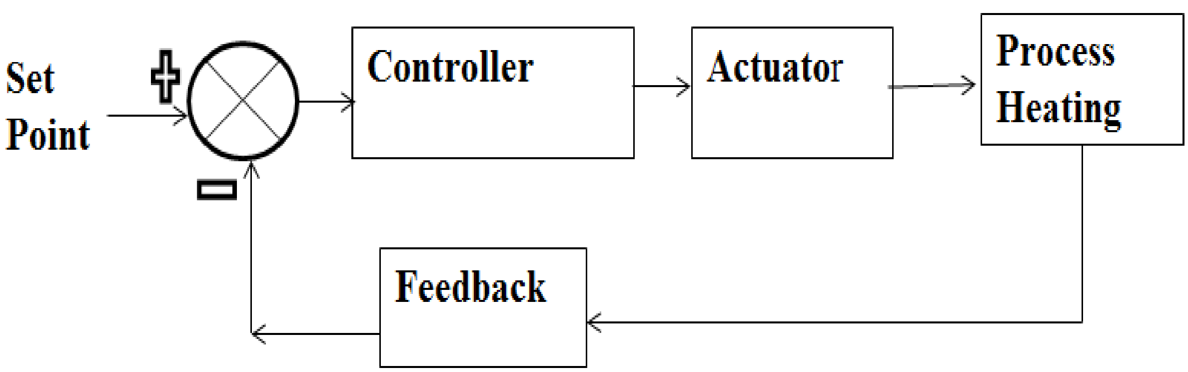


Fig 1.3 Block Diagram of Basic Feedback Control Loop

The basic control loop consists of following basic element

- Process system
- Set point or Reference Input
- Feedback loop
- Error measuring device
- Controller
- Actuator & Final Control Element

It is found, that set point or reference input is given using a Potentiometer in form of voltage divider circuit and RTD PT100 works as feedback element for feed of current temperature to the controller. The controller in this case is eight bit AT89C51 microcontroller; it acts as error measuring device. On generation of error signal, the controller activates its logical program for operation of actuator i.e. Relay -1, Relay-2, and PWM Controller, for control of respective final control element Heater -1, Heater -2, and Cooling Pump. Heater control strategy is selected to be ON-OFF control, and cooling Pump motor control strategy is selected to be PWM. Liquid Crystal Display is provided for visual feedback to the operator for manual setting of revised setting point if needed.

1.4 ON – OFF Control

Heater -1 and Heater-2 in the above control loop is controlled by ON-OFF control technique[15], this is the oldest and the simplest control strategy. The perfect ON-OFF controller is ON when the measurement is below the set point and under such condition the manipulated variable is at its maximum value [7]. When the measured variable is above the set point, the controller is in OFF condition and manipulated variable is at its minimum value

$E > 0;$ $m =$ maximum value

$E < 0;$ $m =$ minimum value

1.5 Pulse Width Modulation (PWM) Control [26]

PWM uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the entire waveform. If we consider a pulse waveform, $f(t)$ with period T, low value Y_{min}, a high value Y_{max} and a duty cycle D fig. 1.4

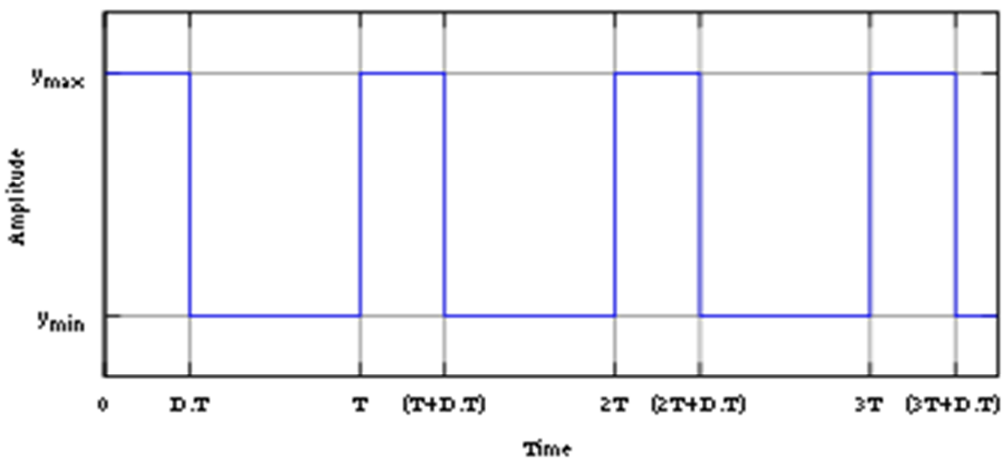


Fig. 1.4 Waveform, Depicting the Basic PWM

The average value of the waveform is given by:

$$\bar{Y} = \frac{1}{T}\int_0^T f(t)\,dt.$$

As $f(t)$ is a pulse wave, its value is Y_{max} for $0 < \mathrm{t} < \mathrm{D.T}$

And Y_{min} for $\mathrm{D.T} > \mathrm{t} > 0$.

The above expression then becomes:

$$\bar{Y} = \frac{1}{T}\int_0^{DT} Y_{max}\,dt + \int_{DT}^{T} Y_{min}\,dt.$$

$$= \frac{D.T.Y_{\max} + T(1-D)Y_{min}}{T}$$

$$= D.Y_{\max} + (1-D)Y_{min}$$

This expression can be simplified

Whereas $\bar{Y} = D.Y_{\max}$

From this, it is obvious that the average value of the signal $\bar{Y}$ directly depends on its duty cycle D. let us consider Intersective PWM, which is amodest method to generate the PWM train of pulse, corresponding to a given signal.the signal in red sinewave is compared with a saw tooth waveform in blue. When the former is more than later, the PWM signal I in magenta color is in high state i.e.1. Otherwise it is in the low state i.e.0.

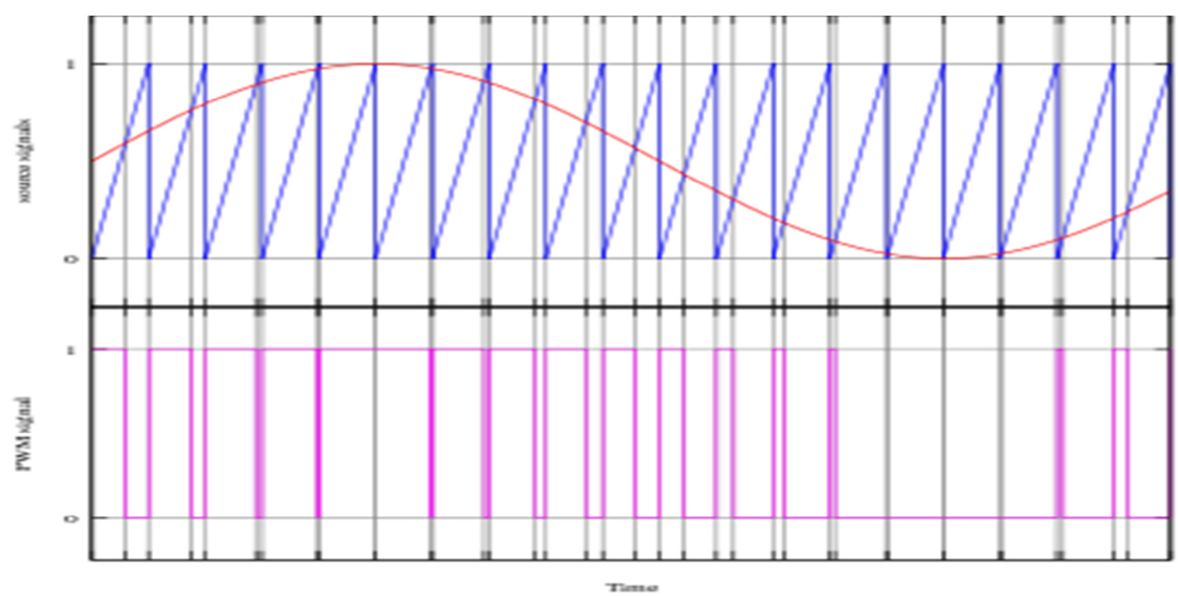


Fig. 1.5 Methods to generate PWM

PWM signal generation using intersective method is the simplest way; this requires only a saw tooth triangle waveform, which can be easily generated by an oscillator and a comparator. When the value of ref. signal depicted in red sine wave is more than the modulation waveform depicted in blue, the PWM signal in magenta color is in the high state i.e. 1, otherwise it is in the low state i.e. 0.

1.5.1 Time proportioning

Commercially available several digital circuits e.g., many microcontrollers, can generate PWM signals. They normally use inbuilt counter that increments after affixed period.. Counter is directly or indirectly connected to the clock signal of the circuit and is reset at the end of every period of the PWM. When the counter value is more than the reference value, the PWM output changes state from high to low or low to high, this technique is called **time proportioning control [26]**. The duty cycle can only be varied in stepladders, as a function of resolution of the counter. However, a high-resolution counter can provide reasonably high performance.

1.5.2 Types of PWM

There are three types of Pulse Width Modulation signals [26], i.e. firstly leading edge modulation, in blue Color: second Trailing edge modulation depicted in middle and third, the saw tooth waveform shown in green lines. First and second cases and a triangle waveform i.e. third case is used to generate the PWM waveforms using the intersective method. This is shown in fig. 1.6:

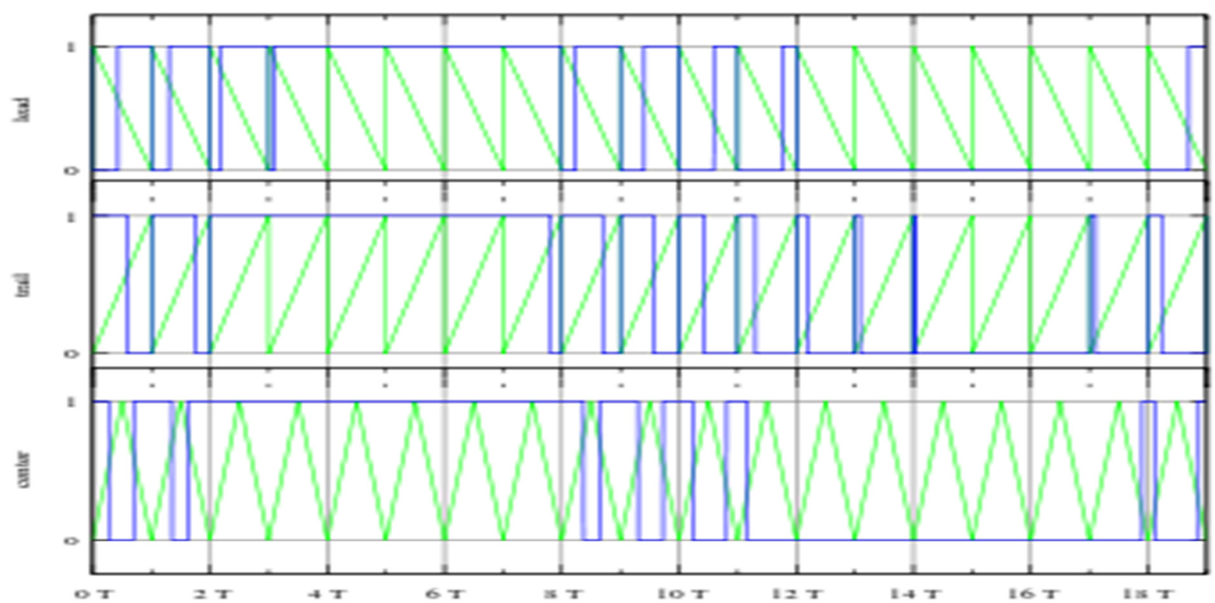


Fig. 1.6 Three Type of PWM Signal

1.5.3 PWM sampling theorem

The PWM conversion process is non-linear and is generally thought of low pass filter signal recovery. This theorem shows that PWM conversion can be perfect. This theorem says that "Any baseband signal bandlimited within ±0.637 can be represented by a pulse width modulation (PWM) waveform with unit amplitude [26]. The Nyquist samples represent the number of pulses in the waveform and the peak constraint does not depend on two-level or three-level." Status of waveform

1.6 Mathematical Modelling of Storage Tank

A liquid level system is the primary requirement of the present system and Process fluid storage facility is for this we require a storage tank with inlet/outlet connection. Schematic diagram of a storage tank with inlet is shown in fig. 1.7.

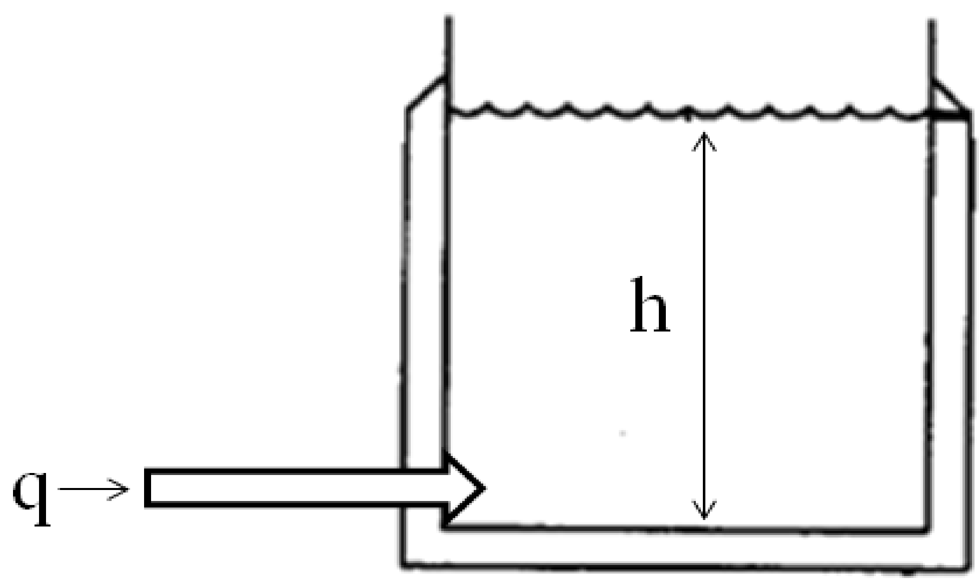


Fig. 1.7 Schematic Diagram of a Storage Tank with Inlet

Capacitance is the ability to store. An illustration of storage ability is a storage tank with inlet. Let us have following assumption:

The flow of the fluid in the tank is the input i.e. Input = q

The level of the liquid in the tank is the output i.e. Output = h

The ability of the tank to store liquid is the capacitance .i.e. Capacitance = C

Change in level of liquid in the tank i.e. $\frac{dh}{dt}$ is directly proportional to inlet flow rate

$$\frac{dh}{dt} \infty\, q$$

$$\mathrm{C}\frac{dh}{dt} = q \qquad - (1.1)$$

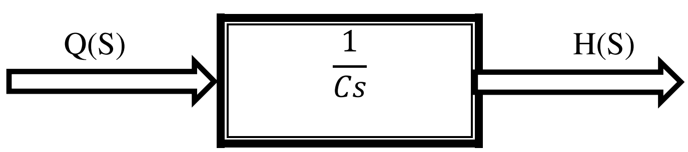
Applying Laplace Transform to equation (1.1)

$$\mathrm{C(S)\ H(S)} \quad = \mathrm{Q(S)}$$

Transfer Functionand its Block diagram representation is shown below

$$G(S) = \frac{Ke^{-\tau s}}{\tau s + 1}$$

$$\frac{H(S)}{Q(S)} = \frac{1}{Cs} \qquad - (1.2)$$



If the inflow is assumed to be constant then

$$h = \frac{q}{c}t$$

1.7 Mathematical Modelling of Thermal System

Consider the stirred tank heating system described by schematic diagram shown in fig 1.8. To reduce the complexity of this problem, certain simplifying assumption is made at this stage:

