Chapter 1

INTRODUCTION

1.1 Relevance

Agro-industry plays a crucial role in the industrialization process of developing countries. The sugar industry is second largest agro-industry in the world. In sugar manufacturing plants, there are various processes for the production of sugar. The juice clarification is the heart of sugar processing from sugarcane for white consumption sugar. Various clarifying agents are used such as MOL, SO_2 gas in this process [1]. The various existing designs of Sulphur burner in a plantation of white sugar factory suffer from a number of drawbacks including irregular SO_2 supplies, sublimation and incompatibility with automation. These at best are partially continuous and do not ensure supply of SO_2 gas in line with the throughput and process requirement. The sugar industry in India therefore has long been in search of a suitable design which is trouble-free and can ensure a continuous supply of SO_2 gas exactly as per process requirement.

Heat recovery of Sulphur burner in a sugar industry is an important problem both from environmental and economic points of view [2]. The combined heat and power system produces steam that provides heat to Sulphur burner where compressed air mixed with Sulphur and get SO_2 for sulphitation process which is useful for the transformation of raw sugar to white sugar. In existing system hot SO_2 (400-500^0 c) from Sulphur burner is cooled in a condenser and then transformed to the sulphitation process but in this system heat energy of SO_2 get wasted. Hence it is decided to implement heat recovery unit for Sulphur burner so that system will be economical

1.2 Background & Motivation

Agro industry with minimum energy consumption is the dream of the industrial sectors, governments and researchers. The energy consumption for mechanical heating forms a major share within the residential and commercial sectors. The use of mechanical heating requires complicated heat recovery systems that consume high grade energy. The demand for heat recovery equipment's is expected to rise in the future. This share is projected to increase in the future with an increase in the energy demand proportionate to industrial growth. Reduction in energy consumption for is the need of the hour.

1.3 Methodology

Methodology to achieve objectives is as follows.

- Initially, the literature survey was made by using paper published in the international journals like Mechanical Automation, Journal of control engineering, International journal of mechanical sciences, energy procedia etc. to understand various concepts related to automation & Heat recovery system
- The second phase will be a Design & Simulation of Automatic Control System. In this phase first to learn Automation Studio software, and creation of ladder logic for PLC and also simulate the design for various temperature sensors.
- The third phase will be simulation of heat exchanger of SO_2 gas tubes in ANSYS software and analyze the heat transfer effect on SO2 gas tubes for economic design of heat recovery system
- The last phase will be Result and conclusion. Comparison with previous system and getting results and conclusion and final dissertation report generation will be done

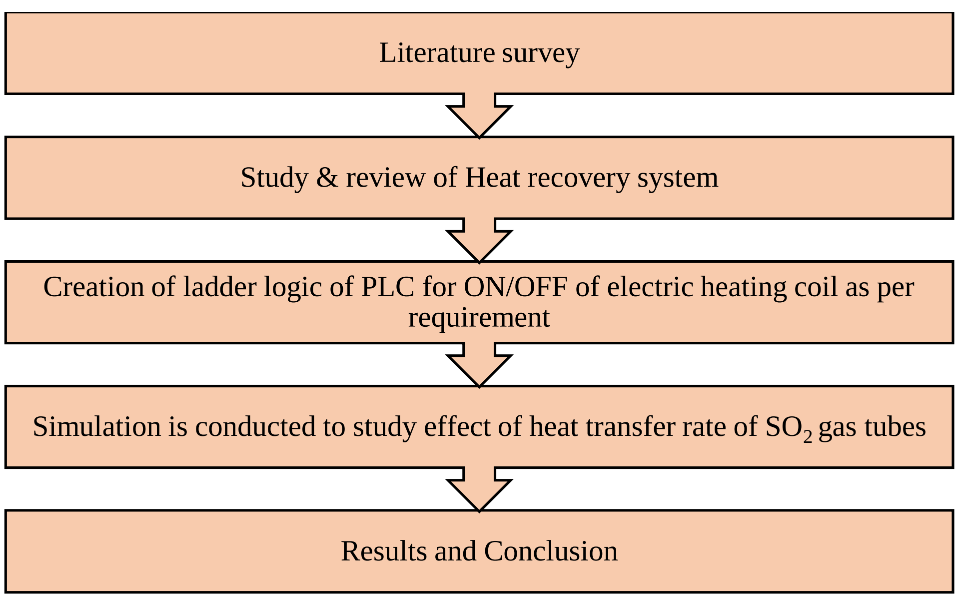


Fig. 1.1. Methodology

1.4 Layout of Report

Chapter 2 includes the literature review is made by using paper published in the international journals like Modern Automation, Journal of Energy Science, International journal of mechanical sciences, Renewable Energy, etc. Chapter 3 contains information about Waste Heat Recovery, Chapter 4 System Visualization, and their framework. Chapter 5 Design & Simulation of Automatic Control System, Chapter 6 Computational Modelling & Simulation, Chapter 7 Results and Discussion, Chapter 8 Conclusion & Future Scope, References**.**

1.5 Conclusion

From this chapter, studied that the overview of the project, Heat Recovery, Sulphitation process, Aim, and objective, Problem statement, Methodology, the scope of work and layout of the report.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The literature review helps to study the work done in the proposed dissertation area. In this chapter literature, the survey is made by using paper published in the international journals like Mechanical Automation, Journal of control engineering, International journal of mechanical sciences, energy procedia etc. to understand various concepts related to automation & Heat recovery system.

2.2 Literature Review

Rukkumani V et al. [1] Neutralizing pH value of sugarcane juice is the important factor to be considered in the sugar manufacturing process since it influences the quality of white sugar. The pH neutralization process is a complicated physical-chemistry process with strong characteristics of non-linearity and time-varying property. Hence there is no optimal solution to control the varying pH without mathematical modeling. For the systems whose mathematical model would be hard to derive, any alternative method could be used. Therefore, PID control and Fuzzy Logic Control was used for the control in clarifying process of sugar juice based on relevant error values of real-time sample data from sugar manufacturing unit. The pH being non-linear in nature, PID control was ineffective for steep changes. In such cases LabVIEW based fuzzy logic method was used to optimize and control the neutralized pH value in the clarifying process of sugar juice. The simulation results indicate that this method had the good control effect. This will build a good foundation for stabilising the clarifying process and enhancing the quality of the purified juice and lastly enhancing the quality of white sugar**.**

Sreyasi Bandyopadhyaya and Santanu Bandyopadhyay [2] Recovery of elemental sulfur from refinery gases is an important problem both from environmental and economic points of view. The major source of recovered sulfur is hydrogen sulphide, mainly produced as a byproduct in oil refineries as well as in natural gas processing plants. In sulfur recovery unit, elemental sulfur is produced via conventional or modified Claus process. Most Claus plants contain one non-catalytic conversion stage (the reactor furnace) followed by two or more catalytic conversion stages in series and can achieve 94-97% recovery of elemental sulfur. Important issues related to the design of the sulfur recovery process are discussed in this paper. The Claus reaction is highly exothermic, releasing a great amount of heat that can be recovered by generating steam in heat exchangers following the conversion stages. The hot combustion products from the furnace enter the waste heat boiler to generate high-pressure steam. Liquid sulfur is condensed in sulfur condensers while medium or low-pressure steam is generated. Unlike most of the shell and tube heat exchangers used in chemical process industry, design of heat recovery equipments in sulfur recovery units are unique. In this paper, special design features of these heat recovery equipments are discussed.

Sahoo A. et al. [3] Process industries generate large amount of heat that needs to be transferred. Shell and tube heat exchangers are extensively used in industries for utilization of the heat energy generated from different processes. For definite utilization of this energy, the temperatures of the hot and cold fluids passing through the heat exchanger should be monitored and controlled efficiently. A proper model of heat exchanger is required for the purpose of monitoring and control. The objective of the paper is to mathematically model the heat exchanger using system identification methods and experimentally evaluate the effectiveness of two PID controller tuning methods such as Internal Model Control (IMC) and relay auto-tuning for temperature control. The Auto Regressive–Moving-Average model with eXogenous inputs (ARMAX) model of the heat exchanger is obtained from the Pseudo Random Binary Signal (PRBS) experiment performed on the heat exchanger system. The outlet temperature of the cold fluid is considered as the controlled variable. Based on the obtained model, PID settings are designed using the two tuning methods, and the closed loop responses such as servo and regulatory are compared experimentally. It is seen from the experimental results that the IMC based controller shows better results than the relay auto tuning method in terms of time integral error

Remelia M. F. et al. [4] A different ways of waste heat recovery and conversion to electricity using a thermoelectric generator (TEG) assisted by heat pipes is introduced in this paper. The system consists of the TEG sandwiched between two heat pipes, one connected to the hot side of the TEG and the second one connected to the cold side of TEG. Experiments were conducted for a proof of concept of such system, and the experimental result was used to validate the theoretical model developed. It was found that both the experimental and the theoretical results share the same graphical trend in term of the rate of heat transfer and the effectiveness of heat exchanger.

Jaume Gasia et al. [5] In this paper, the influence of the addition of fins and the use of two different heat transfer fluids (water and a commercial silicone) have been experimentally tested and compared in four latent heat thermal energy storage systems, based on the shell-and-tube heat exchanger concept, using paraffin RT58 as phase change material. Three European institutions were involved under the framework of the MERITS project. A common approach (temperature and power profiles), and five different key performance indicators have been defined and used for the comparison: energy charged, average power, 5-min peak power, peak power to energy ratio, and time. For the same heat transfer fluid, results showed that finned designs (4.7e9.4 times more heat transfer surface) showed an improvement of up to 40%. On the contrary, for the same design, water (which has a specific heat 3 times higher and a thermal conductivity 4.9 times higher than silicone Syltherm 800), yielded results up to 44% higher.

Bhaskarwar T. V. et al. [6] The paper focuses on implementing the automation of a shell and tube type heat exchanger control system through number of tools such as PLC, SCADA, OPC, LabVIEW and internet. In this paper, PID method is implemented on Allen Bradley Micrologix-1200C PLC. The RSView-32 and LabVIEW as a SCADA has been used for graphically monitoring and controlling. Various performance parameters have been found out from the results comparison with MATLAB and PLC. The improvement in project data analysis is successfully done through the integration of PLC with LabVIEW. The PLC-SCADA LabVIEW control loop is implemented with the functionalities such as, set point modifications, data logging facility, real time data examination and exportation of data with Microsoft-Excel. For getting the signals from PLC to LabVIEW we have used enhanced conventional SCADA based control system with PLC as well as NI-OPC server extensively. The remote monitoring and control of process parameters is done using LabVIEW web publishing tool or remote panel manager. GSM (Global system for mobile communication) modem has been used for sending the

SMS by using LabVIEW (Short Messaging Service) on mobile, if any hazardous situation occurs. The integration of automation can be enhanced furthermore with android mobile application also with the help of LabVIEW dashboard application.

Zhongyi Su [7] carried out the case study on the waste energy utilization in industries at China. He has carried out the analysis on the different industrial processes and finding out huge data for used of organic waste again in the industries. The conclusion of the study shows that reusing the potential wastes for the production is feasible.

Liang-Chen Wang [8] carried out the analysis on the reusability of the energy from the exhaust gas calciner for production of carbon. In this study, the analysis of exhaust is done or production of carbon with used of calciner. The present study aims to develop this method and a combustion model. To demonstrate the correctness of the method and the model, based on the data collected from the working calciners, the energy utilization ratio of a calciner with power of 1250 kW is analyzed

Rakesh Jain [9] carried out the performance improvement of a boiler through waste heat recovery from an air conditioning unit. In this study, the heat from the air conditioning unit of the boiler is used for heating the feed water in boiler. The results of the study concluded that efficiency of Boiler will increase from 76.33% to 76.53%

Satish K. Maurya [10] carried out the work on the analytical study on the waste heat recovery Combined Ejector and Vapour Compression Refrigeration System. The key advantage of the combined plant is the Financial and economic aspects also justify the heat recovery as in most of the cases as in most of the cases returns in term of savings are much greater than the investment costs

The paper [11] [12] explained about methods for recovering the heat of flue gases from boilers using heat of vaporization are analyzed. High profitability of the developed thermal circuit involving deep recovery of the heat of flue gases and its storage, as well as good prospects for using it, are demonstrated by a real example in this paper. It concludes that Use of a comprehensive approach for attacking the problem of deeply recovering the heat of boiler flue gases, including heat of vaporization and involving consideration of all elements participating in the heat supply cycle, makes it possible not only to solve this problem technically, but also to optimize the parameters of coolant.

2.3 Literature gap

Researchers have studied various method of automation control as well as various heat recovery systems for small scale agro industries such as PH control, Clause reaction by using heat recovery method etc. From literature it is observed that various type of automation and heat recovery system are used in industries. These systems have some of its advantages as well as disadvantages. Therefore, some of researchers have studied the different heat exchanger to find out the ideal heat transfer which has better mechanical and thermal properties than already available heat recovery systems.

2.4 Aim and Objectives

Aim- Development of automatic control system & performance analysis of heat recovery system in SO_2 gas generation process

Objectives:

- To summarize various problems associated with SO_2 gas tubes of heat recovery system.
- To create a proper program for PLC in order to perform an automatic operation for heat recovery system.
- Convective heat transfer analysis to find out heat transfer rate of SO2 gas tubes in the heat exchanger.
- Performance analysis of heat recovery system.

