ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

"Waste Heat Recovery & Utilization from furnace flue gas for drying mold: (The Case of G-7 Trading& Industry PLC.)"

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Award of the Degree of Masters of Science in Mechanical Engineering (With Specialization in Thermal Engineering)

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **"*Waste Heat Recovery & Utilization from furnace flue gas for drying mold: (The Case of G- seven Trading& Industrial PLC.)*"** is original work of my own, has not been presented for a degree of any other University and all the resources of materials used for the thesis have been duly acknowledged.

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LIST OF ABBREVIATIONS

WTR	Waste to energy
WHRS	Waste Heat Recovery System
CFD	Computational Fluid Dynamics
LHV	Lower heating value
LDO	Light Diesel oil
GCV	Gross Calorific Value
MW	Mega Watt

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ABSTRACT

As energy crisis become increasingly noticeable, the energy consumption has become the main problem which restricts the sustainable development of industry. The recovery and utilization of different kinds of waste heat can effectively reduce energy consumption of the company. Therefore, recovery and utilization of waste heat become very important. Energy saving is one of the crucial concern, not only from the point of view of fuel consumption but also for the conservation and protection of global environment. So, it is important that a significant and great effort should be made for conserving energy from waste heat. Recovering and reusing this waste heat would provide an attractive opportunity for less costly energy resource. Most industry use furnace to melt metals and metal scraps for manufacturing spare parts, by doing this they can reduce cost of buying spare parts for the machine.

However, during combustion process of furnace oil enormous amount of heat energy is wasted to the environment via chimney which is embedded in the flue gas. The furnace working temperature is about 1400°C.Based on the measured parameters such as the average temperature of flue gas at the hood and chimney was about 240°C and 146°C respectively. From heat transfer analysis calculation, the amount of waste heat obtained from hot flue gas was about 24.4kw, Hence, the amount of heat is recovered from the flue gas is about 37.6%.

This study aims at providing a flue gas as an alternative energy to dry the mold in the foundry shop instead of drying by burning of wood. In this study temperature and velocity of flue gas at different locations were measured and analytical calculation was made on flue gas supply system and mold drying room. Simulation has been done using Computational Fluid Dynamics (CFD) Ansys software to show what is going on inside the hot flue gas supply duct and mold drying room. Tapping hot flue gas from top part of the furnace or chimney and supplying via duct to drying room to dry the mold will benefit the industry-; by reducing fuel consumption, saving the cost of the wood by 90%, making economical and environmental friendly. This will reduce impact of deforestation and create good working environment.

Key words: *ANSYS (CFD), Chimney, Drying room, Furnace, Flue gas, Heat losses, Molds, Supply duct, Waste Heat Recovery*.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Atreya, (2007) Discussed on one of the largest waste heat in high temperature furnaces is the loss of flue gas enthalpy, currently up to 60% of the heating value of fuel used in high temperature furnaces is lost through chimney in the form of flue gases.

Sajan, et.al (2015) defined waste heat as heat energy which is produced in a process by way of fuel combustion or chemical reaction, and then which is released into the environment even though it could still be reused for some useful and economic purpose. Large amount of energy wasted via the flue gas in thermal power station causes great concern in recent years. Removing hot flue gas to the environment is not only wastage of energy but also it contributes the rate of global warming.

Karaoglu & Ozbek(2017) presented energy as the power and important part of life. For the future, we must have a sustainable, affordable and environment friendly energy supply. Jegadeswaran & Daniel, (2015)Energy consumption is the most crucial problem in the today's era, in the present scenario per capita energy consumption determines the development of the nation.

The amount of energy consumed on a daily basis in a foundry shop is large, resulting in enormous amount of energy consumption costs, Foundry is an energy intensive industry and energy accounting is important to determine the amount of actual energy use and the total energy waste. Waste heat recovery of flue gas from industries furnace have great role for saving and minimizing waste heat from furnace. Reusing this waste heat for drying mould in the foundry shop is crucial instead of drying by burning of wood from energy management point of view.

Industrial furnace is used to melt metal and metal scrap for manufacturing spare part and some other products. Suryavanshi & Pitale(2017) discussed about exact amount of industrial waste heat is poorly quantified, but many researches have estimated that at about 20 to 50% of industrial energy consumption is liberated as waste heat.

To reduce these losses, installing waste heat recovery technology is crucial. Waste heat recovery is capturing and reusing waste heat of industrial process for heating or for generating mechanical work or electrical work and preheating combustion air, space heating and some other purposes. Energy recovery serves as purpose to point out the possible deficiency in the energy utilization in an industry to reuse the waste heat as an alternative energy for different purpose.

1.2 Statement of the problem

Energy shortage is one of today's major world problems. The majority of industries use fossil fuel as their main energy sources. But such energy sources are nonrenewable and exhaustible and at the same time cause major environmental pollution. Now a day some industry produces their own spare part for manufacturing their machines parts. The target of this study is to recover waste heat of the flue gas from the furnace for the purpose of drying sand mold.

Ansari & Manager(2016) discussed that more than 48,300 foundries are registered globally and metal casting industry is one of the most energy-intensive manufacturing sectors with the melting process accounting for over half of its energy consumption. In today's global situation, the cost of energy has been increase rapidly, reflecting a critical loss in the supply of energy.

Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. Efforts can be made to design more energy efficient furnaces with better heat transfer and lower exhaust temperatures Thermal efficiency of process heating equipment, such as furnaces, heaters, kilns and etc. is the ratio of heat delivered to a material and heat supplied to the heating equipment.

In most heating equipment, an enormous amount of heat supplied is wasted in the form of flue gases. These losses depend on many factors associated with the design and operation of the heating equipment(BEE-GoI,2015).

Flue gas heat losses are unavoidable in the operation of all fuel-fired furnaces. Air and fuel are mixed and burned to generate heat energy, and a part of this heat is transferred to the heating device which is to the material that is heated. When the energy transfer reaches its practical limit, the spent combustion gases are removed from the furnace through a chimney or stack. While this gas passes via a chimney it still contains considerable thermal energy, often more than what was utilized in the process. In many fuel-fired heating systems, this waste heat is the greatest sources of heat loss in the process, often greater than all the other losses.

The way of drying mold in G7 Trading and industry PLC is traditional and not economical that is by burring of wood this consumes large amount of wood for drying mold, not environmentally friendly, pollute the environment due to burring of wood and also have negative impact in working environment.

Large amount of heat losses exist in the foundry shop of G7 Trading and industry PLC. Recovering and utilizing this waste heat for drying mold purpose are crucial to reduce waste heat, reduce cost of buying wood, reduce deforestation, reduce working time, these will create good working environment, and introducing alternative energy for the industries.

1.3 Objectives

General objective

The main purpose of this research is to study how to recover and utilize the waste heat energy from the flue gas of furnace considering the case of G7 industry.

Specific objectives

The specific objective of the thesis includes;

- Conduct energy audit of the foundry shop
- Design the best option for the use of heat recovery system
- Use Computational Fluid Dynamics (CFD) ANSYS software and justify the suggested solution.
- Suggesting cost-effective measures to improve the efficiency of energy use.

1.4 Significance of the project

Energy use and audit studies were conducted in various units of the foundry shop to evaluate the performance of existing system; technical gaps in existing foundry shop are analyzed. energy, economic, environmental and social advantages of newly design energy efficient furnace over conventional furnace and also it will reduce the waste energy, reduce cost of fuel, reduce deforestation from environment protection point of view, introduces alternative energy to the host industries, create good working environment to the worker.

- **Research Gap**

Numerous technologies are commercially available for waste heat recovery, yet in many applications it remains relatively unexploited. Most of the researcher that has been conducted waste heat recovery and utilization of waste heat system was for boiler preheater, furnace load, space heating, economizer, combustion air preheater etc.

This thesis is not a new technology; however, its application in such industry is important for manufacturing process ,the conversion of waste heat from the foundry shop, has never been carried out before in this industry. Hence, this research brings a new insight into the possibility of utilizing the waste heat from melting furnace for dying sand mold in foundry shop.

Therefore this thesis tries to fill the gap in the way that in our country most of the industry have furnace to melt metal and produce their own spare part and they dried sand molds in the foundry shop using electrical oven and traditionally by burning of wood. But in this research study investigate the alternative way of drying molds using flue gas from furnace.

1.5 Scope of the study

The thesis is intended to recover and utilize the waste heat of foundry shop, specifically the waste heat of flue gas from furnace which is wasted to the environment during combustion process of fuel. It focuses on energy audit of the foundry shop, Heat transfer and thermodynamic analysis of a system and software like (Ansys fluent) or Computational fluid dynamics (CFD) is utilized to justify the analytical result. However performance analysis of recovery system, optimization Furnace efficiency and energy Audit of electrical supply system of the shop is not the focus of this research.

1.6 Thesis outline

This thesis contains a total of five chapters; the contents of the chapters are as follows:

Chapter 1 –Introduction: This chapter gives introductory view to the reader about the thesis, the back ground of the problem, objectives, significance of the study and scope of the study.

Chapter 2 –Literature review: This chapter reviews in detail the literature available in the area of waste heat recovery, waste heat utilization and flue gas heat recovery technological, over view on waste heat in industry system.

Chapter 3 –Material and method: This chapter describes different aspects of the methods used and situations that the researcher must consider during each phase of the study. Different ways of carrying out the study and different ways of collecting information will be discussed. Basic of energy audit procedure are carried on.

Chapter 4 –Analysis and Simulation model development: efficiency analysis**,** heat transfer correlations to calculate the energy recovery and in this study a Full-size CFD model is developed to investigate amount of temperature or heat is reaching the mould drying room and the energy recovery from flue gas.

Chapter 5 –Result and Discussion: Data analysis and presentation based on collected data's, measured data's and result of experimental works and/ or the simulation(CFD) result are presented and discussed. The real system of the foundry shop furnace and the designed system are compared with the previous system will discussed in this chapter.

Chapter 6-Economic Evaluation: In this chapter the economic evaluation of the recovery system and simple payback period of the system is evaluated and discussed

Chapter 7- Conclusion and recommendation: After the analysis and evaluation, the general conclusion and Recommendation has been forwarded.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

This thesis is concerned with the waste heat recovery and utilization of flue gas from furnace in the foundry shop in the case of G-7 Trading & Industrial PLC. A flue gas heat recovery system can make furnace more efficient by capturing and re-using the lost heat energy that would otherwise have escaped out of the chimney**.**

To understand the subject matter of waste heat recovery and utilization of flue gas of furnace and also heat recovery potential of flue gases, different literatures are reviewed and are discussed under this chapter.

There are various direct and indirect benefits, associated with the waste heat recovery. Pre-drying of lignite is very essential in lignite based power plant, to improve the performance of the plants and cycle. By installing the waste heat model to the existing power plant will increase the efficiency and reduce the fuel consumption in one and in other ways.

The main source for the waste heat recovery system is the hot flue gas, which carrying large amount of heat energy. Jegadeswaran & Daniel, (2015)in their work justified that heat is recovered by installing suitable recovery model more than 20 % of fuel saving can be achieved. This recovered heat can be used for useful purpose like primary combustion air heating, pre-heating of boiler feed water.

Suryavanshi & Pitale, (2017)define Industrial waste as heat energy that is generated in some processes without being put to practical use. Li, Duanmu, & Fu, (2016)Waste heat is the heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be utilized for some useful and economic purposes.

Many industrial heating processes generate large amounts of waste energy that simply pass out the stacks and into the atmosphere. Karaoglu & Ozbek, (2017)Energy is the power and vital part of life. In the future, we must have a sustainable, affordable and environment friendly energy supply. Availability of energy determines the increase in the economy in a country. In the present global situation, the cost of energy has been rising quickly, reflecting a critical loss in the supply of energy. Chate, (2015)discussed about Sources of waste heat include hot combustion gases discharged to the atmosphere, heated products exiting industrial processes, and heat transfer from hot equipment surfaces.

The exact quantity of industrial waste heat is poorly quantified, Suryavanshi & Pitale, (2017) studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat. Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. Waste heat losses occur in almost all processes, in an industrial context these losses typically occur in the form of hot water, steam or flue gases. Huge amount of energy wasted through the flue gas in industries. Discharging hot flue gas in the environment is not only wastage of energy but also increases the rate of global warming. Energy Matters,(2007) Present stack losses will consume at least 50% of the total fuel input to the process.

Waste heat recovery offers a great opportunity to put some of this energy to work, reducing energy consumption and emissions and increasing productivity. Peter Gent, (2010) worked on various works focused on waste heat in industry for improving energy efficiency.

Nirmal, Sajan at el. (2015) discussed Flue Gas Low Temperature Heat Recovery System for AC, in this work, the waste heat of flue gas in a 350 MW thermal power plant is utilized in vapor absorption air conditioning plant. Huang et al.,(2017)introduced An Improved System for Utilizing Low-temperature Waste Heat of Flue Gas from Coal-Fired Power Plants. The essence of the proposed system is that the waste heat of exhausted flue gas is not only used to preheat air for assisting coal combustion as usual ,but also to heat up feed water and the low-pressure steam extraction.

Atreya,(2007)worked on a Novel Method of Waste Heat Recovery from High Temperature Furnaces the benefits and technology of re- circulating the hot flue gases back into the furnace to avoid the large heat loss and supplementing the flue gases with oxygen to maintain the desired oxygen concentration .

Karaoglu & Ozbek, (2017)showed that District heating and power generation based flue gas waste heat recovery. Li et al.,(2016)studied application of flue gas waste heat recovery in co-generation based on absorption heat-exchange Introduced the technique of flue gas waste heat recovery in gas cogeneration based on absorption heat exchange.

Jegadeswaran & Daniel, (2015) discussed the Analysis for Efficiency Improvement and Fuel Savings Opportunities in Thermal Power Plant. And also the concept of utilizing the heat of flue gas for pre-drying the lignite to achieve the fuel savings about 40%, the waste heat energy used for drying the lignite before entering into the boiler unit increased the efficiency of boiler and reduced the fuel consumption.

Jadhao, Thombare,et.al.(2013) discussed furnace losses where include: heat storage in the furnace structure, losses from the furnace outside walls or structure, radiation losses from openings, hot exposed parts, etc. Heat carried by the cold air infiltration into the furnace, heat carried by the excess air used in the burners.

Diop, Xiaomeng & Hassan, (2017)Worked on Investigation and utilization of the exhaust flue gas waste energy to preheat aluminum billets before homogenization process in batch homogenizers, And also this work proposes a novel strategy replace the natural gas fired burners with flue gas waste heat extracted from exit from the recuperator. Arink & Hassan,(2017) Work on Metal scrap preheating using flue gas waste heat and the effectiveness of heating profiles with hot flue gases and find the optimal design considerations for a preheating furnace

Prakash & Das, (2015)Presents a general model that assess the technical and the economic feasibility of the installation of a flue gas condensation heat recovery system, applied to waste-to-energy plants.

K. F. Ahmad, Matani & Doifode, (2017)introduced energy audit implementation for energy consumption in a foundry unit towards cleaner environment, this dissertation work is conducted for identifying the opportunities and possibility of finding solutions to the energy wastage and energy conservation of the foundry plants.

The aims of this thesis are analyzing a possible way to recover waste heat of flue gas, re-utilization of waste heat for the purpose of drying molds. The study will be addressed from both a technical and an economical perspective.

Table: 2.1 Survey of selected literature and their works related to waste heat recovery and utilization from flue gas

Author	Title	Findings
Thomas, Arinka & Mohamed et.al	Metal scrap preheating using flue gas waste heat [2017]	Proposed the effectiveness of heating profiles with hot flue gases and find the optimal design considerations for a preheating furnace. Using heat transfer physics are coupled in a CFD model
Feng Li (et.al)	Research and application of flue gas waste heat recovery in cogeneration based on absorption heat-exchange [2015]	They introduced the technique of Flue gas waste heat recovery in gas cogeneration based on absorption heat-exchange
Arvind Atreya	A Novel Method of Waste Heat Recovery from High Temperature Furnaces [2007]	Benefits and technology of recirculating the hot flue gases back into the furnace to avoid the large heat loss and supplementing the flue gases with oxygen to maintain the desired oxygen concentration are discussed
Caglar Karaoglul and Arif Ozbek	District heating and power generation based flue gas waste heat Recovery [2017]	The target of this study is to utilize waste heat of flue gas either via district heating or power generation up to few MW values
Kemal comakil and meryem terhan	Energy and Economic analysis of Heat recovery from boiler exhaust flue gas [2016]	In this study the potential of heat recovery from waste flue gas was examined in 6MW And fuel saving is aimed by using recovered heat as a source
Nirmal Sajan (et.al)	Flue gas low temperature heat recovery system for air-conditioning [2015]	In this work, the waste heat of flue gas in a 350 MW thermal power plant is Utilized in vapor absorption air conditioning plant

Ahmet Fevzi Savas and Erhan Madan	Utilization Of Stack Gas and Kiln Cooling Air Temperature for Factory Heating Through Heat Recovery Method in Ceramic Kilns [2015]	In this study an application in terms of heat recovery from stack gas temperature and waste hot air of tunnel kilns in ceramic industry was carried out
Mr. Rupesh Suryavanshi and Prof.A.D. Pitale	A Review on Waste Heat Recovery in Industries [2017]	This research article presents a review of various works focused on waste heat in industry for Improving energy efficiency also concentrated on the different parameters governing the waste heat recovery in the industries.
Ivars, Veidenbergs (et.al)	Heat and Mass Transfer Processes in Scrubber of Flue Gas Heat Recovery Device [2010]	The paper deals with the heat and mass transfer process research in a flue gas heat recovery device, where complicated cooling, evaporation and condensation processes are Taking place simultaneously.

2.2 Furnaces and classification of furnace

A furnace is an equipment to melt metals for casting or heat materials for change of shape (rolling, forging etc.)or heat treatment.(Furnaces, Bureau of Energy Efficiency, (2016) discussed about the types and classification of different furnaces, based on the method of generating heat, furnaces are broadly classified into two types namely combustion type using fuels and electric type.

In case of combustion type furnace, depending upon the kind of combustion, it can be broadly classified as oil fired, coal fired or gas fired, depending on the mode of charging of material furnaces can be classified as Intermittent or Batch type furnace or Periodical furnace and Continuous furnace, Based on mode of waste heat recovery as recuperative and regenerative furnaces ,Another type of furnace classification is made based on mode of heat transfer, mode of charging and mode of heat recovery. Figure below shows the detail classification of furnace:

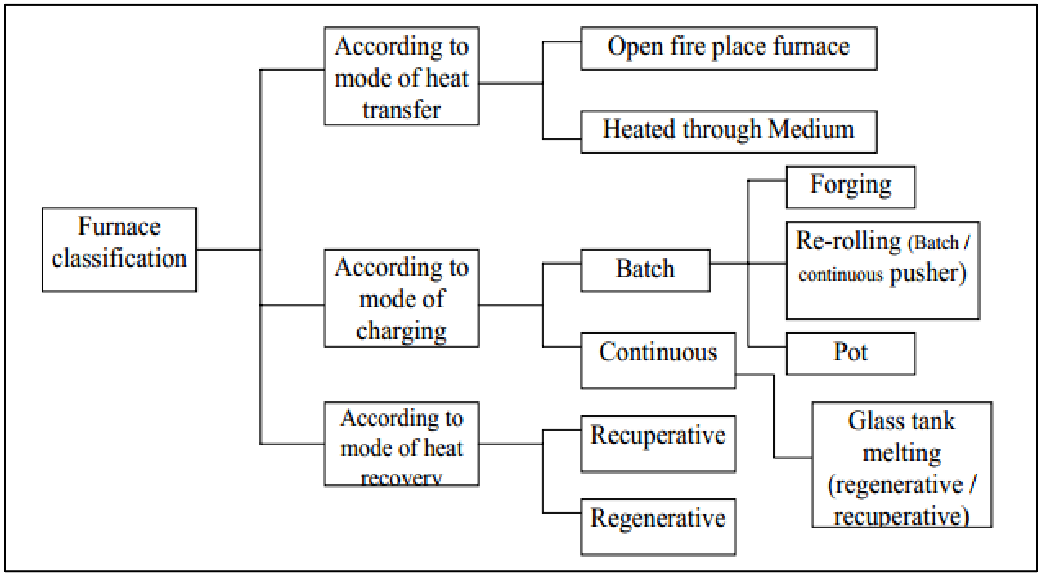


Figure-2.1 Furnace Classification(Markova,2014.)