- Liquid level in the tank is maintained constant during the operations
- The liquid in the tank is well steered for uniform heating of process fluid
- The tank is well lagged so that the heat loss through its wall is negligible
- The operation gain of the actuator circuit is linear

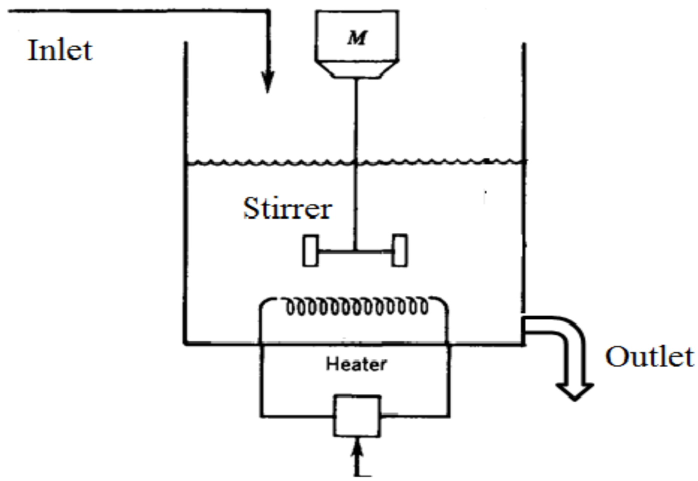


Fig. 1.8 Schematic Diagram of Stirred Tank Heating System

Let us assume the following variables for mathematical description of the system

Heat input rate	= h_i:	Outlet Flow Rate (Kg/min) = q
Temperature of the liquid	= θ	Temp. of outflow liquid = ϑ
Amount of heat stored in the tank	= h_1	

Heat input rate h_i can be expressed as;

$$h_i = h_1 + h_2$$

$$h_1 = \mathrm{MS}\frac{d\theta}{dt} + q_o$$

M = Mass of the Liquid (kg)

S = Specific Heat J/Kg °C

Defining Thermal Capacitance C = MS

$$h_1 = \mathrm{MS}\frac{d\theta}{dt}$$

$$h_2 = \mathrm{qs}\vartheta$$

Defining thermal resistance as R

$$R = \frac{1}{qs}$$

$$\mathrm{h}_2 = \frac{\theta}{R}$$

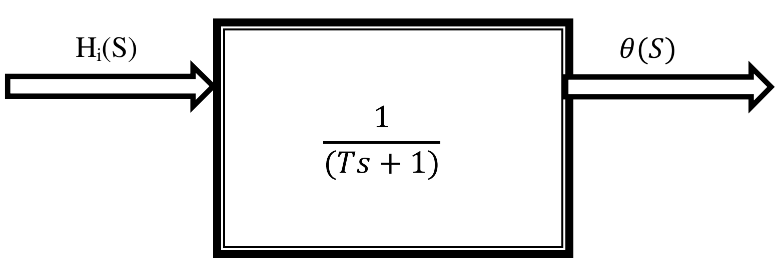
$$\mathrm{h}_i = \mathrm{c}\frac{d\theta}{dt} + \frac{\theta}{R}$$

$$R\mathrm{h}_i = \mathrm{Rc}\frac{d\theta}{dt} + \theta \qquad \text{-(1.3)}$$

Applying Laplace Transform to equation 1.3 and substituting, RC = T = Time Constant,

We have following Transfer Function

$$\frac{\theta(S)}{H_i(S)} = \frac{R}{(Ts+1)} \qquad \text{-(1.4)}$$



1.8 Mathematical Modeling of Temperature Control System

Consider the temperature control shown in Fig 1.2, which is set up to maintain the temperature of process fluid in controlled environment. The temperature of the process fluid is maintained automatically by means of a feedback sensor (RTD PT100) which produces an output voltagee_t proportional to temperature of process fluid, this voltage is subtracted from the reference voltage e_τ to generate the error signal $e = e_\tau - e_t$, which in turn regulates the current through the final actuator by means of solid state relay circuit in case of motor control and analog relay circuit in case of Heater circuit by means of suitable logic circuit.

The heat flow balance equation can be mathematically represented by following expression

$$I_c^{\,2} \; R \;\; = MC \;\frac{d\theta}{dt} + Q_0 \rho C \;\frac{(\theta \; - \; \theta_i)}{R_t}$$

$$= \qquad MC \;\frac{d\theta}{dt} + \frac{(\theta \; - \; \theta_i)}{R_t}$$

Where

M = Mass of the liquid in the tank

C= Specific heat of the liquid

ρ= Density of the Liquid

Q_0= Volume Flow Rate of the Liquid

θ_i= Temp of the inflowing liquid

R = Resistance of heater element

C = MC = Thermal Resistance of liquid in Tank

R_t =Thermal resistance of heat transfer process

Substituting all the variables in terms of their steady state plus incremental values, the above equation can be written as,

$$Ks^2(e_0{}^2 \ -2e_0e)R = C \ \frac{d\theta}{dt} + \frac{(\theta_0 - \theta_{i0})}{R_t} + \frac{(\theta_0 - \theta_i)}{R_t} \qquad - (1.6)$$

$$Ks^2 \, e_0{}^2 = \frac{(\theta_0 - \theta_{i0})}{R_t} \qquad - (1.7)$$

Subtracting equation 1.6 from equation 1.7

$$2Ks^2e_0Re = C \ \frac{d\theta}{dt} + \frac{(\theta_0 - \theta_{i0})}{R_t} \qquad - (1.8)$$

The increment error is given by

$$e = e_\tau - e_t \qquad - (1.9)$$

$$e_t = K_\tau$$

$$e_t = K_t\theta \qquad -(1.10)$$

K_t = Constant of the Temp Sensor

Taking Laplace Transform of equation (1.8),(1.9), and (1.10) and reorganizing we get

$$\theta(S) = \left[\frac{KE(S)}{\tau_s+1}\right] + \left[\frac{(\theta_i \ (S)}{\tau_s+1}\right]$$

$$E(S) = E_\tau(S) - E_t \ (S)$$

Where

$$K = 2Ks^2e_0RR_t$$

$$T = R_tC$$

$E_t(S) = K_t\theta\ (S)$

From this the open loop transfer function is given by

$$G(S) = \frac{K}{\tau_s + 1}$$

And is the change in the temperature of the inflowing liquid, which can be regarded as

Disturbance input entering the through system.

$$\frac{1}{\tau_s + 1}$$

Assuming the disturbance signal θ_i to be zero, the steady change in the temperature of the Out flowing liquid caused by an unwanted step change. E_r in the reference is given by

$$\lim_{t\to\infty} [\theta(t)] = \lim_{s\to 0} [\frac{E_r}{s}][\frac{K}{\tau_s + 1 + KK_t}]$$

$$= E_r K(1 + KK_t)$$

For closed loop

$= \ E_r K$ For Open Loop $K_t = 0$

Thus the change in temperature of the out flowing liquid caused by a change, in temperature of the inflowing liquid can be reduced to any prescribed value by suitable choice of the gain KK_t If desired, the heat loss through the tank wall can be accounted for by introducing the term

$Ah\ (\theta - \theta_e)$

Where h = Heat transfer Constant A = Surface area of the tank

This results in the additional disturbance signal caused by a change in the environmental temperature θ^0 C

1.9 Transportation Lag

All the feedback structures are symbolized by linear, lumped, parameter mathematical representations. This is valid till the time taken for transmission of energy is negligible. This is not the case for thermal model. in this model, certain time surely elapses between the application of input to the system and receipt of output from the system. This Time lag between application of input and appearance of output is known as transportation lag it is also known as dead time [14]. Linear Lumped Parameter Model [8]will not valid in these conditions till the time lag is made negligible as compared to other system lag. Let us consider a system with Time lag of T sec, i.e. its output and input are same but output is delayed by T sec.

Mathematically

$$C_o(t) = C_i(t - T)$$

Taking the Laplace Transform

$$C_o(S) = C_i(S)e^{-st}$$

$$\frac{C_O(S)}{C_i(S)} = e^{-st}$$

This is the transfer function of transportation lag

A thermal system generally has a transportation lag, which is represented by following first order system.

$$G(S) = \frac{Ke^{-\tau s}}{\tau s + 1}$$

1.10 Dissertation Statement

This aim of this dissertation is to present a low cost industrial process temperature controller on embedded platform. Embedded platform selected for design and implementation is Atmel AT89C51 microcontroller, in unification with 08 bit Analog to Digital Converter (ADC) 0809 and Resistance Temperature Detector (RTD) PT100. The proposed controller is designed to control two heating element for forced heating, if the actual process temperature is below desired temperature. Major focus of the work has been given in switching off the two elements individually at different temperature level so that a highly efficient process heating system with reduced power consumption can be obtained. This controller has a provision for generating control signal for variable speed cooling pump for forced cooling of process fluid if the process system requires lowering its operating temperature in between process duration. The approach can be extended to process heating system with multiple heating elements, if the requirement arises. Commercial production in mass scale of this controller using one time programmable chip can substantially reduce its production cost.

The major components of the system are:

- **The Plant** - A water bath with agitation system has been used
- **Heat Exchanger** - A tube type heat exchanger is used for cooling system
- **Sensor** - A RTD PT 100 is used as transduction element
- **Reference Input** -A Potential divider circuit is used for reference input
- **Display** - A LCD screen is used forvisual display to operator.
- **ADC** - Analog to Digital Converter used is 8 bit, 8 channel IC 0809
- **Controller** - AT89C51 is used for processing and logical operation
- **Heating System** - Two 220 V, 250 Watt Element is used for heating system
- **Cooling System** - A 12 V DC cooling pump motor is used for cooling system
- **Calibration System** - Environmental Stress Cracking Resistance system is used as Reference standard set up for sensor calibration
- **Actuator** - A solid state switch is used for cooling system and Mechanical relay is used for Heater system

CHAPTER - 2

HARDWARE DESCRIPTION

Chapter – 2

Hardware Description

2.1 Combined Control loop of Control System

Control loop in this process temperature controller consist of a Heating Sub-system, a cooling Sub-system, a RTD as Feedback element and a Liquid Crystal Display. Complete schematic diagram is shown in Fig 2.1.

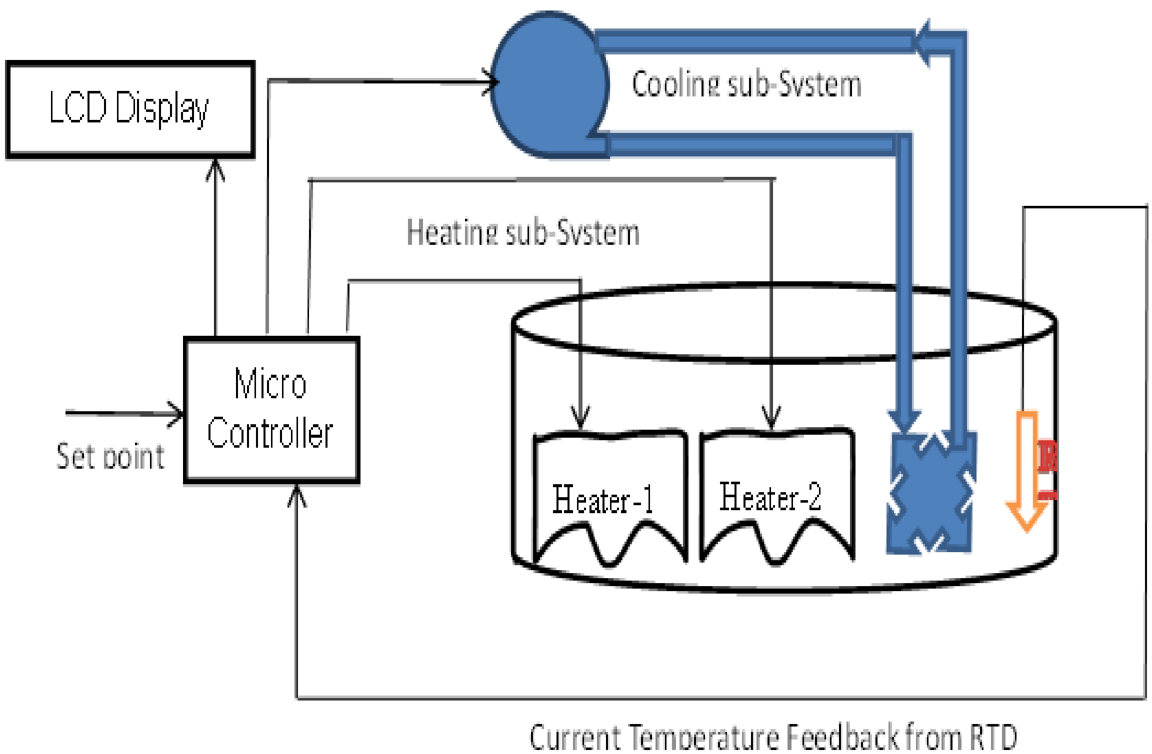


Fig – 2.1 Schematic Diagram of Combined Control loop

The basic control loop in the schematic diagram consists of following subsystems:

- Controller and its accessories
- Reference Input and Feedback loop
- Display subsystem
- Process vessel
- Heating subsystem
- Cooling system
- Power supply module

The RTD touches the water in the container as it fills to sense its temperature. Based on this feedback the microcontroller, perform a control action by adjusting the circulating coolant pressure or switching between the Heating elements, until the temperature stabilizes as desired. If the current temperature deviates above set point, the PWM control action is taken for controlling the temperature of a container filled with water, for this, the controller circulates cold water inside the cooling coil by switching ON the cooling sub-system. The cooling coil is immersed in the container. If the current temperature deviates below set point, the ON –OFF control action is taken for decrease in temperature, for this, the controller switch ON the heating sub-system. The heating system consist of two heating element. The sensed water temperature is the process variable (PV). The desired temperature is called the set point (SP). The input to the process and the output of the controller is called the manipulated variable (MV) or the control variable (CV). The difference between the temperature measurement and the set point is the error (e) and quantifies whether the water in the container is too hot or too cold and by how much. After measuring the temperature (PV), and then calculating the error, the controller decides how much to change the manipulated variable (MV) [1]. Because the temperature can be adjusted for anything from cool water through to very hot. The complete hardware is built around this schematic diagram and software designed is tested on this hardware.

2.2 Micro-controller "AT89C51"

After extensive literature survey, no of popularly available micro-controller was shortlisted, one out of them is AT89C51 from Atmel corporations. It is popular and commercially available, programmable micro-controller built with CMOS technology. It is inexpensive 8 bit, 40 Pin DIP Plastic, 12 MHz chip, with following inbuilt features

(a). ROM	- 4K bytes	(b). RAM	- 128 bytes
(c). I/O Pin	- 32	(d). Timer	- 02
(e). Interrupts	- 6	(e). V_{cc}	- 5 Volt

This version of microcontroller is typically suitable for Process Heating controller Development as this meets the following requirement

(a). Flash ROM - 4K bytes, and RAM 128 bytes

(b). 08 Input Pin for 08 bit digital input from ADC 0809

(c). 08 Output Pin for Control signal to ADC 0809

(d). 08 Output Pin for 08 bit digital output to LCD Panel

(e). 03 Output Pin for Control signal to LCD Panel

(f). 03 Output Pin for final load control and indication (i.e. Heating element and Cooling pump motor)

(g). Timer – 02.