2.5 Closure

From literature it is observed that, there are various types of automation which are commonly used in heat recovery applications. Also, some authors studied the different combinations of heat exchanger to get their mechanical as well as thermal properties to find out the heat transfer. From literature it is also observed that, there are various experimental methods to find out the heat transfer.

From the review of literature presented above, the following major conclusions were arrived at:

i) Heat transfer enhancement techniques are widely applied in industries to obtain the more compact heat exchanger, a lower operating cost and energy savings.

ii) Among many heat transfer enhancement techniques, utilization of Shell & Tube Heat Exchanger is promising method. This approach possesses not only an effective heat transfer enhancement but also the advantage of a low cost and an ease of installation.

iii) The Shell & Tube Heat Exchanger tape generates the swirl flow in the tube which improves higher flow velocity are directly responsible for the improvement of heat transfer within heat exchanger.

Chapter 3

WASTE HEAT RECOVERY

3.1 Introduction

In this era, the continuously increased fossil fuel consumption by human's daily life and industrial production has caused many environmental problems such as global warming, atmospheric pollution, ozone depletion and so on [04]. For these reasons, energy savings has become one of the main issues that governments and researchers all over the world have to face. Therefore, the need to introduce new energy conversion technologies, able to generate power without causing environmental pollution, has increased.

Energy efficiency in the sugar industry is becoming an increasingly important issue due to the rising costs of both electricity and fossil fuel resources, as well as the tough targets for the reduction in greenhouse gas emissions outlined in the Climate Change Act 2008. A significant amount of research has been done on the proactive approach to improve energy efficiency optimization in manufacturing; however, reactive approach of energy minimization such as recovery and utilization of waste energy back into the main energy supply of production facilities should also be emphasized.

3.2 Waste heat recovery

Waste heat is defined as heat which is rejected from the process at a temperature above the ambient temperature to permit the extraction of additional useful energy from it. The recovery of waste heat is the most beneficial single energy conservation technique which can significantly help to conserve fuel and bring about substantial cost reduction in energy-intensive industries [09]. Waste heat is the heat which is produced in a process by combustion of fuel or exothermic chemical reaction and then ejected into the environment even though it can still be utilized for some useful and economic purpose. In most general case, waste heat is the energy associated with the waste streams of air, gases and liquid leaving the boundaries of a plant, section or building and lost to the environment [12]. The strategy of recovery of this heat not only depends on the temperature of waste heat sources but also on the economics involved in the technology used. Even 1% energy saving in industries mean saving a lot of money.

Methods of utilization of waste heat:

- Direct Utilization: For drying or process heating
- Energy Cascading
- Cogeneration
- Recuperators: Shell and Tube, plate, heat exchangers
- Regenerators: Stationary or rotating type
- Waste Heat Boilers

3.3 Factors affecting waste heat recovery system

Following parameters allow for analysis of the quality and quantity of the stream and also provide insight into possible materials/design limitations. For example, corrosion of heat transfer media is of considerable concern in waste heat recovery, even when the quality and quantity of the stream is acceptable [13].

3.3.1 Heat Quantity & Quality

The quantity, or heat content, is a measure of how much energy is contained in a waste heat stream, while quality is a measure of the usefulness of the waste heat.

3.3.2 Waste Stream Composition

Although chemical compositions do not directly influence the quality or quantity of the available heat (unless it has some fuel value), the composition of the stream affects the recovery process and material selection. The composition and phase of waste heat streams will determine factors such as thermal conductivity and heat capacity, which will impact heat exchanger effectiveness [13].

3.3.3 Minimum Allowable Temperature:

The minimum allowable temperature for waste streams is often closely connected with material corrosion problems. Minimum exhaust temperatures may also be constrained by process-related chemicals in the exhaust stream; for example, sulfates in exhaust gases from glass melting furnaces will deposit on heat exchanger surfaces at temperatures below about 510ºF [270ºC].

Table 1.1. waste heat source and quality

Sr.no	Source	Quality
1	Heat in flue gases	The higher the temperature, the greater the potential value for heat recovery
2	Heat in vapour streams.	As above but when condensed, latent heat also recoverable
3	Convective and radiant heat loses from exterior of equipment	Low grade – if collected may be used for space heating or air preheat
4	Heat losses in cooling water	Low grade – useful gains if heat is exchanged with incoming fresh water
5	Heat stored in products leaving the process	Quality depends upon temperature
6	Heat in gaseous and liquid effluents leaving process.	Poor if heavily contaminated and thus requiring alloy heat exchanger.

3.4 Benefits of heat recovery system

Benefits of 'waste heat recovery' can be broadly classified into two categories:

3.4.1 Direct Benefits:

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by a reduction in the utility consumption & costs, and process cost.

3.4.2 Indirect Benefits:

1) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc., releasing to the atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.
2) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to a reduction in the flue gas produced. This results in a reduction in

equipment sizes of all flue gas handling equipment such as fans, stacks, ducts, burners, etc.

3) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of a reduction in auxiliary energy consumption like electricity for fans, pumps etc.

3.5 Waste heat recovery technologies

Methods for waste heat recovery include transferring heat between gases and/or liquids (e.g., combustion air preheating and boiler feed-water preheating), transferring heat to the load entering furnaces (e.g., batch/cullet preheating in glass furnaces), generating mechanical and/or electrical power, or using waste heat with a heat pump for heating or cooling facilities.

3.6 Challenges

Today the demand for energy is increasing tremendously, but available energy lacks in supply. Hence, there is no option for proper and efficient utilization and conservation of energy [14]. There are many technologies for waste heat recovery, but it is observed that it suffers many problems.

- Waste heat recovery systems are frequently implemented but constrained by factors such as temperature limits and costs of recovery equipment.
- Most unrecovered waste heat is at low temperatures.
- There are certain industrial subsectors where heat recovery is less common, due to factors such as heat source’s chemical composition and the economies of scale required for recovery.
- Losses from non-traditional waste heat sources are difficult to recover but significant.

3.7 Closure

From Waste Heat Recovery chapter, it is studied that, various waste heat recovery systems and their implementation in industries, factors affecting to the waste heat recovery system, Benefits and various heat recovery technologies.

Chapter 4

SYSTEM VISUALIZATION

4.1 Introduction

In this chapter, existing and proposed waste heat recovery is introduced through system thinking methods and establish a system boundary for a better waste heat processing solution to be architected. Much work has been carried out for obtaining usefulness of waste heat in sugar industry. The work proposed in this study is to obtain useful heat from the waste of Sulphur burner's heat.

4.2 Existing system

Heat recovery of Sulphur burner in sugar industry is an important problem both from environmental and economic points of view. The combined heat and power system produces steam that provides heat to Sulphur burner where compressed air mixed with Sulphur and get SO_2 for sulphitation process which is useful for transformation of raw sugar to white sugar [15]. In existing system hot SO_2 (400-500^0 c) from Sulphur burner is cooled in condenser and then transformed to the sulphitation process but in this system heat energy of SO_2 get wasted. Existing system for SO_2 gas generation process is as shown in Fig. 4.1.

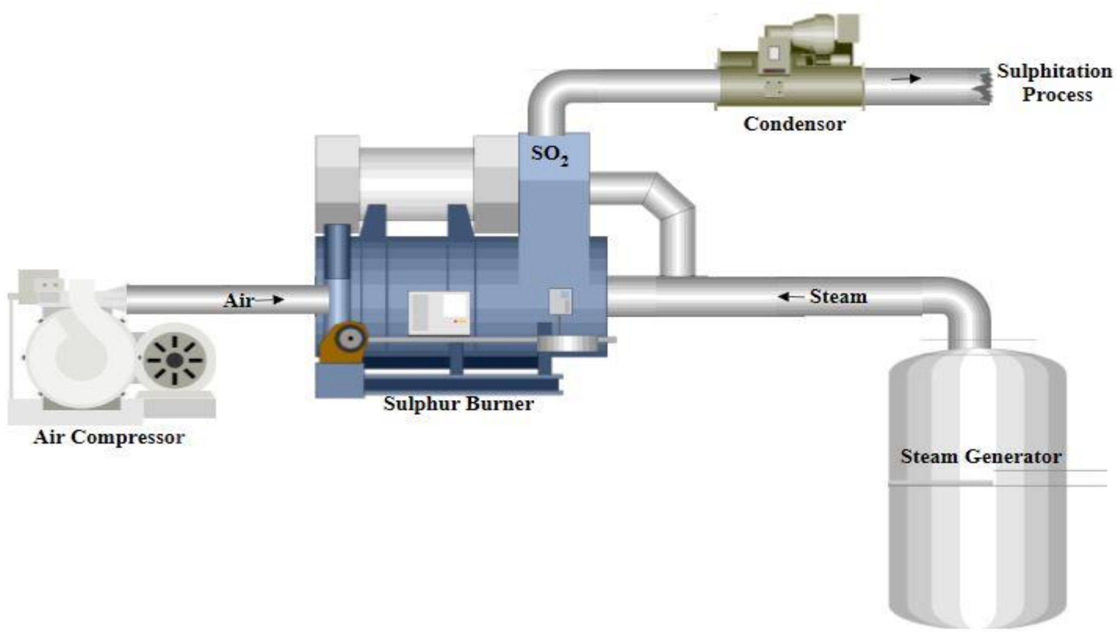


Fig. 4.1. Existing System for SO_2 gas generation process.

4.3 Proposed system

In existing system heat of SO_2 gas is wasted through condenser. Hence proposed system will focus on using waste heat recovery subsystem in SO_2 gas generation process. In proposed system the heat of SO_2 gas before giving to sulphitation process is passed through steam generator where heat will exchange, and some amount of steam will generate with the help of waste heat. Hence required amount of heat for steam generation will be less. Proposed system for SO_2 gas generation process is as shown in Fig. 4.2.

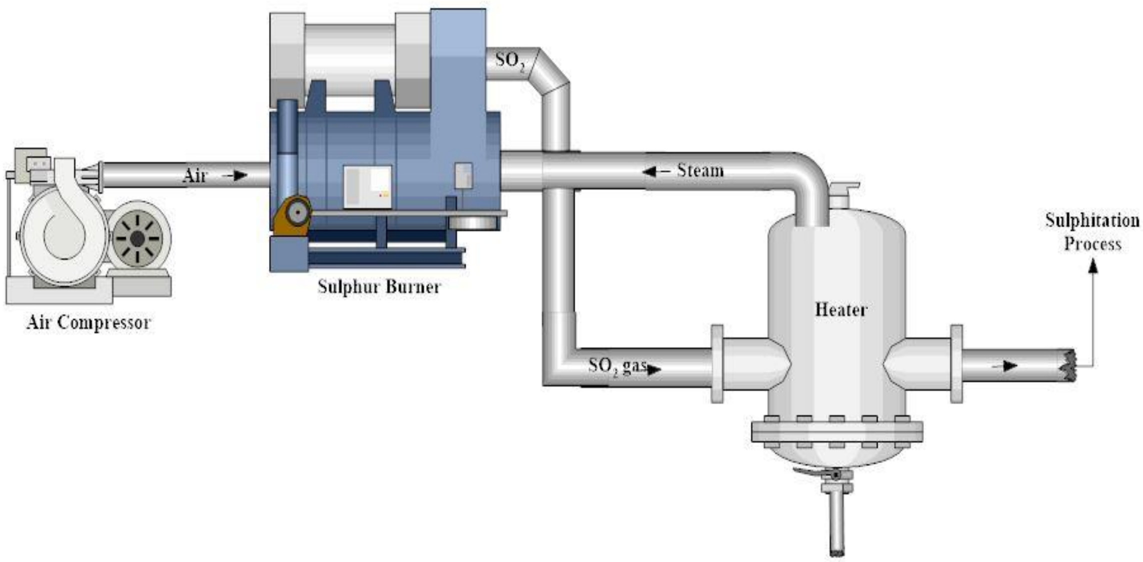


Fig. 4.2. Proposed system for SO_2 gas generation process

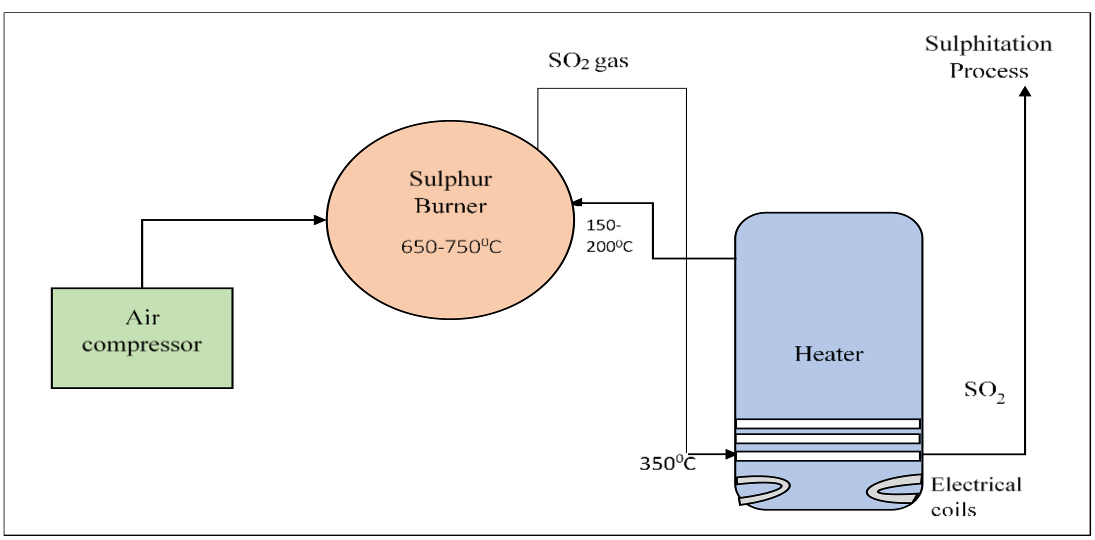


Fig. 4.3. Block diagram of heat recovery system in SO_2 gas generation process

For this proposed system there must be automatic temperature control system for performing ON or OFF heating coils operation. For performing automatic temperature control system there should be requirement of programable logic control. The design and simulation of automatic control system is performed in Automation Studio software.