According to Markova,(2014.) There are different criteria applied to the classification of industrial furnaces. Most frequently they are divided by the following characteristics

According to the technological purpose: Melting is intended for melting materials (blast furnaces, cupola furnaces, glass melting bath).Heating is intended for heating the material before rolling, forging, pressing, etc. (forge furnaces, rolling mill furnaces).heat treatment is intended for heat treatment such as hardening, annealing, tempering. Burning is intended for firing products (kilns for firing refractory ceramic materials, lime kilns).Drying is to remove moisture from the material (drying of mold in Foundries).

According to the heat source; Flame is heat energy is obtained by combustion of solid, liquid or gaseous fuels; thermal energy is generated from electricity (arc furnaces, resistance furnaces, plasma furnaces, induction furnaces, electron furnaces).

❖ **Furnace Energy Supply and Energy Sources**

A melting furnace derives its heat from solid fuels (coke and breeze), natural gas, electricity, or other sources of energy. To be smart user of energy we need find the ways to maximize the output by minimum input of the energy in each respect.

Since the products of flue gases directly contact the stock, type of fuel chosen is of importance. Some materials will not tolerate sulphur in the fuel. Also use of solid fuels will generate particulate matter, which will inhibit the stock place inside the furnace. Hence, vast majority of the furnaces use liquid fuel, gaseous fuel or electricity as energy input. Melting furnaces for steel, cast iron use electricity, in induction and arc furnaces, Nonferrous melting utilizes oil as fuel. Some other kinds of furnace described below;

a) Oil Fired Furnace

Furnace oil is the major fuel used in oil fired furnaces, especially for reheating and heat treatment of materials. LDO (Light Diesel Oil) is used in furnaces where presence of sulphur is undesirable. The key to efficient furnace operation lies in complete combustion of fuel with minimum excess air. Ansari & Manager, (2015)discussed about Furnaces operation with efficiencies as low as 7% against up to 90% achievable in other combustion equipment such as boiler. This is because of the high temperature at which the furnaces have to operate to meet the required demand. For example, a furnace heating the stock to 1200^{o}C will have its exhaust gases leaving at least at 120^{o}C resulting in a huge heat loss through the stack. However, improvements inefficiencies have been brought about by methods such as preheating of stock, preheating of combustion air and other waste heat recovery systems.

b) Tilting Furnace

Oil fired tilting furnace is a type of Crucible furnace for the melting of nonferrous metals. Its capacity may range from 30 to 150 kg. This furnace is a kind of furnace that is used in some industry for melting nonferrous metals in small quantity and is fired by oil and furnace is mounted on two pedestals above the floor level. For pouring the molten metal, the furnace is rotated by the geared hand wheel; Oil and air are admitted with pressure through a nozzle. The crucible is placed in the heating chamber and is heated by the flame. The furnace can be stopped whenever needed and temperature can be controlled easily and also they give lesser pollution.

2.3 Process description of foundry shop

Foundries melt ferrous (iron and steel) and nonferrous (mainly aluminum, copper, zinc, lead, tin, nickel, magnesium, and titanium) and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould, The typical foundry process activities are shown in the figure below.

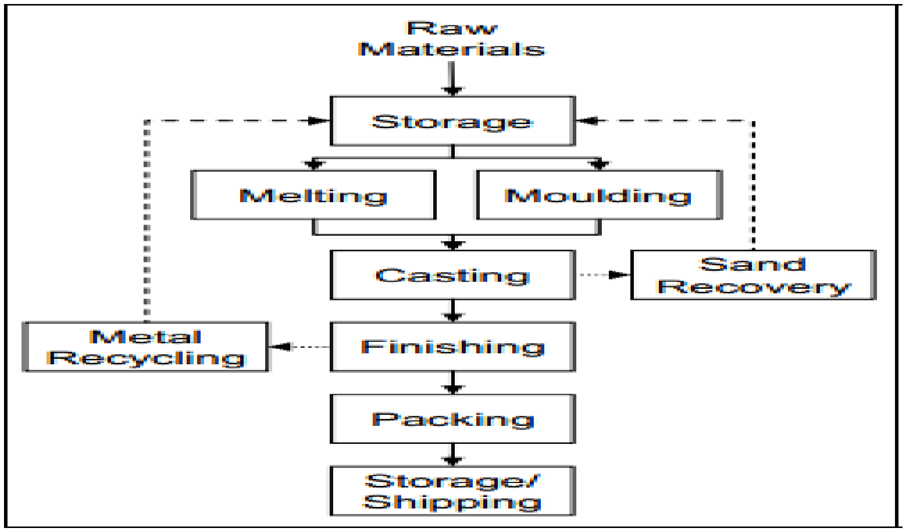


Figure-2.2 Flow diagrams for foundry process activities (Environmental, 2013)

- ✓ **Melting**: different types of furnaces are used depending on the type of metal. The metal may require treatment such as desulphurization, refining, and deoxidization. Metal flux can be added to the melt to combine with impurities to form a slag which is removed before pouring.
- ✓ **Molding**: there are two basic types of molds; Lost Molds (single use): These molds are generally made from sand and are lost in the process. These are mainly used in ferrous casting but are also used in non-ferrous casting

Permanent molds (multi-use): These molds are normally metallic and are mainly used for non-ferrous casting. Sand molds are bonded together to form the desired shape using the natural properties of the clay particles within the sand 85% of molds are made from green sand which is a mix of sand, clay, carbonaceous material and water or a chemical binder.

Permanent molds are made from metal with a higher melting point than the casting metal and can be reused to produce large quantities of the same piece.

- ✓ **Casting**: different pouring systems are used depending on the metal and the type of mould, e.g. by gravity (lost mould), injection under low or high pressure, or by centrifugal force. The metal is allowed to solidify and the mould is broken away and, in the case of lost molds, the sand is shaken from the metal parts. Most of the sand can be reused. The casting is then subject to further controlled cooling.

- ✓ **Finishing**: depending on the casting process, different steps may be required, e.g. shot blasting, grinding, thermal treating, inspection and testing. Welding to join or repair castings may be required as well as chemical cleaning before coating operations

- **Mold Making**

A suitable and workable material possessing high refractoriness in nature can be used for mould making. Thus, the mold making material can be metallic or non-metallic. For metallic category, the common materials are cast iron, mild steel and alloy steels. In the non-metallic group molding sands, plaster of Paris, graphite, silicon carbide and ceramics are included. But, out of all, the molding sand is the most common utilized non-metallic molding material because of its certain inherent properties namely refractoriness, chemical and thermal stability at higher temperature, high permeability and workability along with good strength. Moreover, it is also highly cheap and easily available.

- **Molding sand**

The general sources of receiving molding sands are the beds of sea, rivers, lakes, granular elements of rocks, and deserts. Molding sands may be of two types namely natural or synthetic. Natural molding sands contain sufficient binder, Whereas synthetic molding sands are prepared artificially using basic sand molding constituents (silica sand in 88-92%, binder 6-12%, water or moisture content 3-6% (Guili, 2012).and other additives in proper proportion by weight with perfect mixing and considering in suitable equipment.

- **Constituents of Molding Sand**

Silica sand: Silica sand in form of granular quarts is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand. But along with silica small amounts of iron oxide, alumina, lime stone, magnesia, soda and potash are present as impurities. The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. Present. The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point to a considerable extent which is undesirable. The silica sand can be specified according to the size (small, medium and large silica sand grain) and the shape (angular, sub-angular and rounded)

- **Binder**

In general, the binders can be either inorganic or organic substance. The inorganic group includes clay sodium silicate and port land cement etc. In foundry shop, the clay acts as binder which may be Kaolonite, Ball Clay, Fire Clay, Limonite, Fuller's earth and Bentonite. Binders included in the organic group are dextrin, molasses, cereal binders, linseed oil and resins like phenol formaldehyde, urea formaldehyde etc. Organic binders are mostly used for core making.

- **Moisture**

The amount of moisture content in the molding sand varies generally between 2 to 8 percent(Cove & Corporation, 2017)This amount is added to the mixture of clay and silica sand for developing bonds. This is the amount of water required to fill the pores between the particles of clay without separating them. This amount of water is held rigidly by the clay and is mainly responsible for developing the strength in the sand. The effect of clay and water decreases permeability with increasing clay and moisture content.

Kinds of molding sand

Molding sands can also be classified according to their use into number of varieties which are described below:

I. **Green sand:-** is also known as tempered or natural sand which is a just prepared mixture of silica sand with 18 to 30 percent clay, having moisture content from 6% to 8% (Introduction to Basic Manufacturing Processes and Workshop Technology,2014). The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Molds prepared by this sand are not requiring backing and hence are known as green sand molds. This sand is easily available and it possesses low cost. It is commonly employed for production of ferrous and non-ferrous castings.

II. **Dry sand:-** Green sand that has been dried or baked in suitable oven after the making mold and cores is called dry sand. It possesses more strength, rigidity and thermal stability. It is mainly suitable for larger castings. Mold prepared in this sand are known as dry sand molds.

- **Cast iron molding process**

The green sand uses as sand mold prepared with a mixture of sand, clay, water and sea coal as the organic component. Molding process consist of sand being squeezed or compacted on pattern (steel pattern), when the pattern removed the sand gain the shape of the pattern. The mold consists of two halves at the top and at bottom top is placed on the bottom and the melted iron is poured into the top of cape forming casting void formed by the pattern as the molten cast iron fills void space of patter.

2.4 Waste Heat and source of waste heat

2.4.1 Waste Heat

According to Suryavanshi & Pitale(2017)waste heat is industrial heat energy that is generated in industrial processes without being put to practical use. A large amount of energy used by industry is wasted as heat in the form of exhaust gases, air streams, and liquids leaving industrial facilities. Arzbaecher, Fouche, Parmenter, et.al (2007)introduce waste heat as the energy that is rejected from a process at a temperature high enough to permit the recovery of some fraction of the energy for useful purposes in an economic manner. Solid Waste et al.(2016) waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln.

2.4.2 Source of waste heat

Waste heat is generated from a variety of industrial systems distributed throughout a manufacturing plant. According to Waste Heat & Systems, (2015)The largest sources of waste heat for most industries are exhaust and flue gases and heated air from heating systems such as high-temperature gases from burners in process heating; lower temperature gases from heat treating furnaces, dryers, and heaters; and heat from heat exchangers, cooling liquids, and gases. About 92% of process heat energy used by U.S. Industry is directly provided by fossil fuels Milano,(2017). The waste heat produced from direct-fired processes categorized in the high and medium temperature ranges. In the high temperature range, sources of waste heat include refining furnaces, steel heating furnaces, glass melting furnaces, and solid waste incinerators.

High-temperature waste heat is the highest quality and most useful because it provides more heat recovery options and thus greater potential cost-effectiveness than lower temperature waste heat. It can be made available to do work through the utilization of steam turbines or gas turbines to generate energy in a cogeneration plant.

In the medium temperature range, sources of waste heat include exhaust gases from steam boilers, gas turbines, reciprocating engines, water heating boiler furnaces, fuel cells, and drying and baking ovens. Potential heat recovery opportunities include, among others, low pressure steam generation and incoming product preheating. In the low-temperature range, sources of waste heat include process steam condensate, cooling water from refrigeration condensers, and air compressors. In some applications low-temperature waste heat can be used for preheating through heat exchangers, and used to preheat the ventilating air for winter space heating. In considering the potential for heat recovery, it is useful to note all the opportunities, and grade the waste heat in terms of prospective value as shown in the following Table.

Table -2.2 Waste Heat Source and quality

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 lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats
4	Heat losses in cooling water	Low grade – useful gains if heat is exchanged with incoming fresh water
5	Heat losses in providing chilled water Or in the disposal of chilled water	a) High grade if it can be utilized to reduce Demand for refrigeration b) Low grade if refrigeration unit used as a form of heat pump
6	Heat stored in products leaving the process	Quality depends upon temperature.
7	Heat in gaseous and liquid effluents leaving process	Poor if heavily contaminated and thus requiring. Alloy heat exchanger

2.4.3 Waste Heat recovery

(Feng Lia, Lin Duanmua and Lin Fub et,al ,2016)identified that the largest sources of waste heat for most industries are exhaust flue gases and heated air from heating systems such as high-temperature gases from burners in process heating; lower temperature gases from heat treating furnaces, dryers, and heaters; and heat from heat exchangers, etc. While waste heat in the form of exhaust flue gases is readily identified, waste heat can also be found within liquids and solids. Waste heat within liquids includes cooling water, heated wash water, and blow-down water. Solids can be hot products that are discharged after processing or after reactions are complete, or they can be hot by-products from processes or combustion of solid materials. Other waste heat sources are not as apparent such as hot surfaces, steam leaks, and boiler blow-down water.

Heat recovery includes any technique or method aiming at reducing the primary energy consumption of a system, by utilizing thermal energy that would be otherwise wasted. Heat losses must be minimized before waste heat recovery is investigated.

Energy Audit Standard for Process Heat Systems, (2016.)Waste heat can be recovered in several ways, such as: Boiler feed water pre-heating, Combustion air preheating-can often just be a simple redirecting of HVAC exhaust air towards a burner inlet, Process heating e.g. product preheating, Use of thermal storage, Direct heating of heat-transfer medium such as hot water or steam and Cascading -multiple processes with successively lower heating requirements can use the heat waste from the process at a higher temperature. It is estimated that 20-50% of industrial energy input is lost as waste heat in the form of hot exhaust gases, cooling water, or heat loss from equipment surfaces and heated items. Any industrial process which uses heat can reduce energy use either by using heat exchangers to transfer the heat somewhere else to where it is useful in another process, or, if the temperature is sufficiently high, to generate electricity.

The most common use of recovered heat is to preheat inputs to furnaces. Heat may either be reused within the same or a different process, or sometimes by a neighbouring industrial facility. The temperature of the heat determines its possible use, e.g. paper production only needs heat at around 150 – 200°C to evaporate water from wet pulp, while plastics manufacture at 200°C.

Abundant technologies are commercially accessible for waste heat recovery; so far in many applications it remains relatively unexploited. For it to be successful, an accessible source of waste heat, the correct recovery technology, and a use for the recovered energy need to be present. Facilities may need specialist help in identifying these and in evaluating the feasibility of waste heat recovery.

Heat-cascading systems, where waste heat from one company is used by another, are a promising option for saving energy. In parts of Sweden waste industrial heat is used to provide heat into district heating which heats nearby houses. Elsewhere it is used to heat greenhouses which may grow crops such as tomatoes. Greater integration of heat sources and heat demand through heat recovery is a valuable opportunity

Reducing exhaust losses should always be the first step in a well-planned energy conservation program. Once that goal has been met, consider the next level – waste heat recovery. Waste heat recovery elevates furnace efficiency to higher levels, because it extracts energy from the exhaust gases and recycles it to the process. Significant efficiency improvements can be made. There are different methods which are used widely:

Direct heat recovery to the product. If exhaust gases leaving the high-temperature portion of the process can be brought into contact with a relatively cool incoming load, energy will be transferred to the load and preheats the load. This reduces the energy that finally escapes with the exhaust. This is the most efficient use of waste heat in the exhaust.

Use of waste heat recovery to preheat combustion air is commonly used in medium- to high temperature furnaces. Use of preheated air for the burners reduces the amount of purchased fuel required to meet the process heat requirements. Preheating of combustion air requires the use of a recuperator or a regenerator. Recuperators: A recuperator (Figure Below) is a gas-to-gas heat exchanger placed on the stack of the furnace. There are numerous designs, but all rely on tubes or plates to transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing. Recuperators are the most widely used heat recovery devices.

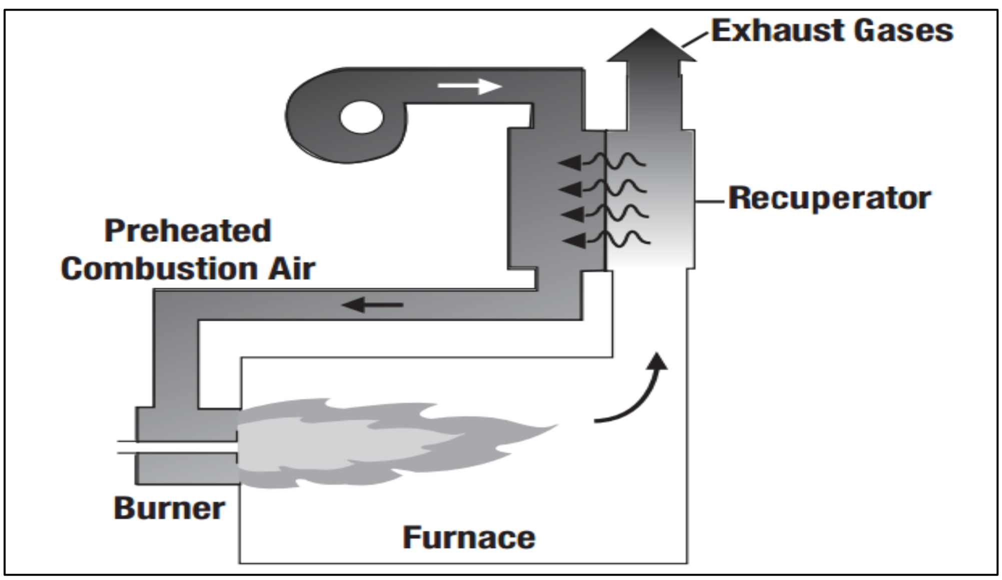


Figure-2.3 Gas to gas recuperator(Matters, 2007)

Today's challenging issues such as climate change; energy prices and fuel security have focused the attention of process industries on their energy efficiency and opportunities for improvement. Heat recovery can be applied both in residential and industrial utilities, whenever the conditions are feasible for its technical and economic successful application.

2.5 Available heat in flue gas

Available heat is defined as the difference between the heat entering a heating system and the heat discharged from the flue gas. The available heat represents the amount of heat that remains within the heating system(Furnace) as a fraction of the heat input (California Energy Commission (2012)).

A higher percentage of available heat means more of the heat input remains in the heating system and results in reduced losses through the flue gases. This results in better performance for the system. The value of available heat is independent of the heating system designed as long as the following parameters are known: Fuel composition, flue gas temperature, percentage of oxygen in exhaust gas, Combustion air temperature used for the burners and Fuel temperature.Figure-2.2 below show available heat and heat loss from furnace.

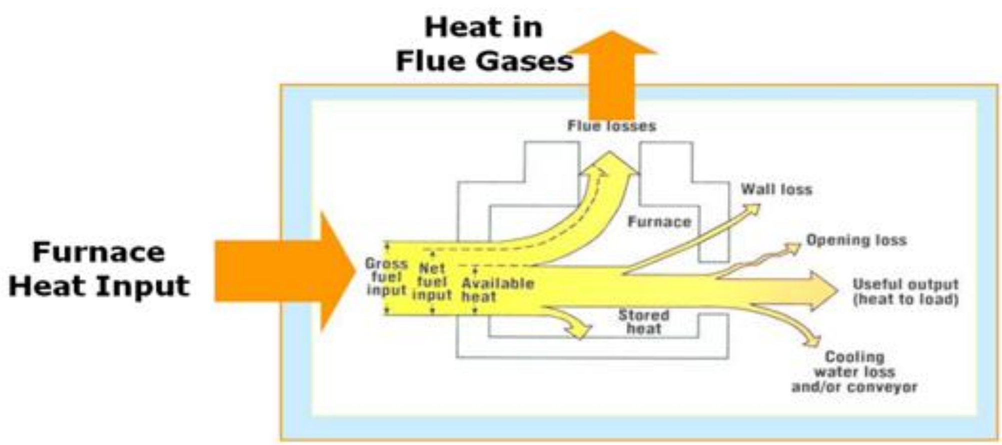


Figure-2.4 Heat losses in industrial Furnaces (BEEM,2012)

2.6 Heat characterization

Thermal energy recovered in a heat recovery application can be characterized by different factors that influence its possible utilization. In addition to these aspects, peculiar to the available waste energy, other factors must be considered, including possible scale economies, heat accessibility, national polices and so on; all these are going to affect the cost at which the heat could be recovered, and thus the feasibility of the project.