There is one time programmable version of 8051 available. When the controller is designed and absolutely finalized, the OTP version of the 8051 can be used for mass production as it is much cheaper in terms of price per unit.

2.3 Current Temperature feed to ADC

The controller needs to know the present process temperature so that it can compare it from the reference process temperature so as to generate the control command for selecting one or both the Heating element i.e. Element – 1 and Element - 2 and to switch it ON based on the temperature requirement. Current temperature feed is given from a Resistance Temperature Detector (RTD). PT100-sensor, it is a passive transducer. This is suitable for precise temperature measurement. The linear relationship of the resistor with temperature makes it suitable for various electronic applications. Its precision allows the universal application from temperature monitoring, governing, and controlling in many industrial applications. The advantages of this sensor are - very precise measurement ±0.5°C (-50°C to +230°C), linear temperature to resistance characteristic, Rugged construction, Light weight, plus little response time. For PT100 Nominal resistance is 100 Ω at 0°C

Fig. 2.2 PT100 sensor probe

For accurate measurement, the manufacturer of RTD provides table of resisiance vs temperature. Although this graph is not linear, there is sufficient linearity over short span to make a good approximation of this equation as equation of a straight line. The minimum change in resistance for PT 100 is 0.36Ω /◦C

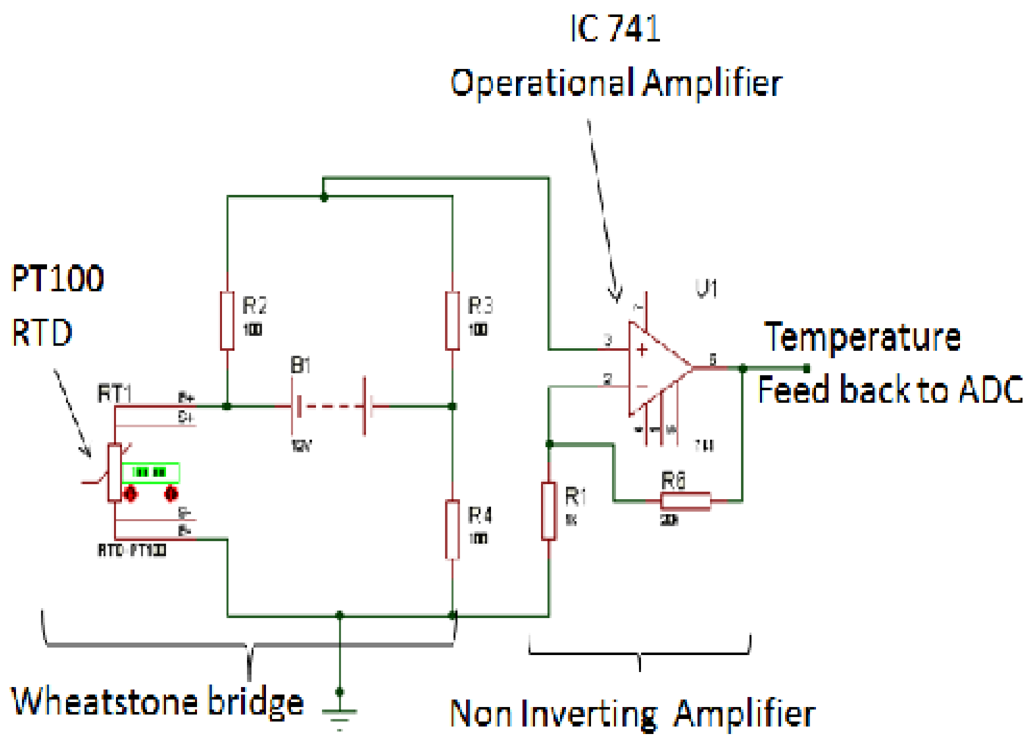


Fig.2.3 Wheatstone bridge and non- inverting amplifier circuit

Change in process temperature is sensed by the PT100 in terms of variation in resistance, this resistance variation has to be converted in terms of analogous voltage variation. For this a Wheatstone bridge is constructed with one arm RT1 to be of Pt 100 and rest three arm R2, R3 and R4 to be of 100Ω. 5Volt DC is given as reference bridge voltage. Wheatstone bridge circuit is shown in figure 2.3. When the process temperature is at zero degrees the bridge circuit is at balance, no voltage pulse is generated at output terminal of bridge circuit. When the actual temperature deviates from current value, an imbalance occurs within the bridge circuit. As a result a voltage signal is generated at output terminal of bridge circuit the magnitude of this voltage signal is analogues to the temperature variation experienced by the RTD. This output voltage signal is given to the Analog to Digital circuit (ADC) for conversion into equivalent digital signal in binary form.

2.4 Amplification of Current Temperature feed to ADC

Current temperature is available at the output of bridge circuit in analog form. It is observed that this analogous signal is very small in magnitude. On measurement following data was observed for every one degree centigrade increase in process temperature,

The minimum change in resistance for PT 100 is 0.36Ω /◦C
The minimum change output of bridge circuit 01mV /◦C
The minimum change in the input signal (Resolution) of the ADC be 20 mV/Bit
Amplification needed before the ADC circuit 20mV/ 01mV = 20
Therefore there is a need of 20 times amplification of the analog output of the bridge signal before being fed to ADC. An Op Amp based Non-inverting amplification circuit is shown in fig. 2.2. The circuit is designed with following parameters for achieving a gain of 20
For a non-inverting amplifier in circuit of fig 2.3, we have following formulae

Gain = 1+ R6/R1 Where R6 = 20KΩ, R1= 1KΩ
= 1+ 20KΩ /1KΩ
≈20

2.5 Reference Temperature feed to Micro-Controller

The operator of the process temperature controller needs to inform the controller about the reference process temperature i.e. set temperature, in order to compare it from the current process temperature so as to generate the control command. For setting the reference temperature a potential divider circuit made of 250Ω potentiometer in series with a resistance of 1KΩ is used. A 5V DC voltage is connected across the series connection of Potentiometer and resistance. The diagram of potentiometer circuit is shown in fig. 2.4.The output of potentiometer is in terms of voltage is analogues to the reference temperature. This output voltage signal is given to the Analog to Digital circuit (ADC) for conversion into equivalent digital signal in binary form.

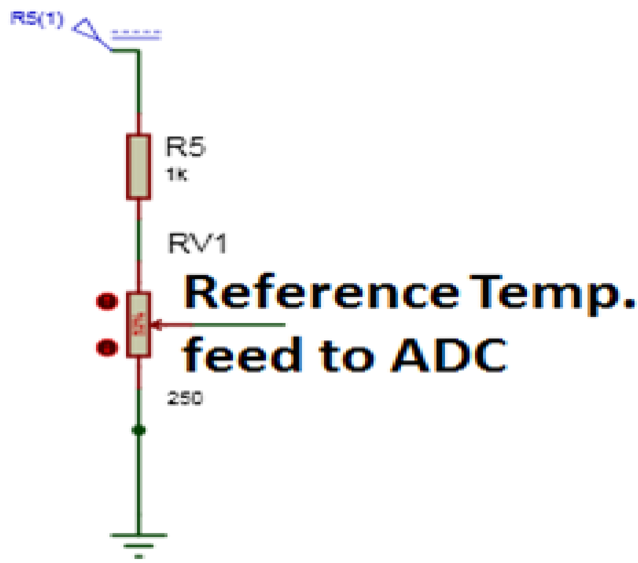
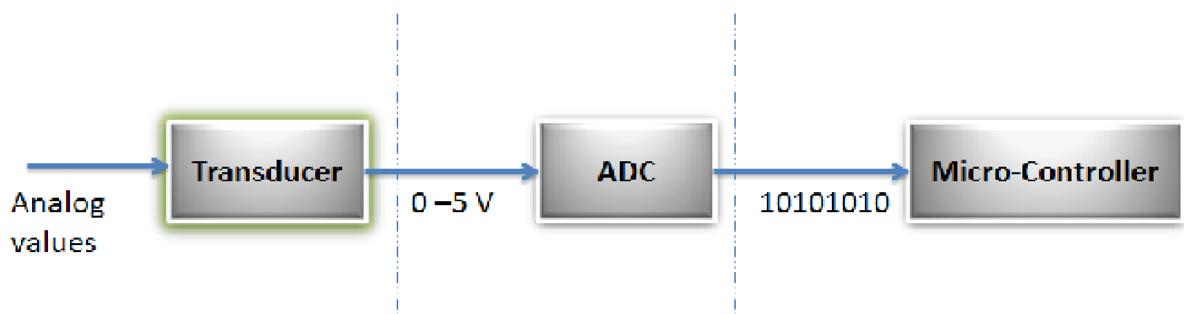


Fig.2.4 Reference Temperature Feed circuit

The minimum change in the input signal (Resolution) of the ADC is 20 mV/Bit so the output of the potentiometer is to be adjusted so that its output increase in step of 20 mV/Step, So that the accurate set point adjustment can be achieved

2.6 Analog to Digital conversion

Analog to Digital Conversion [27] is done using ADC0809 IC. It is an eight-bit parallel ADC with Reference input +5 volts. The block diagram for analog to digital conversion is shown in fig. 2.5



Figure–2.5. Block diagram of Analog to Digital Conversion.

The conversion time varies depending on the clock signal applied to the ADC. This chip allows us to monitor upto eight different analog input, the eight analog input channels are selected using three pins. A, B and C by multiplexing. For simplicity of circuit design, Set point input is connected at input channel 3 (pin no 1) and current temperature feedback is connected at input channel 2 (pin no 28). The V_{ref} (+) and V_{ref} (-) pin of ADC is connected to +5V DC and Ground respectively. The resolution (step size) of the ADC is as follows

Reference voltage of ADC	= 5V.
Maximum count of 8 bit ADC	= 255
Resolution (Step Size) of ADC	= 5V/ 255
	≈20 mV

The ADC digital output is incremented by a unit value for every ≈20 mV increase in input analog signal. Both the analog input is converted into digital equivalent and is given to microcontroller at Port no 1. The set point input and current temperature feedback is stored inside the memory of microcontroller as byt1 and byt2 respectively. Pin wise connection of ADC 0809 to micro controller is in fig 2.6.

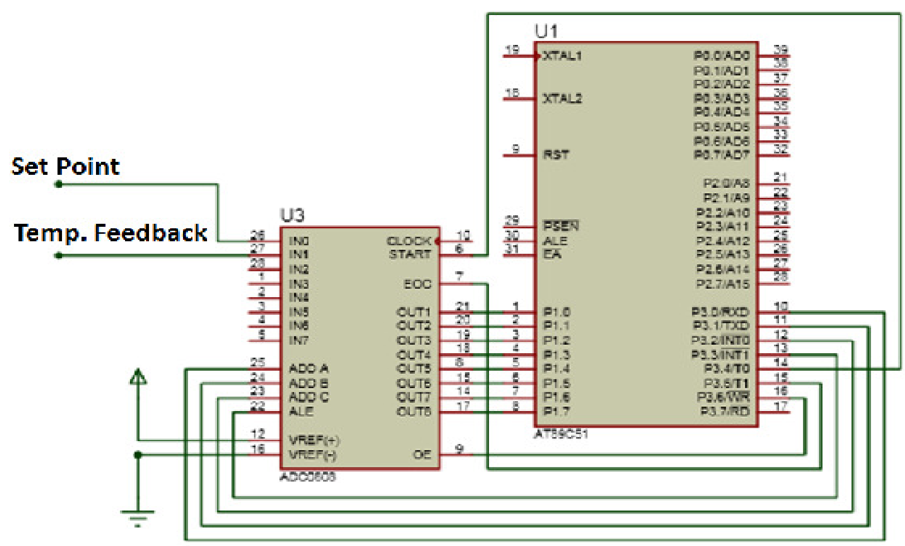


Fig – 2.6 Pin connection of ADC 0809 to microcontroller 8051

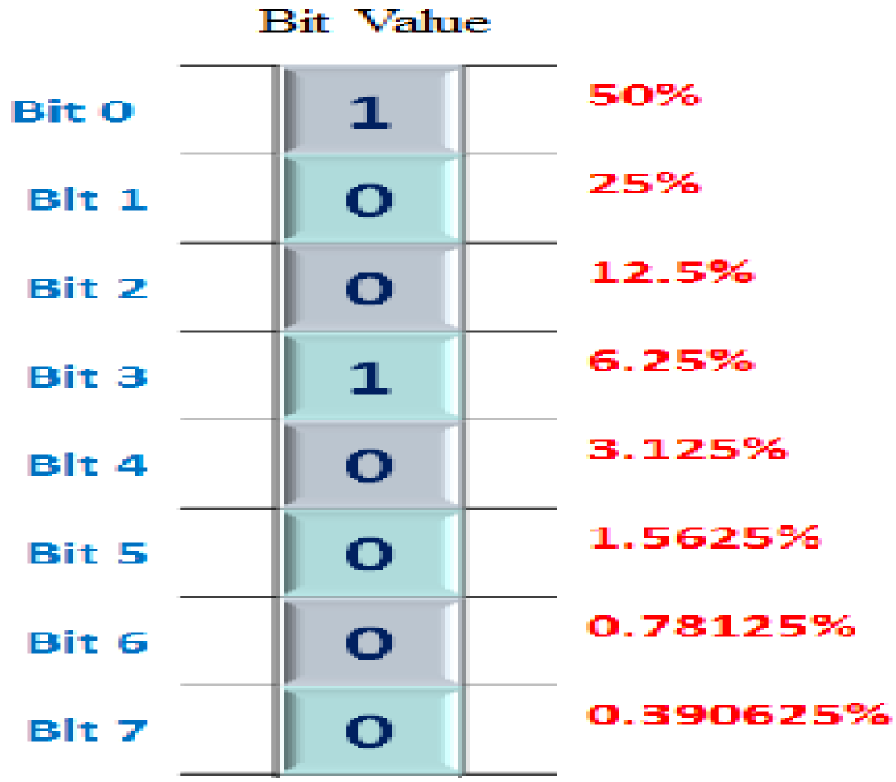


Fig 2.7 (a) Analog Control Register [27]

Usually, there are eight to sixteen bits of ADC, but for simplicity conversion of four bit Analog to digital conversion of 3 Volt analog signal is done. The largest bit is called the MSB and the smallest LSB. The MSB is 1/2 of full-scale value. Each subsequent bit is 1/2of the previous bit Consider a typical ADC conversion process 1s depicted in fig 2.7. The +3.000-volts is given to the first level of the converter. The converter tries to subtract 2.500 volts from it. It can (3.000 > 2.5000), so it outputs +5 volts signal to the enable input of the 2.500-volt bit (MSB) of the register. The next positive going clock pulse will force the register MSB to output a "1." The remainder (3.000 – 2.500 = 0.500 volts) is fed to the second stage. The converter tries to subtract 1.250 volts from it. It cannot (0.500 < 1.250 volts), so it output a 0 – volt signal to the enable input of the 1.250 – volt bit of the register. The next clock will force that register bit to a "0."