4.4 Closure

From System Visualization chapter, it is clear the view of SO_2 gas generation process. From this chapter it is conclude that proposed system for SO_2 gas generation process requires automation for the heating coils and also shell & tube heat exchanger as heat recovery system.

Chapter 5

DESIGN & SIMULATION OF AUTOMATIC CONTROL SYSTEM

5.1 Introduction

This chapter presents simulation of automatic temperature control system in Automation Studio software. It covers simulation software selection process, PLC ladder logic in different conditions for temperature control system.

5.2 Automation Studio 3.05 software

Automation Studio is the all in one innovative software solution to increase engineering productivity. Automation Studio is a circuit design, simulation and project documentation software for fluid power systems and electrical projects conceived by Famic Technologies Inc [15]. Features of Automation Studio is as shown in Fig. 5.1. It is used for CAD, maintenance, and training purposes. Mainly used by engineers, trainers, and service and maintenance personnel. Automation Studio can be applied in the design, training and troubleshooting of hydraulics, pneumatics, HMI, and electrical control systems.

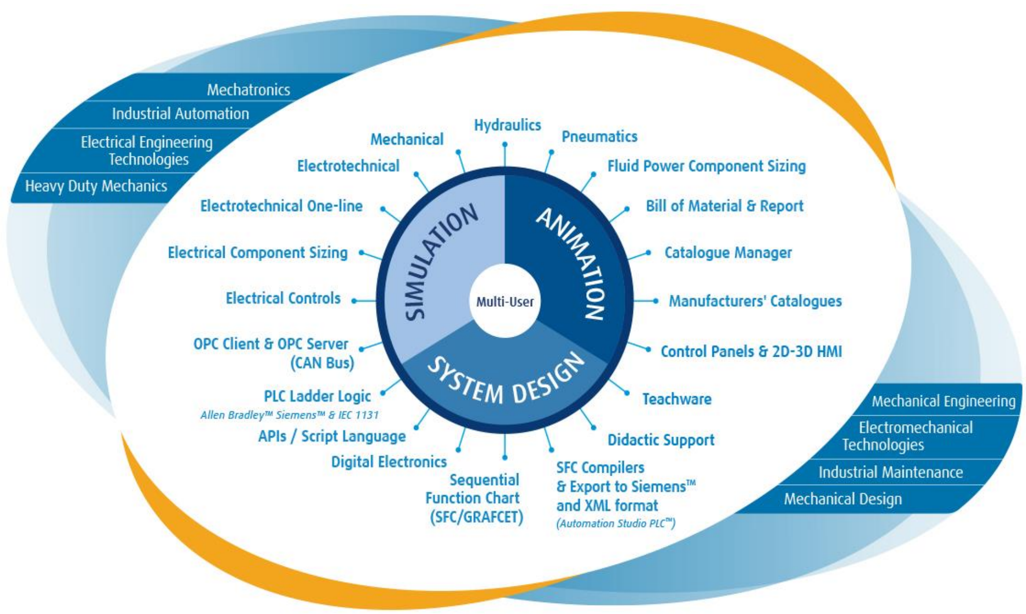


Fig. 5.1. Features of Automation Studio software [15]

5.3 Automatic temperature control system

Industrial controllers are made up of many specific automated processes, called control loops. The term “loop” derives from the ladder logic that is widely used in these systems. A controller device, such as a PLC, is programmed with specific logic. The PLC cycles through its various inputs, applying the logic to adjust outputs, and then starts over scanning the inputs [16]. This repetitive control action is necessary in order to perform a specific function. This cycle or “loop” automates that function. In a closed loop, the output of the process affects the inputs, fully automating the process.

5.4 Temperature sensors

Temperature sensors are located separately at the sensing point inside or near the process and outputs are used for further conditioning and converting to standard output, i.e., 4-20 mA DC, and/or superimposed digitized signal.

5.4.1 Types of Temperature sensors

There are various types of sensors/elements, namely RTDs, THCs, and thermistors, the application of which depends mainly on the process temperature

1) Bimetallic Thermostat

A simple form of temperature sensor that can be used to provide an on/off signal when a particular temperature is reached is the bimetal element. This consists of two strips of different metals. The two metals have different coefficients of expansion. Thus, when the temperature of the bimetal strips increases, the strip curves in order that one of the metals can expand more than the other [13]. The higher expansion metal is on the outside of the curve. As the strip cools, the bending effect is reversed. This movement of the strip can be used to make or break electrical contacts and hence, at some particular temperature, give an on/off current in an electrical circuit. The device is not very accurate but is commonly used in domestic central heating thermostats because it is a very simple, robust device.

2) Resistive Temperature Detector (RTD)

The electrical resistance of metals or semiconductors changes with temperature. In the case of a metal, the ones most commonly used are platinum, nickel, or nickel alloys. Such detectors can be used as one arm of a Wheatstone bridge and the output of the bridge taken as a measure of the temperature [18].

3) Thermocouple

The thermocouple consists essentially of two dissimilar wires, A and B, forming a junction. When the junction is heated so that it is at a higher temperature than the other junctions in the circuit, which remain at a constant cold temperature, an EMF is produced that is related to the hot junction temperature [18]. The thermocouple voltage is small and needs amplification before it can be fed to the analog channel input of a PLC. The amplification and compensation, together with filters to reduce the effect of interference from the mains supply, are often combined in a signal processing unit. Thermocouples have the advantages of being able to sense the temperature at almost any point, ruggedness, and being able to operate over a large temperature range.

5.5 Problem Statement

A water heater is programmed to heat water to a set point of 90°C. An electric heating coil is energized to heat the water, and the water temperature is measured and fed back as an input into the control process. When 90°C is reached, the heater turns off the heating coil, and continues to monitor the temperature until it drops below the set point.

The basic algorithm might be considered to be:

```
IF temperature below set value
THEN
    DO switch on heater
ELSE
    DO switch off heater
ENDIF
```

Basic algorithm [19]

5.5.1 Solution 1:

Using bimetallic thermostat as a temperature sensor.

What is required to give the input to a PLC is a sensor-signal conditioner arrangement that will give no input when the temperature is below the required temperature and an input when it is above. One such device is the bimetallic thermostat. A bimetallic strip consists of two different metals strips of the same length bonded together. Because the metals have different coefficients of expansion, when the temperature increases the composite strip bends into a curve with the higher coefficient metal on the outside of the curve. In Fig 5.2 the movement may be used to open or close electrical contacts and so operate as a temperature-dependent switch. If the actual temperature is above the required temperature, the bimetallic strip is in an off position and there is no circuit voltage output. If the actual temperature is below the required temperature, the bimetallic strip moves into the on position and the voltage is switched on, so there is an output. The thermostat output is thus just off or on and the input to the PLC is no voltage /a voltage as shown in Fig. 5.3

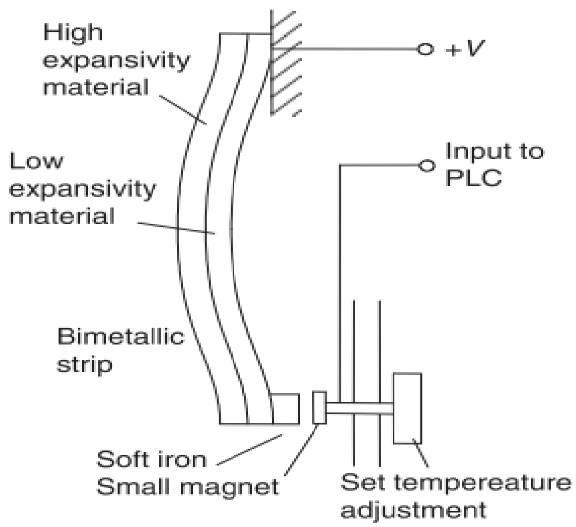


Fig. 5.2. Bimetallic Thermostat [21]

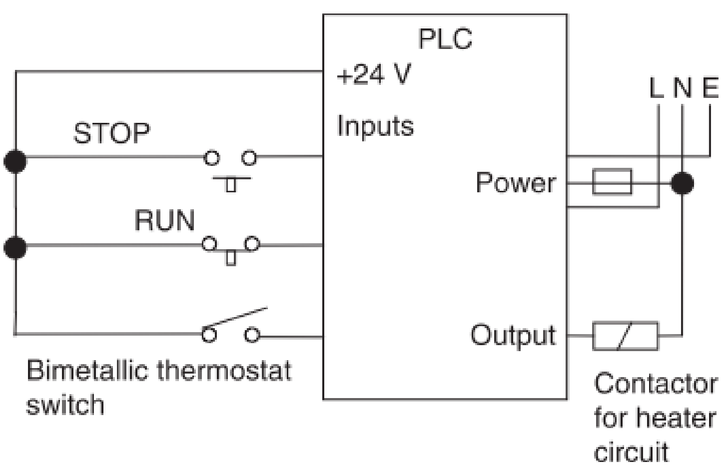
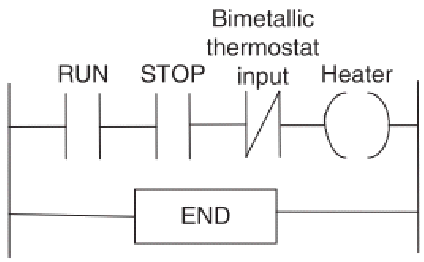
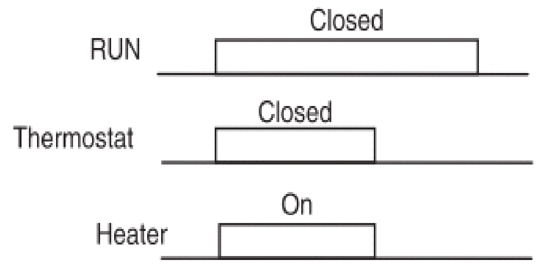


Fig. 5.3. Thermostat PLC Arrangement



Ladder Logic



Timing Diagram

Fig. 5.4. Thermostat PLC ladder logic and timing diagram

5.5.2 Solution 2:

By using Thermistor or Thermocouple

When connected in an appropriate circuit, the sensor will give a suitable voltage signal related to the temperature. For example, with a thermistor, its resistance changes when the temperature changes, and this can be converted into a voltage signal by using a potential divider circuit [21].

This voltage output from the thermistor can be compared, using an operational amplifier, with the voltage set for the required temperature so that a high-output signal is given when the temperature is above the required temperature and a low-output signal when it is below, or vice versa. Operational amplifiers are widely used to give on/off signals based on the relative value of two input signals—a set-point voltage and a sensor voltage One signal is connected to the noninverting terminal and the other to the inverting terminal. The operational amplifier determines whether the signal to the inverting terminal is above or below that of the noninverting terminal.

Thus we can arrange that when the temperature falls from above the required temperature to below it, the output signal switches from a high to a low value. The PLC can then be programmed to give an output when there is a low input, and this output can be used to switch on the heater and switch off the heater when the input goes high.

Figure 5.5 shows the arrangement that might be used and the basic elements of a ladder program. The input from the operational amplifier has been connected to the input port. This input has contacts that are normally closed. When the input goes high, the contacts open. The output to the heater is taken from the output port. Thus there is an output when the input from the sensor is low and no output when the input is high as shown in Fig 5.6.

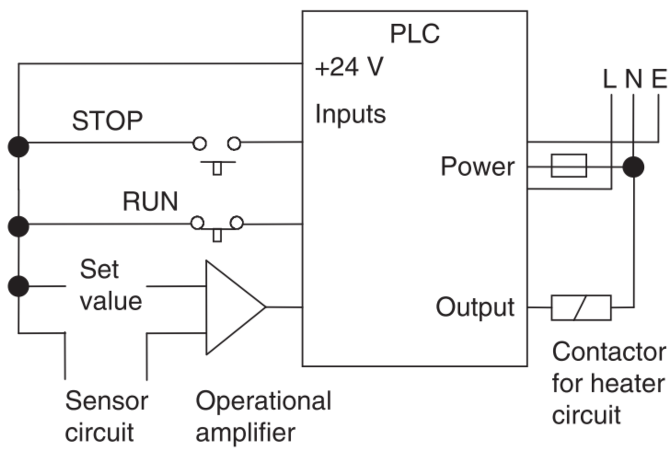
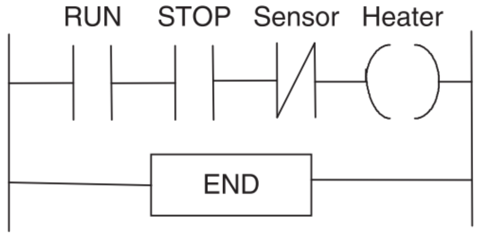
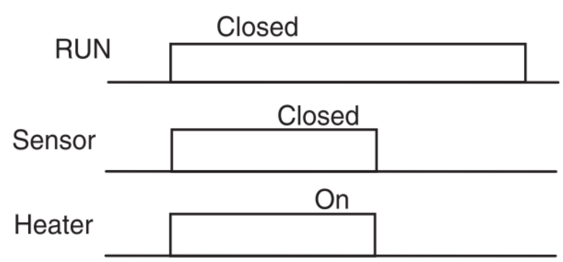


Fig. 5.5. Thermocouple PLC Arrangement



Ladder Logic



Timing Diagram

Fig. 5.6. Thermocouple PLC ladder logic & timing diagram

5.6 Design and Simulation of automatic temperature control system.

5.6.1 Components used for project work

- **Switch:** Switches are the basic components of PLC. There are two types of switches are available in plc.

i)Digital switch (ON/OFF).

ii) Analog switch (continuous varying).