2.6.1 Waste Heat Quantity

The first aspect to be considered is the quantity of the available heat. Obviously, the heat recovery process will be unjustified for small quantities of available energy. An accurate estimation of the possible magnitude of energy recoverable must be the first step of a feasibility study. The quantity or heat content is a measure of how much energy is contained in the waste heat stream. The quantity of waste heat contained in the waste stream is a function of the temperature and mass flow rate of the stream, which is given by:

$$Q = \dot{m}\ C_P\ (\Delta T) \tag{2.1}$$

Where: Q: Waste heat

$\dot{m}$: The waste stream mass flow rate (kg/s)

ΔT: Change in temperature

2.6.2 Waste Heat Quality

The quality of waste heat is directly related to the temperature of waste heat. The higher the temperature, the higher the quality of waste heat stream and it is more economically viable to recover it, higher the temperature at which the heat is supplied, the higher is its quality. Milano, (2017) presented Three different temperature levels have been used for describing the quality of the demand for heat, in various industrial branches **High temperature heat**: supply temperature higher than 400^{o}C, required for processes such as manufacture of metals. These temperatures are reached by using hot flue gases, electric induction, etc. **Medium temperature heat**: supply temperature between 100 and 400°C, Normally supplied through steam as a local heat carrier, usually in processes like evaporate or drying, **Low temperature heat**: supply temperature lower than 100 °C, typical heat demand for space heating. Industrial Process Heat Recovery,(2014) Process heat recovery involves blending the waste streams before they liberated to the environments from the plant, harvesting some of the heat contained, and utilizing that heat.

2.7 Factors Affecting Waste Heat Recovery System

Deshmukh, et,al. (2017) described the parameters allow for analysis of the waste heat recovery such as; quality and quantity of the Waste Stream, Composition and Minimum Allowable Temperature. These parameters 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 some other factor affecting the available waste heat is described below;

1) Heat Quantity

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

Waste Stream Composition: Although chemical compositions do not directly influence the quality or quantity of the available heat, 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.

2) Flue gas temperature

Higher flue gas temperature increase the heat content of flue gases and lowers the amount of heat remaining in the heating system. This would result in lower available heat, 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, sulphates in exhaust gases from glass melting furnaces will deposit on heat exchanger surfaces at temperatures below about 110ºC.

3) Fuel composition

The initial composition of fuel directly affects the ultimate composition of combustion products and the amount of heat released into heating system. In general, with all other conditions remaining the same, flue gas containing higher CO and H_2 would have lower available heat.

4) Percent oxygen (O_2) in exhaust gases

The amount of excess air in flue gases is represented by amount of O_2 in flue gases. Higher O_2 value indicates higher excess air and a greater amount of heat contained within the flue gases. This results in a lower available heat.

5) Fuel temperature

Preheated fuel increases value of available heat, in almost all cases, it is recommended that high heating value fuels such as natural gas should not be preheated, but in this study it recommend that the furnace oil is pre heated to some extent.

Other factors

Several factors which are not related to fuel combustion in a heating process can affect available heat for a fuel. The discharge of water vapor, water, or other gases such as carbon dioxide into a heating system will reduce value of available heat. In such cases it is necessary to conduct detail flue gas analysis using special instruments to measure the composition and total heat content of the flue gases.

2.8 Applications of waste heat recovery

Heat recovery can be functional in many industries. For example, the pulp and paper industry can utilize heat recovery through several processes, from preheating milling water with steam to cooling effluent waste water before sending it to waste treatment. The chemical industry can apply heat recovery to most processes, including chemical manufacturing, as well as to emissions control devices such as recuperative and regenerative thermal oxidizers. Waste heat to power (WHP) is the process of capturing heat discarded by an existing industrial process and using that heat to generate power.

2.9 Data Collection

The data for the research work was collected from different sources- such as from literatures, measurement, observation and documented data. Generally, two types of data have been collected: primary data and secondary data. Primary data is obtained by the researcher, and is the result of self-studies of the problem. It includes the collection of information through direct observation, personal interviews, and conducting conversation. The secondary data, on the other hand, is the result of other people’s research in the same problem area, or from other related problem areas. It includes the study of document, web-sites and other historical and documentary records relevant for the research or from different literature.

G-seven industry has a conventional type of furnace, which is installed in the foundry shop. The types of the furnace is conventional oil fired furnace with crucible and fired by oil which is furnace oil with a gross calorific value of 10500kcal/kg Fuel et al. (2010). All the data for the analysis of the foundry shop, is available heat and heat loss have been collected and examined before the installation of the newly designed heat recovery and utilization system.

2.9.1 Energy audit of the foundry shop

Energy audits have been internationally used across all sectors to identify efficiency measures that can be implemented in a cost-effective manner. However to be effective, it has often required both the audits as well as the implementation of measures to be compulsory or to be supported by appropriations.

The Strategy will promote energy audits as a means of improving efficiency. Grinbergs &Gusta, (2007)Studies undertaken to design ways in which audits will achieve the greatest impact, an industrial energy audit is a process that facilities energy usage patterns, equipment efficiency, and overall building efficiency are determined in order to propose energy efficiency measures. The result of a successful energy audit is decreased energy consumption, reduced raw material usage and increased quality of the end product. The data collected by an energy auditor is the basis on which the energy efficiency suggestions will be created.

The implementation of these measures will reduce manufacturing costs and also the negative effects on the environment; industrial energy audit is a new term in G7 industry. It is a process aimed at finding gaps in the production process, a design task in order to save raw materials and energy. Energy audit study helps an organization to understand and analyze its energy utilization and to identify areas where energy use can be reduced, to budget energy use, plan and implement feasible energy conservation measures that will enhance their energy efficiency, restrain energy wastage and substantially reduce energy costs.

The Energy Audit serves to identify all the energy streams in the foundry shop, quantifies energy usage with its discrete functions, in an attempt to balance the total energy input with its usage. Undertaking industrial energy audits makes it possible to save raw materials, energy, optimizing the manufacturing process or raising the company's profits, to choose best available technology for waste heat recovery, increase energy competitiveness.

2.9.2 Types of energy audit

Rasmeni & Pan, (2014) describe energy audit is commonly used to show a broad spectrum of energy studies ranging from a quick walk-through of a facility to identify major problem areas to a comprehensive analysis of the implications of alternative energy efficiency measures sufficient to satisfy the financial criteria of sophisticated investors. Energy audit in a plant is generally conducted in two stages.

- **Preliminary Audit**

The preliminary audit alternatively called a simple audit, walk-through audit, is the simplest and quickest type of audit. It involves minimal interviews with site operating personnel, a brief review of foundry shop or facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and identify areas of energy waste or inefficiency. This level of audit is not detail, so that not sufficient for reaching a final decision to propose measures, is adequate to prioritize energy efficiency projects and determine the need for a more detailed audit.

- **General Audit**

General audit is also called a site energy audit or complete site energy audit which expands from the preliminary audit described above by collecting more detailed information about facility or foundry shop operation and performing a more detailed evaluation of energy conservation measures identified. Utility bills are collected for a minimum of 6 to 12 month to allow the auditor to evaluate the facility's energy usage profiles. Additional measuring of specific energy-consuming systems or equipment is often performed to supplement utility data.

In-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy consuming systems as well as insight into variations in daily and annual energy consumption.

- **Energy bill of the foundry shop**

Energy bills, especially those for electricity and fuel oil are very useful for determining and analyzing the shop energy consumption and costs. Tabulating energy bills over time and making simple calculations will give us the following advantage:

- To set our saving objectives and targets
- To make a preliminary correlation between the energy and demand figures and the operation of the foundry shop.

- To know and analyze any unexpected increases in demand and/or consumption, later, we can track down and, where necessary, to correct the condition those is causing the increase and thereby identify an Energy Management Opportunity.
- To confirm the savings expected from any energy conservation measures that have been recommended for implementation.
- To choose the best available technology for heat recovery technology and to apply it these technology.
- To evaluate and compare the energy use and demand of the foundry shop to another facility or to standards (benchmarks) on different bases.

Therefore, Energy management tasks will be simplified if records of data and any information related to the factory foundry shop energy consumption are measured and obtained as needed. It is also important to know how much the industry is paying to run and how the energy costs are calculated.

- **Benchmarking**

Benchmarking is used to assess an industries performance relative to that of its competitors or its own performance in the past. Benchmarking can also be to prioritize energy-saving options and to design method to reduce greenhouse gas emissions. International comparisons of energy efficiency can provide a benchmark against which a company’s or industry’s performance can be measured to that of the same type of industry in other countries.

Comparing the energy performance of the facility to its own past performance, the specific electricity consumption and specific fuel consumption are nearly constant or within a narrow range. But this doesn’t mean that the company is performing well, rather this shows the similarity between the amounts of energy consumed to melt metal and dry sand molds. Yet the company is expected to increase its performance by incorporating waste heat recovery and utilization technologies and energy saving equipment.

By implementing the energy efficient oil fired furnace in place of the former one will reduce consumption of furnace oil. In proposed energy efficiency oil fired furnace, oil consumption is low compared to conventional oil fired furnace. The principal sources of energy losses are exhaust hot air, distribution losses and chimney or stack losses. Therefore energy auditing action in foundry shop is appropriate.

CHAPTER THREE

3 MATERIAL AND METHOD

3.1 Introduction

This thesis work begins with data gathering for the research work, and a review of literatures is conducted on the area of energy use specifically in the foundry shop and efficiency in related to the furnace and some other equipment in the shop. Available books, journals, case studies, previous research works, guidelines and related sources are surveyed in order to have a clear understanding of the subject matter. Before dealing with the design of waste heat recovery system to the foundry shop, the data's can be collected through; Interview with the foundry shop personnel, Visiting the various energy consuming systems, Direct measurement of some parameters with the help of measuring instrument, such as Infrared gun Thermometer, Anemometer, Thermocouple and etc. and then Energy audit of the foundry shop is manipulated.

The current studies on waste heat recovery and utilization from furnaces flue gas use basic heat transfer correlations to calculate the energy recovery. In this study a Full-size CFD model is developed to investigate amount of temperature or the heat reaching the mold drying room and the energy recovery from flue gas, for drying mold.

Simulations start by modeling illustrative geometries, like flue gas collecting hood, supply duct, mold drying room and chimney. And then Ansys fluent software used to simulate the fluid flow temperature distribution and heat transfer phenomenon to predict the performance of heat recovery system.

3.2 Methodology of data gathering

The methodologies of conducting energy audit includes, preliminary visit (walk through audit) to the company, then examine the entire production process of the foundry shop like; What is produced?, What input are used and amount of energy used?, Characteristics and quantity of raw material used? , And others specific information is investigated. And also we need to examine Where/how energy is being consumed /wasted, where corrective actions are needed and then data collection as per the requirements and scheduled is followed. After the data collection energy conservation opportunities are identified through data analysis.

In the case of G-7 industry the energy audit of the foundry shop has to be carried out before directly goes to waste heat recovery opportunity from flue gas and its utilization. In order to quantify how much heat the process requires and how much fuel is required, we must know the amount of heat available and how to measure it. In walk through energy audit identified equipment's that consume energy inside the shop, such as: Furnace, Fan, oil heater and Mold drying section.

Figure: 3.1 Furnace in the shop

Figure: 3.2 Mold drying system

Figure 3.3: Air blower Fan and oil heater which consume electrical energy

The first step to determine the importance of a heat recovery installation for any Facility or foundry shop is to gather all of the existing process data for the heating system of concern such as; Temperature measurements: Temperature data are particularly important for calculating the energy use of the unit processes like for example oil heater and furnace. Temperature measurements can also be used to calculate the efficiency of the furnace. To calculate the heat losses, the exhaust air temperature is important. Temperature sorting can be used to identify operating time for equipment. Air flow measurements: Air flow measurements can be used to calculate the heat losses due to amount air supplied by the fan, and also mass flow rate or volume flow rate of the flue gas at the exhaust of the chimney. To roughly estimate the electric power used for the fan motors. On the other hand, the electric power used for the fan motor can also give you an idea about the air flow.

3.3 Energy Usage of Foundry Shop

Fuel oil consumption

The amount of oil consumed in factory and the associated cost of oil for the last six years is shown in table 3.4 below. The maximum amount of fuel oil consumed is 11,520 Lt.in 2016GC. The consumption fuel oil is slightly increasing through the six years. The increase in the consumption of fuel is mainly due to the increase in the total production of the cast iron and lack of awareness about energy conservation and management.

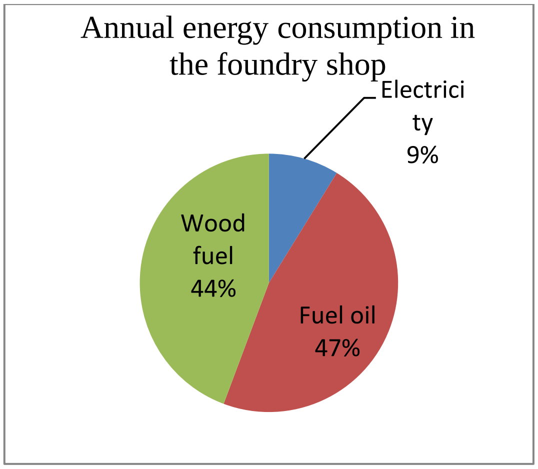
In addition to the increase in the amount of fuel oil consumed, the cost of fuel is increasing day to day. Because of this, the company cost to fuel is increased. The Company could improve and reduce the Specific fuel consumption by adapting an appropriate energy conservation measures.

Wood fuel consumption

The consumption of wood fuel in the shop are uniform it is about 50kg/day but, the cost of wood fuel for the last six years are increasing linearly. The maximum consumption of wood for drying molds occurs in 2017 GC, is about 9600kg/yr.

Electricity consumption

The consumption of electricity and the cost of electricity of the foundry shop for the last six years are uniform, which is about 67.30birr/month only for foundry shop use. From the figure below we can see that the total annual consumption of fuel oil, wood fuel and electricity of the foundry shop are 46.9%, 44.4%and 8.8% respectively



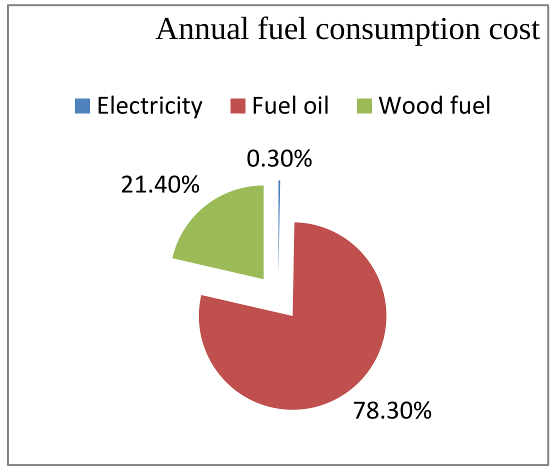


Figure-3.4 Breakdown of energy use and cost

Energy management tasks will be simplified if records of data and any information related to the factory foundry shop energy consumption are measured and obtained as needed. It is also important to know how much the industry is paying to run and how the energy costs are calculated, in table below shows summary of fuel consumption

Table-3.1: Summary of yearly consumption of fuel oil and wood with their respective costs

Year	Fuel consumption (Lts/yr.)	Cost of fuel (Birr/yr.)	Wood consumption (kg/yr.)	Cost of fuel (wood) (Birr/yr.)
2012	8,640	101,001	8064	28224
2013	9,600	112,224	9216	48,000
2014	9,600	142,464	9216	48,000
2015	10,560	168,960	9600	48,000
2016	11,520	184,320	9600	48,000
2017	10,560	173,184	9600	52,800

The recent foundry shop working condition is not best available technology for this energy intensive system from energy management point of view. Therefore, first energy audit of the foundry shop should be conducted to know what amount of energy is used by the system specifically inside the foundry shop.

3.4 Data Obtain by measurement

Table below shows measurement of hood temperature, chimney duct temperature and flue gas temperature after one hour (1hr) at the gap of 15 minute has been collected

Table 3.2: Measured temperature of flue gas at different location of system

No:	Flue gas temperature at the hood(^{0}C)	Flue gas Temperature at Middle of chimney (^{0}C)	The flue gas temperature at the out let of the chimney(^{0}C)
1	302	210	131
2	334	207	122
3	208	182	139
4	238	201	146
5	205	153	138
6	192	163	143
7	205	169	140

Some of measured data using instrument mentioned above and by examining the process visually we have the following parameters:

- ✓ Hours of operation per day = 4:00 hr/day on average
- ✓ Operating temperatures of the furnace = 1100-1400 ^{0}c
- ✓ Weight or amount of metal scrap melted = 150 Kg
- ✓ Fuel usage of the furnace = 55L per batch/day on average
- ✓ Amount of fuel (wood) used for drying mold = 48Kg-50Kg on average

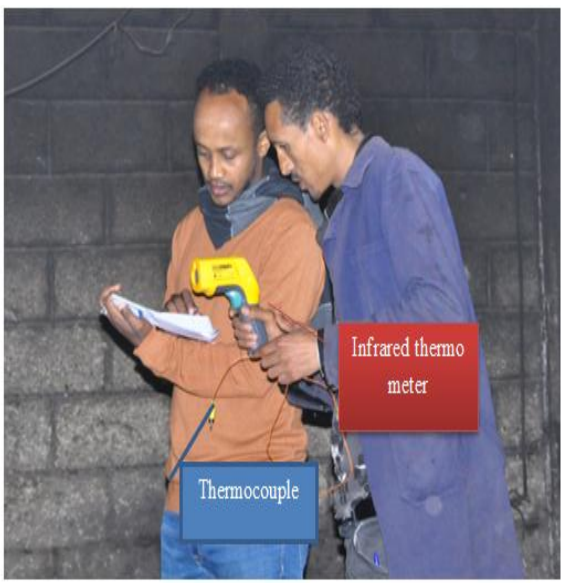
Table: 3.3 Average temperature of flue gases at furnaces exit, chimney & drying room (measured)

Average flue gas temperature @exit of furnace	240^{o}C
Average chimney duct temperature	184^{o}C
Average flue gas temperature exit of furnace chimney	146^{o}C

3.5 Instruments used for data collection

Data collection as per the requirements was recorded by using different mechanism, The following measurements was made to know amount Flue gas temperature, Temperature of furnace out let, walls and oil transport pipe, velocity of flue gas etc. Instruments like infrared thermometer, surface thermocouple and other measuring devices were used to measure the above stated parameters.

- Infrared thermometer :For measuring temperature of exhaust flue gas
- Anemometer: For measuring the velocity of flue gas at the top of the chimney
- Thermocouple: For measuring surface temperature of the pipes and some other equipment.



a) Infrared thermometer b) air flow measuring device (anemometer)

Figures-3.5 Instruments used for measuring data

Instruments like infrared thermometer, thermocouple and Anemometer are used to measure the flue gas temperature, surface temperature of pipes and velocity of the flue gas respectively.

CHAPTER FOUR

4 ANALYSIS AND SIMULATION MODEL DEVELOPMENT

4.1 Energy Loss Analysis in furnace

The efficiency of the furnace is lowered by the losses and out of all furnace losses, the major one being the exit flue gas loss which turn, mainly depends upon the exit gas temperature and excess air levels. Energy analysis is carried out based on the first law of thermodynamics, which is concerned with the law of conservation of energy. The energy losses in the furnace is calculated on the basis of first law of thermodynamics which mainly concentrates on the quantity of energy.

It is usually observed that a certain portion of heat input is lost due to many reasons. This loss represents the amount of energy exiting the furnace with the flue gas compared with the total energy entering the furnace with the fuel. Ideally, all heat added to the furnaces should be used to heat the load or stock.

Analysis of heat recovery opportunities involves determination of the current heat loss associated with a process and heat generation system, or other utilities. This requires the measurement of temperature and flow through different sections of the system. In practice, however, a lot of heat is lost in several ways as shown in the figure below.

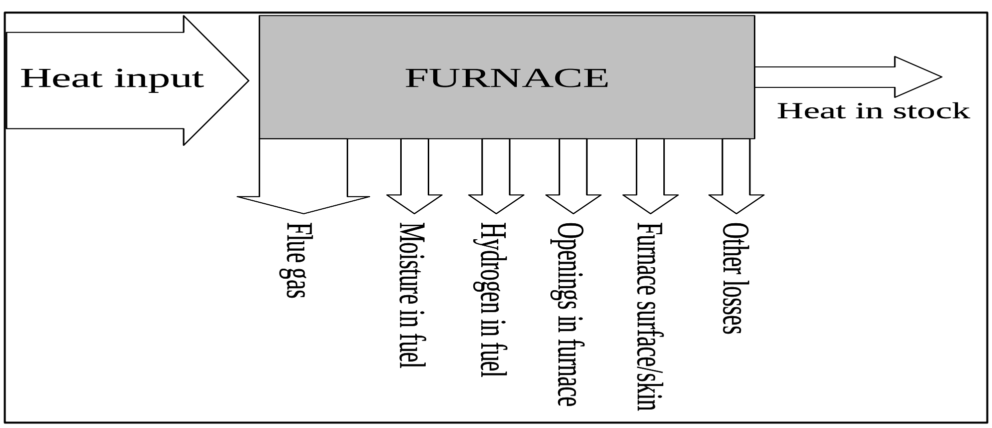


Figure-4.1 Heat Losses in All types of Furnace(Grinbergs et al., 2007)

Average fuel consumption of the furnace is about 0.01375m^3/hr. The flue gas exit temperature is 240^{o}c.Considering waste heat utilization from hot exhaust flue gas for drying molds having ambient temperature of 19^{o}c.