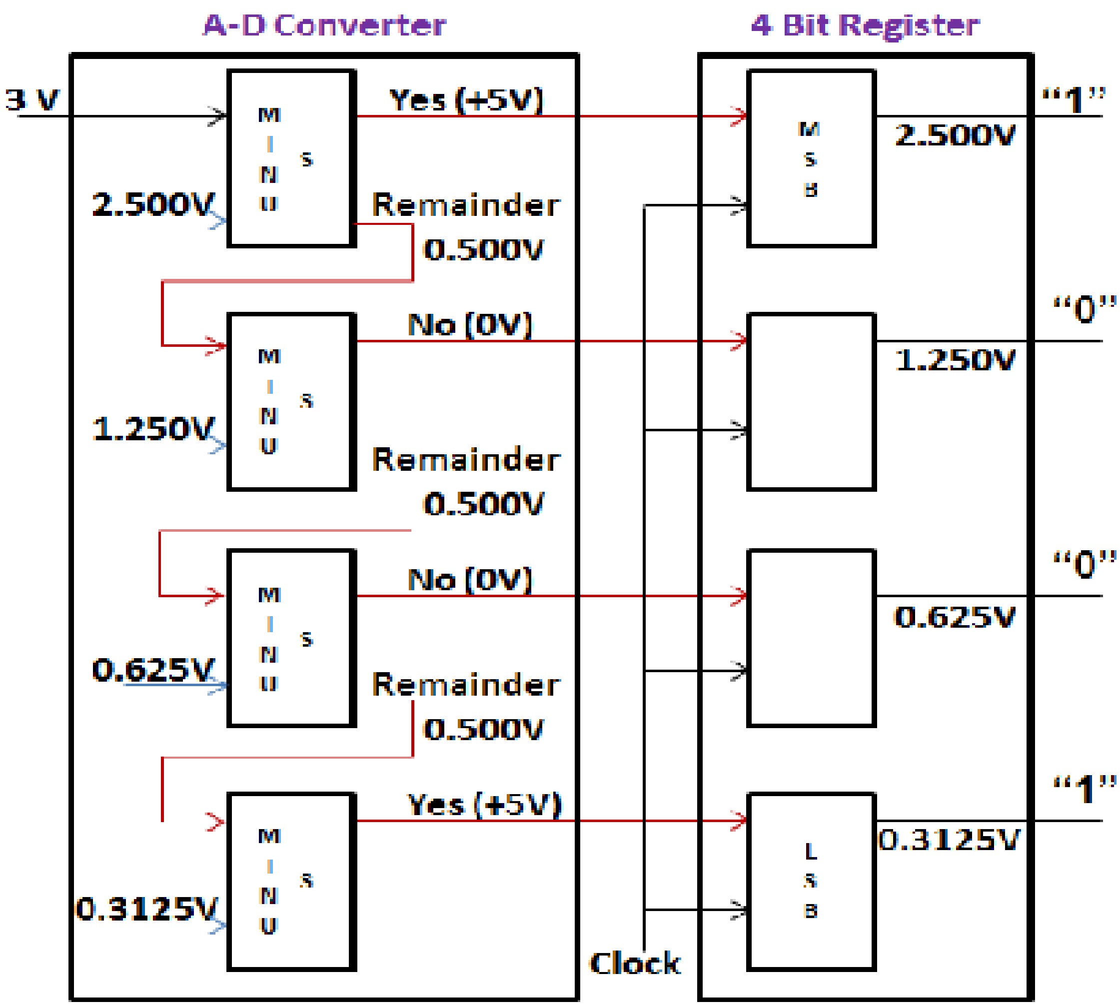


Fig2.7 (b) Analog to Digital Conversion [27]

The remainder (still 0.500 volts) is fed to the third stage. The converter tries to subtract 0.625 volts from it. It cannot (0.500 <0.625 volts), so it output a 0 – volt signal to the enable input of the 0.625 – volt bit of the register. The next clock will force that register bit to a "0." The remainder (still 0.500 volts) is fed to the fourth stage. The converter tries to subtract 0.3125 volts from it. It can (0.500 > 0.3125 volts), so it output a +5 – volt signal to the enable input of the LSB of the register. The next clock will force that register bit to a "1."

The final result is a four-bit binary word that describes the 3.000 volts as follows:

MSB	+1 x 2.500 volts	=	2.500 volts	
	+0 x 1.250 volts	=	0 volts	2.500 + 0 + 0 + 0.3125
	+0 x 0.625 volts	=	0 volts	= 2.8125 Volts
LSB	+1 x 0.3125 volts	=	0.3125 volts	

A four-bit register provides precision of 1 in 2^4, or 1 in 16, of the full-scale value, this is as close as we can get to 3.000 volts.

2.7 Display of Current / Reference Temperature

Reference / Set Temperature or Current Temperature needs to be displayed to the operator of the process system, so as to take informed decision regarding the future course of action for further processing. Micro-controller receives the information in binary form for comparison and logical decision making. The binary data is in eight bit parallel format. The eight bit data is converted into corresponding alphanumeric ASCII code. This code is then sent to Liquid Crystal Display for display.

LCD display is chosen above other multisegment LEDs, for this project because of its ability to display numbers, characters, and graphics. Incorporation of refreshing controllers in the LCD relieves the microcontroller from this task. Additionally it is easy to develop program for characters, and graphics. Additionally it’s cheap. Connection LCD screen with microcontroller is shown in fig 2.8

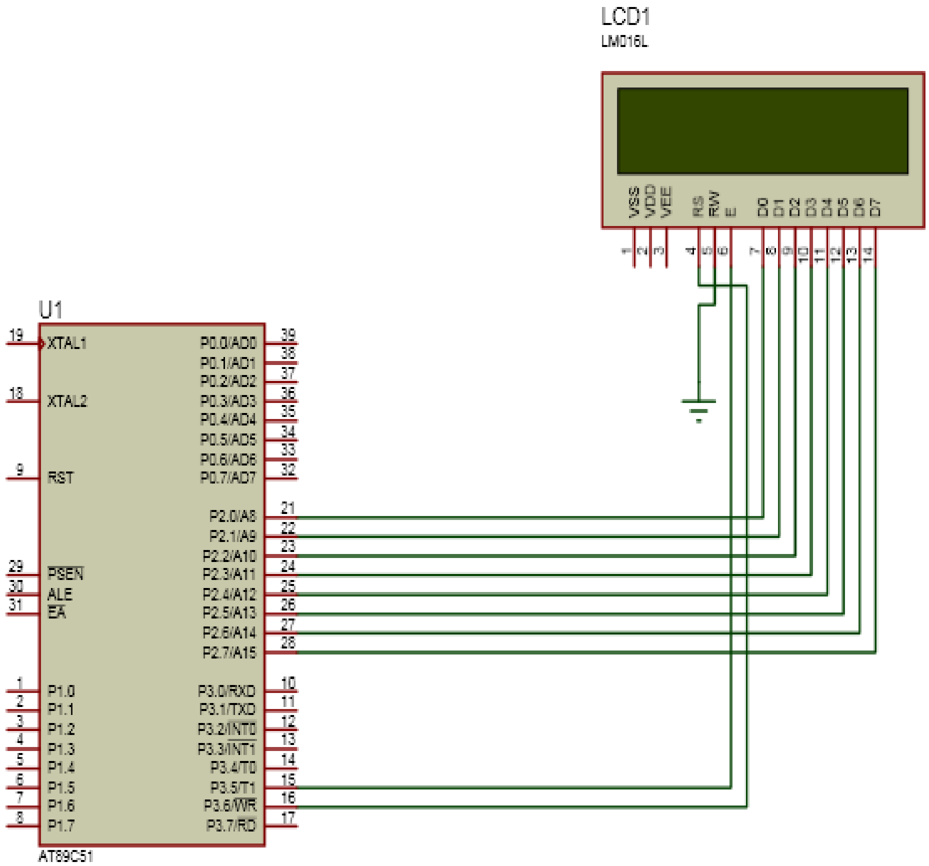


Fig.2.8 LCD Connection to Micro Controller

2.8 Driver circuit for Heating and Cooling System

The final control element for Cooling and Heating System is connected at Port 0 Pin 1, 2 and 3. Port0 is open drain so a pull-up register of 10KΩ is connected between controller pin and driver circuit. Schematic diagram is shown in fig 2.9, ULN2003 IC is used for driver circuit; it is a Darlington pair transistor array having high current and high voltage.

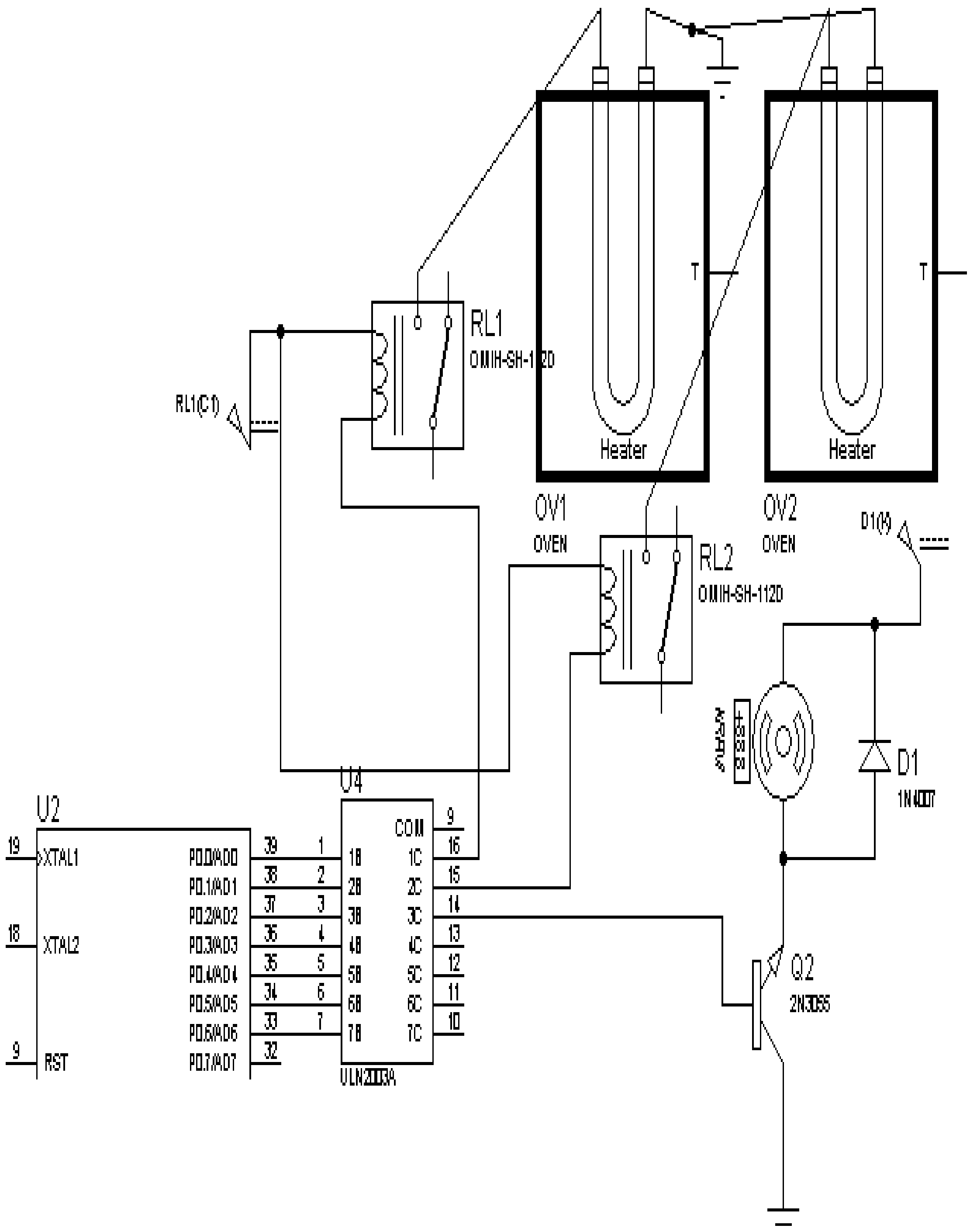


Fig.2.9 Schematic Diagram of Driver circuit for Heating and Cooling System

2.8.1 Driver circuit for Heating System

The water chamber used in experimental circuit is of small capacity and two low range water resistive load type heater is used with following Specification.

Heater Specification

Power developed - 250 Watt

Power Input - 230 Volt

Heater Resistance - Water Load

Current drawn - 1.25 A (Max)

There are number of solid state actuators available for switching operation [21] of the heater element, i.e. MOSFET, TRIAC, SCR, Power Transistor etc. however for present circuit the need is of low range power control so a 12 V 6A Relay RL 1 and RL 2 is used for switching operation of Heater -1 (OV1) and Heater 2 (OV2) respectively. Connection diagram is shown in fig. 2.8. For high power heating load, Power Electronic based solid state switching device will be more suitable instead of Analog Relay.

2.8.2 Driver circuit for Cooling System

The water chamber used in experimental circuit is of small capacity so heat exchanger required is of small heat transfer capacity. For experimental circuit a 12V DC Motor controlled pump is used for cooling system,as in present circuit there is need of low range power control so a solid state actuators 2N3055 [21] is used for switching operation. Connection diagram is shown in fig. 2.8 the specification of power transistor is as below:

Type - Bipolar silicon NPN Power Transistor

Voltage - 110 V

Power rating - 115 Watt

Temperature - 200◦C

2.9 Power Supply Module

Input to the power supply module is 230V+/- 10%, 50Hz. The module gives the following output

- 230 V AC for Heater -1 (OV1) and Heater 2 (OV2)
- 12 V DC supply to Relay circuit
- 12 V DC supply to Cooling Pump Motor and Agitator Motor
- 12 V DC supply to ULN 2003
- +12V and -12V DC to Op Amp IC's 741
- +5V DC to different IC's

The power supply module consists of following parts.

- Transformer 12-0-12
- Bridge Rectifier Circuit of Diode IN4007
- Noise Filter Circuit
- Voltage Regulator IC's LM 7805, LM 7809, LM 7812, LM 7912,
- Output connectors for load circuit

CHAPTER - 3

SOFTWARE DESCRIPTION

Chapter – 3

Software Description

3.1 Software and Simulation

The entire circuit was simulated using simulation software, on simulation, the programming was done and hex code generated. The hex code was tested for proper working before being implemented on actual experimental circuit. The complete simulated circuit is shown in fig 3.1 Following software's were used in this project

- **PROTEUS Simulation Software:**

  This software is used for hardware simulation and analysis. It allows design, of the circuit, simulation of designed circuit, analysis of the circuit and modification in the circuit if need for improved performance of the system. Simulated Schematic Diagram of Final Control circuit is shown in Fig 3.1

- **KEIL IDE Platform**

  Integrated Development Environment KEIL is used for writing the program in C language, later the program is debugged, tested and Hex code generated for burning into the Microcontroller

- **ECE Flash Software**

  This software is used to burn the Program Hex code into microcontroller for actual implementation of experimental circuit.