(i) Digital switch: There are two types of states are available under digital type i.e NO (normally open) or NC (normally closed).

Normally open: A switch is said to be NORMALLY OPEN when it doesn't allow current to pass till it is off. When the switch is made on by applying appropriate voltage, in case of PLC, it allows current to pass and actuate the coil or component attached to it. NO switches are used when we required no current till we made the switch ON and again it can be made OFF by removing voltage source from the respective switch. A NO switch is represented as Fig. 5.7 [23].

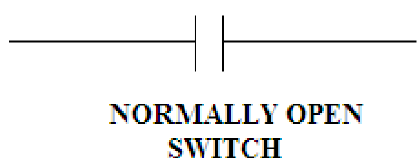


Fig. 5.7. NO switch

Normally closed:A switch is said to be NORMALLY CLOSED when at off condition (i.e when voltage is not applied to the switch in PLC) is act as closed that is it allows the current to flow through it. When the voltage is applied to the switch it becomes open circuited. circuit symbol is as Fig. 5.8

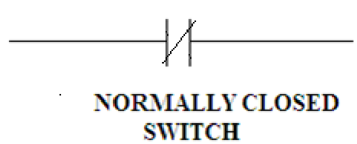


Fig. 5.8. NC switch

In PLC point of view, the transition from ON to OFF or OFF to ON is done by applying 24V DC to the respective switch. The following diagram shows the switches ON and OFF conditions

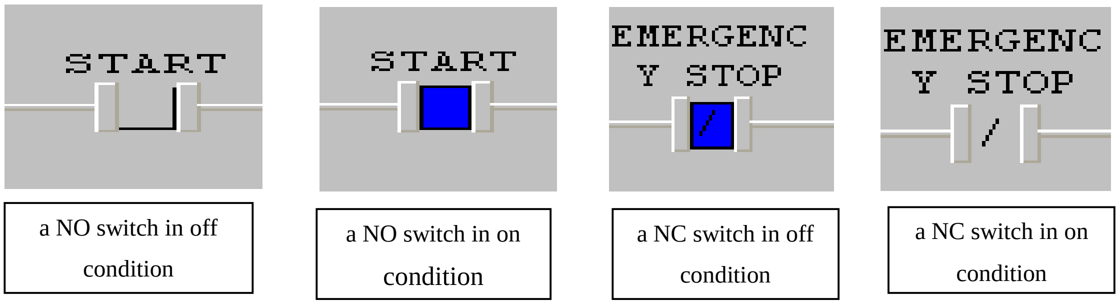


Fig. 5.9. Various conditions of switches

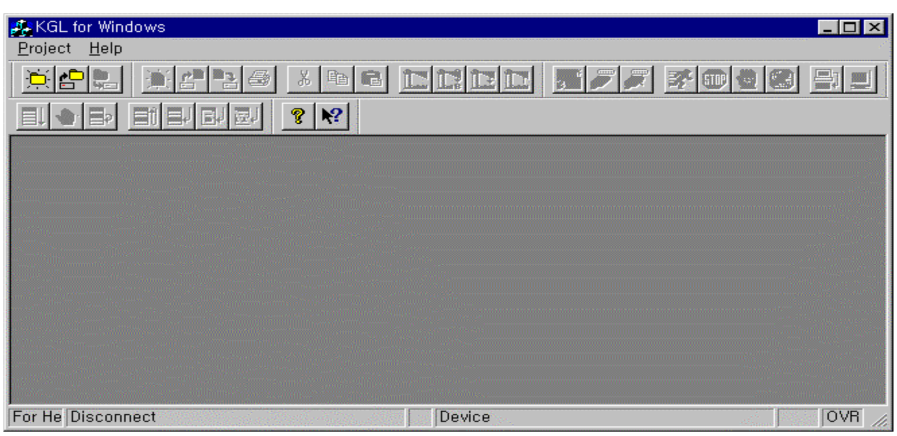
(ii) Analog switch: As the name indicates the analog switches are continuously varying switches. These switches are the combination of sensor output and comparator circuit. Analog switches are used when a device (heater, valve) has to be turned on or off with respect to the set value of continuously varying parameters (temperature, pressure etc.).

- **Adjusting the set point:** The range of analog input variable linearly varies from 0-4000 units, in which for voltage change it varies from 0-10 volts and in case of current circuit it varies from 0-20mA. 4000 is analogous to 10 volts in voltage circuit and 20mA in case of a current circuit [23].

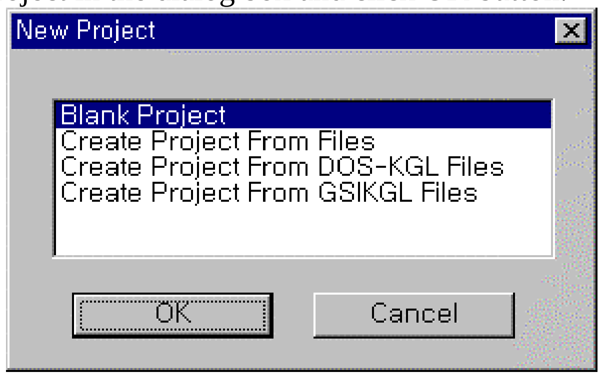
5.6.2 Step to open a project

Different brand of PLC uses different software. As we are using LG-K120S PLC and Automation studio software.

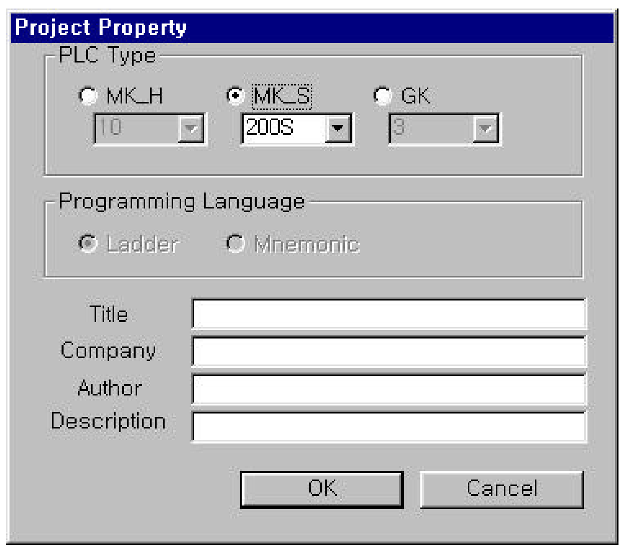
Opening a project



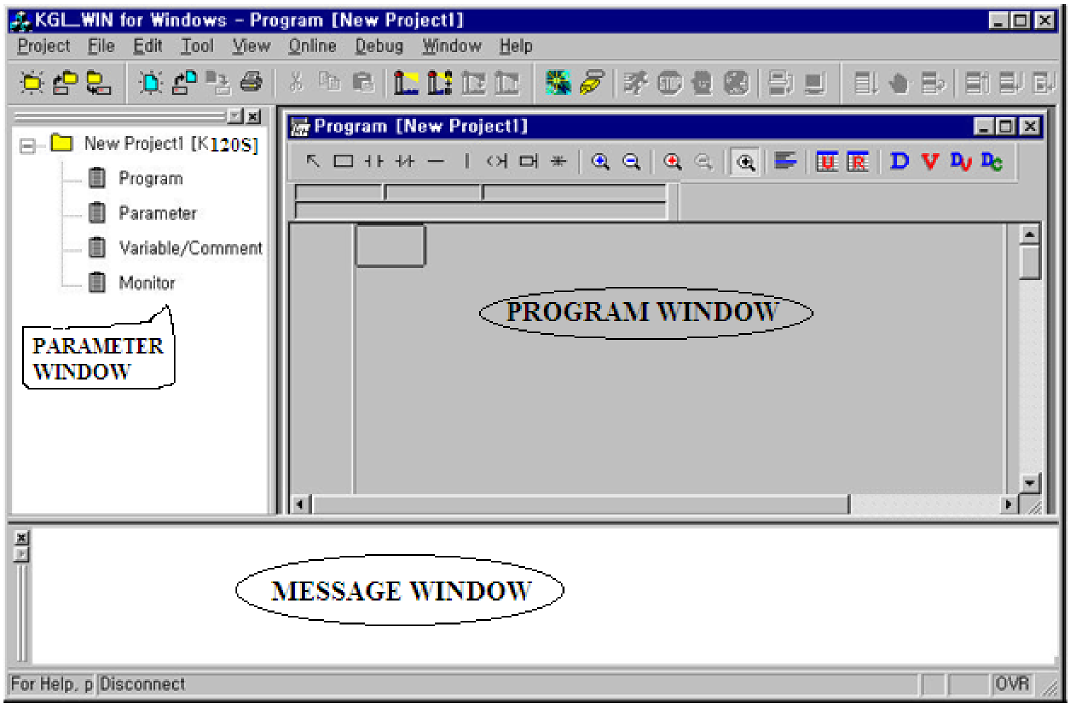
- Double-click Automation_Studio3.0.5.exe file to run it.
- The Start-up Screen will be shown as before.
- To create a new project, select Project- New Project…  in the Start-up Screen.
- Select Blank Project in the dialog box and click OK button.



- In the following dialog box will appear, type in PLC Type, Programming Language, Title, Company, Author and Description

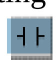


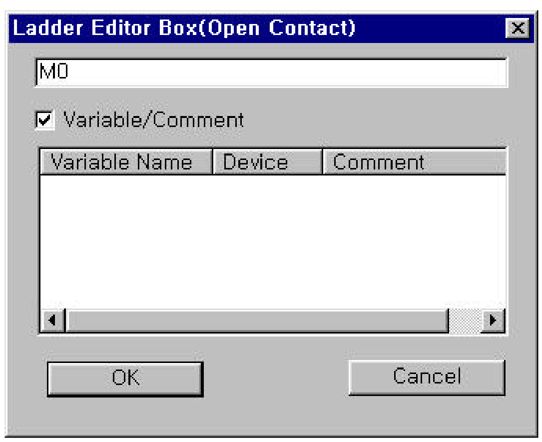
- Select MK_S and 120S in the above dialog box.
- Click OK button. Then, Project, Message and Program Windows are displayed automatically.



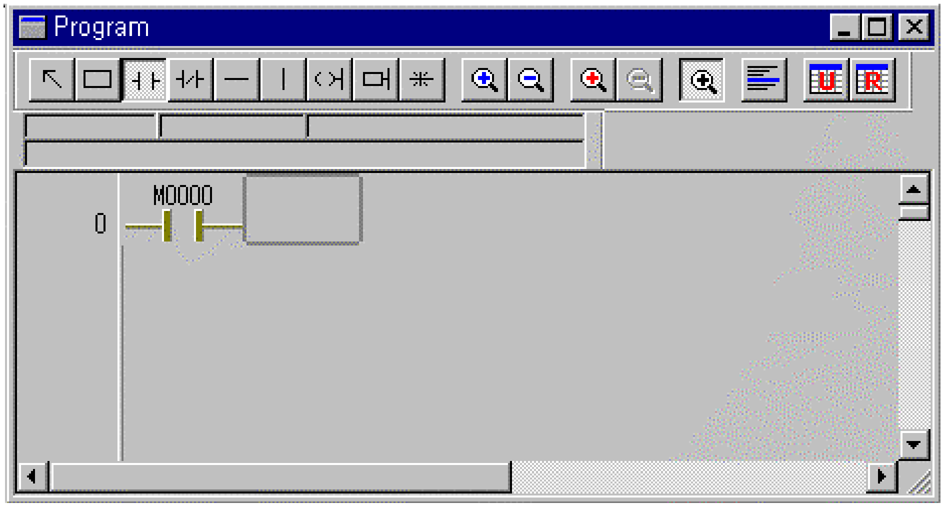
5.6.3 Creating a ladder program

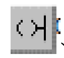
In this heading we discuss how to create a program, so we only concentrate on program window.

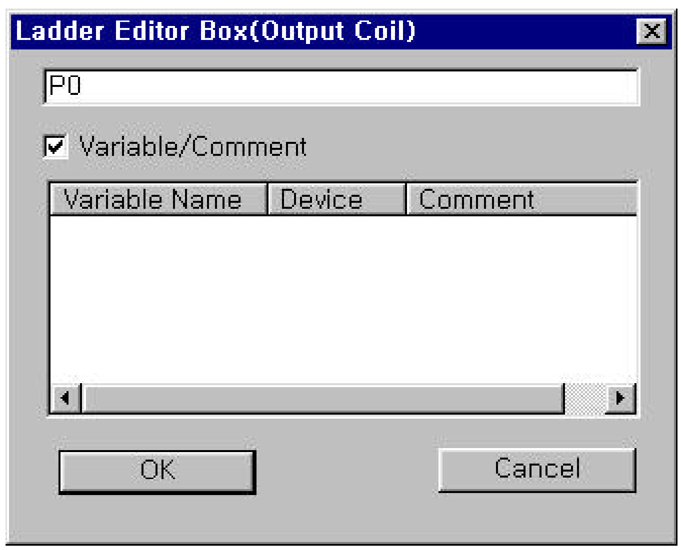
- A tool bar and a view bar are present at the top of the program window to easy access to the parameters.
- After selecting the Normally Open Contact icon in the Ladder Tool Bar, Move the  cursor to the place to insert the contact.