The fuel used in G-seven trading &industrial PLC. For the furnace is No. 2 oil (furnace oil) and its ultimate analysis are listed in Table-4.1 below

Table 4.1: chemical composition of furnace oil (BEE ,2017)

Chemical composition of furnace oil (Ultimate analysis)		
Constituents	**% By weight**	**Mass(kg)**
Carbon (C)	84.5	46.475
Hydrogen (H_2)	12.4	6.82
Oxygen (O_2)	1	0.55
Nitrogen (N_2)	0.6	0.33
Sulphur (S)	0.4	0.22
Moisture (H_2O)	1	0.55

To calculate the amount of heat carried away by the exhaust flue gases as percentage of the energy input and heat recovered by the system as percentage of the energy input.

- Heat Loss due to flue gas (BEE,2017)

$$\% \text{ heat loss due to dry flue gas}(L_1) = \frac{m^* C_p * (T_f - T_a)}{GCV} * 100$$

Heat in dry flue gas $(Q) = \dot{m}_{fg} C_{pf} (\Delta T)$

$\dot{m}_{fg}$= ρ×A×v

$= 0.6679 \text{kg/m}^3 \times \frac{\pi}{4} (0.4)^2 \times 1.2 \text{m/s} \quad = 0.1 \text{kg/s}$

Q_{fg} = 0.1kg/s ×1.1053kJ/kg.^{o}C ×221 ^{o}C =24.4kJ/s (87,840kJ/hr.)

- Loss due to evaporation of moisture present in the fuel

$$\%\text{loss} = \frac{M\{584+0.45(Tfg-Ta)\}}{\text{Cv of the fuel}} \ 100\%$$

Where: ρ-density, A - area of chimney, and v- is measured velocity of flue gas

- 584 is the latent heat corresponding to the partial pressure of water vapor.
- M: Mass of Moisture in % weight of Fuel = 0.55kg

M {584+Cp×ΔT} = 0.55kg{584+1.9kJ/kg.^{o}C×221^{o}C

= 552kJ (138kJ/hr.)

- Loss Due to Evaporation of Water Formed due to H_2 in Fuel

$$\% \text{ loss} = \frac{9N\{584+Cp(Tfg-Ta)\}}{\text{Cv of the fuel}}\ 100\%$$

Q = 9×N {584+Cp (ΔT)

Where; N = Mass H_2 in weight of Fuel

= 6.8kg (from table 4.2)

C_p = Specific heat of superheated steam (0.45kcal/kg.^{o}C)

= 9×6.8 kg {584+1.9kJ/kg.^{o}C (221 ^{o}C) =13,501kJ/hr.

- Heat Loss due to Openings

If a furnace body has an opening on it the heat in the furnace escapes to the outside as radiant heat. Heat loss due to openings can be calculated by computing blackbody radiation at furnace temperature, and multiplying these values with emissivity (usually0.8 for furnace brickwork) and the factor of radiation through openings. Black body radiation losses can be directly computed from the curves as given in the graph below

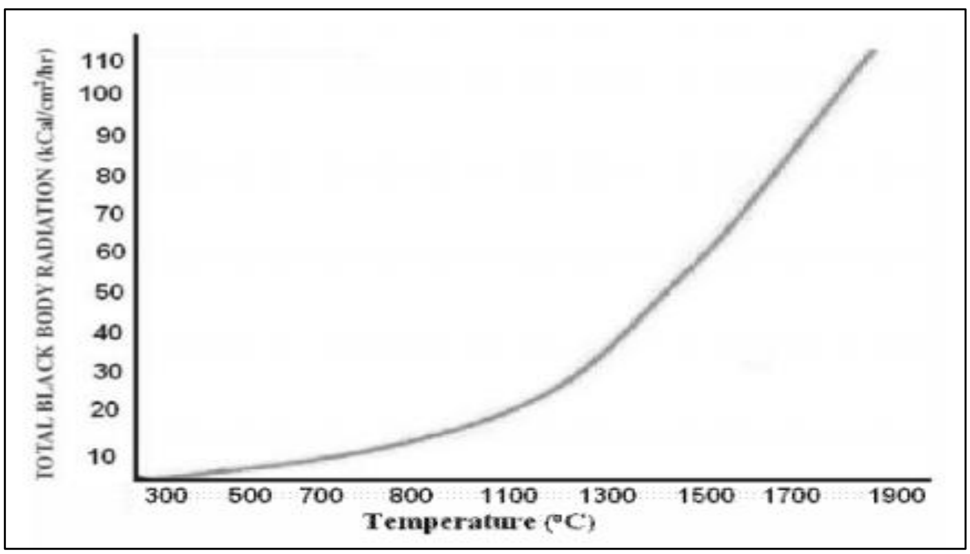


Figure-4.2 Graphs for Black Body Radiation at a Particular Temperature(Institute, 2015)

⇨ Black Body Radiation Corresponding to1350°C = 35kcal/cm^2/hr. in the figure above

The shape of the opening is circular

The Factor of Radiation = 0.75

Area of Opening = $\frac{\pi}{4}D^2 = \frac{\pi}{4}(60cm)^2$ = 3600cm^2

Opening Heat Loss = black body radiation x area of opening x factor of radiation x emissivity

= 35 kcal/cm^2/hr. x3600cm^2x0.75x0.8= 75600kcal/hr. (316,310kJ/hr.)

The Standard specified requirements, sampling and test methods for fuel oils, especially residual in their behavior, for industrial uses. (Fuel et al., 2010)These fuel oils are primarily intended for oil fired furnaces. Typical specification of fuel oil is summarized below in table-4.2

Table 4.2: Typical specification of fuel oil(Fuel et al., 2010)

Properties	**Furnace oil**	**Low sulphur heavy stock**	**Light diesel oil**
Density(Approx./cc at 15^{0}C)	0.89-0.95	0.88-0.98	0.85-0.87
Flash point(^{0}C)	66	93	66
Pour point(^{0}C)	20	72	18
G.C.V(Kcal/Kg)	10,500	10,600	10,700
Sediment.% Wt.Max	0.25	0.25	0.1
Sulphur total,%Vol.Max	Up to 4.0	Up to 5.0	Up to 1.8
Water content,%Vol.Max	1.0	1.0	0.25
Ash %Wt.Max	0.1	0.1	0.02

❖ **Energy Input**

Heat in the Fuel Consumed = Heat Input of Fuel

Heat Input of liquid Fuel = $m_f C_v$

Where: m_f = mass of fuel

C_v = calorific value of fuel = 10500kcal/kg = 43932kJ/kg

Density of furnace oil on average = 0.89-0.95 g/cc = 900kg/m^3

Volume of fuel consumed per hour = $0.01375m^3/hr$.

Mass of fuel = Density× Volume

= $900kg/m^3 \times 0.055m^3$

= 49.5kg = 12.4kg/hr.

$\dot{m}_f$ Cv =12.4kg/hr.× 43932kJ/kg

Heat Input of liquid Fuel = 544,756kJ/hr.

Heat in the Stock Q = $m_s C_{pi} \times \Delta T$

Where: m_s is mass of cast iron =150kg

Cpi-Specific Heat of cast Iron = 0.47KJ/Kg. °C=0.11kcal/kg.^{0}c(Ahmad et al., 2016)

T_i: Melting Temperature of Iron (1482°C) (Ahmad et al., 2016)

T_a: Ambient Temperature (19°C)

$\Delta T = 1482^0C - 19^0C = \Delta T = 1463°C$

Therefore; Heat in the Stock (Q)

Q = $m_s \times Cps \times \Delta T$=150kg×0.47kJ/kg.°C×1463°C

= 25785.4kJ/hr.

The simplified representation of furnace heat loss and heat in put to the furnace as well as the energy balance of the heating system can be presented by using Sankey diagram as shown below. The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler, fired heaters, furnaces after carrying out energy balance calculation (BEE, 2015).

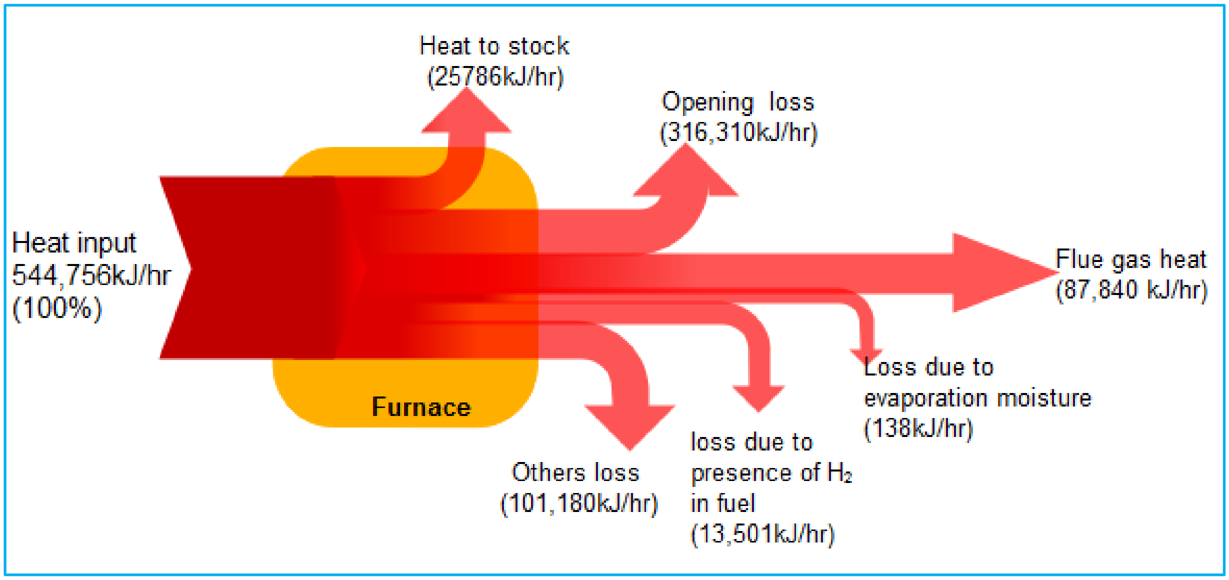


Figure-4.3: Sankey diagram representations of existing furnace in the shop

4.2 Analytical calculation for exit temperature of flue gas at out let of supply duct

The circular supply duct of length 10 m and the cross-section area of supply duct calculated to be 12.56 m^2 are analyzed having the following inlet conditions from measured data:

- ✓ Inlet temperature of flue gas 240°C
- ✓ The flow rate of flue gas through the duct is 0.1kg/sec.
- ✓ Ambient temperature is 19°C

The exit temperature of the flue gas at the out let of the supply duct is unknown ,so the properties of the fluid are calculated at the inlet temperature which is 240°C or 513K and some properties of flue gas at different temperature calculated using Lauterbach Verfahrenstechnik (LV) software as attached in appendix B,

The flow of fluid is governed by a non-dimensional quantity called the Reynolds number(*Simulation of waste heat recovery*, 2017).

$$Re = \frac{Vd}{v} \qquad (4.3)$$

Where,

V – Velocity (m/s)

d – Diameter (m), v – Kinematic Viscosity (m^2/s)

The kinematic viscosity(ν) of flue gas at temperature t in ^{o}C is calculated using Lauterbach Verfahrenstechnik (LV) software as attached in appendix B.

$\nu = (0.1335 + 0.925x10^{-3}t)\ x10^{-4}\ m^2/s$

Where t - is temperature entering to supply duct

The temperature of the flue gas entering to supply duct is 513K or 240^{o}C. So the kinematic viscosity becomes:

$\nu = (0.1335 + 0.925x10^{-3}\ x240\ ^{o}C)\ x10^{-4}$

$= 0.00003555\ m^2/s$

The velocity of flue gas is taken from measured value, the Reynolds number for a flue gas with given velocity (V) of 1.2m/s(from measurement) in a duct of 0.4 m diameter (d) is;

$Re = \frac{1.2 \times 0.4}{0.0000355} = 13,502$

Reynolds number, which is greater than 4000 then the flow is turbulent.

In heat transfer analysis, a non-dimensional heat transfer coefficient, called Nusselt number, Denoted by "Nu" is defined

$$Nu = \frac{hd}{k} \quad (4.4)$$

Where;

h - Heat Transfer Coeff. (W/m2-K)

d- Diameter (m), K -Thermal Conductivity (W/m-K)

The correlation for the calculation of Nusselt number for fluid flowing through the duct is given by Dittus and Boelter (Gupta, 2017). Dittus-Boelter Equation is the most common correlation used in turbulent flows.

$$Nu = 0.023\ Re^{0.8}\ Pr^{n} \quad (4.5)$$

Where; n = 0.4 for heating, n = 0.3 for cooling

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

Prandl number, Pr - is, given by; $Pr = \frac{C_p \mu}{k}$

But, most gases have a value of Pr of about 0.74, and this value is significantly independent of temperature(Shah, 2003) Hence the above equation simplifies to:

$Nu = 0.023\ Re^{0.8}$

$= 0.023(7894.7)^{0.8} = 30.2$

Based on the expression in equation (4.5) rearranging the parameters the supply duct heat transfer coefficient is calculated to be;

$h = \frac{Nu \times k}{d}$ (W/m^2.K)

Where K is thermal conductivity of flue gas can be calculated using Lauterbach Verfahrenstechnik (LV) software calculated result as attached in appendix B

Therefore; based on the expression below the heat transfer coefficient is calculated to be

$h = \frac{Nu \times k}{d}$ in (W/m^2.K)

$h = \frac{30.2 \times 0.03997}{0.4} = 3$ W/m^2 .K

from the measurement, the distance from melting furnace mold drying room is 5m and the length of supply duct needed is 10m ,surface area of supply duct will be;

$A_s = \pi DL = 3.14 \times 0.4m \times 10m = 12.56m^2$

Hence, Based on the equation below the exit temperature of flue gas can be calculated as follows;

$$T_e = T_s - (T_s - T_i)e^{-\frac{hA}{\dot{m}C_p}} \quad (4.6)$$

$$T_e = 35 - (35 - 240)e^{-3\times12.56/0.1\times1.1053}$$

$= 157.1\ ^oC$

Hence, as the flue gas pass via supply duct from inlet of the hood to the exit of the duct it losses heat or temperature of the existing flue gas. Since we have the inlet and exit temperature of the flue gas of supply duct, we can evaluate rate of heat loss from the duct by using, the (LMTD) logarithmic mean temperature difference.

Then rate of heat loss from the flue gas becomes(Singh, 2015)

$$\Delta Tlm = \frac{Te - Ti}{\ln\left(\frac{Ts - Te}{Ts - Ti}\right)} \quad (4.7)$$

Where; Ti-inlet temperature of flue gas

Ts-Surface temperature of the duct

Te- Exit temperature of flue gas

Substituting the value of temperature we will find mean temperature of the flue gas to be;

$$\Delta Tlm = \frac{157.1 - 240}{ln\left(\frac{35 - 157.1}{35 - 240}\right)} \quad (4.8)$$

$= 160.0\,^{o}C$

Rate of heat loss due to the flue gas is calculates as

$$\dot{Q} = hAs\Delta Tlm$$

$$\dot{Q} = 3w/m^2.K \times 12.56\,m^2 \times 160o_C$$

$= 6028.8W$

The temperature of flue gas drops by nearly 80°C as it flows in the duct as a result of heat loss.

4.3 Determination of Available Heat Analysis

In a heat recovery system it is essential to know the amount of heat recoverable. After analyzing and calculating the amount of heat recovered, justification of how it can be used effectively is crucial for recovery system. The process of determining amount of heat energy contained in gaseous form can also be applied for flue gas, where specific heat capacity, Cp, mass, m, and temperature differential between flue gas and heat sink, ΔT are required in order to calculate the energy content. The understanding of the amount of the heat that could be recovered by implementing flue gas utilization is essential in order to evaluate the technical effectiveness of the process. The thermal energy to be recovered from the furnace flue gas is evaluated as follow:

4.3.1 Heat available at exhaust of furnace

Heat available in part of the foundry shop system can be calculated as follow, the quantity of heat in available is given by the formula(Gupta, 2003).

$$Q = \dot{m}_{fg} C_{pf} (\Delta T) \quad (4.9)$$

$\dot{m}_{fg}$= mass flow rate of flue gas

C_p = Specific Heat of Flue Gas=1.1053kJ/kg. ^{0}C (Annex B)

Δ T = Temperature Difference=T_{fg}-T_a

T_{fg} = Flue Gas Temperature at exit of furnace =240.2^{0}C (on average measured)

T_a = Ambient Temperature =19^{0}C (measured)

Δ T = 221^{0}C

Available Heat at exhaust of furnace

= $\dot{m}_{fg}$ x C_{pf} x Δ T

$\dot{m}_{fg}$ = ρ×A×v where; ρ-density, A- area of chimney, and v- is measured velocity of flue gas

= 0.6679kg/m^3 ×$\frac{\pi}{4}(0.4)^2$ ×1.2m/s = 0.1kg/s

= 0.1kg/sx1.1053kJ/kg ^{0}C x221^{0}C = 24.4kJ/s (24.4kw)

4.3.2 Available heat arriving at mold drying room

$$\dot{Q} = \dot{m}_{fg} C_{pf} (\Delta T)$$

Where;

C_p = Specific Heat of Flue Gas =1.1053kJ/kg. ^{0}C (Annex B)

Δ T = Temperature Difference=T_{fg}-T_a

T_{fg} = Flue Gas Temperature at exit of supply duct which is from calculated result

= 157.1^{0}C or 430K

T_a = Ambient Temperature =19 ^{0}C (measured result)

Δ T = 138.1^{0}C= 411K

Available Heat in mold drying room, from equation (4.9) given by;

$\dot{Q} = \dot{m}_{fg} C_{pf} (\Delta T)$ =0.1kg/sx1.1053kJ/kg ^{0}C x138^{0}C

Substituting and rearranging the values we have heat at mold drying room will be;

$\dot{Q}$ = 15.3kJ/s = (15.3kw)

= 55,080kJ/hr.

Temperature based recovery efficiency of the recovery system can be calculated as

$\eta = \frac{T_{egb-}T_{ega}}{T_{egb-}T_a} \times 100$ where;

T_{egb} = Temperature of exhaust flue gas before recovery system (^oC)

T_{ega} = Temperature of flue gas after heat recovery system (^oC)

T_a = Ambient Temperature (^oC)

$\eta = \frac{240-157}{240-19} \times 100$ = 83/221×100

= 37.6%

From the above recoverable heat, value from flue gas, we can justified that 37.6% waste heat from furnace exhaust can effectively recovered and utilized for different purpose The main source for the waste heat is the hot flue gas, which carrying large amount of heat; if that heat is recovered by installing suitable recovery system enormous amount of fuel saving can be achieved.

Considering that hot flue gas is used to vaporize moisture from moist sand mold need to find the amount of heat used to rise the temperature of sand.

When water is take heat from a hot flue gas, both a change of temperature and a change of state occur. Heat absorbed by the water (moist sand) is given by:

⇨ Heat Absorbed = Mass x Specific Heat x Temperature Change

To calculate the heat absorbed during a change of state;

⇨ Heat Absorbed = Mass x Latent Heat

The water (moisture) contained in sand mold has a temperature of 19^{o}C and is converted by the heat from the hot flue gas which have temperature of 138^{o}c. Amount of heat required to vaporize the water from moist sand mold is given by equation above or(equation 4.9).the mixture of sand mold is synthesized in the shop are 44kg of silica sand and 4kg bentonite which is measured before mixed with water, after mixed with water the sand mold weight become 50kg therefore the remaining mass of water(moisture) is about 2kg.