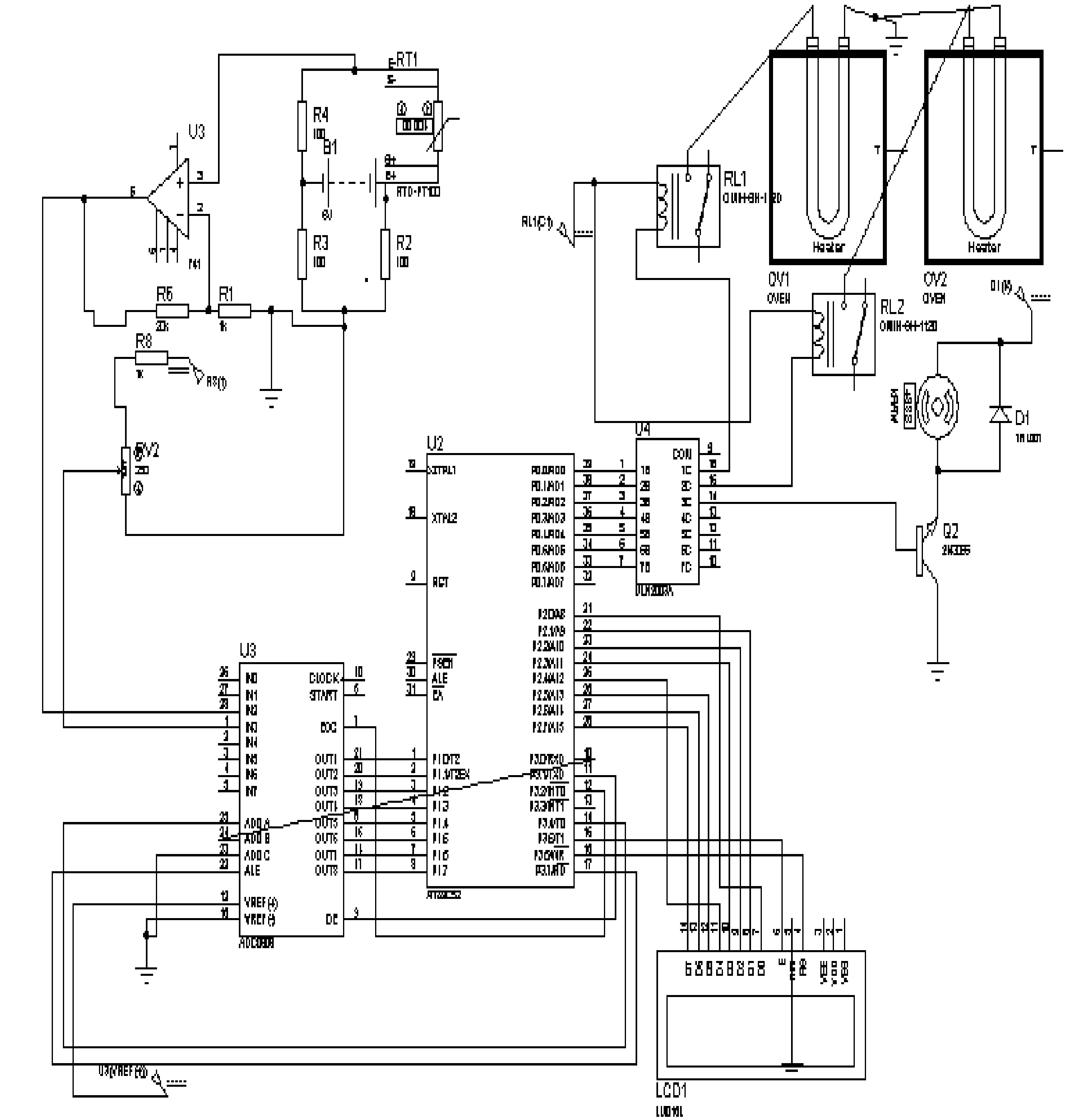


Fig – 3.1 Schematic Diagram of Final Simulated Control circuit

3.2 Controller Circuit Algorithm

The Controller circuit in this process heating system is required to follow the following function in order to perform the specified task

a) Initialize the Microcontroller
b) Read the Temperature Feed from RTD
c) Analog to Digital conversion
d) Display of Current Temperature in LCD
e) Read the Reference Temperature from POT
f) Analog to Digital conversion
g) Display of Reference Temperature in LCD
h) Negative Temperature Error generation
i) Control of First Heating Element
j) Control of Second Heating Element
k) Positive Temperature Error generation
l) Pulse Width Modulation Control Signal generation
m) Continue the step a to m with 2 sec interval

To perform the above function various subroutines are written in C program [24]. Each subroutine is executed when called by the main program during the course of operation of controller. The flow chart for entire program is shown in fig 3.2

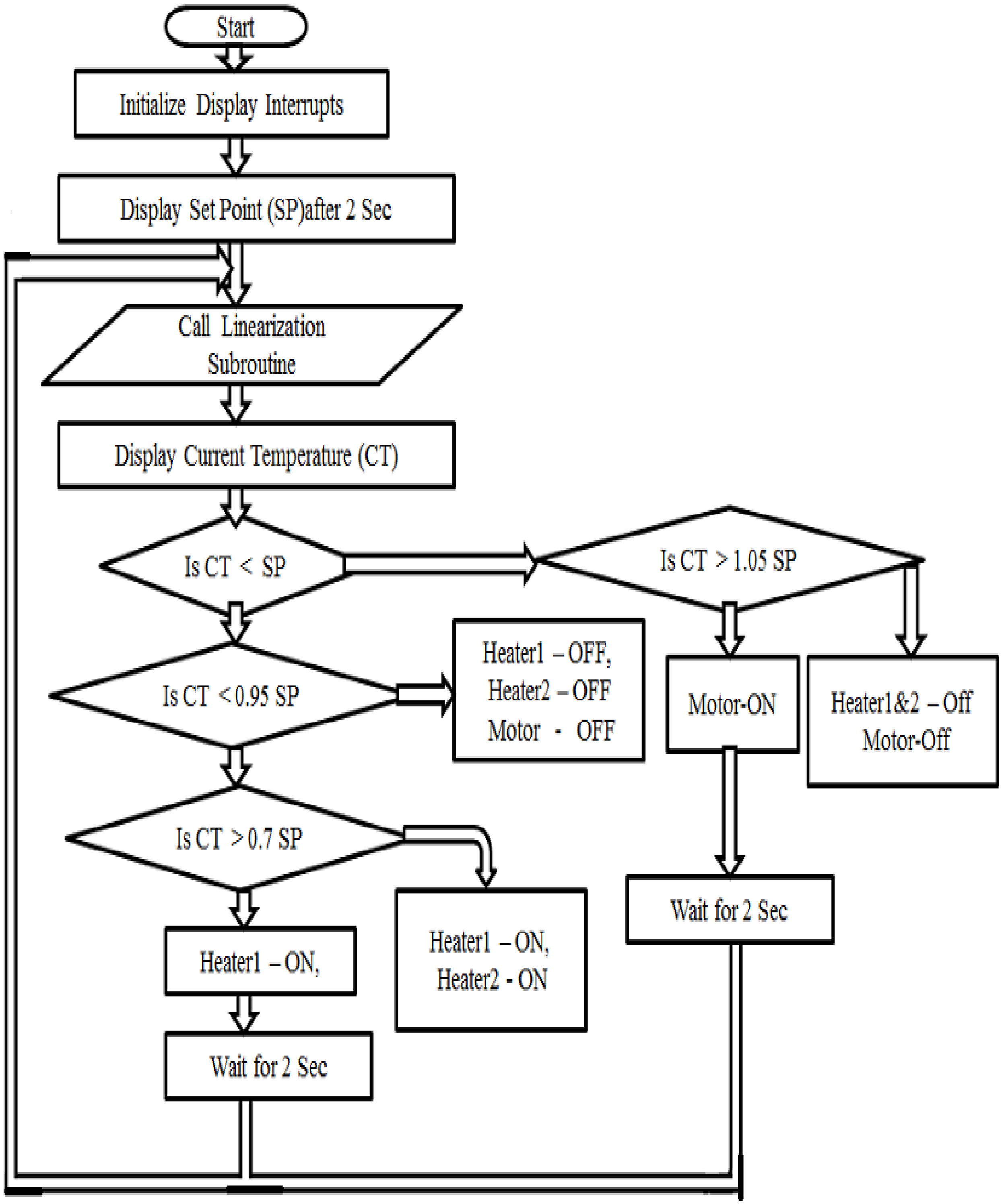


Fig – 3.2 Flow Chart for Main Program

3.3 The Subroutine

Subroutine is the cluster of instructions written to be executed so as to perform certain task, which is to be repeated again after predefined interval of time. In this program, the predefined interval of time is selected to be 2 sec, this interval is known as sampling time for the program. These programs are written separately so that the main program is not complex and large in size. Subroutine reduces the overall size of the program.

3.4 ADC Subroutine

Analog to digital conversion is required for conversion into decimal value by microcontroller. ADC subroutine includes following algorithm.

- Select Channel 2 as analog input source
- Convert analog input into equivalent Binary value
- Put binary value at 8 bit output pin for microcontroller as byt1
- Select Channel 3 as analog input source
- Convert analog input into equivalent Binary value
- Put binary value at 8 bit output pin for microcontroller as byt2

C program for ADC Subroutine is as below

```
c1++;if(c1==1)
{a=0; b=1; }                          // select ADC input channel 2 & 3 alternatively
 Else {  a=1; b=1;}
 ale=1; sc=1;                         // start conversion
 ale=0;  sc=0;
while(eoc==1);  while(eoc==0);        // wait for end of conversion
oe=1;                                 // enable output alternatively
if(c1==1) byt1=P1 ;
else byt2=P1;
oe=0;
```

3.5 Display Subroutine

Display Subroutine includes following Algorithm

- Reading the binary data available at Port 1 of microcontroller
- Store the Binary data as byt1 & byt2 for Set temp. & Current Temp. respectively
- Conversion of Binary data into Decimal data
- Conversion of Decimal data into ASCII Code
- Out of ASCII code to Port 2 for display into LCD panel

C program for Display Subroutine is as below

```
P1=0xFF;
P2=0x00;
P2=0x0F;
if(c1==1){ writecmd(0x80);
 writestr("set temp:");                // display set temp:
display(byt1); }                        // Set temperature
else {writecmd(0xC0);
 writestr("current temp:");             // display current temperature
display(byt2);                          // current temperature
unsigned int,t,t1,a;
unsigned char asci[3];                  // decimal to ASCII Conversion
{ t=z;
t1=t%10;
asci[2]=t1+0x30;
t=t/10;
asci[1]=t+0x30;
asci[0]=0x30; }
writedata(asci[0]);
writedata(asci[1]);
writedata(asci[2]);
```

3.6 Subroutine for Pulse Width Modulation Generation

Pulse Width modulation signal generation makes use of Timer 0 and Timer1 of microcontroller AT89C51 in 8-bit auto reload mode, this mode is also known as Timer operation Mode - 2. This subroutine includes following algorithm

- 8 Bit auto reload Mode 2 selection of Timer 0 and Timer 1
- Load byt1 (Set Temperature) in Timer 0
- Load byt2 (Current Temperature) in Timer 1
- Start Motor
- Start Timer 0, Timer 1
- Stop Motor on Overflow of Timer1
- Clear Timer 0, Timer 1

C program for PWM generation Subroutine is as below

```
{TMOD=0x22;IE=0x8A;      \\ Mode 2 selection of  Timer 0 &1, interrupt Enable
MOTOR=1;                  \\ Timer 0 interrupt 1, start motor
TF0=0; TR0=0; TR1=0;     \\ Clear Timer 0 Flag, Stop Timer 0, Stop Timer 1
TH1=byt2;                \\ Load Timer 1 with byt 2
TR0=1;TR1=1;}            \\ Start Timer 0, Start Timer 1
{ MOTOR=0;               \\ Timer 1 interrupt 3
TR1=0;TF1=0; }           \\ Clear Timer 1 Flag, Stop Timer 1
{if(byt2>1.1*byt1)       \\  Logical statement
TH0=byt1;                \\ Load Timer 0 with byt 1
TR0=1;}                  \\ Start   Timer 0
else {TR0=0;TF0=0;       \\ Clear Timer 0 Flag, Stop Timer 0,
TR1=0;TF1=0;             \\ Clear Timer 1 Flag, Stop Timer 1,
MOTOR=0;}                \\ Stop Motor
```

CHAPTER - 4

RESULT, CONCLUSION & FUTURE ASPECTS

Chapter – 4

Result, Conclusion & Future Aspects

4.1 Results

The entire controller circuit is physically realized and hard-wired in a PCB. Complete assembly of controller and various power supplies are assembled in a metallic box for permanent fixture, so as to have smooth and durable operation. The Heating circuit assembly, Cooling Circuit Assembly, and Water bath tub with steering assembly is gathered together for experimental setup and testing of controller circuit operation. Various sub-assemblies and its complete hardwire assembly is depicted in fig.4.1, the final program and experimental hardware setup is tested and analyzed for various selected Set Points. This is done in following stages

- Testing sensor output for faithful conversion and display.
- Testing the ON-OFF control
- Analysis of the ON – OFF control Algorithm
- Testing of Pulse Width Modulation Control