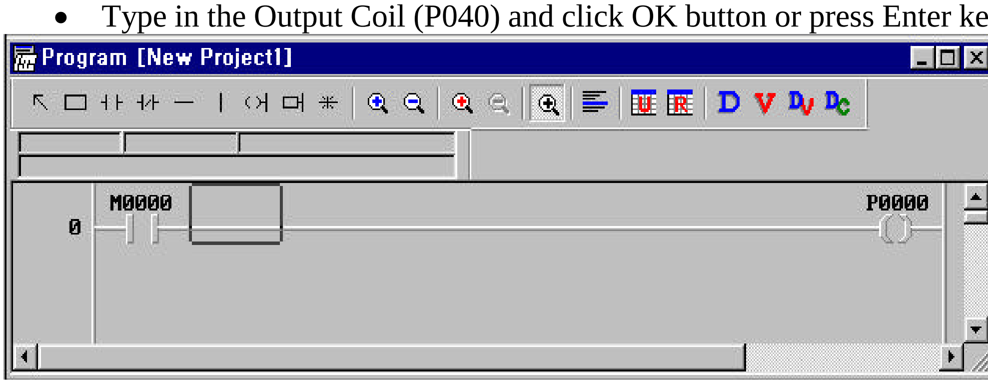
- Click the left button of the mouse or press Enter key, then the contact input dialog box appears.
- Type in the contact name(M0000) you want to insert and click OK button or press Enter key.



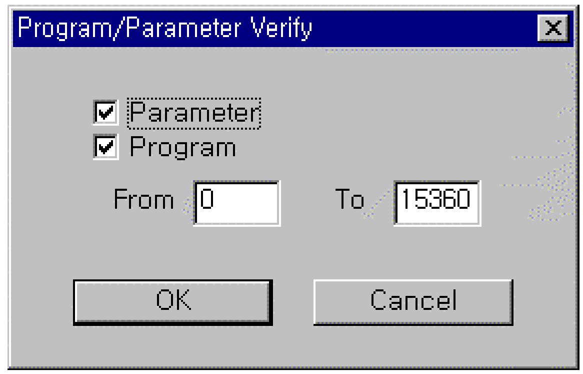
- Select the Output Coil () icon in the Ladder Tool Bar and move the cursor to the next column of M000.
- Click the mouse button or press Enter key.



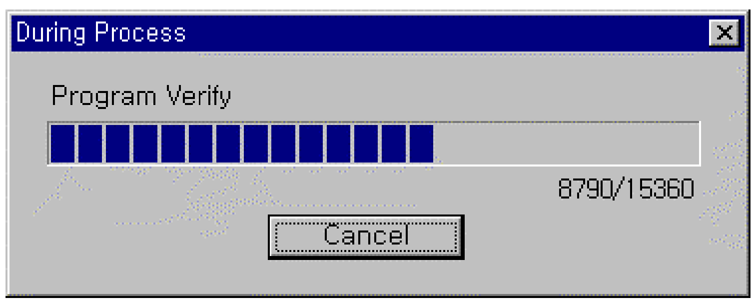
- Type in the Output Coil (P040) and click OK button or press Enter key.



- After inserting required switches and coil an ‘END’ command has to be inserted this shows the end of the program.
- ‘END’ is inserted from the applied instruction.
- Select Run () Mode in Online - Change Mode menu.
- To examine the program and parameters stored in PLC are the same one of KGLWIN, select Online-Verify menu. Then,the following message box will appear. Click OK button to verify.



- Click OK button to start verifying. If you want to stop verifying, click Cancel button.



- Connect, Download, Run and Monitor Start above Functions at one time by clicking the Connect+Download+Run+Monitor Start button in the Pull-down menu. Then following box will appear.

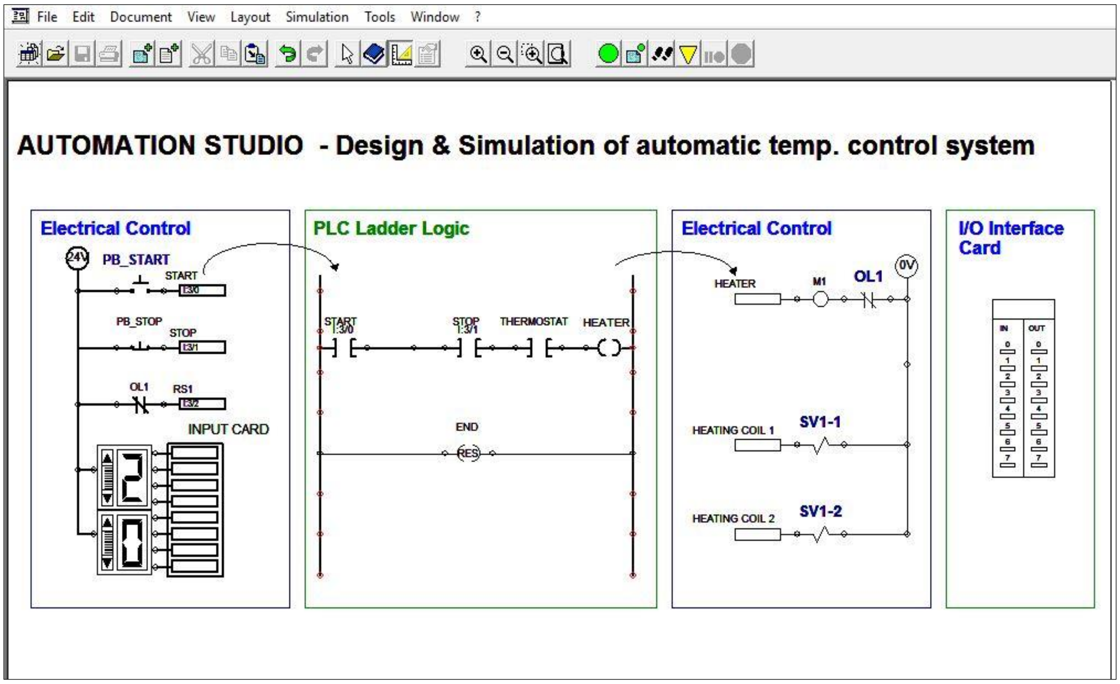


Fig. 5.10. System design of control system

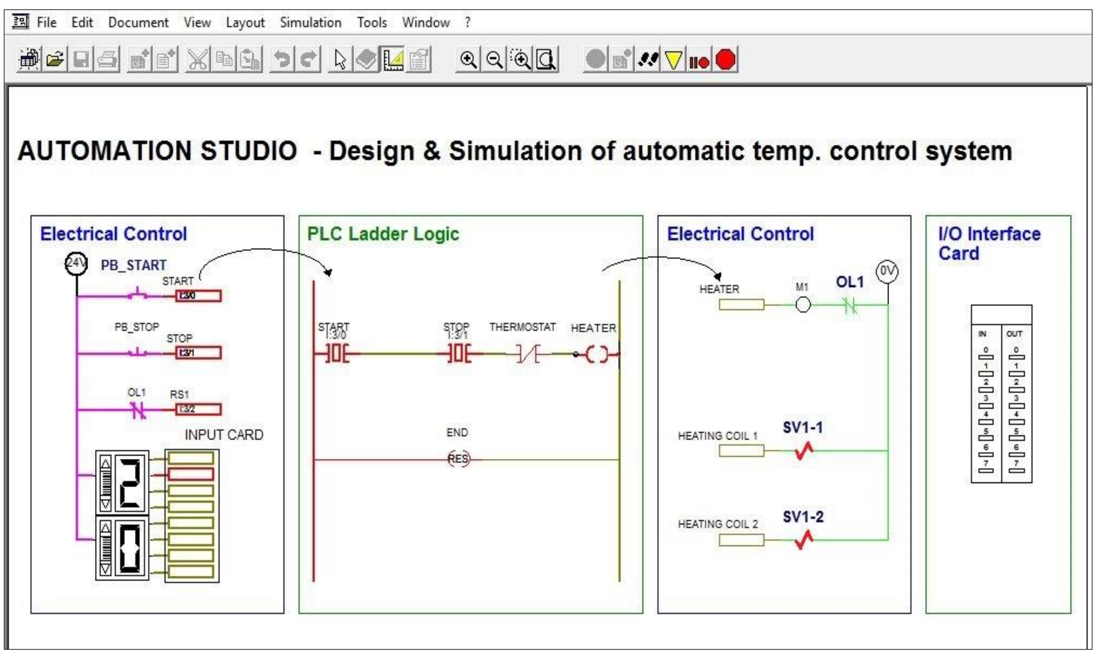


Fig. 5.11. Simulation for Heater ON system

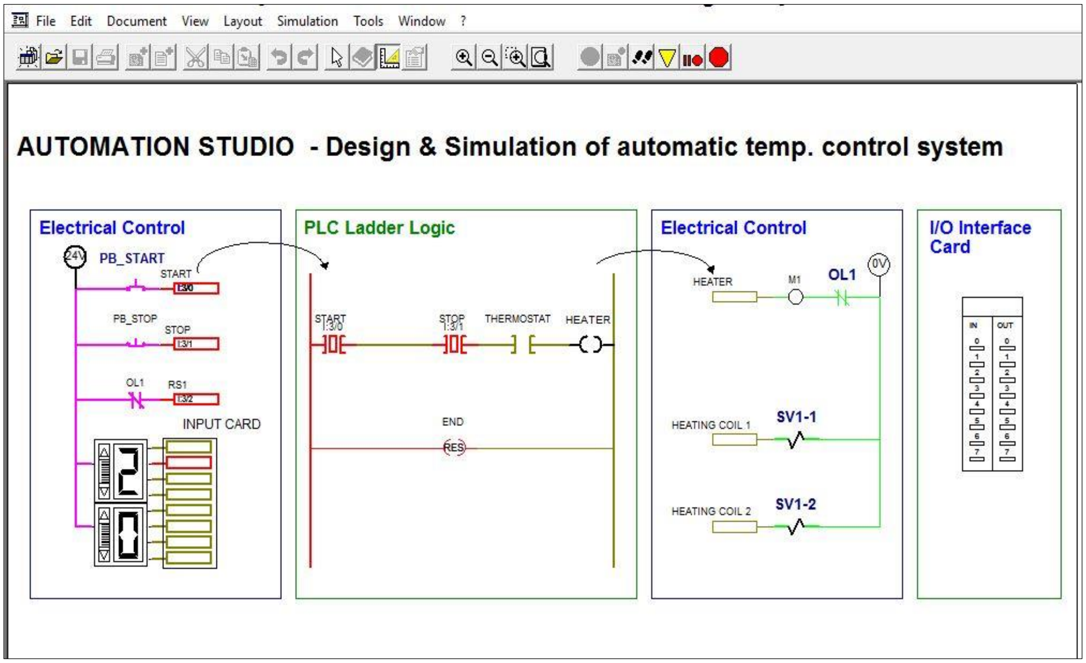


Fig. 5.12. Simulation for Heater OFF

5.7 Closure

From chapter Design & Simulation of Automatic Control System it is studied that Automation Studio Software 3.00 for design & simulation of automatic heating coils control system and also the knowledge about ladder logic, PLC programming and various temperature sensors.

Chapter 6

COMPUTATIONAL MODELLING & SIMULATION

6.1 Heat Exchanger

Heat exchangers are one of the mostly used equipment in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involve cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purpose. Process fluids, usually are heated or cooled before the process or undergo a phase change. Different heat exchangers are named according to their application. For example, heat exchangers being used to condense are known as condensers, similarly heat exchanger for boiling purposes are called boilers [6]. Performance and efficiency of heat exchangers are measured through the amount of heat transfer using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an insight about the capital cost and power requirements (Running cost) of a heat exchanger. Usually, there is lots of literature and theories to design a heat exchanger according to the requirements.

Heat exchangers are of two types: -

- Where both media between which heat is exchanged are in direct contact with each other is Direct contact heat exchanger,
- Where both media are separated by a wall through which heat is transferred so that they never mix, indirect contact heat exchanger.

A typical heat exchanger, usually for higher pressure applications up to 552 bars, is the shell and tube heat exchanger. Shell and tube type heat exchanger, indirect contact type heat exchanger. It consists of a series of tubes, through which one of the fluids runs. The shell is the container for the shell fluid [13]. Generally, it is cylindrical in shape with a circular cross section, although shells of different shape are used in specific applications. For this particular study shell is considered, which is generally a one pass shell. A shell is the most commonly used due to its low cost and simplicity, and has the highest log-mean temperature-difference (LMTD) correction factor. Although the tubes may have single or multiple passes, there is one pass on the shell side, while the other fluid flows within the shell over the tubes to be heated or cooled. The tube side and shell side fluids are separated by a tube sheet [05].