From property of steam table the property values Specific heat water and steam are given below;

Specific heat of water (C_{pw}) = 4.2 kJ/kg.^{o}C

Specific heat of steam (C_{ps}) = 2kJ/kg^{o}C (BOLES, 5th Edition.)

Latent heat of vaporization of water (h_{fg}) = 2257 kJ/kg

✓ Heat to raise temperature of water from 19^{o}Cto100^{o}C

$Q = m_w \times C_{ps} \times \Delta T$

= 2kg x 4.2 kJ/kg.^{o}C x 81 ^{o}C = 680 kJ

✓ Heat to change water at 100^{o}C to steam at 100^{o}C

$Q = m_w \times h_{fgw}$

= 2kg x 2257kJ/kg = 4514 kJ

✓ Heat to raise temperature of steam at 100^{o}Cto138^{o}C

$Q = m_w \times C_{ps} \times \Delta T$

= 2kg x2kJ/kg.^{o}C x 38 ^{o}C = 152KJ

The total heat energy needed to vaporize the water (moisture) completely from sand mold is the sum of sensible and latent heat which is;

Total heat = 5346kJ

4.4 Analytical Design Inside the mold drying room

The flue gas flow regime, whether the flow is laminar, transitional or turbulent) is indicated by the Value of Reynolds number which is as state in equation 4.3 above.

$$Re = \frac{Vd}{v}$$

The temperature of the flue gas entering to mold drying room is 430K or 157^{o}c. So the kinematic viscosity(ν) of flue gas at the measured temperature T (^{o}c) is calculated using Lauterbach Verfahrenstechnik (LV) software as attached in appendix B.to became: (0.0000531 m^2/s)

The Reynolds number for a flue gas with given velocity (V) of 1.2 m/s in a drier of 2 m diameter (d) is;

$Re = \frac{1.2 \times 2}{0.0000531}$ = 45,197.7

Reynolds number, which is greater than 4,000 Therefore, the flow is turbulent.

In heat transfer analysis, a non-dimensional heat transfer coefficient, called Nusselt number, Denoted by "Nu" is defined in equation (4.4) above which is;

Nu = $\frac{hd}{k}$

Dittus-Boelter Equation is the most common correlation used in turbulent flows(Gupta, 2017). Will be as follows;

Nu = 0.023 $Re^{0.8} Pr^{n}$ Where; n = 0.4 for heating   n = 0.3 for cooling

Nu = 0.023 $Re^{0.8} Pr^{0.4}$

Prandl number Pr - is, given by: Pr = $\frac{C_p \mu}{k}$

Hence, the above equation simplifies to;

Nu = 0.023 $Re^{0.8}$

= 0.023$(45197.7)^{0.8}$ = 121.8

Based on the expression in equation (4.4) rearranging the parameters the drying room heat transfer coefficient is calculated to be;

$h_i = \frac{Nu \times k}{d}$ ($W/m^2.K$)

Where: k is thermal conductivity of flue gas and, can be calculated using Lauterbach Verfahrenstechnik (LV) software as attached in appendix B,

$h_i = \frac{122 \times 0.03997}{2}$ = 2.43 W/m^2 .K

4.5 Outside of Mold Drying Room

Radiation heat transfer has a significant role to the surface of the dryer will exchange heat by radiation to the surrounding environment, and the convective heat loss will be affected by the dominant wind speed. In calm conditions, the convective heat transfer from the outside surface of the dryer will be by natural convection. As the wind velocity increases, forced convection will become the dominant mechanism.

For external flow normal to a dryer Nusselt number is given by:

$Nu = 0.26\ Re^{0.6}Pr^{0.3}$

Assuming a constant value for Prandtl number of 0.74, this expression simplifies to:

$Nu = 0.24Re^{0.6}$

In this case the Reynolds and Nusselt numbers refer to the outside diameter (do) of the mold drying room. Then the outside convective heat transfer coefficient (h_{co}) of the dryer is given by:

$h_{co} = \frac{Nu \times k}{d}$ W/m^2.K

The outside temperature of mold drying room is 19 ^{o}C (292K). At 292K the kinematic viscosity and thermal conductivity of atmospheric air is calculated by equation below respectively at different temperature.

$v = (0.1335 + 0.925x10^{-3} \text{ x } 292) \text{ x}10^{-4} = 0.000040 \text{ m}^2/\text{s}$

$k = 0.02442 + (0.6992\times10^{-4}) \text{ x}292 = 0.044$ W/m .K

The Reynolds number at environment air inside foundry shop with velocity of 1m/s is:

$Re = \frac{Vd}{v}$ Substituting the value we have = 50,000

From the above equation the Nusselt number is;

$Nu = 0.26(50{,}000)^{0.6} = 171.5$ Therefore, the outside convective heat transfer is;

$h_{co} = \frac{171.5 \times 0.044}{2} = 3.8$ W/m^2.K

The overall heat transfer coefficient for the sand mold dying room is given

$U = \frac{1}{\frac{1}{hi}+\frac{1}{hco}} = 1.7$ W/m^2.K

- **Insulation Thickness**

The most important characteristics of any insulation material is a low thermal conductivity; the most common insulator is fiberglass. Fiberglass is generally more appropriate for our work with temperatures about 240^{0}C, critical insulation thickness of supply duct should be included to decrease heat loss by convection and radiation(Michael Kelly,Insulation, 2014).

Critical insulation thickness given by;

$Y_{cr} = \frac{K}{h_o}$ Where;

Y_{cr} - Critical thicknesses

K- Thermal conductivity of fiber glass (0.04w/m.K)

ho - Convective heat transfer (3.8w/m^2.k)

$Ycr = \frac{0.04 w/m.K}{3.8 w/m2.k} = 0.01m$

But, the proposed insulation thickness of fiber glass (insulator) about 0.04m for the supply duct

4.6 Heat Transfer rate in mold drying room

The first law of thermodynamics requires that the rate of heat transfer from the hot flue gas should be equal to the rate of heat transferred to the moist sand mold

Energy balance equation is expressed as, Heat rejected from flue gas ($Q_{fg)}$ = Heat absorbed by moist sand mold (Q_{sm})

$\dot{Q} = \dot{m}_f C_{pf}\left(T_{fi} - T_{fo}\right)$ (Y.BOLES-5thEdition.) (4.11)

$\dot{Q} = \dot{m}_{ms} C_{ps}(T_{mso} - T_{msi})$ (4.12)

Where: $\dot{m}_f$, $\dot{m}_{ms}$ - Mass flow rate of flue gas and moist sand respectively

C_{pf} , C_{ps} - Specific heat of flue gas and moist sand at constant pressure

T_{fi} , T_{fo} - Inlet and outlet temperature of flue gas respectively

T_{msi} , T_{mso} - Inlet and out let temperature of moist sand mold respectively

In this analysis, it is often convenient to combine the product of the mass flow rate and the specific heat of a fluid into a single quantity which is called the heat capacity rate and it is defined for the hot flue gas and cold mold sand streams as follows;

$C_{hf=\dot{m}_f} c_{pf}$ (a)

$C_{Cs=\dot{m}_{cs}} c_{pc}$ (b)

Where; the subscripts Cs and h_f stand for cold moist sand and hot flue gas, respectively the heat capacity rate of a fluid stream represents the rate of heat transfer needed to change the temperature of the fluid stream by 1°C as it contacted with the moist sand.

The heat capacity rate from the above equation (1) and (2) can be simplified as:

$$\dot{Q} = C_{hf}\left(T_{fi} - T_{fo}\right) \quad (4.13)$$

$$\dot{Q} = C_{cs}(T_{mso} - T_{msi}) \quad (4.14)$$

The rate of heat transfer in a mold drying room is equal to the heat capacity rate of fluid multiplied by the change of temperature of the fluid.

A heat exchanger or mold drier system can be designed by, a) LMTD (Logarithmic Mean Temperature Difference), if inlet and outlet conditions are specified. However, when the problem is to determine the inlet or exit temperatures mold drier ,b) the analysis is performed more easily by using a method based on effectiveness of the dryer and number of transfer units.

The dryer effectiveness (ε) is defined as the ratio of actual heat transfer to the maximum possible heat transfer(Shah, 2003) Thus

$$\varepsilon = \frac{Actual\ Heat\ Transefer\ rate}{Maximum\ possible\ Heat\ transer\ rate} = \frac{\dot{Q}}{\dot{Q}_{max}} \quad (4.15)$$

The actual heat transfer rate for a sand mold drier can be determined by setting an energy balance on hot or cold fluids, and can be expressed as;

$$\dot{Q} = C_{hf}\left(T_{fi} - T_{fo}\right) = C_{cs}(T_{mso} - T_{msi})$$

The maximum possible heat transfer rate in a dryer is:

$$\dot{Q}_{max} = C_{min}\left(T_{fi} - T_{msi}\right)$$

Where; C_{min} is the smaller of $C_{hf}\left(T_{fi} - T_{fo}\right)$ and $C_{cs}(T_{mso} - T_{msi})$

The dryer effectiveness **ε,** is Evaluated according to the formula given by:

$$\text{NTU} = \frac{UA_s}{C_{min}} = \frac{UA_s}{\left(\dot{m}_{C_p}\right)min} \quad (4.16)$$

Where; A_s- is the heat transfer area

Hence, the problem is to determine the exit temperatures of a sand mold (final temperature that sand mold contains), among these two methods of dryer design, the effectiveness method is more appropriate than the LMTD (Logarithmic Mean Temperature Difference) method.

Therefore, from equation (4.14) the rate of heat transferred to the moist sand mold is: $\dot{Q} = C_{cs}(T_{mso} - T_{msi})$

$\dot{Q} = \dot{m}_{ms} C_{ps}(T_{mso} - T_{msi})$

From the given Data of moist sand mold and by substituting the parameters we have;

$= 0.04 \times 3038.7(T_{mso} - 292K)$

=121.5KJ/s .K $(T_{mso} - 292)$

So, temperature of sand mold at outlet is;

$T_{mso} = \frac{\dot{Q}}{121.5kJ/s_{.K}} + 292K$

But the actual heat transfer rate ($\dot{Q}$) is given by;

$\dot{Q} = \varepsilon C_{min}\left(T_{fi} - T_{msi}\right)$

Now let compare C_{hf} & C_{cs} to select the values of C_{min} & C_{max}:

$C_{hf} = \dot{m}_f c_{pf}$ = 0.1kg/s ×1.1053KJ/Kg.K = 0.2 KJ/s.K

$C_{Cs} = \dot{m}_{cs} c_{pc}$ =0.04kg/s×3038.7KJ/Kg.K = 121.5KJ/s.K

And therefore: C_{min} =0.2KJ/s.K

Hence, once the effectiveness of the dryer is known, the actual heat transfer rate can be determined from Equation (4.16) above as follows:

NTU= $\frac{UA_s}{C_{min}}$ Where; A_s -is surface area given by;

$As = 4a^2 = 4\times 2^2 = 4\times4 = 16m^2$

Therefore substituting in the above equation

NTU = $\frac{1.7w/m2.k \times 16m2}{220\text{J/s.K}}$ = 0.124

The dryer effectiveness ε is, given by:

$$\varepsilon = \frac{1-exp[-NTU(1-c)]}{1-c\ exp[-NTU(1-c)]}$$

where; c- is calculated to be;

$$c = \frac{C_{min}}{C_{max}} = \frac{0.22 \text{kJ/s.K}}{121.5 \text{ KJ/s.K}} = 0.002$$

$$= \frac{1-exp[-0.124(1-0.002)]}{1-0.002\ exp[-0.124(1-0.002)]} = 0.12$$

Thus the actual heat transfer rate will be;

$$\dot{Q} = (0.12) \times (0.2\text{kJ/s.K}) \times (430\text{K}-292\text{K}) = 3.64\text{kJ/s}$$

Hence, the temperature of mold at outlet is:

$$T_{mso} = \frac{3.64\ kJ/S}{0.03 kJ/s_{.}K} + 292K$$

$$= 411\text{K or } 138^{0}\text{C}$$

To evaluate the temperature of flue gas after heat rejection in mold drying room, the first law of thermodynamics that states, the rate of heat transfer from the hot flue gas should be equal to the rate of heat transferred to the moist sand mold or heat given by the flue gas should be equal to the heat absorbed by the sand mold. i.e,

$$\dot{m}_f C_{pf}\left(T_{fi} - T_{fo}\right) = \dot{m}_{ms} C_{ps}(T_{mso} - T_{msi}) \quad (4.17)$$

Therefore, temperature of flue gas after heat rejection to the sand mold (outlet temperature of flue gas) will be;

$$T_{fo} = T_{fi} - \frac{\dot{m}_{ms} C_{ps}(T_{mso} - T_{msi})}{\dot{m}_f C_{pf}}$$

$$T_{fo} = 430 - \frac{0.04\text{kJ/s.K}(413\text{K} - 292)}{0.22 \text{ KJ/s.K}} = 409.4\text{K or } (135.4\ ^{0}\text{c})$$

4.7 Description of Proposed Flue gas heat recovery system

The flue gas heat recovery system comprised a direct-contact flue gas to the mould to be dried via supply duct, to the mould drying room. The system was expected to simultaneously achieve energy saving (cost), working time saving, and pollutant emission reduction. The new system was applied at the foundry shop of G7 trading and industrial PLC. Where waste heat was recovered from oil fired furnaces.

This work mainly focus on the heat recovery from the flue gas in order to dry the molds with flue gas having the Temperature of the flue gas available is about 240°C. The temperature of the flue gas available is good enough to dry the mold, commercially available drying system does not require very high temperature for mold drying just simply to vaporize the moisture from moist sand mold, hence proposed to design simple flue gas supply duct system to transport hot flue gas from the top of furnace to drying room to recover waste heat from flue gas.

The heat supply system is circular supply ducts which have 10 m length, 0.4 m diameter which has; flue gas harvesting hood, one up ward flue gas transport duct, one horizontal supply duct, and also there are dawn ward supply system which directed to mold drying room. Figure.4.4 below shows the proposed model of the waste heat recovery system.

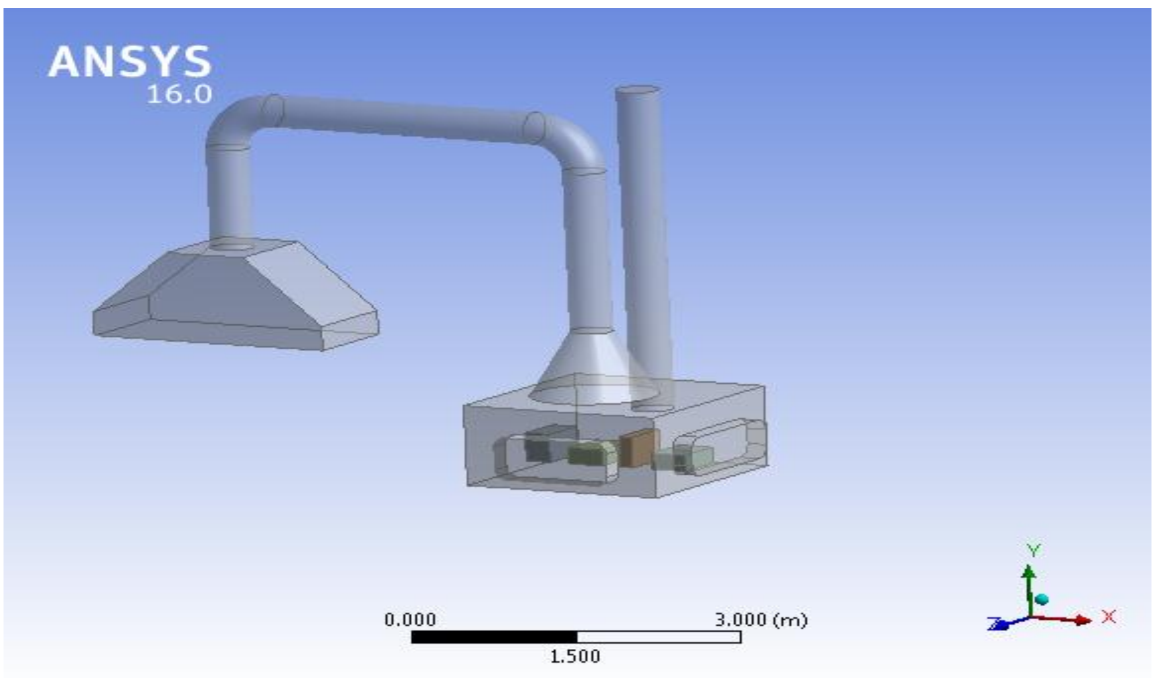


Figure-4.4 Flue gas supply duct of heat recovery system

4.8 CFD Simulation Model Development

4.8.1 Introduction to CFD approach

Simulations of fluid flow and heat transfer in various pieces of equipment within waste-to-energy plants may provide very useful information both in the design phase and in troubleshooting. The CFD methodology itself is a very broad field so here we rather focus on a recent specific application, related to the area of the present research.

Drying of sand molds is a time consuming, as well as energy and capital intensive process. CFD simulations can be used as a tool to decrease the design time and lower the possible risk and costs related to the start- up of drying operations

In this study we consider the case of molds coated with water based foundry coatings dried with hot flue gas from furnace exhaust by natural convection. The heat transfer, which depend on the flue gas speed and exhaust temperature, plays a major role in the removal of water and therefore in the reduction of drying times

The goals of this work can therefore be: Asses heat transfer and temperature distribution throughout the supply duct with CFD simulation, Propose an optimum temperature arriving at the molds drying room.

The target is to simulate the temperature and the heat transfer inside the supply duct using fluent software. Comparison of temperature profiles of the hot flue gas in the duct using constant temperature heat source and linearly fluctuating temperature of the heat source for unsteady state is found out.

4.8.2 Model Development and Simulation Process

To study the feasibility of drying system with flue gas from oil fired conventional furnaces, a system design as illustrated in figure4.4 below is used as the basis of the CFD model. The system contains different parts to be assembled and installed. Flue gas harvesting hood is 1050x1050mm and it has a height of 800mm.as shown on figure 4.5 below.

This heat recovery system was modeled to approximate actual system .As shown in Figure below the model was built with an inlet harvesting hood, flue gas supply duct, mold drying room and an outlet chimney. The simulations were carried out at inlet temperatures and in inlet velocities of the waste heat stream.

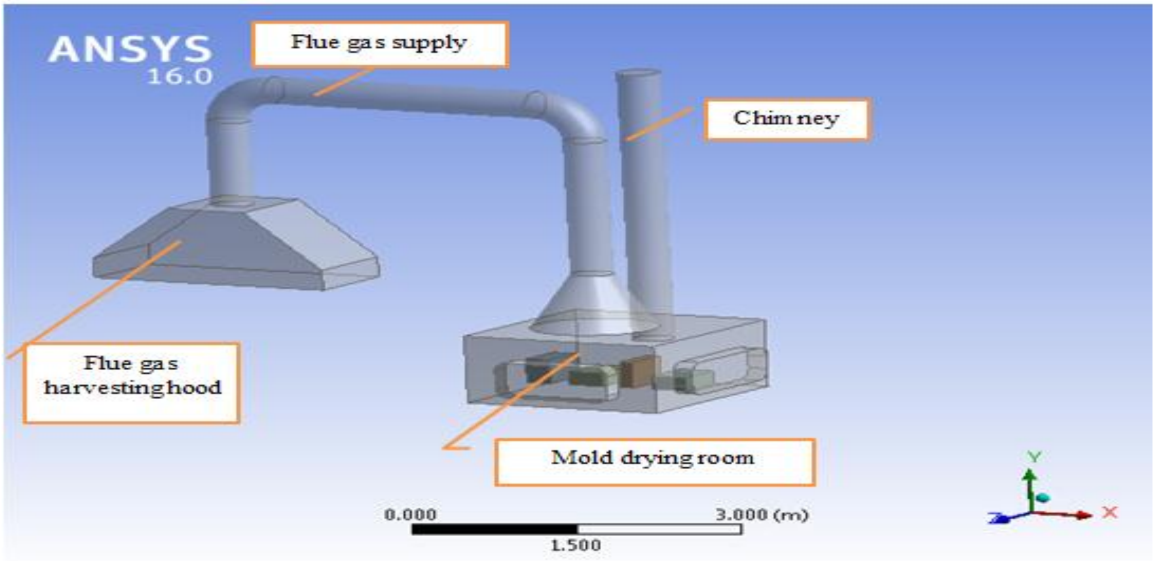


Figure-4.5 Model drawing of recovery system

To validate the truthfulness of the ANSYS Fluent simulation results, the value of waste heat recovered by a flue gas waste heat supply duct was compared with the calculated results obtained from exit temperature of flue gas which is admitted to mold drying room.