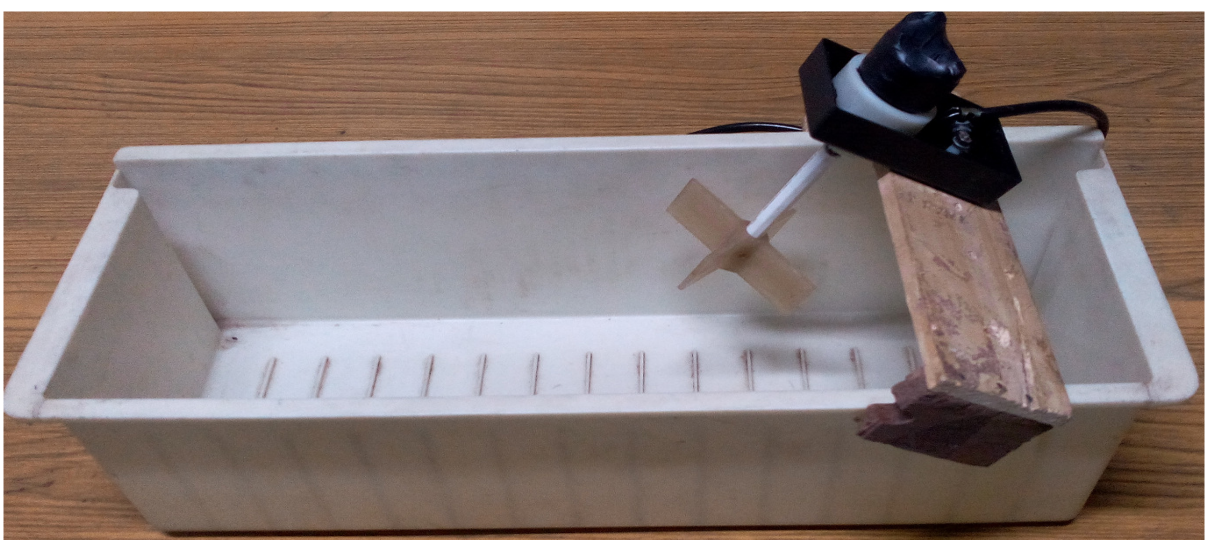
- 

Fig – 4.1(a) Water Tub with Stirrer assembly

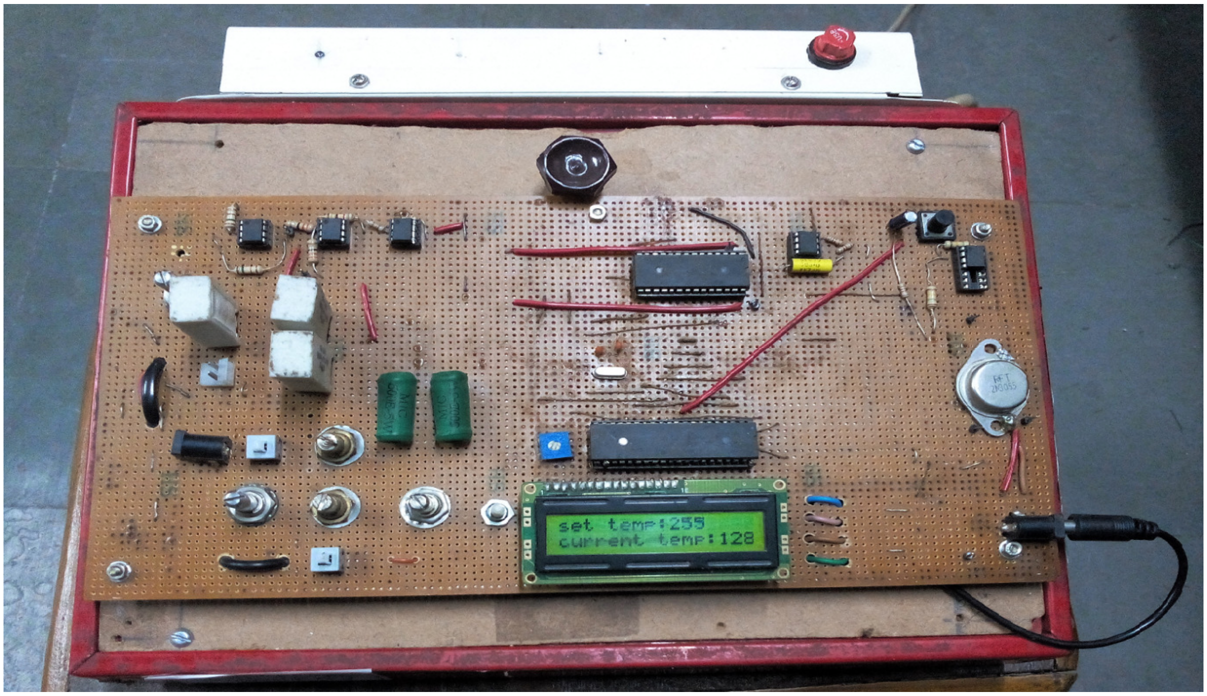


Fig – 4.1(b) Controller Circuit

Fig – 4.1(c) Heating Assembly

Fig – 4.1(d) Heating Assembly

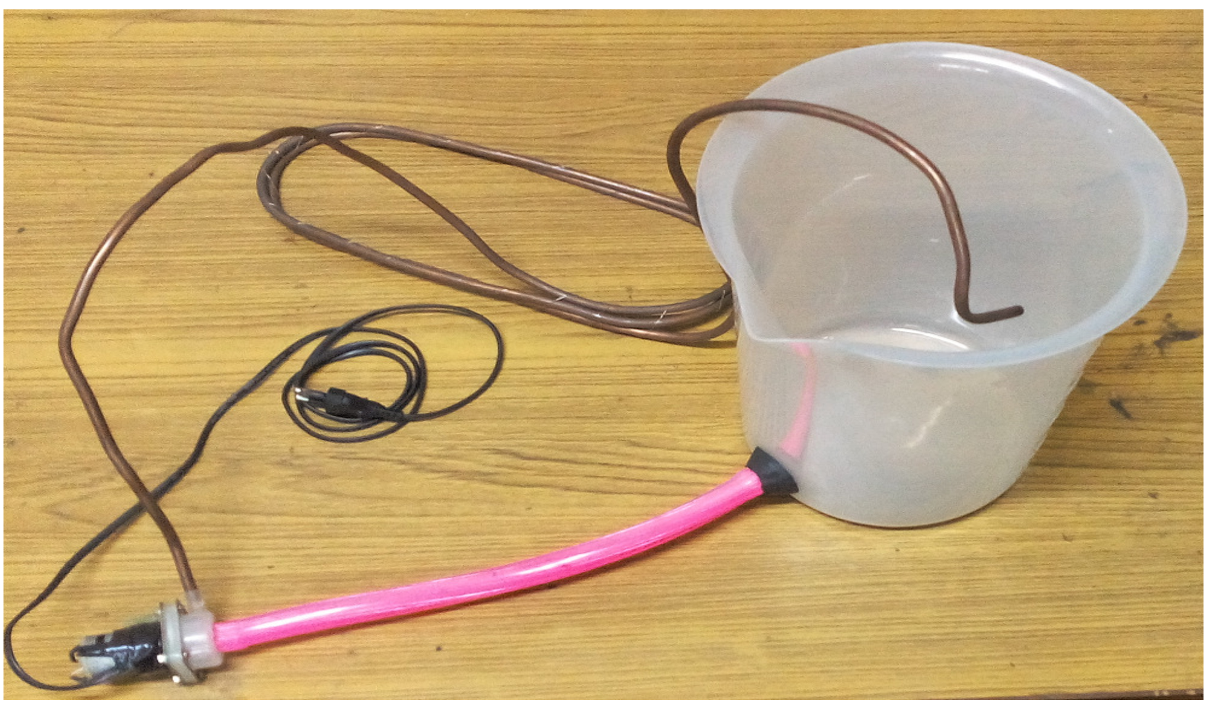


Fig – 4.1(e) Cooling assembly

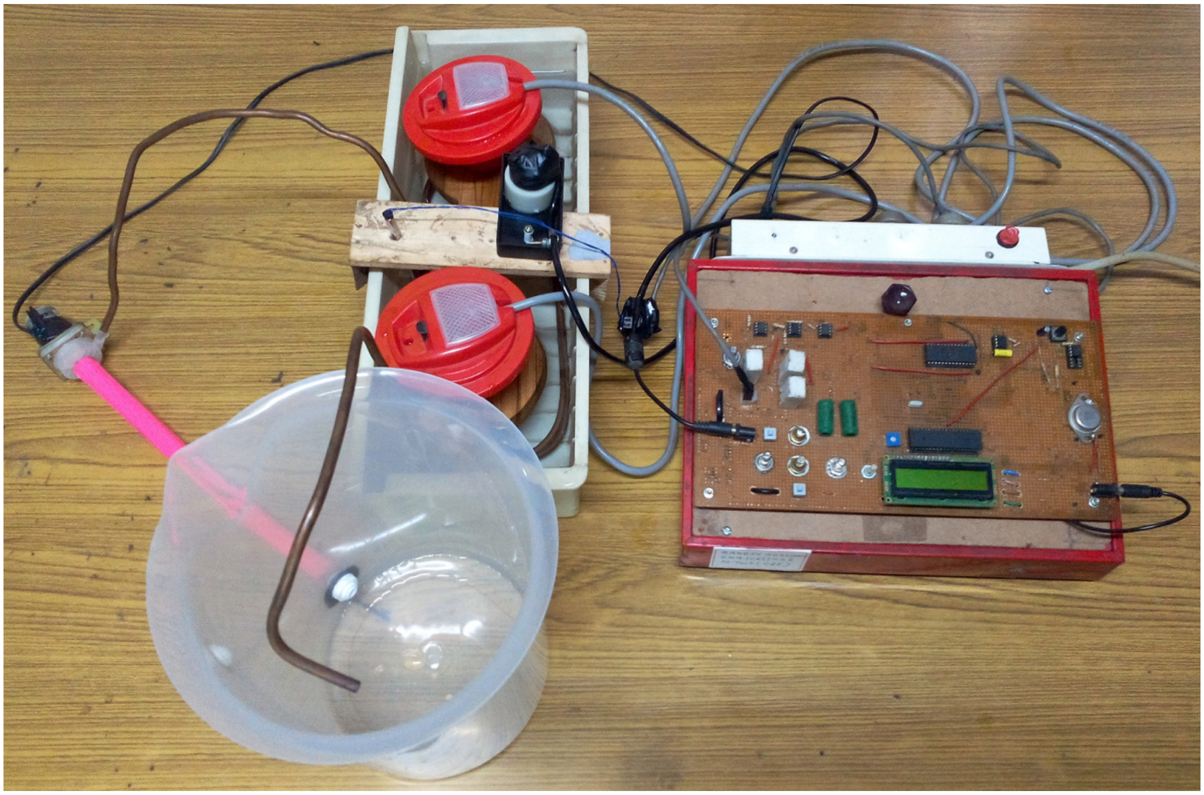


Fig – 4.1(f) Controller assembly and experimental Hardware set up

4.2 Testing and verification of the Sensor Calibration

A commercially available ISO Certified laboratory setup with inbuilt Digital Temperature Indicator i.e. Environmental Stress Cracking Test Equipment, shown in fig – 4.2 is used as reference for the Sensor calibration, and verification of experimental set-up. During the calibration process, incremental output of amplifier connected with RTD is measured for increasing process temperature; corresponding temperature displayed on LCD is compared with the Digital temperature displayed on Reference setup. If both the incremental temperature differs from each other, the Bridge circuit output voltage is adjusted by tunning its amplifier gain, again incremental process temperature reading displayed on LCD screen is verified with the incremental temperature displayed on Reference setup. This calibration process is repeated until both the display indicates same incremental temperature over the entire operating range. The Result and observation table on completion of calibration process is shown in Table 4.1.

Table 4.1. Verification of the Sensor Calibration

Sr. No.	O/P of amplifier (mV)	Displayed Temp. on LCD (◦C)	Displayed Temp. on Ref. Lab Setup (◦C)
1	261.5	20	20
2	330.10	25	25
3	394,20	30	30
4	465.00	35	35
5	531.90	40	40
6	615.10	45	45
7	665.00	50	50
8	742.00	55	55
9	810.00	60	60
10	871.00	65	65
11	934.00	70	70
12	971.00	72	72
13	996.00	74	74

Fig – 4.2 Reference Laboratory setup for Calibration of Sensor

4.3 Testing of the ON-OFF control

The complete hardware setup is installed for testing and validation, with the then Current Temperature as 22◦C and Set Temp as 70◦C, the setup is operated and the process fluid temperature is allowed to increase up to 70◦C. The arrangement is allowed to operate in accordance with control algorithm. The incremental temperature and corresponding Heater ON- OFF cycle is recorded in tabular form shown in Table 4.3. As Set Temperature is provided for the control command, Heater switching is observed to be at 70% and 100% for Heater Element–2, and Element–1 respectively which establish the proper functioning of controller programming. After analysis of the above table, ON-OFF control strategy is validated

Table 4.2 Testing of the ON-OFF control

Sr. No.	Set Temp (◦C)	Current Temp (◦C)	Heater-1	Heater - 2
1	70◦C	22	ON	ON
2	70◦C	25	ON	ON
3	70◦C	30	ON	ON
4	70◦C	35	ON	ON
5	70◦C	40	ON	ON
6	70◦C	45	ON	ON
7	70◦C	49	ON	OFF
8	70◦C	55	ON	OFF
9	70◦C	60	ON	OFF
10	70◦C	65	ON	OFF
11	70◦C	67	ON	OFF
12	70◦C	70◦C	OFF	OFF

.

4.4 Analysis of the ON – OFF Control Algorithm

For analysis of the control circuit algorithm, the hardware setup is operated with following three hardware setting

- One Heating Element Operating and Control Algorithm Deactivated
- Two Heating Element Operating and Control Algorithm Deactivated
- Two Heating Element Operating and Control Algorithm Activated

With above three hardware setting, the each setup is operated alone and is allowed to achieve the following Set point. The process fluid incremental temperature is recorded with respect to time in Tabular form and corresponding comparative graph is plotted for each case,

- Set point 50◦C, reading Tabulated in Table 4.3(a), and comparative graph Fig – 4.3(a)
- Set point 70◦C, reading Tabulated in Table 4.3(b), and comparative graph Fig – 4.3(b)
- Set point 95◦C, reading Tabulated in Table 4.3(c), and comparative graph Fig – 4.3(c)

Table 4.3(a) Comparative Observation Table for Set Point 50◦C

Sr. No.	Current Temp (◦C)	Heater-1- ON (Time in Min)	Heater-1- ON Heater-2-ON (Time in Min)	Heater-1- ON Heater-2-ON Control Algorithm–ON (Time in Min)	Remarks
1	18	0.16	1.23	0.59	
2	20	1.26	2.18	1.14	
3	22	3.16	3.05	1.57	
4	24	4.08	3.3	2.22	
5	26	5.52	4.24	3.1	
6	28	6.54	5.47	4.01	
7	30	8.1	6.36	5.03	
8	32	9.32	7.16	6.21	
9	34	10.5	7.34	7.03	
10	35	11.2	8.04	8.33	Heater 2-OFF
11	36	12.1	8.46	9.39	
12	38	13.2	9.32	11.01	
13	40	14.5	10.18	12.59	
14	42	15.54	10.5	14.35	
15	44	17.16	11.32	16.03	
16	46	18.31	12.08	17.58	
17	48	20.64	12.32	19.33	
18	50	23.05	13.01	20.25	Heater 1-OFF
19	50	-	-	23.49	
20	44	-	-	25.2	Cold water added as Disturbance (Heater 1-ON)
21	46	-	-	26.5	
22	48	-	-	28.2	
23	50	-	-	30.05	Heater 1-OFF
24	50	-	-	35.0	