Baffles are used to support the tubes for structural rigidity, preventing tube vibration and sagging and to divert the flow across the bundle to obtain a higher heat transfer coefficient. Baffle spacing (B) is the centre line distance between two adjacent baffles, Baffle is provided with a cut (Bc) which is expressed as the percentage of the segment height to shell inside diameter. Baffle cut can vary between 15% and 45% of the shell inside diameter. In the present study 36% baffle cut (Bc) is considered. In general, conventional shell and tube heat exchangers result in high shell-side pressure drop and formation of recirculation zones near the baffles. Most of the researches now a day are carried on helical baffles, which give better performance than single segmental baffles but they involve high manufacturing cost, installation cost and maintenance cost.

6.2 Problem Description:

Modelling of shell and tube heat exchanger with baffle & study the temperature analysis of shell and tube heat exchanger by using Ansys CFx. The task is to model the heat exchanger between two fluids at different temperatures, flowing in opposite directions. In the shell of the heat exchanger, water enters at a velocity of 0.5m/s and a temperature of 60°C, passing through the baffles and leaving on the other side & hot SO_2 gas is at 350°C is entering the tubes at a velocity of 0.5m/s.

6.3 ANSYS:

Ansys is the finite element analysis code widely used in computer aided engineering (CAE) field. ANSYS software help us to construct computer models of structure, machine, components or system, apply operating loads and other design criteria, and study physical response such as stress level temperature distribution, pressure etc. [11]

In Ansys following Basic step is followed:

- During pre-processing the geometry of the problem is defined. Volume occupied by fluid is divided into discrete cells (the mesh). The mesh may be uniform or non-uniform. The physical modelling is defined. Boundary condition is defined. This involves specifying the fluid behaviour of the problem. For transient problem boundary condition are also defined.
- The simulation is started and the equation are solved iteratively as steady state or transient.
- Finally, a post procedure is used for the analysis and visualisation of the resulting problem.

6.4 Computational Model:

The model is designed according to TEMA (Tubular Exchanger Manufacturers Association) Standards Gaddis (2007).

Table 6.1. Geometric dimensions of shell and tube heat exchanger

Parameter	Dimensions
Heat exchanger length, *L*	600 mm
Shell inner diameter, *Di*	90 mm
Tube outer diameter, do	20 mm
Tube bundle geometry and pitch Triangular	30 mm
Number of tubes, *Nt*	7
Number of baffles. *Nb*	6

The computational model of a Shell and Tube Heat Exchanger (STHX) is shown in Fig. 6.1, and the geometry parameters are listed in Table 6.1. As can be seen from Fig 6.1, STHX has total number of tube 7. The whole computation domain is bounded by the inner side of the shell and everything in the shell contained in the domain. The inlet and out let of the domain are connected with the corresponding tubes.

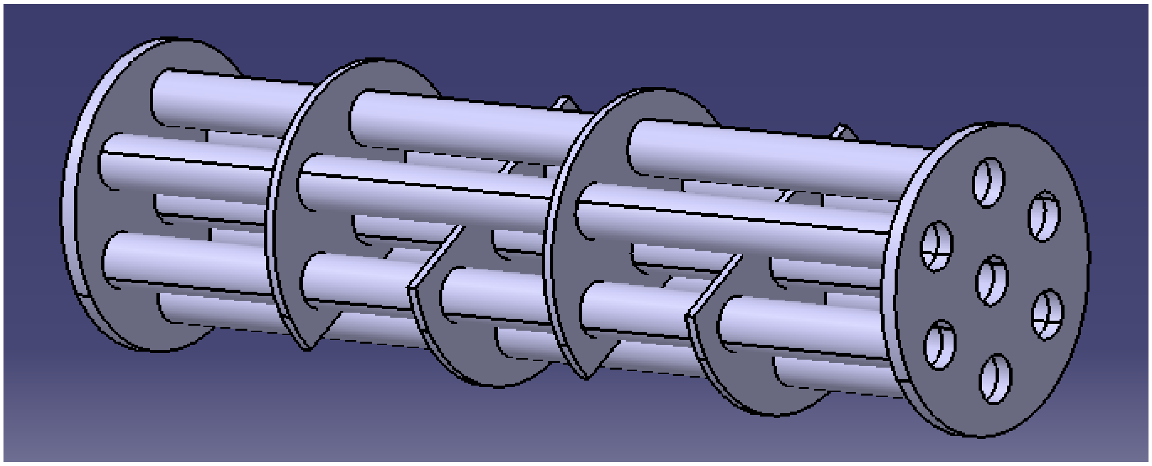


Fig. 6.1. Geometry of Tubes and baffels

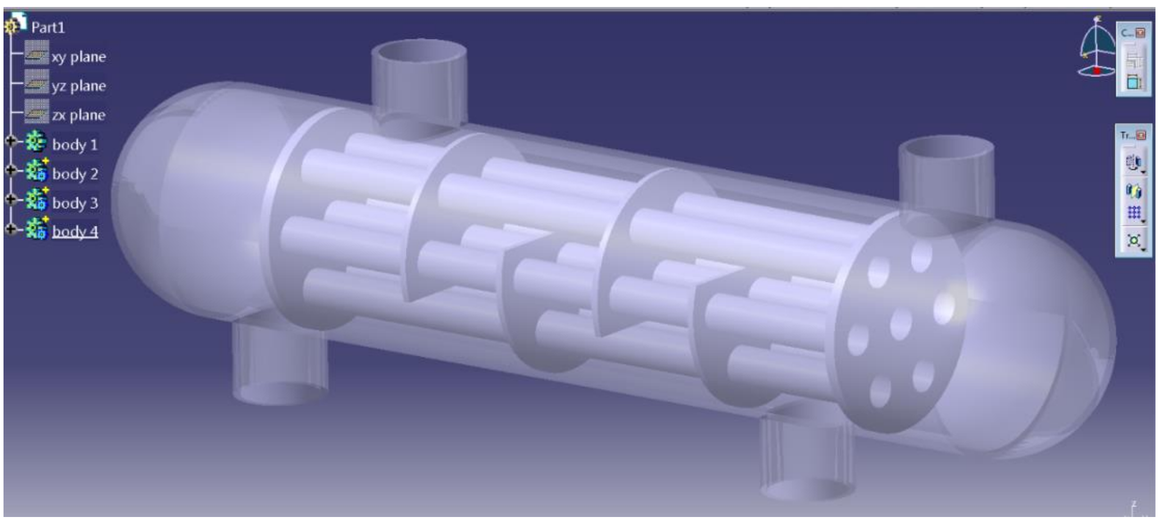


Fig. 6.2. Computational model of a Shell and Tube Heat Exchanger (STHX)

6.4.1 Assumptions

To simplify numerical simulation, some basic characteristics of the process following assumption are made:

- The shell side fluid is constant thermal properties
- The fluid flow and heat transfer processes are turbulent and in steady state
- The leak flows between tube and baffle and that between baffles and shell are neglected
- The natural convection induced by the fluid density variation is neglected
- The tube wall temperature kept constant in the whole shell side

- The heat exchanger is well insulated hence the heat loss to the environment is totally neglected.

6.4.2 Navier-Stokes Equation:

It is named after Claude-Louis Navier and Gabriel Stokes, He described the motion of fluid substances. It's also a fundamental equation being used by ANSYS and even in the present project work. These equations arise from applying second law of newton to fluid motion, together with the assumption that the fluid stress is sum of a diffusing viscous term, plus a pressure term [26]. The derivation of the Navier Stokes equation begins with an application of second law of newton i.e conservation of momentum. In an inertial frame of reference, the general form of the equations of fluid motion is

$$\underbrace{\rho\left(\frac{\partial \mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}\right)}_{1}=\underbrace{-\nabla p}_{2}+\underbrace{\nabla\cdot\left(\mu(\nabla\mathbf{u}+(\nabla\mathbf{u})^{T})-\frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right)}_{3}+\underbrace{\mathbf{F}}_{4}$$

Where **u** is the fluid velocity, ***p*** is the fluid pressure, ***ρ*** is the fluid density, and ***μ*** is the fluid dynamic viscosity. The different terms correspond to the inertial forces (1), pressure forces (2), viscous forces (3), and the external forces applied to the fluid (4). The Navier-Stokes equations were derived by Navier, Poisson, Saint-Venant, and Stokes between 1827 and 1845.

6.4.3 How Do They Apply to Simulation and Modeling?

These equations are at the heart of fluid flow modeling. Solving them, for a particular set of boundary conditions (such as inlets, outlets, and walls), predicts the fluid velocity and its pressure in a given geometry. Because of their complexity, these equations only admit a limited number of analytical solutions. It is relatively easy, for instance, to solve these equations for a flow between two parallel plates or for the flow in a circular pipe. For more complex geometries, however, the equations need to be solved. This Navier Stokes Equation slove in every mess shell and the simulation shows the result.

6.5 Mesh:

The three-dimensional model is then discretized in ICEM CFD. In order to capture both the thermal and velocity boundary layers the entire model is discretized using hexahedral mesh elements which are accurate and involve less computation effort. Fine control on the hexahedral mesh near the wall surface allows capturing the boundary layer gradient accurately. The entire geometry is divided into three fluid domains Fluid_Inlet, Fluid_Shell and Fluid_Outlet and six solid domains namely Solid_Baffle1 to Solid_Baffle6 for six baffles respectively. Fig. 6.3 shows meshing diagram of shell and tube heat exchanger

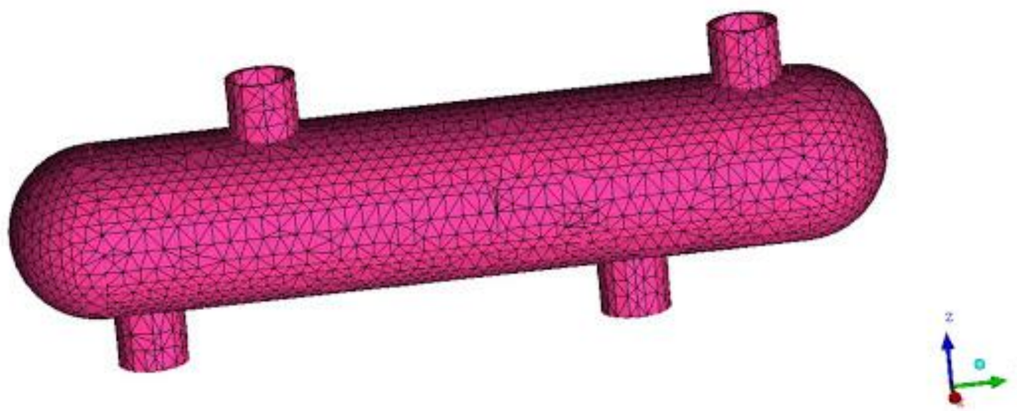


Fig. 6.3. Meshing diagram of shell and tube heat exchanger

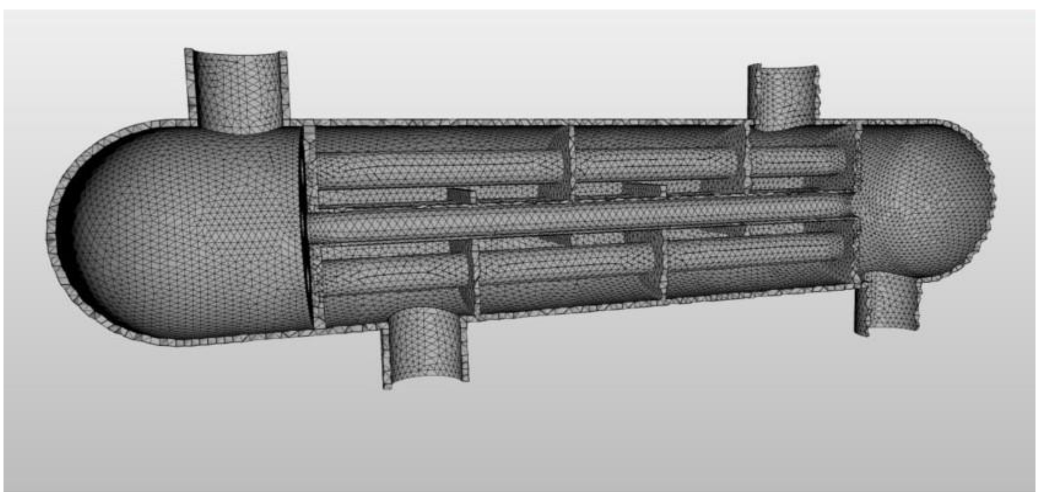


Fig. 6.4. Sectional Meshing diagram of shell and tube heat exchanger

Initially a relatively coarser mesh is generated with 1.8 Million cells. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured cells (Hexahedral) as much as possible, for this reason the geometry is divided into several parts for using automatic methods available in the ANSYS meshing client. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, for the mesh independent model, a fine mesh is generated with 5.65 Million cells. For this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed.