The flue gas recovery system has different parts like Hood, vertical supply duct, horizontal supply duct, drying room etc. Other parts and detail manufacturing drawing of the whole system is described in Annex C. With diameter (D=400mm), length =2000mm, Flue gas enters the drying room through the top center (D=400mm), leaves through the diameter having 400mm circular chimney at top-corner of the drying room.

In this work we perform ANSYS Fluent studies with the aim to show amount of temperature which arrive in mold drying room via supply duct of waste heat recovery system. Representative geometries are modeled, as illustrated in figure 4.5 above.

4.8.3 CFD Simulation

CFD is widely used to investigate the flow pattern, pressure drop across ducting and particle trajectory within various equipment.CFD can be used to address problems with existing geometrical or performance errors like erosion of duct material due to ash particles, flow non-uniformity at tube bundles entry. Such problems may lead to lower efficiency of the equipment. Therefore, CFD can provide insight in the behavior of the system and contribute to resolving the problem.

In this works CFD is used to analyze & improve flow distribution inside the WHRS, which enhance the Thermal efficiency of the mold drying room, proper distribution of flue gas temperature inside duct or in WHRS. The geometry and mesh was created and the analysis was conducted using advanced CFD software tool, Ansys Fluent, Fluent solves numerically the Navier-Stokes equations, the fundamental fluid dynamics governing equations.

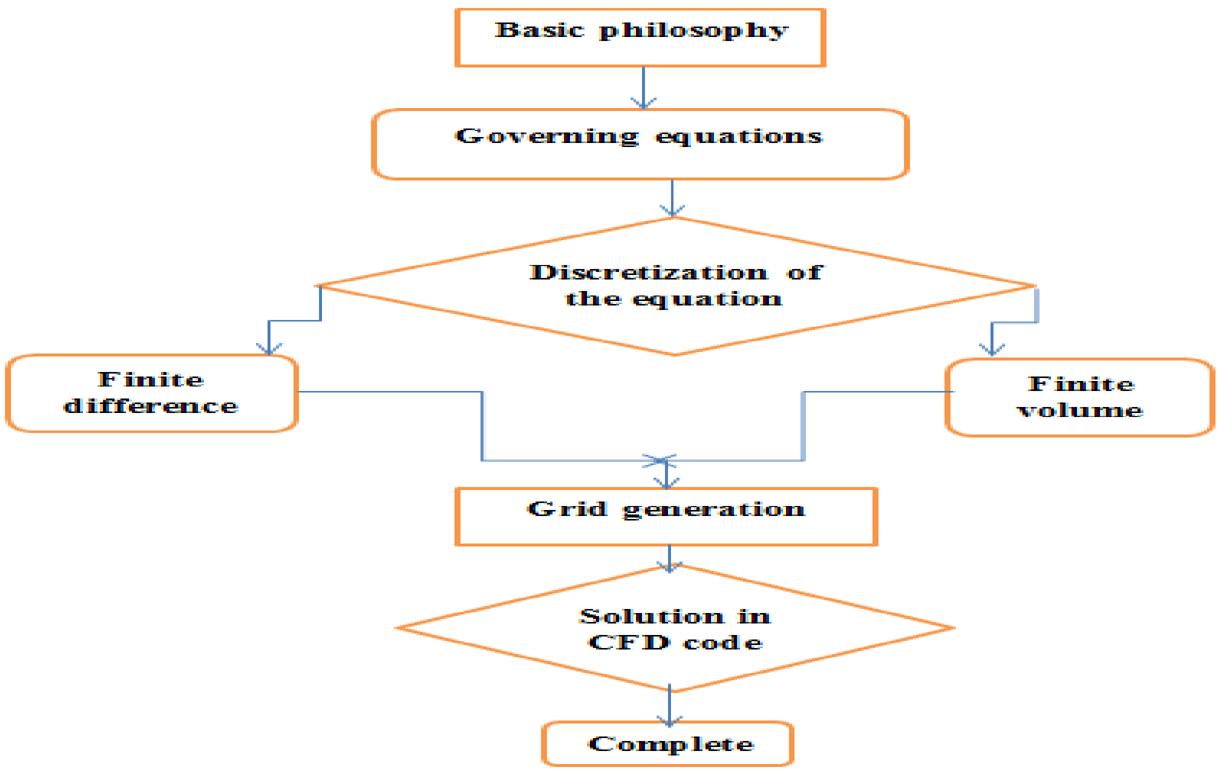


Figure-4.6: Basic Flow Chart of CFD Methodology

4.8.4 Governing Equations

The governing equations of fluid flow represent the mathematical statements of the conservation laws of physics, such as;

- the mass of a fluid is conserved
- The rate of change of momentum equals the sum of the forces on a fluid particle (Newton's second law).
- The rate of change of energy is equal to the sum of the rate of heat addition to and the rate of work done on a fluid particle (first law of thermodynamics).

- **Mass conservation equations**

According to the mass conservation, the rate of the mass increase in fluid element is equal to the net rate of the flow into the fluid element. For the compressible flow this can be formulated as follows and is called the continuity equation for an unsteady compressible fluid at a point can be written as;

$$\frac{\partial \rho}{\partial t} + div(\rho.\vec{u}) = 0 \quad (4.18)$$

Where; p- density, time, $\vec{u}$-direction velocity vector

The first term on the left hand side is the rate of change in time of the density (mass per unit volume). The second term describes the net flow of mass out of the element across its boundaries and is called the convective term.

- **Momentum conservation equations**

According to the second law of Newton the net forces on a fluid particle is equal to the net momentum change of the particle. There are two kinds of forces on a fluid particle; body forces such as gravity or centrifugal and surface forces such as pressure or viscous forces.

- ✓ The momentum equation in the x direction:

$$\frac{\rho\, Du}{Dt} = \frac{\partial_{(-p+\tau_{xx})}}{\partial_x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx} \quad (4.19)$$

- ✓ The momentum equation in the y direction:

$$\frac{\rho\, Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial_{(-p+\tau_{yy})}}{\partial_y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My} \quad (4.20)$$

- ✓ The momentum equation in the z direction:

$$\frac{\rho\, Dv}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial_{(-p+\tau_{zz})}}{\partial_z} + S_{Mz} \quad (4.21)$$

Where u, v and w are the components of the velocity and SM include the body forces respectively.

- **Energy conservation equation**

  The energy equation is derived from the first law of thermodynamics which states that the rate of change of energy of a fluid particle is equal to the rate of heat addition to the fluid particle plus the rate of work done on the particle:

$$\rho \frac{DE}{Dt} = div(p\bar{u}) + \begin{bmatrix} \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} \\ \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} \\ \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z} \end{bmatrix} + div(k.gradT) + S_E \qquad (4.22).$$

The term on the left side of the equation represents the change of energy on a fluid particle. The first and second terms in the right represent the rate of work done on the fluid particle by surface forces, and the third term is the net rate of heat addition to the fluid. The last term is the rate of increase of energy due to sources.

- **Navier-Stokes equations**

The governing equations contain as further unknowns the viscous stress components τ_{ij}. The most useful forms of the conservation equations for fluid flows are obtained by introducing a suitable model for the viscous stresses τ_{ij}. In a Newtonian fluid the viscous stresses are proportional to the rates of deformation. The three-dimensional form of Newton's law of viscosity for compressible flows involves two constants of proportionality: first dynamic viscosity, μ, to relate stresses to linear deformations, and the second viscosity, λ, to relate stresses to the volumetric deformation. The nine viscous stress components are:

$$\tau_{xx} = 2\mu\frac{\partial u}{\partial x} + \lambda.\mathrm{div}(\bar{u}) \qquad \tau_{xy} = \tau_{yx} = \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \qquad (4.23)$$

$$\tau_{yy} = 2\mu\frac{\partial v}{\partial y} + \lambda.\mathrm{div}(\bar{u}) \qquad \tau_{xz} = \tau_{zx} = \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right) \qquad (4.24)$$

$$\tau_{zz} = 2\mu\frac{\partial w}{\partial z} + \lambda.\mathrm{div}(\bar{u}) \qquad \tau_{yz} = \tau_{zy} = \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right) \qquad (4.25)$$

Substituting the viscous stress components into the conservation momentum equations it reaches the Navier-Stokes equations:

X-component $$\frac{\partial(\rho v)}{\partial t} + div(\rho w\bar{u}) = -\frac{\partial p}{\partial x} + div\big(\mu.grad(u)\big) + S_{Mx}$$

Y-component $\frac{\partial(\rho v)}{\partial t} + div(\rho v \bar{u}) = -\frac{\partial p}{\partial x} + div(\mu . grad(v)) + S_{My}$

Z –component $\frac{\partial(\rho v)}{\partial t} + div(\rho w \bar{u}) = -\frac{\partial p}{\partial z} + div(\mu . grad(w)) + S_{Mz}$

And together with the continuity equation governs the time-dependent three dimensional fluid flow of a compressible Newtonian fluid; thus there are three different momentum equations that together comprise the Navier-Stokes Equation

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \rho g_x + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial p}{\partial y} + \rho g_y + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \rho g_z + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

The above three expression of the energy equation is valid for most applications(Naveen & Krishna, 2017).

4.8.5 CFD Simulation Procedure

The simulation procedure start with initial parameters such as; The Exhaust flue gas at 513 k which represents the waste heat, ρ is the density, $\boldsymbol{\mu}$ is the viscosity, v is the velocity, $\boldsymbol{c_p}$ is the specific heat, $\boldsymbol{k}$ is the thermal conductivity. The diameter of the supply duct is 0.4m. $\boldsymbol{Pr}$-is the Prandtl Number. Some properties are evaluated from flue gas literature.

- ✓ **Geometry and Mesh**

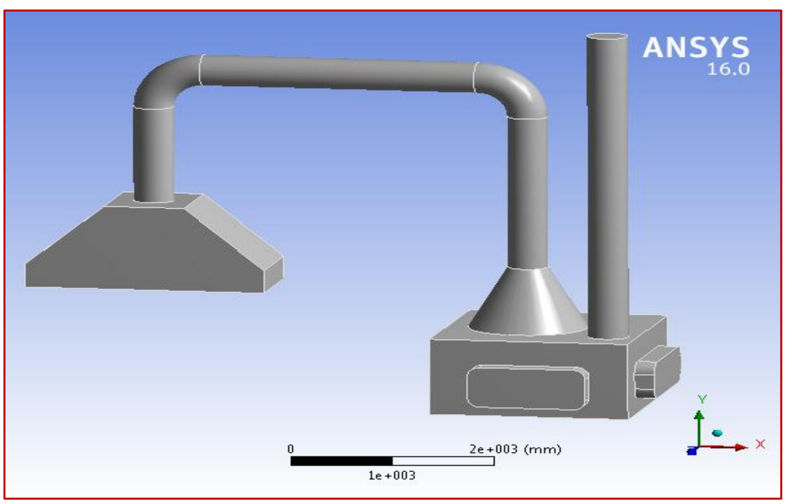
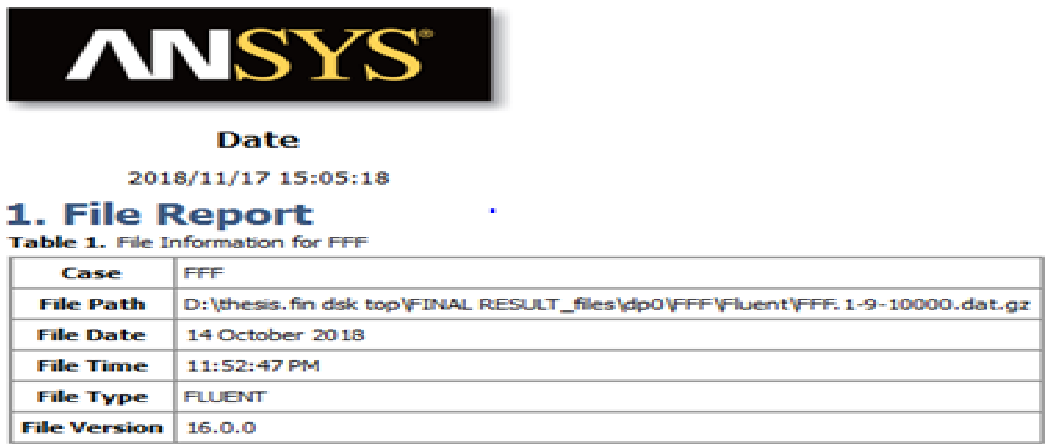


Figure-4.7: Geometry of flue gas supply system

To illustrate the time and date of the simulation process takes place, can be generated or shown on Ansys fluent report viewer as shown below.


ANSYS

Date

2018/11/17 15:05:18

1. File Report

Table 1. File Information for FFF

Case	FFF
File Path	D:\thesis.fin dsk top\FINAL RESULT_files\dp0\FFF\Fluent\FFF.1-9-10000.dat.gz
File Date	14 October 2018
File Time	11:52:47 PM
File Type	FLUENT
File Version	16.0.0

Figure 4.8: Ansys fluent report viewer for time and date

To compare the simulation results with calculated result, the ANSYS Fluent simulation process was carried out under the same conditions with calculated condition. As shown in Figure 4.7 above, the supply duct represents the flue gas passage, which has a length of 10 m, diameter of 0.4m, and 0.05m wall thickness considering insulation thickness of fiber glass to be 0.04m and sheet metal thickness 0.01m. Mesh of the geometry is shown in Figure 4.9 below. The fine mesh was generated with relevance of 100.

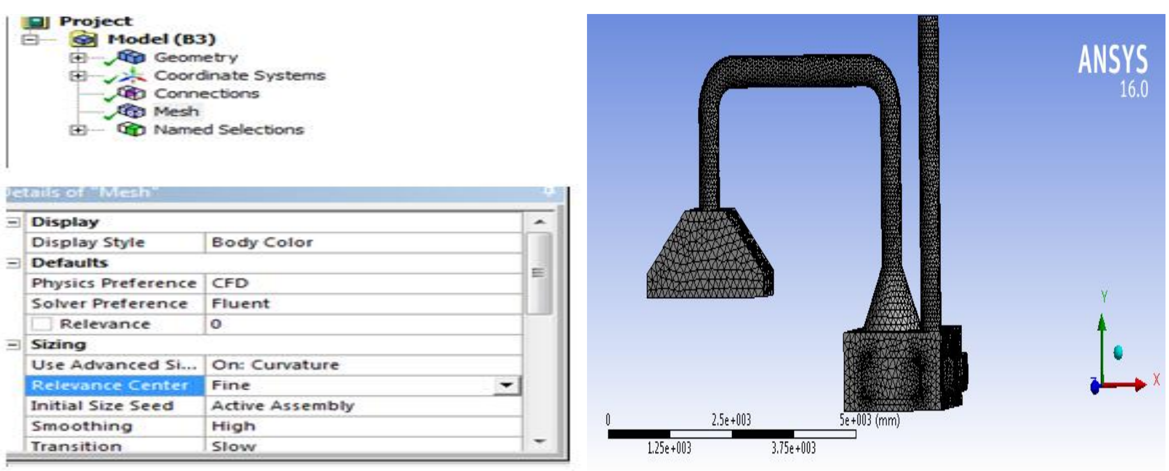


Figure-4.9: Mesh quality and mesh generated

To initiate the physical setup in Fluent, the “Double Precision” selection was chosen in the fluent launcher, as shown in Figure 4-9 below.

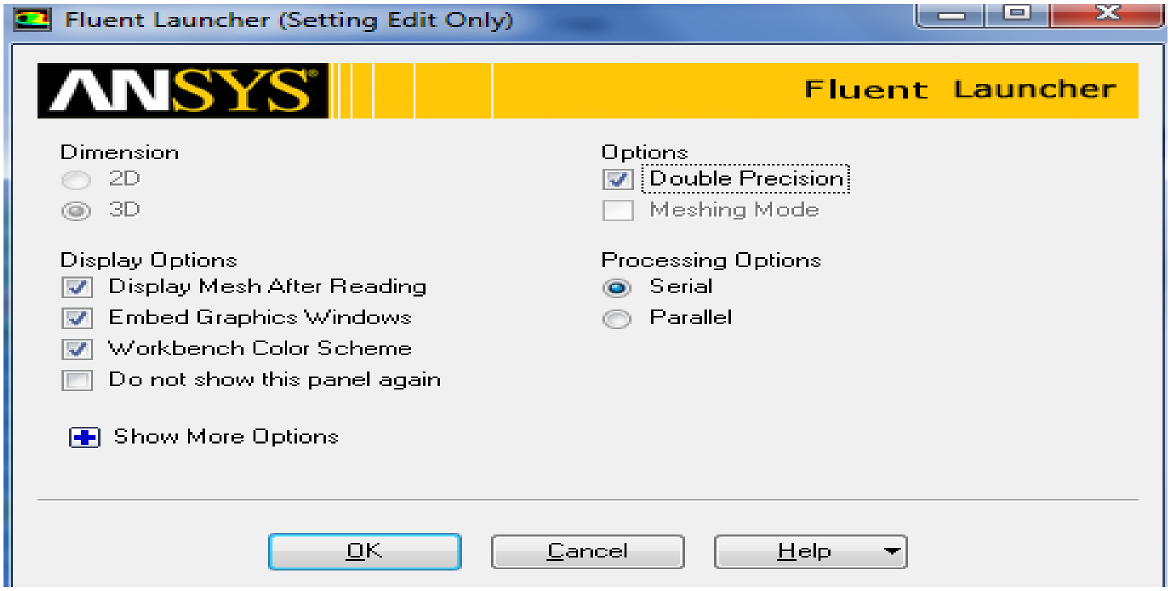


Figure-4.10: Fluent launcher

As shown in Figure 4.11 below need to define Solver Properties, the various solver properties were specified to obtain the proper solution.in our case transient heat transfer is selected.

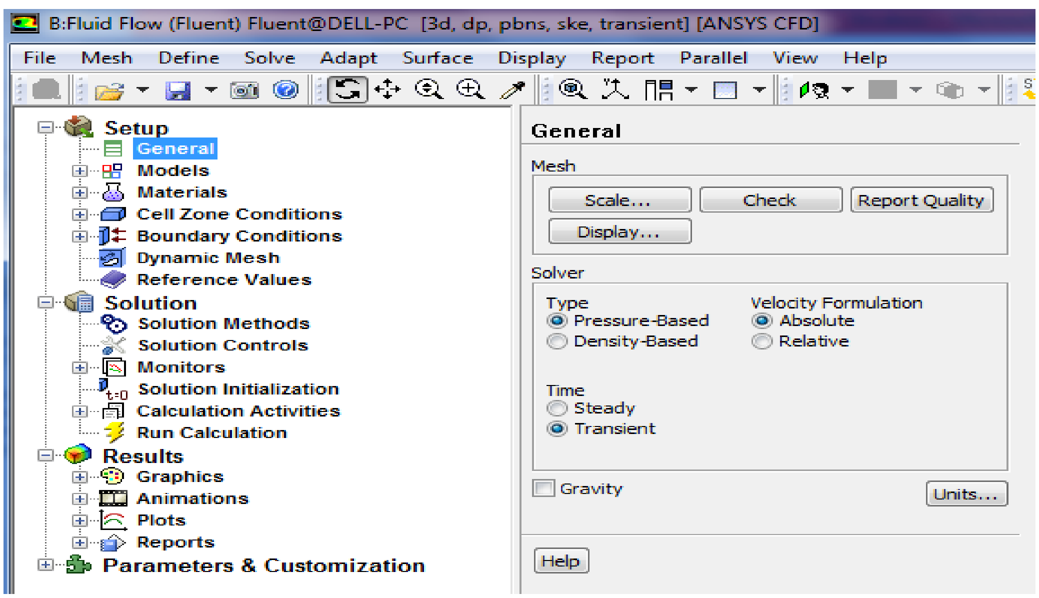


Figure -4.11 Defining Solver Properties

Next, as shown in Figure 4.11 below, the Viscous Model parameters were quantified. We need to solve the energy equation since we are interested in determining the temperature distribution, so we set the "Energy Equation" to on. The k-e transition model is chosen because it is used to estimate boundary layer development and to calculate transition onset.