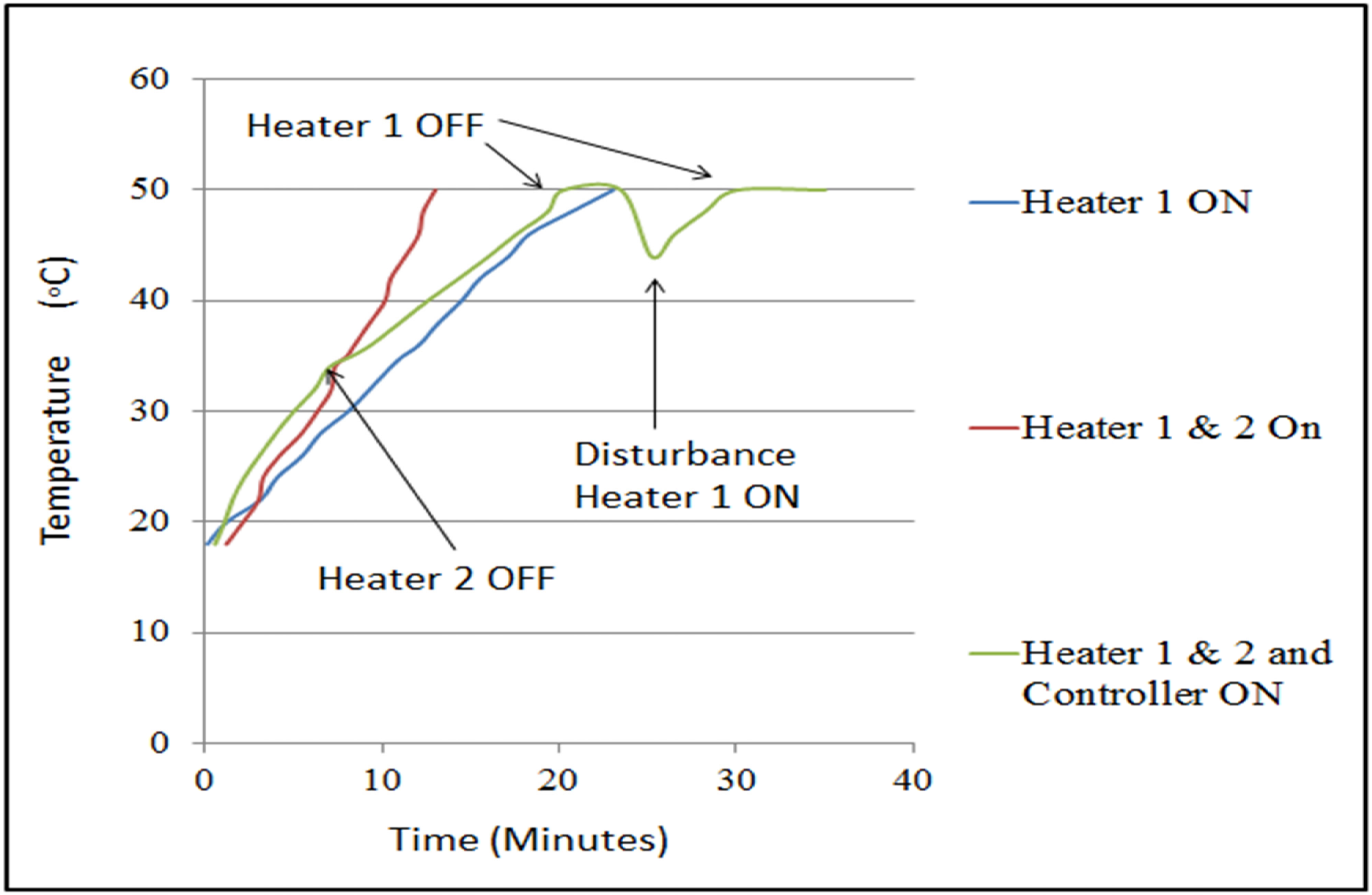


Fig – 4.3(a) Comparative Study of Tabular Data for Set Point 50◦C

Table 4.3(b) Comparative Observation Table for Set Point 70◦C

Sr. No.	Current Temp (◦C)	Heater-1- ON (Time in Min)	Heater-1- ON Heater-2-ON (Time in Min)	Heater-1- ON Heater-2-ON Control Algorithm–ON (Time in Min)	Remarks
1	18	0	0	0.28	
2	20	0.25	0.25	1.59	
3	25	3.16	2.3	3.43	
4	30	6.15	4.08	5.0	
5	35	9.4	5.51	6.1	
6	40	12.4	7.33	7.3	
7	45	15.4	9.1	8.59	
8	49	18.31	10.5	10.04	Heater 2-OFF
9	52	20.05	11.25	11.43	
10	54	21.25	12.11	12.59	
11	56	22.58	12.55	14.18	
12	58	24.07	13.32	15.44	
13	60	25.22	14.14	17.14	
14	62	26.4	14.5	18.3	
15	64	28.14	15.36	20.04	
16	66	29.4	16.09	21.39	
17	68	31.14	16.35	23.19	
18	70	32.5	17.32	25.02	Heater 1-OFF
19	70	-	-	28.23	
20	65	-	-	29.39	Cold water added as Disturbance (Heater 1-ON)
21	66	-	-	31.09	
22	67	-	-	32.44	
23	68	-	-	34.3	
24	70	-	-	36.19	Heater 1-OFF
25	70	-	-	44.0	

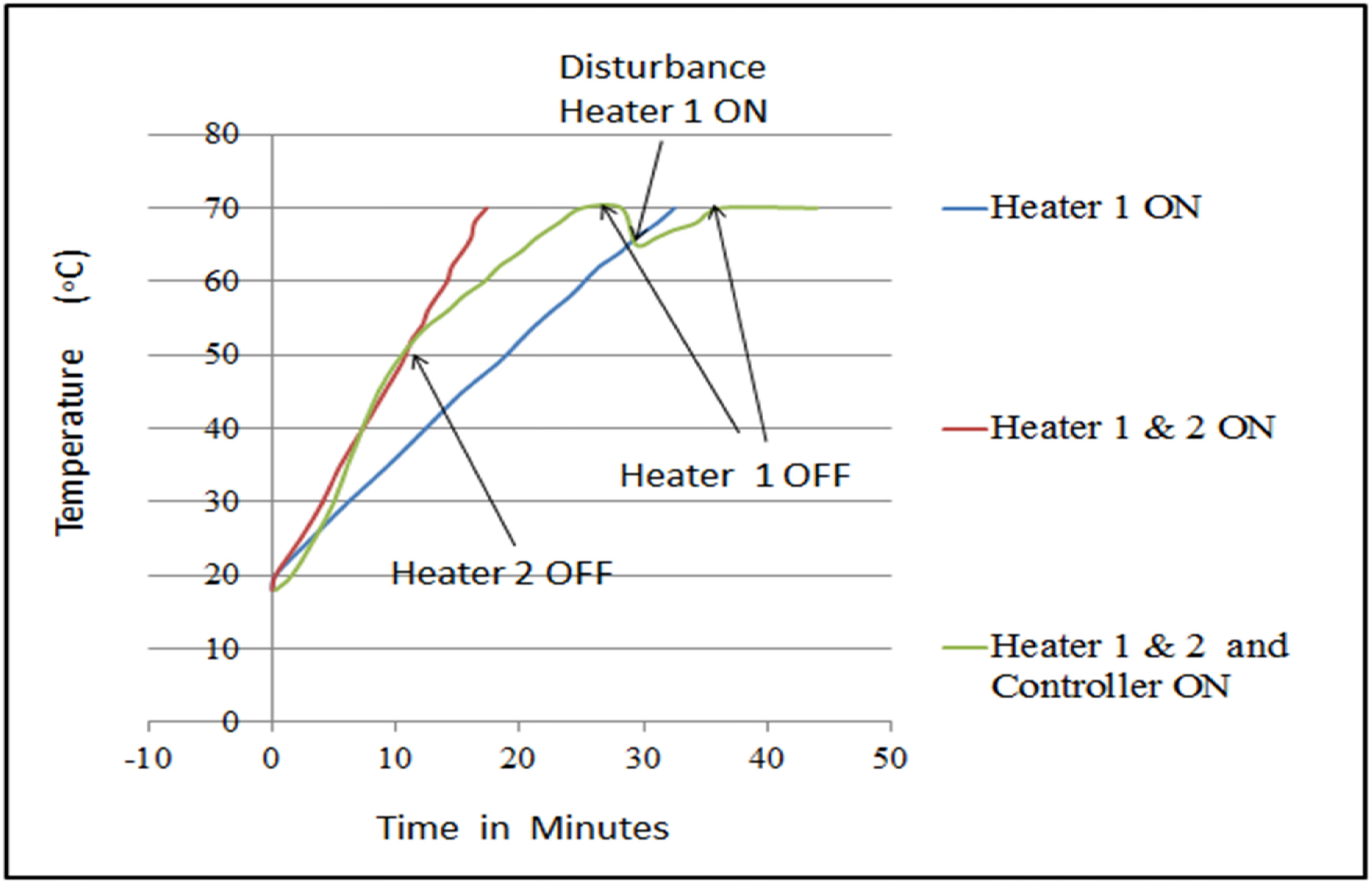


Fig – 4.3(b) Comparative Study of Tabular Data for Set Point 70◦C

Table 4.3(c) Comparative Observation Table for Set Point 95◦C

Sr. No.	Current Temp (◦C)	Heater-1- ON (Time in Min)	Heater-1- ON Heater-2-ON (Time in Min)	Heater-1- ON Heater-2-ON Control Algorithm–ON (Time in Min)	Remarks
1	18	0	0	0	
2	20	0.25	0.25	0.23	
3	25	3.16	2.3	2.4	
4	30	6.15	4.08	3.59	
5	35	9.4	5.51	5.33	
6	40	12.4	7.33	6.4	
7	45	15.4	9.1	8.32	
8	50	18.31	10.5	9.55	
9	52	20.05	11.25	11.01	
10	54	21.25	12.11	12.35	
11	56	22.58	12.55	13.03	
12	58	24.07	13.32	14.04	
13	60	25.22	14.14	15.18	
14	62	26.4	14.5	16.21	
15	64	28.14	15.36	17.42	
16	66	29.4	16.09	18.39	
17	67	31.14	16.35	19.12	Heater 2-OFF
18	70	32.5	17.32	20.59	
19	72	34.4	18.2	22.22	
20	74	35.01	19.08	24.01	
21	76	36.49	19.5	25.43	
22	78	38.13	20.33	27.13	
23	80	39.54	21.15	28.32	
24	82	41.34	22.1	30.03	
25	84	43.05	23.05	31.57	
26	86	44.59	24.15	33.14	
27	88	47.2	25.35	34.33	
28	90	49.32	27.3	35.49	
29	92	50.19	28.5	37.35	

30	94	51.84	30.03	39.57	
31	95	53.37	31.61	41.55	Heater 1-OFF
32	95	-	-	45.15	
33	87	-	-	46.46	Cold water added as Disturbance (Heater 1-ON)
34	89	-	-	48.4	
35	91	-	-	50.38	
36	93	-	-	52.34	
37	95	-	-	54.2	Heater 1-OFF
38	95	-	-	60	

In first and second arrangement, the Heating system is kept isolated of Heating Control algorithm and in third setup the arrangement is allowed to operate in accordance with control algorithm. The reading recorded in the above observation table Table 4.3(a), 4.3(b) and 4.3(c), is plotted in Fig. 4.3(a), 4.3(b) and 4.3(c), respectively. After study of the comparative graph, it is found that; controller allowed both the Heating element to operate till 70% of Set Point, after this point; it cut off power to Heater -2, and only Heater -1 was operated till the current Temperature achieved the Set point. At this point, it cut off power to Heater-1. Whenever a system disturbance was introduced and current temperature dropped below set point, the controller restored the power to Heater -1 till the temperature is restored to Set point. Hence the controller was able to maintain the specified process temperature. Therefore, multiple heating Element ON-OFF control algorithm is validated.

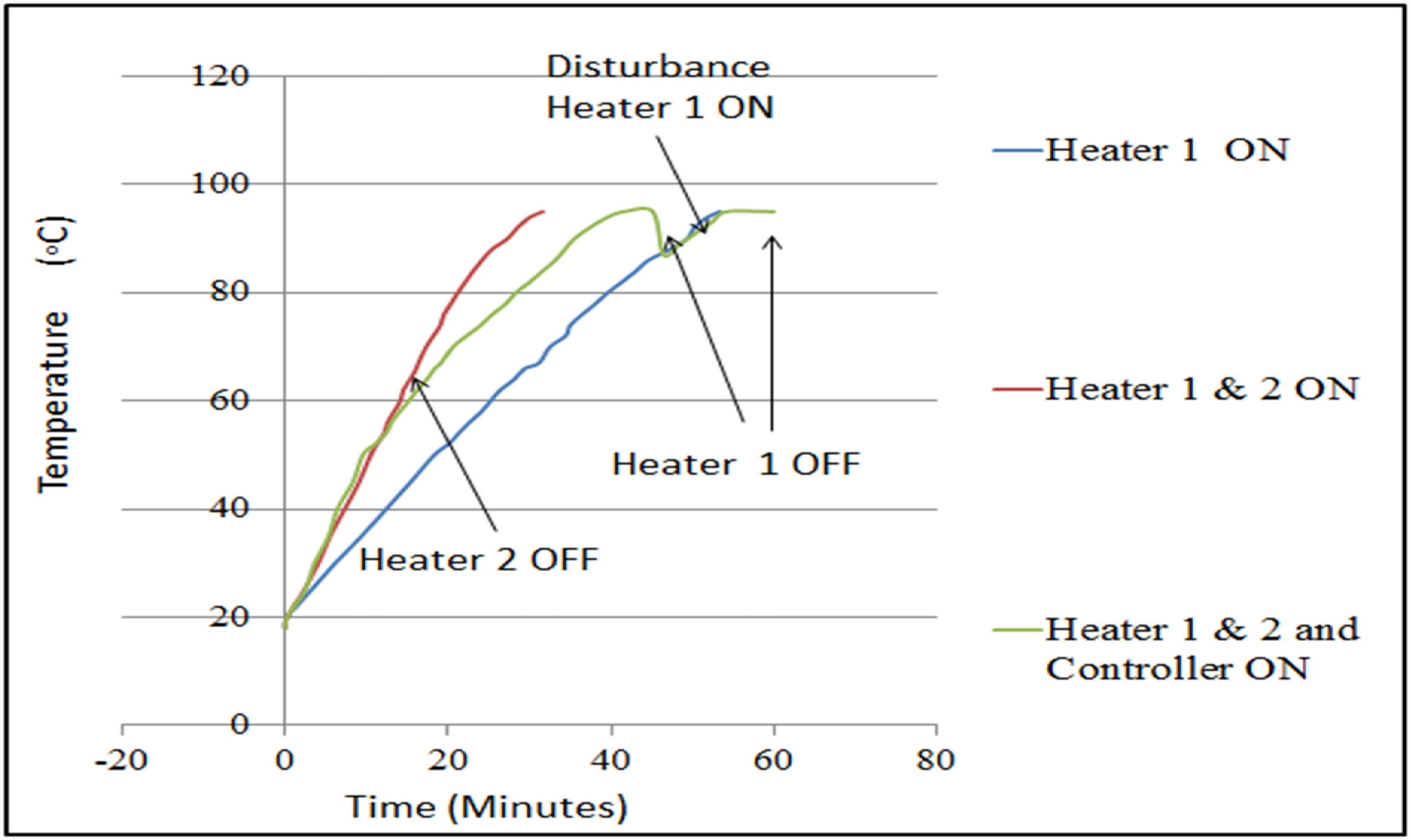


Fig – 4.3 (c) Comparative Studies of Tabular Data for Set Point 95◦C

4.5 Testing of the Pulse Width Modulation Control

The controller is operated and the process fluid temperature is allowed to increase up to 80◦C, now the desired temperature is set at 50◦C, and cooling system is allowed to operate in accordance with control algorithm. The Generated PWM control signal at 80◦C, 70◦C, and 60◦C, is observed and recorded using Digital Signal oscilloscope. The PWM control signal waveform corresponding to current temp 80◦C, 70◦C, and 60◦C, and Set Temperature 50 ◦C, is shown in Fig.4.2(a), 4.2(b), and 4.2(c), respectively. After analysis of the above set of PWM Control signal waveform, the PWM control algorithm is validated.