6.6 Problem Setup

The task is to model the heat exchange between two fluids at different temperatures, flowing in opposite directions. In the shell of the heat exchanger, water enters at a velocity of 0.5m/s and a temperature of 80°C, passing through the baffles and leaving on the other side. The hot SO2 gas at 350°C is entering the tubes at a velocity of 0.5m/s

6.6.1 Problem steps

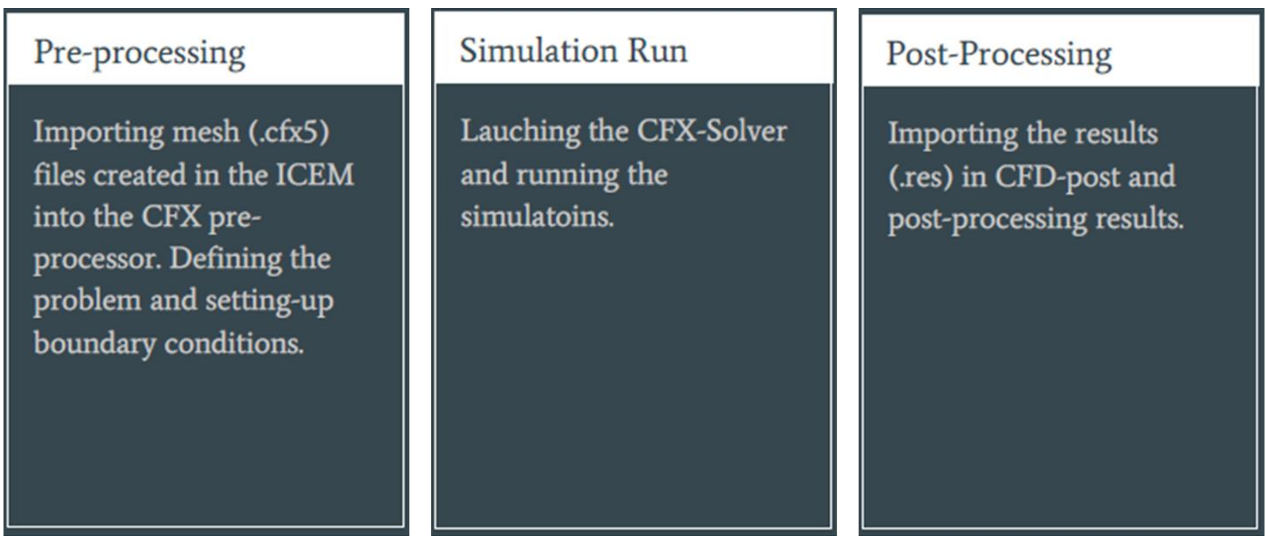


Fig. 6.5. Problem steps

Pre-processing Data:

Simulation was carried out in ANSYS® CFX® 15. In the CFX solver Pressure Based type was selected, absolute velocity formation and steady time was selected for the simulation. In the model option energy calculation was on and the viscous was set as standard k-e, standard wall function

In cell zone fluid water-liquid was selected. Water-liquid and aluminium was selected as materials for simulation. Boundary condition was selected for inlet, outlet.

Solution Initialization:

Pressure Velocity coupling selected as SIMPLEC. Skewness correction was set at zero. In Spatial Discretization Zone Gradient was set as least square cell based, Pressure was standard, Momentum was First Order Upwind, Turbulent Kinetic energy was set as First Order Upwind, and Energy was also set as First order upwind. In Solution control, Pressure was 0.7, Density 1, Body force 1, Momentum 0.2, turbulent kinetic and turbulent dissipation rate was set at 1, energy and turbulent Viscosity was 1. Solution initialization was standard method.

Table 6.2. Domain Physics for Heat Exchanger

Domain – TubeSide	
Type	Fluid
Location	BODY
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Thermal Energy
Turbulence Model	SST
Turbulent Wall Functions	Automatic

Domain – Shellside	
Type	Fluid
Location	BODY2
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Thermal Energy
Turbulence Model	SST
Turbulent Wall Functions	Automatic
Domain Interface - Default Fluid Fluid Interface	
Boundary List1	Default Fluid Fluid Interface Side 1
Boundary List2	Default Fluid Fluid Interface Side 2
Interface Type	Fluid Fluid
Settings	
Interface Models	General Connection
Heat Transfer	Conservative Interface Flux
Mass And Momentum	No Slip Wall
Mesh Connection	GGI

Simulation Run & Post Processing:

After simulation run we got following result.

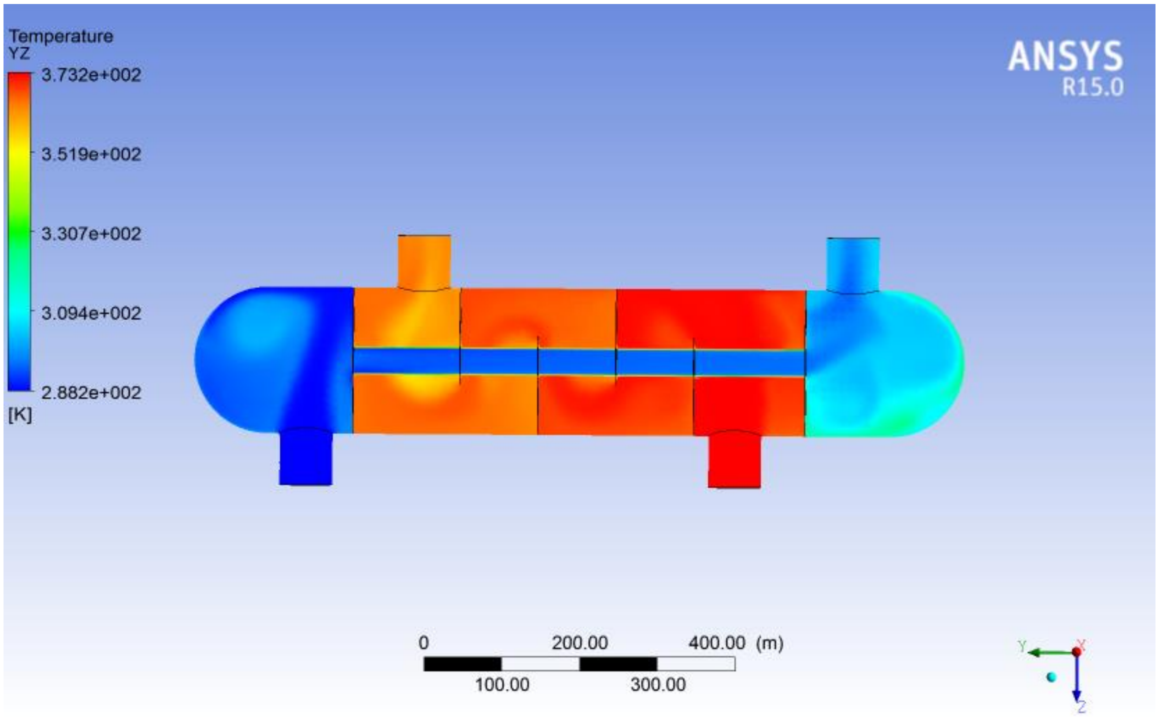


Fig. 6.6. Temperature Distribution across the tube and shell heat exchanger

Table 6.3. Result analysis of heat transfer

Accumulated Time step	H-Energy (Shell Side)	H-Energy (Tube Side)
2	7.01E-03	1.36E-04
4	9.03E-03	3.18E-02
6	1.33E-02	4.23E-02
8	1.16E-02	2.52E-02
10	1.09E-02	1.38E-02
12	9.40E-03	1.12E-02
14	8.79E-03	9.73E-03
16	8.40E-03	6.66E-03
18	8.20E-03	4.91E-03

20	8.01E-03	4.25E-03
22	7.89E-03	3.78E-03
24	7.72E-03	3.44E-03
26	7.54E-03	3.15E-03
28	7.35E-03	2.92E-03
30	7.15E-03	2.77E-03
32	6.86E-03	2.61E-03
34	6.55E-03	1.36E-04

From Table 6.3 heat energy at shell side and heat energy at tube side is obtained. The results from table conclude that the heat energy increases as time period increases. The graph for combined heat energy of shell and tube side is as shown in Fig.:6.7

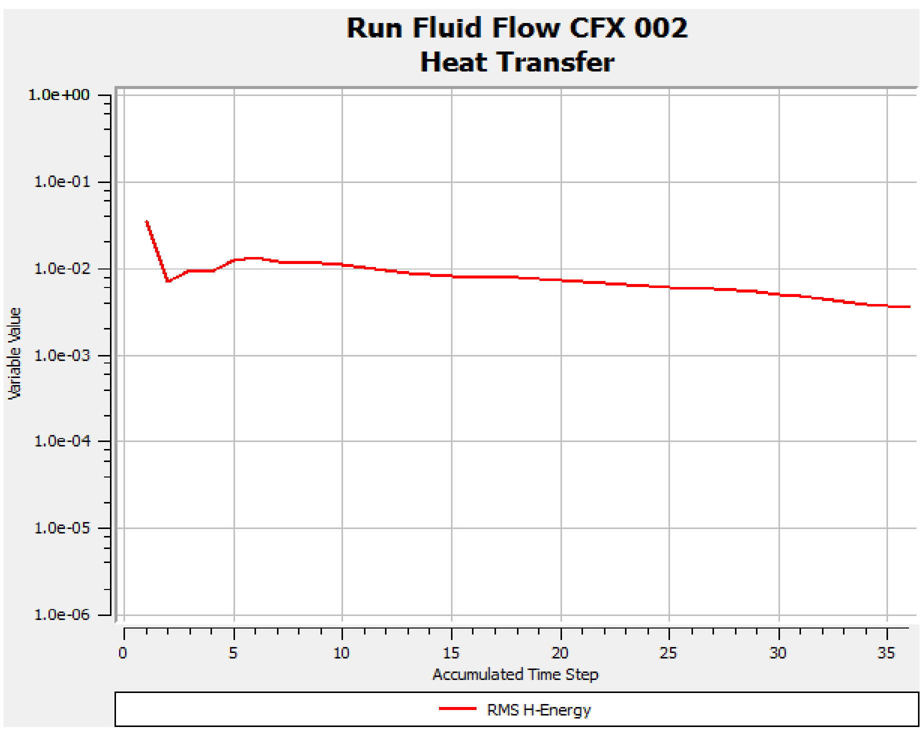


Fig. 6.7. Heat energy Vs Time

6.7 Closure

From this chapter it is studied that geometry creation, meshing & simulation of heat exchanger with proper boundary conditions required for analysis purpose.

Chapter 7

RESULTS AND DISCUSSION

In this chapter, flow and heat transfer studies for the SO_2 gas flowing through the tubes in the heat exchanger module is carried out using commercially available ANSYS-CFX software.

7.1 Variation of Temperature:

The Fig. 7.1 temperature Contours plots across the cross-section of heat exchanger give an idea of the heat flow in detail. The maximum temperature at cross section is 371.22k and minimum temperature is 293.15k.

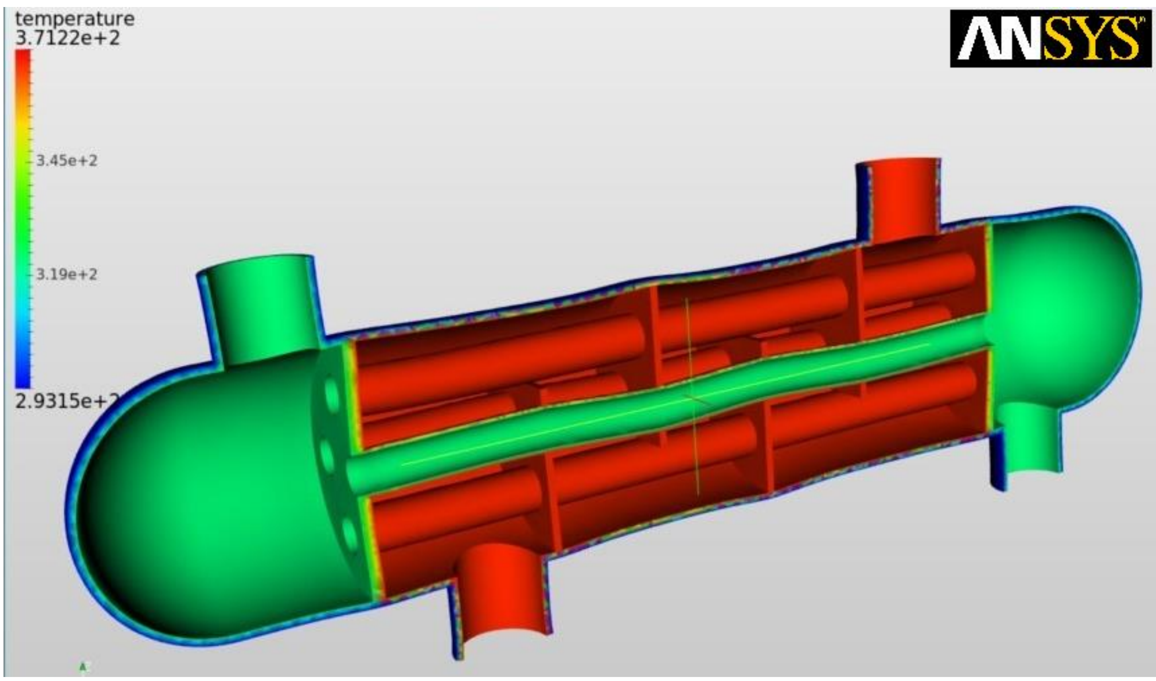


Fig. 7.1. Temperature Distribution across the tube and shell heat exchanger

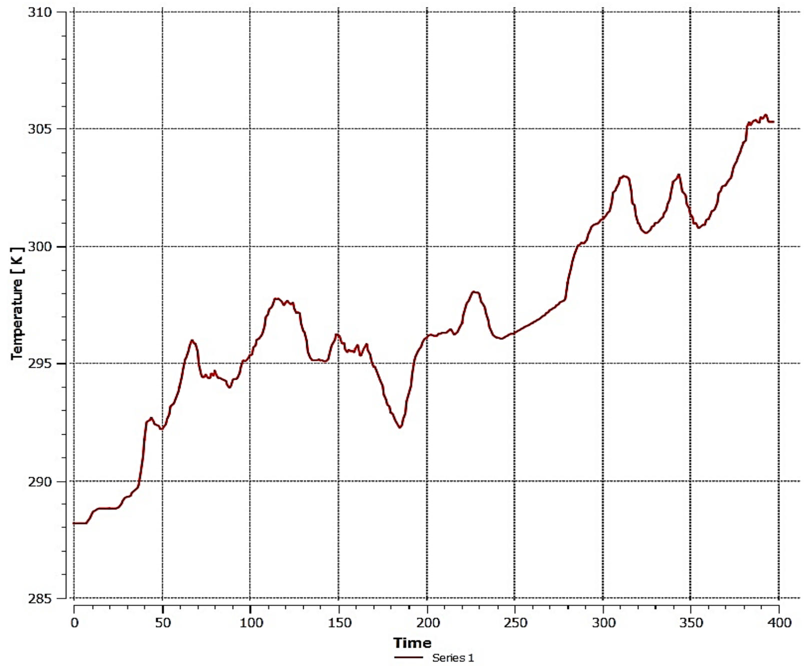


Fig. 7.2. Temperature Distribution Vs Time

The Fig.7.2 shows the surface temperatures of the heat exchanger. It can be observed that the temperature of surface increases as runtime increases