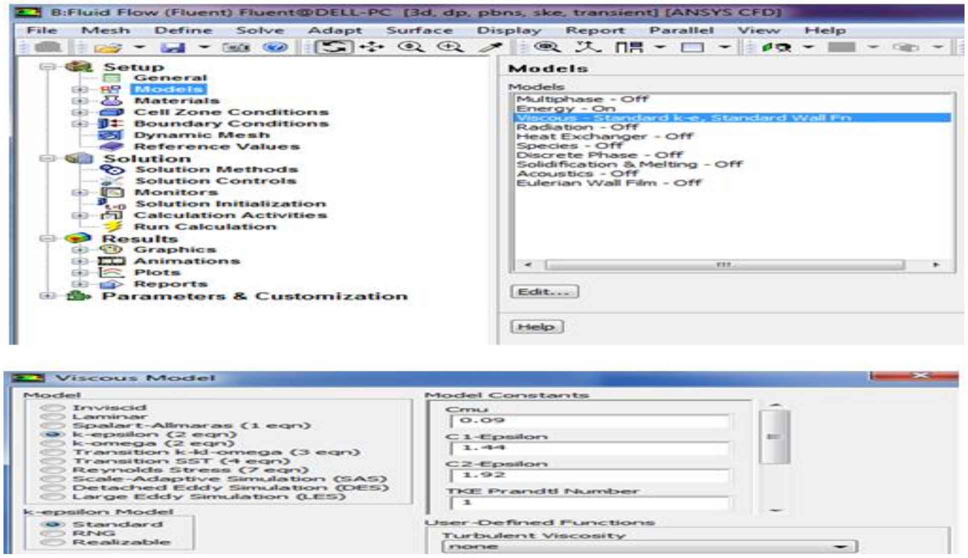


Figure-4.12: Viscous Model set up

This model can be used to effectively address the transition of the boundary layer from a laminar to a turbulent regime. And then, the properties of the material that was being modeled were stated. As shown in Figure 4.13 below, the properties of flue gas and the dried mold were specified in the Create/Edit Materials section.

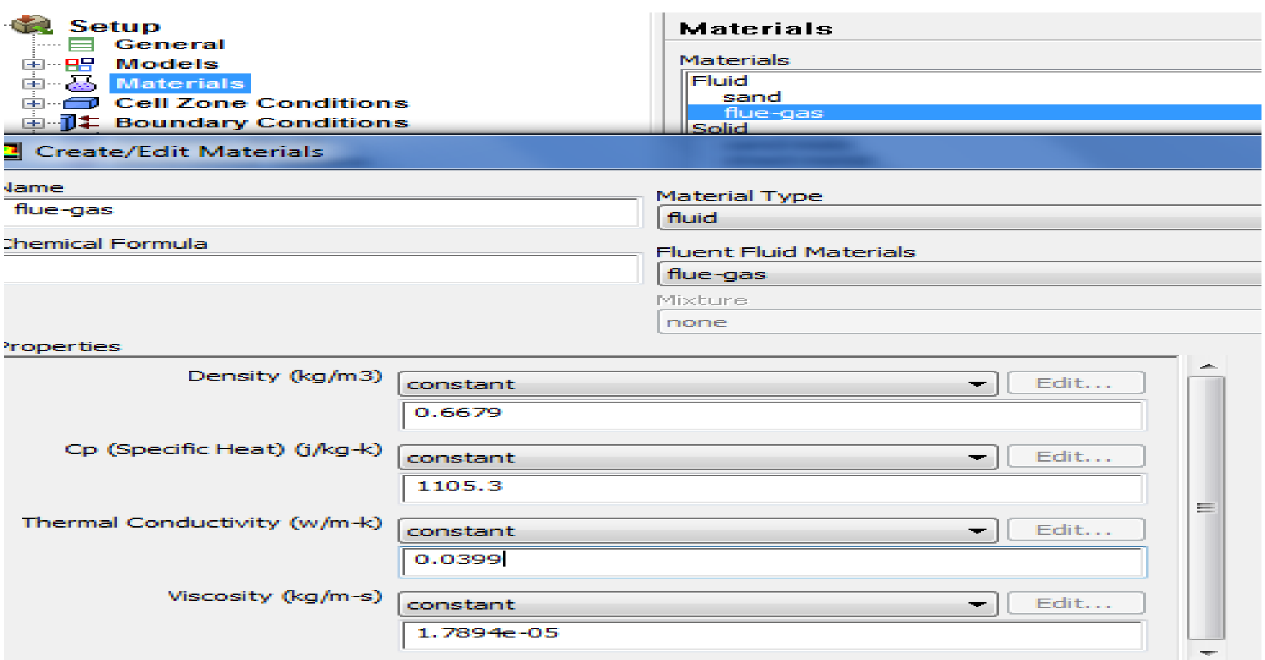


Figure-4.13: Material selection

✓ **Define Boundary Conditions**

At this stage the boundary conditions for the three Name Selections were specified. The boundary condition for the inlet will be specified first, as shown in Figure 4.14. Boundary Condition type should be Inlet Velocity and we set the Velocity Magnitude to1.2m/s from the measured data. And also in the thermal section we set the temperature to 513K, which means the temperature of flue gas inlet.

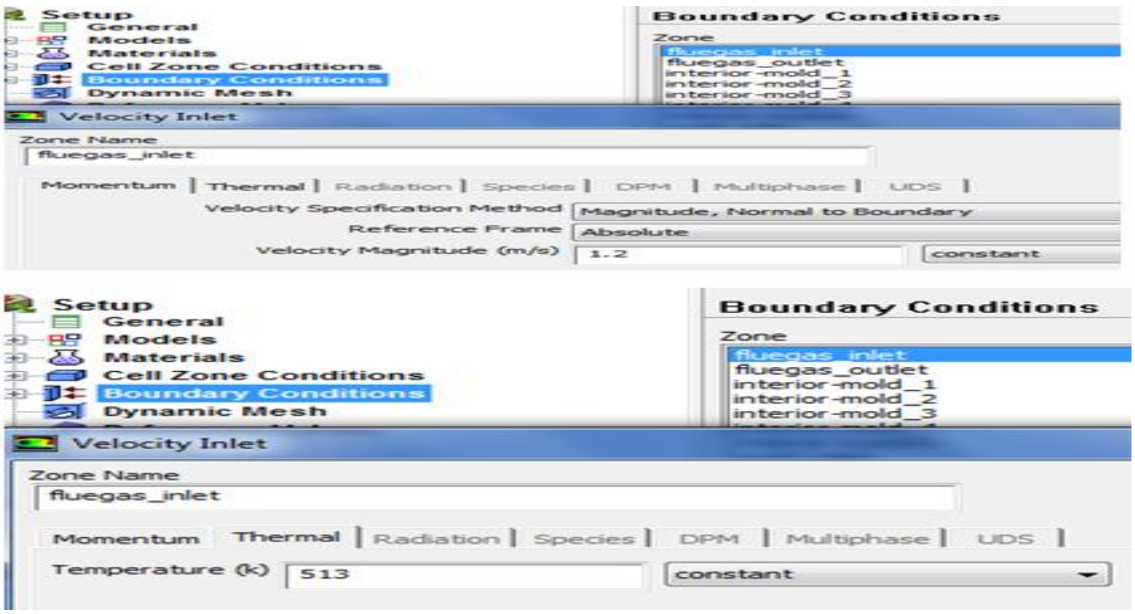


Figure-4.14: Defining Boundary Conditions

✓ **Solution Initialization**

Hybrid Initialization method was selected to initialize the calculations as shown below;

Figure-4.15: Solution Initialization

✓ **Run Calculation**

In this stage which is to run the calculations, we need to establish the number of iterations. Define the maximum number of iterations; set the number of Iterations to 10,000 and maximum iteration or number of time step to be 1 second, as shown in Figure 4.16 below. Then Click on the Calculate, the residuals for each iteration are printed out as well as plotted in the graphics window as they are calculated.

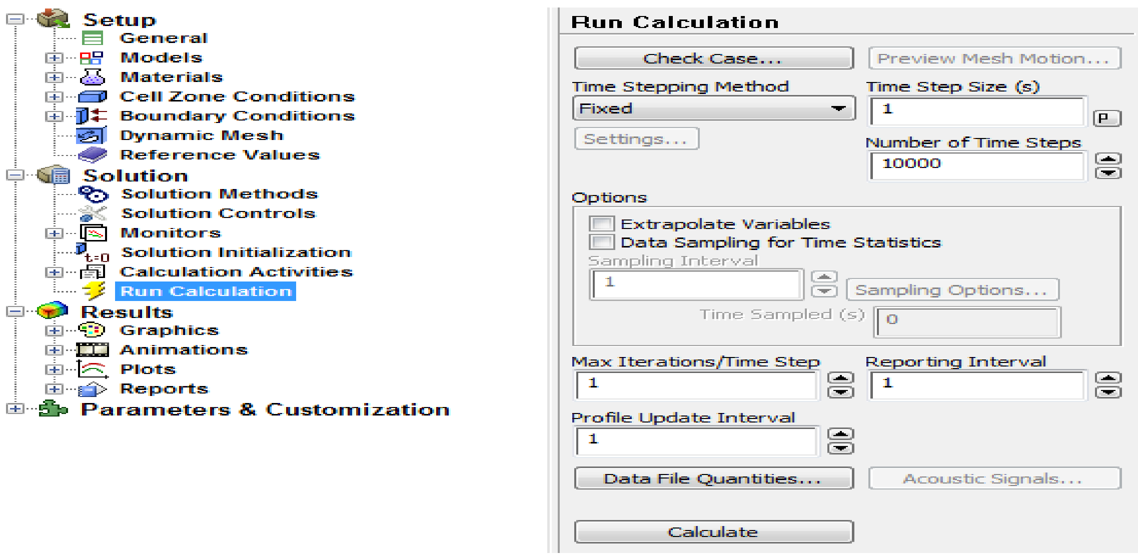


Figure-4.16: Run Calculation

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CHAPTER FIVE

5 RESULT AND DISCUSSION

5.1 RESULT

From the collected data it is found that the major energy consuming device is metal melting furnace and mold drying system, to save energy from these system energy recovery system was implemented. One of the main results of energy audit is the possibility of determination of the energy consumption systems. Identifying the energy consuming device is the key in understanding the way energy is used in a foundry shop and helps to control energy cost by identifying areas where waste can occur and where option for improvement may be possible.

5.1.1 Measured Data Results

Figure 5.12 below presents measured (experimental) result of temperature versus time, estimated for the inlet flue gas temperature profile for the first 120min after the start of combustion.

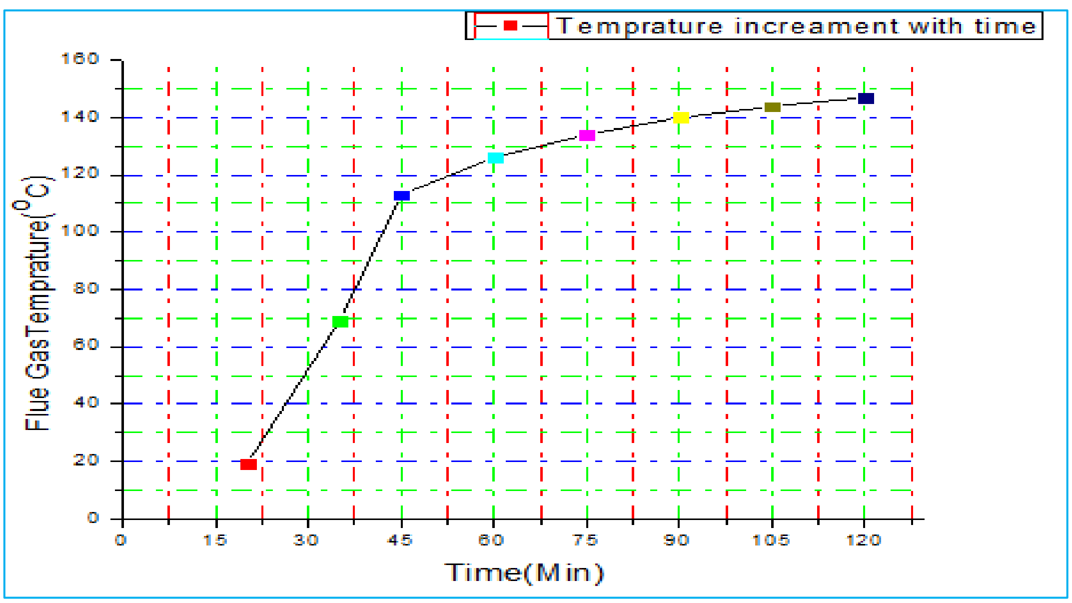

Figure-5.1 Flue gas inlet temperature profile within the first 120mins

Prior to starting of the combustion system inside the furnace the ambient temperature of the foundry shop was 19 ºc, after the combustion process of the furnace oil, the temperature of the flue gas entering to inlet duct was increased after 30 minute measurement.

A maximum temperature of 240°C on average was obtained after one hour of combustion from the furnace exhaust flue gas as it exits the furnace. This temperature obtained from leaving hot flue gas through top part of furnace.

As the hot flue gas stream pass via supply duct and, arrive in mold drying room at out let of supply duct during this time, decrease in temperature was observed as shown by Figure 5.12 below. This is as a result of 1) convective and radiation heat loss through supply duct to the environment and 2) the utilization of some of the sensible heat of the flue gas in heating the moist sand molds.

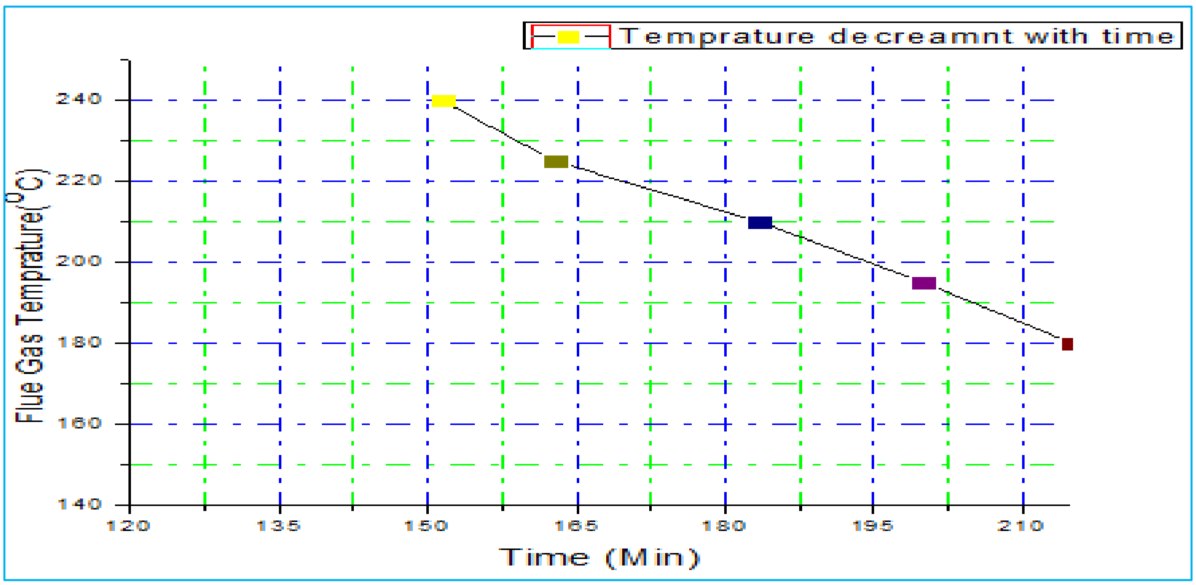

Figure-5.2: Temperature decrement with time for the last 60 min

Not only temperature varies with time but also the position of mold drying room from source of heat is affected by distance of heat supplied via the ducting system, the measured and some of estimated data shows the temperature distribution along with distance can be seen as indicated in the figure 5.3 below.

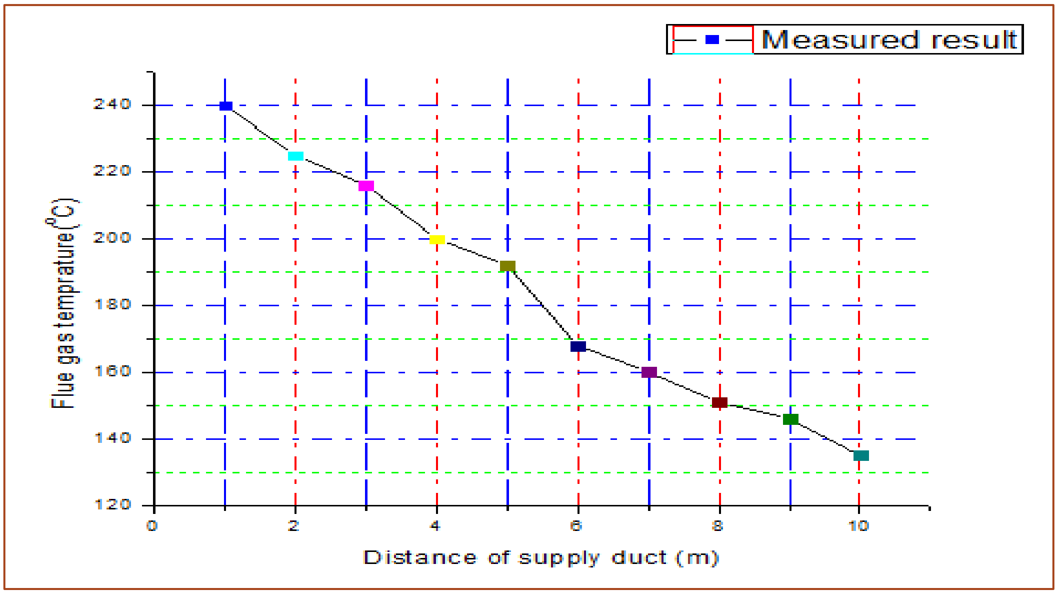

Figure-5.3 Temperature gradient along with the length of flue gas supply duct

There is a downward decrease of temperature along the length of the supply duct, as observed from Figure above the highest obtained temperature was around 240ºC. The temperature profiles of the exhaust gas were measured using a digital infrared thermometer, the data were measured at various distance and time, and effort has made to put these data graphically using origin software, shown above.

5.1.2 Analytical calculated result

The parameter of consideration for this research study was temperature. The exit temperature of flue gas at out let of supply duct

$$T_e = T_s - (T_s - T_i)\, e^{-\frac{hA}{\dot{m}C_p}}$$

$= 157\ ^{o}C$ or 430K

From the rate of heat transferred to the moist sand mold

$$\dot{Q} = \dot{m}_{ms} C_{ps} (T_{mso} - T_{msi})$$

$T_{mso} = 411K$ or $138\ ^0C$

The temperature of sand mold after hot flue gas rejected to the moist sand it gained about 138 ^{o}C that is the sand mold attains higher temperature.

The rate of heat transfer from the hot flue gas should be equal to the rate of heat transferred to the moist sand mold or heat given by the flue gas should be equal to the heat absorbed by the sand mold.

To evaluate the temperature of flue gas after heat rejection in mold drying room, i.e,

$$\dot{m}_f C_{pf}(T_{fi} - T_{fo}) = \dot{m}_{ms} C_{ps}(T_{mso} - T_{msi})$$

$$T_{fo} = 410K \text{ or } 136\ ^0c$$

(T_{fo}) is the exhaust flue gas temperature rejected to atmosphere.

5.1.3 CFD Simulation Result

To evaluate the performance of the WHRS based on the measured data and Analytical calculation it is essentially validated by CFD simulation, to get approximately accurate result. The parameter which is in consideration more for this research study were temperature. After running calculation we have the following result such as static temperature, velocity, and different other parameters, which is displayed on report result section as shown below

Static temperature results of the Ansys fluent simulation are as shown below;

Static Temperature (k)	
Flue gas inlet to duct	513
Flue gas outlet from	420
Mold inlet	292
Mold outlet	414

The value of temperature obtained by simulation at the outlet of mold is about 414K, which is almost the same with that of analytically obtained 411.3K. And flue gas out let temperature achieved by simulation result approximately same with analytically calculated, hence the heat recovery system is safe.

- Result of flue gas velocity for inlet, out let and for the system.

Velocity Magnitude (m/s)	
Fluegas_inlet	1.2
Fluegas_outlet	3.9
Interior-system	10.5

- **CFD Post result**

Flue gas temperature distribution, velocity profiles and some other parameters, at the inlet and outlet of the recovery system is shown below;

- **Temperatures stream line throughout the system**

The figures below show the distribution of temperatures in side supply duct starting from inlet of flue gas to the out let of chimney, the graphics result obtained from Ansys fluent results are shows temperatures stream line throughout the system.