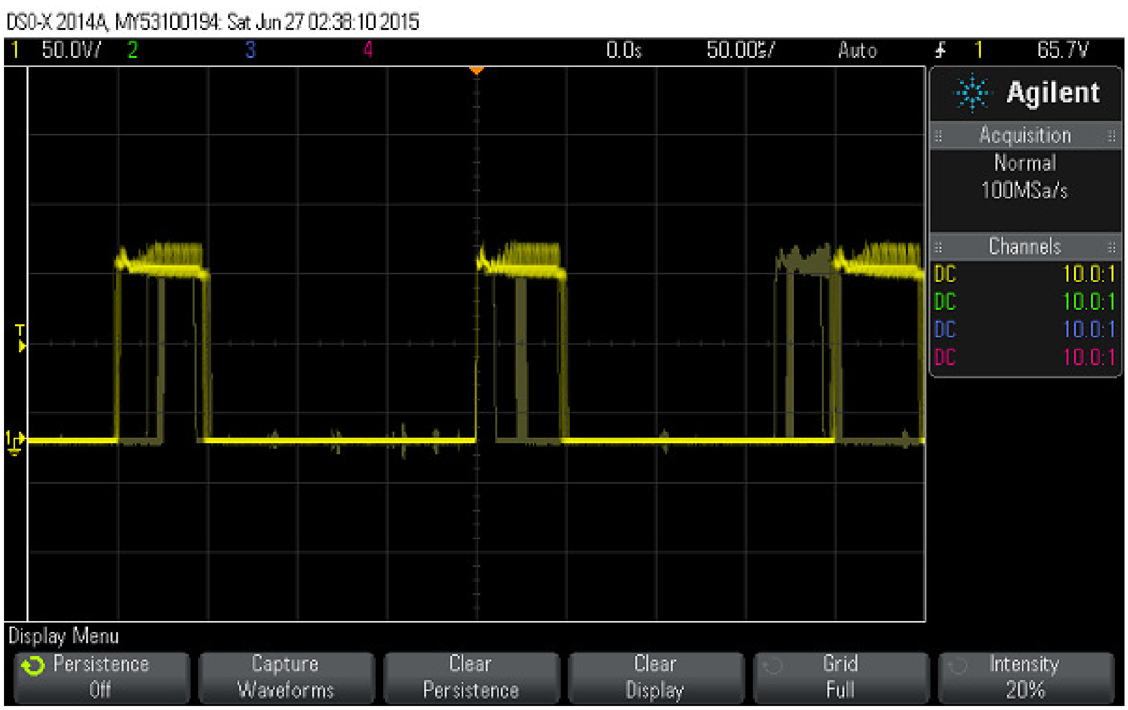


Fig 4.4(a) PWM control pulse with Set Temp = 50, Current Temp= 80

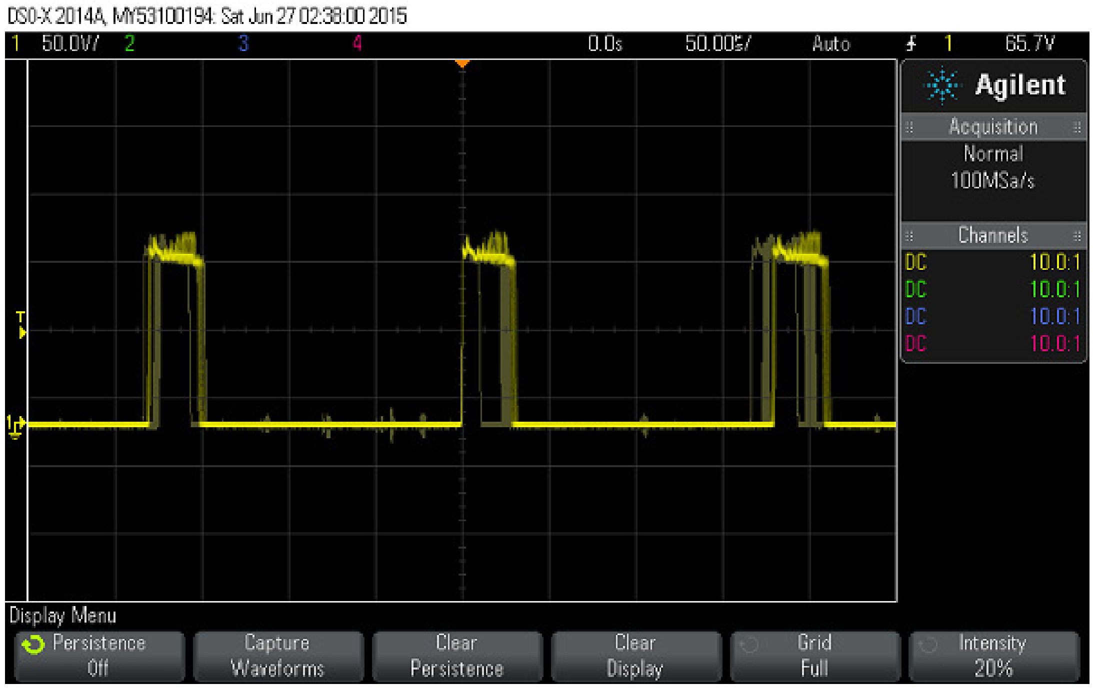


Fig 4.4(b) PWM control pulse with Set Temp = 50, Current Temp= 70

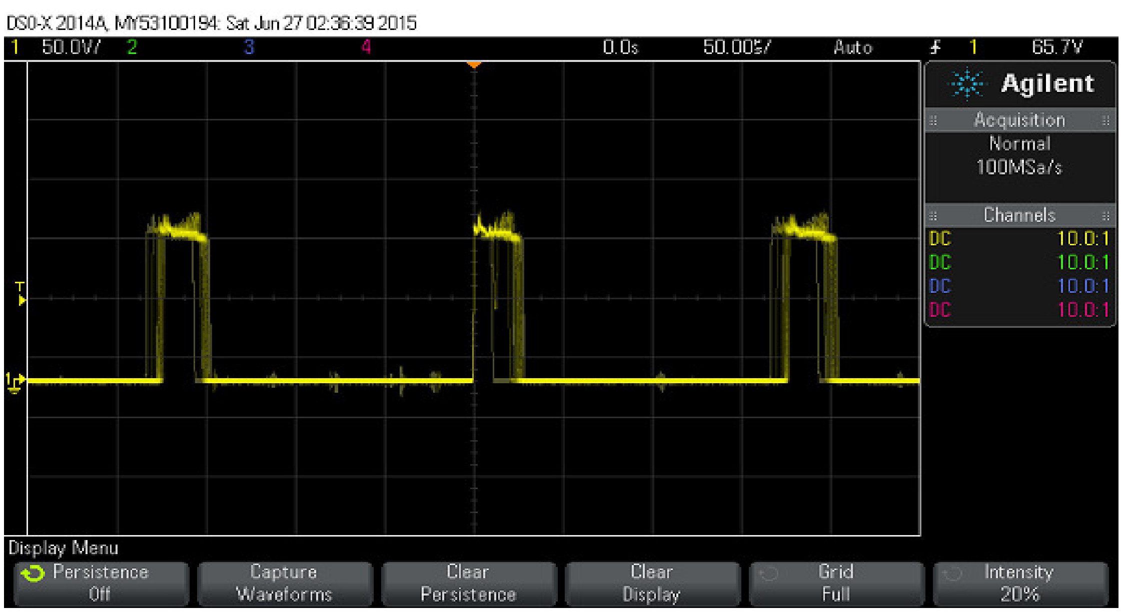


Fig 4.4(c) PWM control pulse with Set Temp = 50, Current Temp= 60

4.6 Conclusion

❖ The present arrangement is intended to control temperature with the help of micro controller. The software program and hardware assembly has been developed in-house, the sensor is successfully calibrated and the reading verified by operating ISO certified Environmental Test Cracking Resistance Industrial Temperature Controller and process temperature controller system, side-by-side from 20◦C to 74◦C. The complete calibration process was recorded live and uninterrupted for future reference. After the calibration process is complete, it was established that the system works with accuracy of +/- 0.5◦C. as compared to Ref setup.

❖ During system analysis, the entire setup was operated for three different setting, and with three different set point. The observations were tabulated in Table 4.3 (a), (b) and (c). The comparative observation is tabulated below.

	Current Temp = 70% of Set Temp	Current Temp = Set Temp	Remarks
Set Temp 50°C	Heater 1 = ON Heater 2 = OFF	Heater 1 = OFF Heater 2 = OFF	Controller could maintain Set point with Frequent switching of Heater
Set Temp 70°C	Heater 1 = ON Heater 2 = OFF	Heater 1 = OFF Heater 2 = OFF	Controller could maintain Set point with Frequent switching of Heater
Set Temp 95°C	Heater 1 = ON Heater 2 = OFF	Heater 1 = OFF Heater 2 = OFF	Controller could maintain Set point with Frequent switching of Heater

❖ From this table it was observed that, the controller disconnected power to Heater element -2, the moment current temperature reached 70% of the Set value. From here only Heating Element-1, was operational till the time operating temperature was not achieved. For the entire operating cycle one Heating element remained OFF for almost 30% of total time, thereby saving 50% Energy for 30% time. Moreover when the disturbance was less than 30% of the Set value, only one Heating Element was actuated till operating temperature is not achieved, therefore we were able to save, substantial amount of energy.

❖ Thermal system is usually described by first order system with dead time; therefore such system should ideally exhibit operating differential or thermal hysteresis which prevents the heater from frequent switching. This operating differential is considered to be the function of, process tank characteristics, process fluid characteristics, heat transmission rate to the sensor, thermal efficiency of Heater, and Heat exchange rate of Heat exchanger, etc. In the experimental setup, the rectangular tank is of 3 ltr capacity which is quite small. Generally indirect heating is used, but for this setup Heater uses process fluid i.e. Water, as resistive load for direct heating. Further metal enclosed RTD gives much faster response

.

❖ From observation table, it was noted that, the present experimental setup did not exhibit significant operating differential or thermal hysteresis, and Controller could maintain near to Set point with frequent switching of Heater element. This could indicate the very small or negligible presence of operating differential or thermal hysteresis. To validate the presence of operating differential in this system, the observations tabulated in Table 4.3 (a), (b) and (c), were analyzed and following time domain specification of first order system was calculated and tabulated.

Table 4.4 Time Domain Specification

Set Temperature	Time Domain Specification	Heater -1 ON (Time in minutes)	Heater -1 & 2 ON (Time in minutes)	Heater -1 & 2 and Controller ON (Time in minutes)
50 ◦C	Delay Time	3.01	2.52	1.47
	Rise Time	15.3	9.56	16.11
	Settling Time	22.5	12.58	19.45
70 ◦C	Delay Time	3.1	2.3	3.33
	Rise Time	24.59	13.04	16.08
	Settling Time	31.4	16.28	23.05
95 ◦C	Delay Time	3.14	2.3	2.28
	Rise Time	44.06	23.05	32.08
	Settling Time	51.58	30.07	39.57

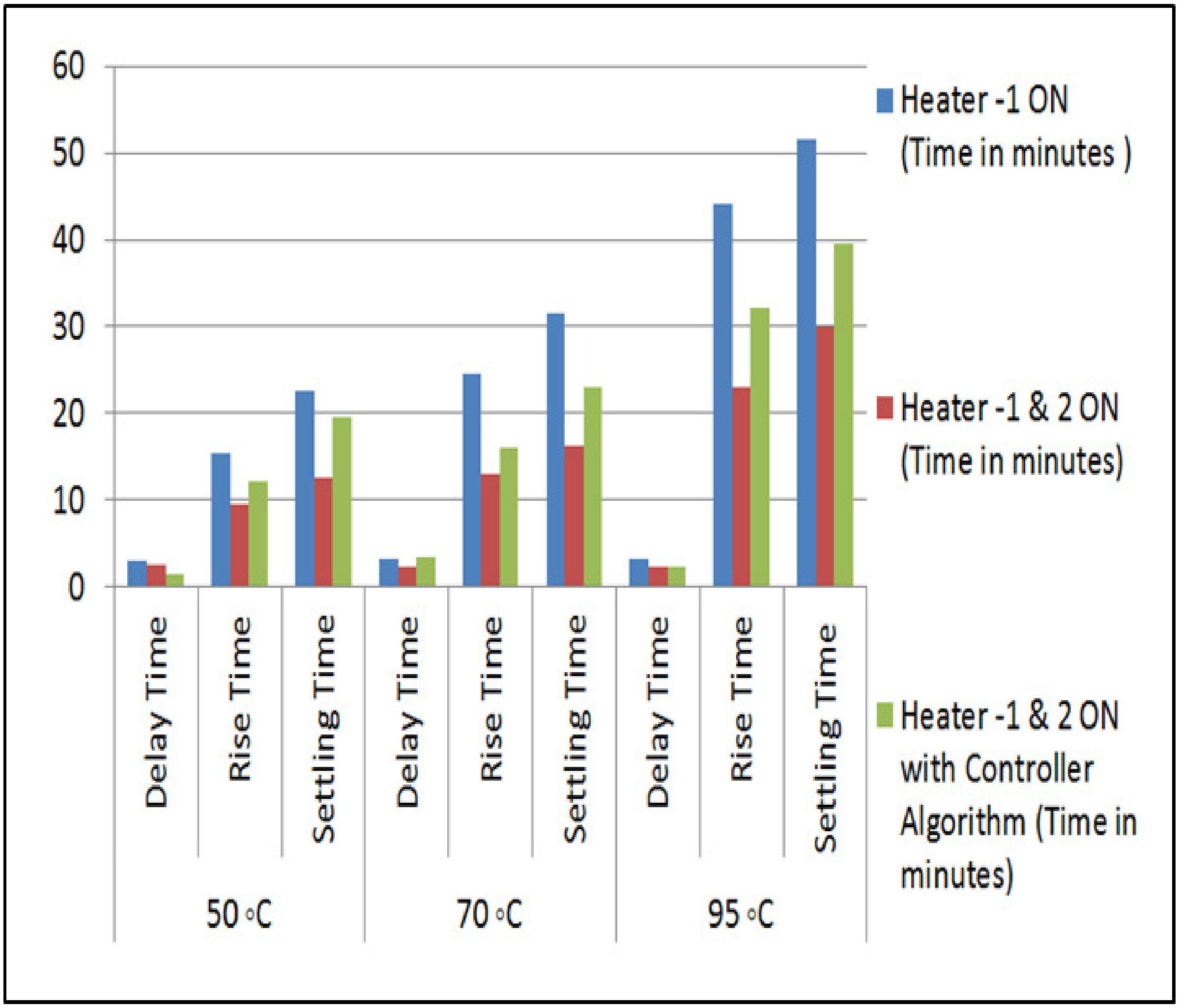


Fig. 4.5 Bar Chart for Time Domain Specifications at various set points

❖ From the time domain specification in Table 4.4, above Bar chart was drawn for further analysis. From the time domain specification and corresponding Bar chart based on experimental data, we could find the small presence of delay time and steady state error in the system. Therefore this thermal process system can be approximated by a stable first order system with very small time delay. Hence, whenever the experimental set-up was operated with a set point, it was able to achieve the desired operating temperature every time, further when the disturbance was introduced, the controller was able to regain its operating temperature.

Hence we can conclude by stating that following aim was successfully achieved.

- Design, Simulation, hardware implementation was successfully done
- Faithful conversion of sensor output, and its calibration was successfully verified
- Heating system was successfully split into multiple element type system.
- An Interactive ON-OFF Control strategy, and PWM control strategy was successfully designed, implemented, tested and validated.

Last but not least that, we were able to design a Low cost, Reliable, and interactive Control System with high energy efficiency which is the need of present scenario.

4.7 Future Aspect

The major focus of this Dissertation was to implement two basic and effective control strategies i.e. ON – OFF Control & PWM control strategy, however many other control strategies i.e. PID, Fuzzy logic, Genetic Algorithm, PSO, etc., are available for better control. Future course of study for the present arrangement may focus on implementing one or a combination of many of these control strategy with auto-tunning capability, so as to improve the system performance. Further Heating elements was split into two for analysis, and to achieve better energy efficiency, it may be spilt into multiple element system placed at various location of process vessel for further analysis, so as to achieve much better energy efficiency. Following few considerations must be made before extension of this system

- LCD Display resolution can be brought up to decimal value for more accuracy
- Inbuilt Timer circuit can be programmed to act as Event Counter for recording and counting the process duration for record purpose.
- Inbuilt Timer circuit can be programmed to act as Event Counter for controlling the process duration to reduce manual intervention in process system.
- Integration of more physical parameters (Pressure, Flow, Humidity etc.) in this system for multiple application range as ADC is still left with six spare analog input channel.
- 16 bit ADC may be considered for increasing the operating range of controller beyond 255◦C