7.2 Streamlines of Temperature

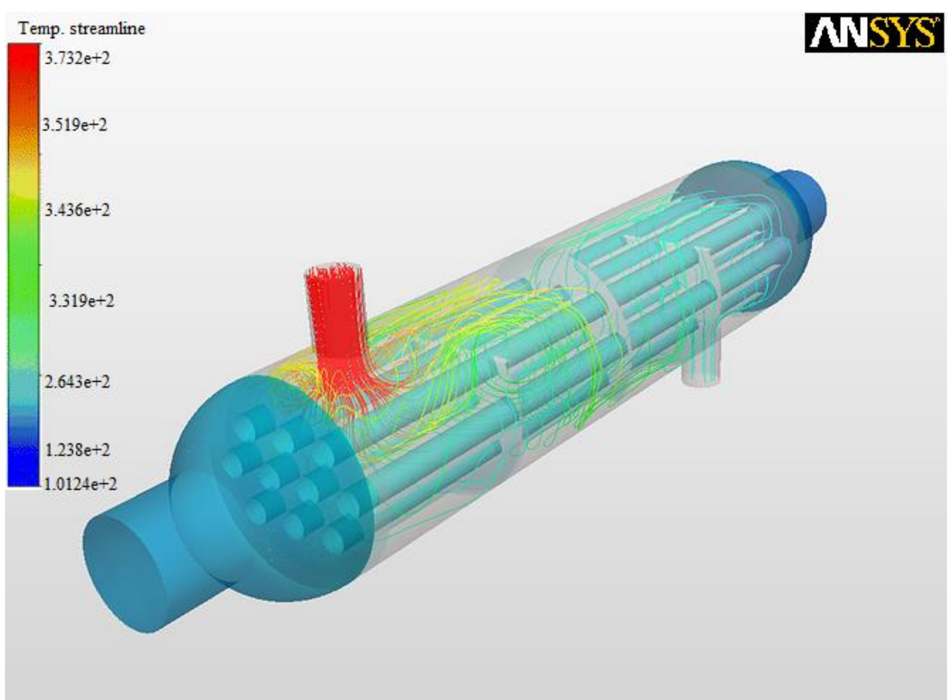


Fig. 7.3. Streamlines of Temperature

The Fig.7.3 illustrates the flow of the temperature streamlines in the shell of the heat exchanger. As can be seen in the Fig.7.3, the temperature gradient of the water is much steeper at the exit and gradually decreases with the furtherance of the fluid across the shell.

7.3 Streamlines of Temperature (SO_2 gas tubes)

The following Fig.7.4 displays the temperature contour of the SO_2 gas tubes. The SO_2 gas enters from the right-hand side and flows towards the left. The SO_2 gas transmits heat to the water through tube surface. Subsequently, the water receives heat through conduction from the tube surfaces through which it flows. As a result, as the flow progresses the area of the red region at the circumferential boundary of the SO_2 gas decreases.

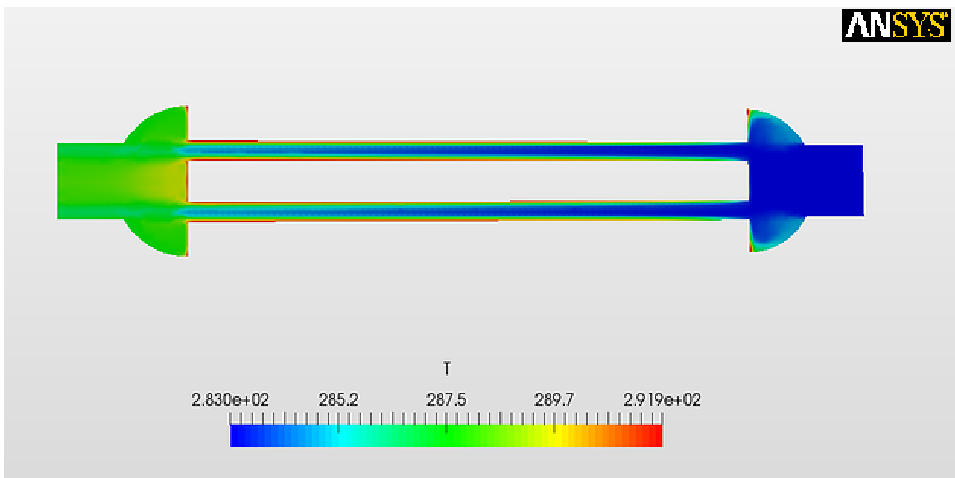


Fig. 7.4. Streamlines of Temperature (SO_2 gas tubes)

7.4 Heat transfer rate

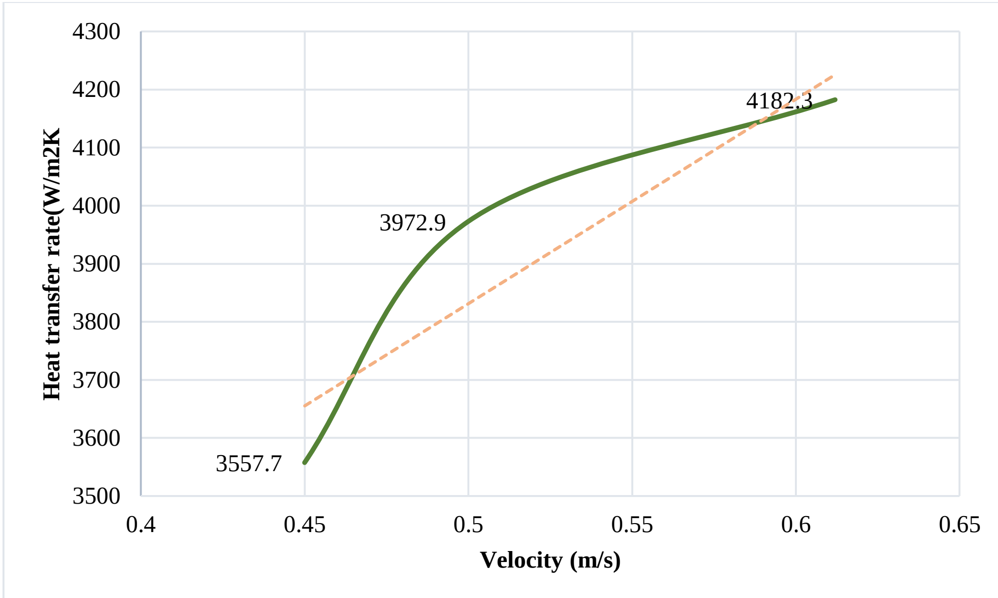


Fig. 7.5. Heat transfer rate Vs SO_2 gas Velocity

The Fig.7.5 shows the heat transfer rate across the gas tubes. From the above plot it is observed that as the velocity of SO_2 gas increases, the heat transfer rate across the tubes is also increased. For better heat transfer rate velocity of SO_2 gas should be 0.612 m/s.

7.5 Outlet Temperature

The Table: 7.1 shows simulated outlet temperature of shell side and tube side for the various velocities of SO_2 gas.

Table 7.1. Outlet Temperature of the Shell Side and Tube Side

The velocity of SO_2 gas (m/s)	The outlet temperature of Shell side (K)	The outlet temperature of tube side (K)
0.45	363.431	329.896
0.5	368.910	333.563
0.612	369.0162	336.127

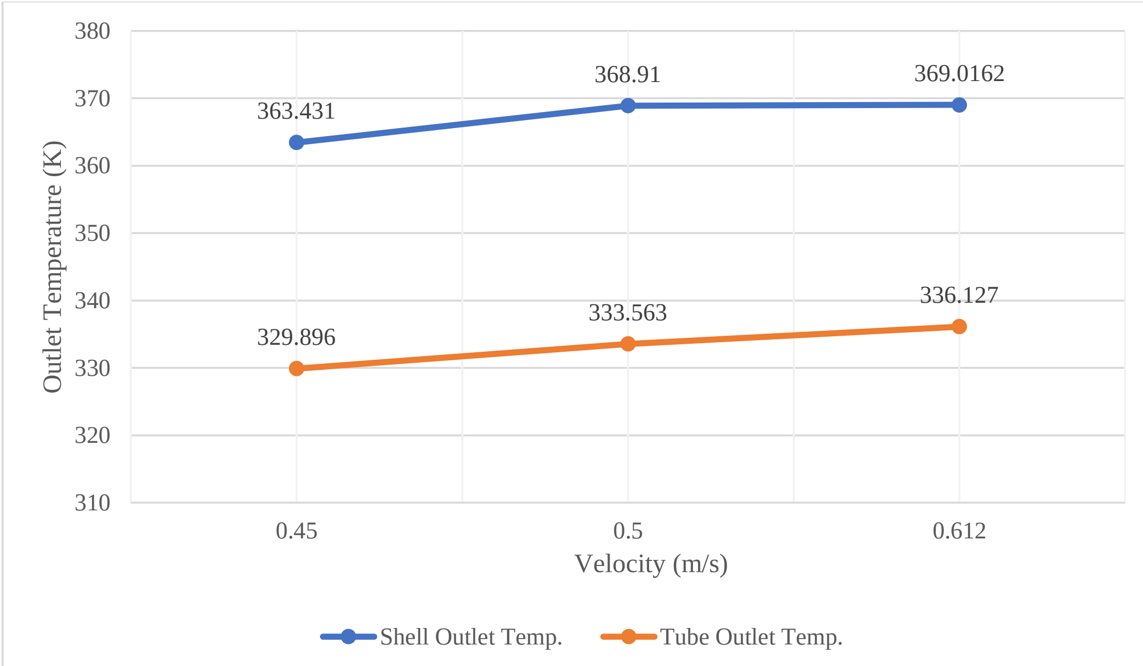


Fig. 7.6. Outlet Temperature Vs Velocity

From Fig.7.6 it has been found that there is much effect of the outlet temperature of shell side with increasing the SO_2 gas velocity from 0.45 to 0.612.

Chapter 8

CONCLUSION

8.1 Conclusion

Recovering Waste heat is the need of the day for the industries of developing countries. Many big industrial plants have already realized the importance of heat recovery and they are effectively utilizing it in one or other way. Efforts are being done to improve the heat recovery efficiencies by using the latest technological advancements and optimization methods like automation & heat exchangers

Several promising developments are taking place in the field of sugar industry. In the present work, a tiny contribution has been made to the energy saving technology of SO_2 gas generation process which is used for the converting raw sugar in to white sugar.

In the present work we have conducted automation simulation and computational fluid analysis for improving better heat transfer and for energy efficiency particularly in sugar industry. The simulation results gives good response for heat transfer rate among the water and SO_2 gas. Hence, heat recovery system of SO_2 gas generation process is one of the option for proper and efficient utilization and conservation of energy in sugar industry.

The automation of steam generator along with heat transfer and flow distribution of shell and tube heat exchanger is discussed in detail and then proposed model is compared with previous existing system of SO_2 gas generation process.

The computational model predicts the heat transfer increases with an average of 58% as compared with existing system of SO_2 gas generation process.

8.2 Scope for Future Work

1) By using the Baffle inclination in shell & tube heat exchanger, heat transfer augmentation for SO_2 gas can be studied.
2) The performance of automatic control system can also be studied under different combinations of temperature sensors and PLC programming.
3) The thermal enhancement of shell & tube heat exchanger can be studied by increasing and decreasing the number tubes.
4) The performance of Heat Recovery system can also be studied under different combinations of heat exchangers.

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LIST OF PUBLICATIONS ON PRESENT WORK

1. Deshmukh A. K., Kavade. M. V, and Pawar B. Y., 2017, "Study & Review of Heat Recovery Systems for SO_2 Gas Generation Process in Sugar Industry," International Research Journal of Engineering & Technology, (2017): pp. 485–488.

2. Deshmukh A. K., and Kavade. M. V, "Development of Automatic Control System & Performance Analysis of Heat Recovery Systems for SO_2 Gas Generation Process in Sugar Industry," RITNCONPG, (2018): pp. 259–265

3. Deshmukh A. K., and Kavade. M. V, "Development of Automatic Control System & Performance Analysis of Heat Recovery Systems for SO_2 Gas Generation Process," International Journal of Mechanical & Production Engineering Research & Development. (Under review)