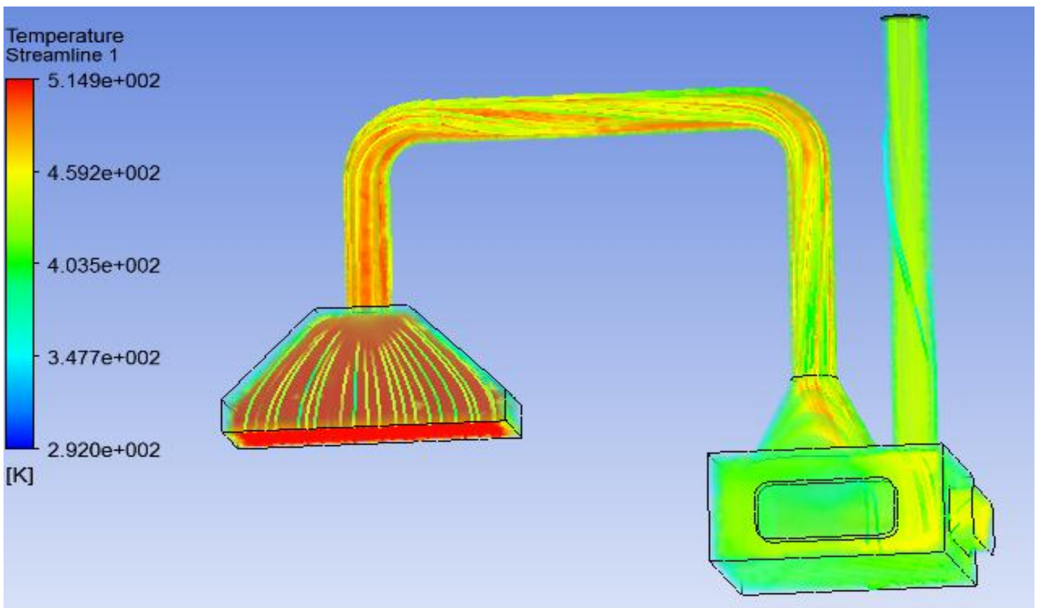

Figure-5.4: Temperature Distribution and streamline of recovery system

The temperature profiles shows that, the temperature starting from inlet flue gas supply duct to mold drying room and to chimney, the time for the temperature to become steady for a constant temperature and linearly decreasing temperature was found. It was found that: Temperature at the mold drying room for a fixed temperature of 157^0c or 430K was found, and the maximum temperature which is admitted to the system as an inlet was found to be 240^0c or 513K from measured data. As shown in diagram below which represent Ansys fluent result of temperature distribution with time, which shows temperature of flue gas increase at first and then it will decrease with time and also the temperature of the moist sand start to rise at some time in drying room. As shown in below;

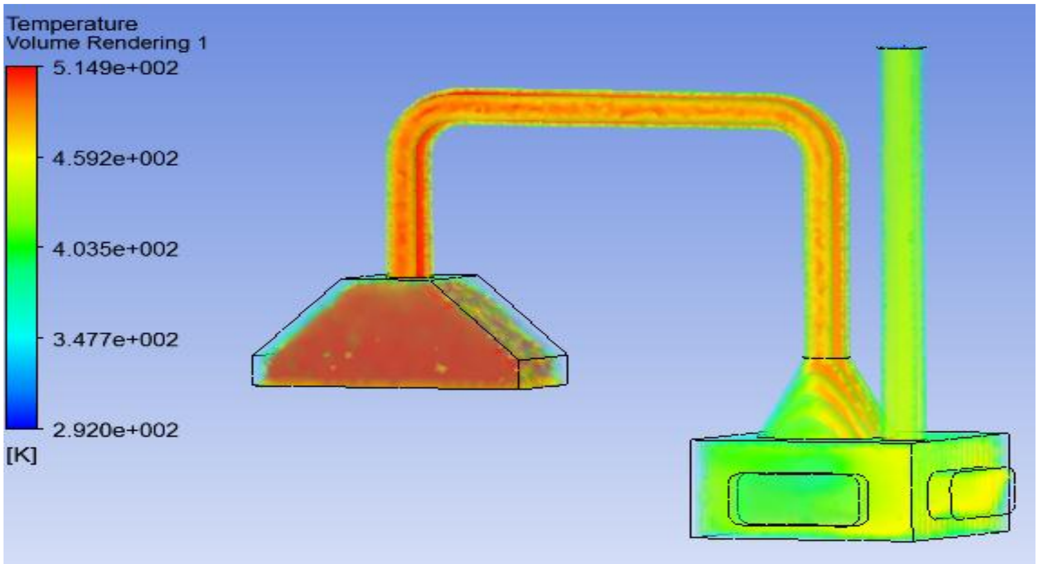

Figure-5.5: Temperature Distribution of flue gas along system

The above figure represents the whole recovery system representation of temperature distribution of the hot flue gas inside the supply duct, which is temperature interpretation with10, 000(s) flow time. The graph below presents CFD result of temperature versus time, that attain sand mold temperature with simulated time of 10,000(s).

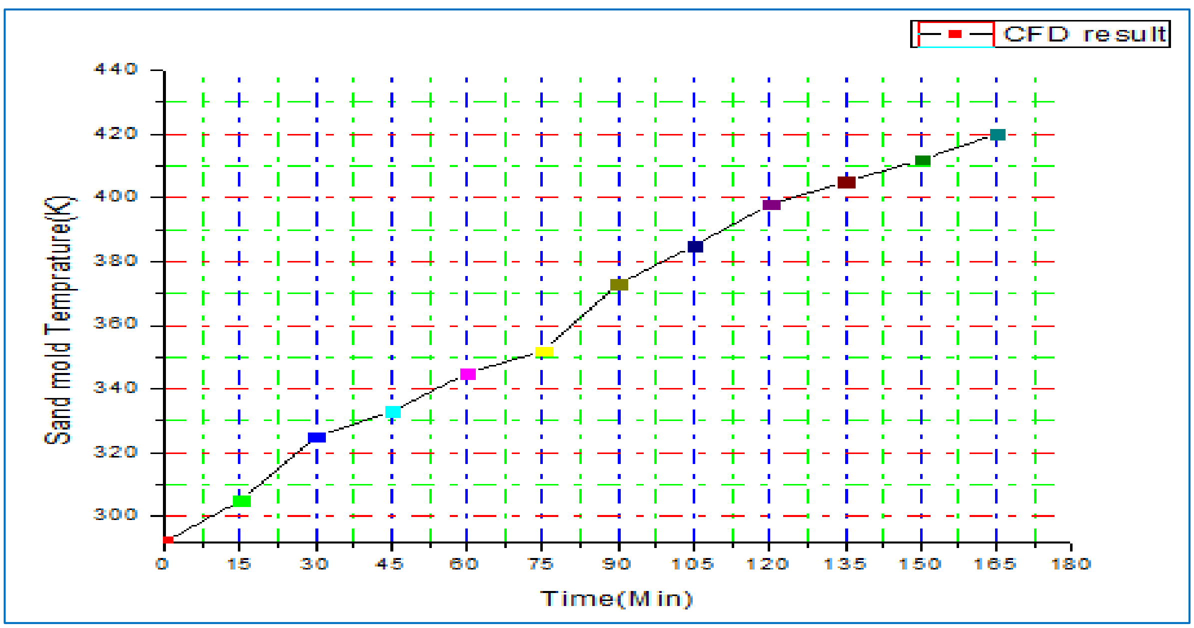

Figure-5.6 CFD Result of Temperature of sand mold increase with Time

And after some time of heat of flue gas rejection the temperature of the flue gas start to decline as shown in the diagram below from Ansys fluent simulation result within specified.

- **Velocity magnitude & contour across complete supply duct**

Velocity magnitude in flue gas supply duct were shown in below figures, from below figures it is evident the velocity of flue gas at inlet of supply duct is specified and along some distance it will decrease and also at some point it is increased.

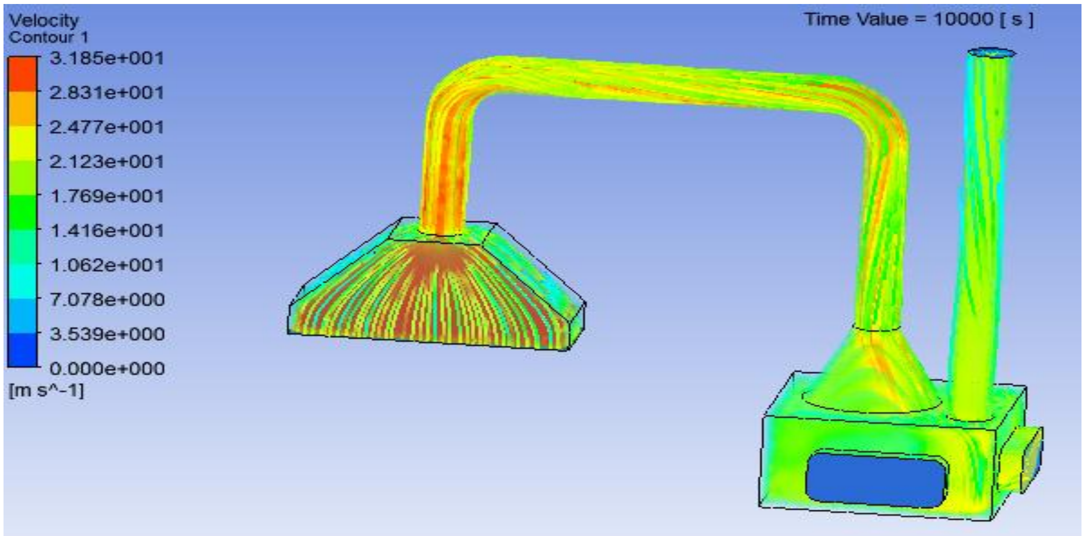

Figure-5.7 velocity contour within a system

In the above figures, we can observe concentration of higher velocities at inlet ducting and also Uniform velocity distribution is identified across the ducting which is around the middle of the duct. This result was because of chaotic properties of turbulent flow.

To validate the accuracy of the ANSYS fluent simulation result, the value of waste heat recovery by the flue gas through supply duct was compared with analytical result obtained from temperature distribution value and heat transfer correlation.

Therefore from Analytical calculation result we have the out let temperature reaching in mold drying room is about 157^{o}C or 430K.and amount of temperature (heat) that gained by the mold from analytical calculation was 138.3 ^{o}C or 411.3K, amount of temperature leaving the system after heat rejection to moist sand was about 135.4 ^{o}C or 409.4K This result implies the amount of temperature carried by the flue gas passing through supply duct and mold drying room was large enough to dry the moist sand mold. Actually, the ANSYS result should be more precise or-accurate than the calculation results, since ANSYS Fluent solves the relevant flow variables at each of the grid points.

Table 5.1: Comparison of Temperature of flue gas and mold between Analytical and CFD results

Parameters(Temperature)	Analytical Value	CFD Simulation Value	Difference
Inlet Temperature Of Moist Sand Mold(T_{msi})	292K	292K	0
Out Let Temperature Of Sand Mold(T_{mso})	411.3K	414K	2.7
Out Let Temperature Of flue gas(T_{fo})	409.4K	419K	9.6

It was found that, Analytical and simulated values of the flue gas temperatures and sand molds temperature were approximately same.

Mold drying Process accompanied by flue gas having temperature 157^0c. The moist sand mold was dried by burning of wood for about 2:00hr.Which is accompanied by temperature ranging about 261^0C on average.

In this research study the flue gas supply duct transport hot flue gas from furnace outlet to mold drying room which have inlet temperature of 240^0C, and out let temperature which arrive at mold drying room was 157^0C with velocity of 1.2 m/s, the flue gas is supplied to the drying room for about 3:00hr.to vaporize the moisture from the sand mold. The above mentioned values are measured and analytically calculated.

As we can see from Ansys and Analytical result it reveal that the temperature of the hot flue gas decrease from 513K to 420K and the temperature of sand mold was increased from 292K to 414K which implies that the sand mold get some latent heat, so that it can vaporize the moisture from sand mold and get dried.

5.2 Economic benefits of the system

Energy use and audit studies were conducted in various units of the foundry shop to evaluate the performance of existing foundry shop; technical gaps in existing shop are analyzed. These systems have many benefits which could be direct or indirect;

Direct benefits: The recovery process will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process.

Indirect benefits: Thermal and air pollution will radically decrease since less flue gases of high temperature are released from the plant since most of the energy is recovered which means the temperature of the flue gas decreased from 513K to 420K which is about 93K temperature is reduced instead of liberated to environment. Hence some of energy, economic, environmental and social advantages of recovery system are;

i. Fuel Saving

From Energy use and technology audit studies it was observed that energy consumption of oil fired furnace depends on the type of fuel and temperature of furnace. Analysis was carried out on conventional oil fired furnace, average fuel consumption in cast iron melting furnace in G7 trading and industrial plc.60lts/batch. And wood Fuel consumption is about 50kg/batch.

The proposed energy efficient oil fired furnace is will save about 18lts/day of oil fuel and 90% saving of wood fuel. Which means it can save cost of wood completely. Hence, Implementation of this system would save about 2160lts of furnace oil annually and 9600kg of wood will be saved.

Even a small reduction in the energy consumption of an energy intensive industry in such foundry shop is highly appreciable. An appropriate energy audit was able to save about 4.5 kg/hr. of fuel amounting to about 35,424birr annually. This was equivalent to about another month's energy consumption value of the foundry. As the data in this audit varies with the energy requirements of the foundry every month, the results depend on the energy consumption.

ii. Environmental benefits

The exhausting flue gas contain very hazardous gases e.g. carbon mono-oxide, carbon dioxide, sulphur oxides, nitrogen oxides, etc. These gases are dangerous for human life in many ways. They also serve as the greenhouse gases which are the main cause of global warming.

It means that if the efficiency of furnace and other installed equipment is enhanced, insulations is improved and leakages are mitigated the escape of these harmful gases can be reduced up to a considerable amount.

iii. Social benefits

Replacing mold drying system with WHRS will reduce furnace heat loss, smoke due wood burning, high casing temperature, all those things will improves the working condition & safety of workers near to oil fired furnace

iv. Productivity improvements

Due to improved design of foundry shop will improves melting temperature; this automatically reduces melting time of scrap cast iron. It was observed that melting is one of major time intense area, melting time reduction in cast iron manufacturing unit will improves productivity ways of mold drying in the shop of G- seven industry

- **Comparison of the former system with new recovery system**

Economical, Technical, Environmental, safety aspects of conventional furnace in foundry shop and energy efficient oil fired furnace are compared on life cycle of equipment, is Presented in Table 5.2 below:

Table 5.2 Comparison of the former system with new recovery system

No	Parameters	Before recovery &utilization of	After recovery &utilization of waste heat
1	Oil consumption	High	Low
2	Environment pollution	High	Low
3	Safety of workers	Poor	Good
4	Maintenance	High	Low
5	Operational cost	High	Low

From the above table it is clear that installing waste heat recovery system in foundry shop has significant advantages with respect to Energy, Environmental, Economic & safety aspects. It is technically justifiable to install energy efficient oil fired melting furnace in place of conventional oil fired melting furnace.

CHAPTER SIX

6 ECONOMIC EVALUATION

6.1 Introduction

This section will focus on the calculation of cost-benefit analysis of the heat recovery systems for which we have found the energy saving and cost saving, the investment cost required to implement these recovery system in order to achieve the savings and the simple payback period will be calculated in order to make sure that the implementation of the recovery system is feasible.

The energy and cost saving from the recommended opportunity of Waste heat recovery from furnace hot flue gas and wood fuel saving was obtained. Now we will determine the feasibility of implementing these opportunities by making the cost benefit analysis.

To perform this research study, there are expected expenses over a specified period of time that enhances the significance of the research. The expenditures are incurred for equipment; materials are listed below in tabulated form.

Table 6.1 Material cost for waste heat recovery and utilization system

No:		Description of the Cost			
1	Part	Material type	Amount	Specific cost In birr	Total cost in birr
2	Harvesting hood	Galvanized Thickness -1.5mm	6m	18,795	18795
3	Supply duct	Galvanized sheet metal 0.8 thickness & 1m*2m	18.5m	470	8695
4	Elbow &Reducer	Sheet metal	2ps&1ps	1620	1620
5	Drying room	Bricks block	Max. 300	2000	2000
6	Insulation(fiber glass)	Insulation Thickness -4cm One role	10m	7500	7500
7	Labor cost	Duct installer technician	3	3500	10500
8	Contingency	For the whole system installation			4000
		Grand total cost of the research			53,110

6.2 Annual fuel and cost saving in the Foundry shop

For analyzing the fuel savings the system we should know the ways to achieve the fuel savings. Waste heat recovery system is one the efficient way to increase efficiency and fuel savings in industries furnace. From the furnace flue gas generated having heat energy, that energy should be recovered and utilized for drying of molds. Heat Transferred by the flue gas through supply duct.

The heat recovered by the hot flue gas in mold drying room (heat exchanger) is used to heat the moist sand mold to vaporize the water from the sand mold.

The heat recovery (Q_R) is therefore equal to the amount of additional fuel that would have been necessary to produce heat for the load.

To find the fuel energy savings (Q_{FS}) to heat exchanger or heat recovery system, with furnace efficiency 28% by using the following equation:

$$Q_{FS} = \frac{QR}{\eta \times \text{GCV of fuel in kJ/kg}}$$

Where: Q_{FS}- Fuel energy saving

Q_R- heat recovery =15.3kJ/s (15.3kw)

η- Efficiency = 28%

Amount of energy saved is already calculated (kJ/hr.) to be 55,080 kJ/hr

The amount of fuel that will be obtained with this amount of energy saving is:

Fuel saved = Energy saved in kJ/hr. / (efficiency of furnace× GCV of fuel in kJ/kg)

= 55080kJ/hr. / (0.28× 43932 kJ/kg) = 4.5 kg/hr.

The estimated annual fuel and cost saving was as follows

Annual money saved = fuel saved annually ×cost of fuel

= 2160lt/yr×16.40 birr/lt = 35,424birr/yr.

Now based on a total number of 768 operating hours annually, this gives 2160 kg of fuel can be saved annually, with cost saving of 35,424 Birr annually.

6.3 Cost-benefit analysis for Installing Heat recovery system

Installing waste heat supply duct in the foundry shop was done by installing circular duct with material type is galvanized sheet metal, the only system installation needed are addition of circular duct at the out let of exhaust chimney and installing mold drying room with bricks block. The implementation cost of the whole system is the cost of purchasing ducts, the labor cost and the maintenance cost. It is estimated around 53,110Br. The cost saving obtained from this opportunity which is from fuel oil and wood fuel was equal to 88,224 Br/year. The simple payback period therefore will be:

$$\text{Simple pay back period(SPP)} = \frac{\text{Implemnetation cost}}{\text{Annual cost saving}}$$

$$\text{Simple pay back period(SPP)} = \frac{53{,}110\text{birr}}{88{,}224\text{birr/yr}}$$

= 0.6 year (about 7 month)

The above simple payback period is from cost saving of fuel oil and wood fuel saved, by Avoiding drying of mold sand by burning of wood fuel is crucial from economic benefit point of view.

CHAPTER SEVEN

7 CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Now a day most of industries in Ethiopia are energy intensive. Therefore to carry out studies on, Alternative energy usage, like waste heat recovery and utilization for saving energy and reduce thermal energy is very significant. Recovering and utilizing waste heat in developing countries like Ethiopia is crucial from energy saving point of view.

Extent of literature available shows a continuously increasing interest of researchers, managements and engineers in recovering the heat. 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 recovery efficiencies by using the latest technological advancements and optimization methods.

This research study evaluated current waste heat recovery practices in a foundry shop of G-7 trading and industrial PLC. The furnace consumes a total of 159kw energy, and the melting furnace account about 24 kW of the energy was wasted as exhaust flue gas, Furnaces continue operating at low efficiencies, due to high exhaust temperature and some other loss, this indicates that the furnace is performing low and the heat of the flue gas recovered in the heat recovery mold drying room is 15 kW. It means that 37.6% of the waste flue gas energy is recovered.

The system of drying mold in this shop consume large amount of wood which was around 9600kg/yr. Different energy saving measures were made for different energy intense system in the shop. The factory can save more than 52,800 birr annually, from the wood.

Based on the measured and analytical analysis of the WHRS and its consequent computational studies using Ansys fluent (CFD), gives the approximately related values.
Temperature of flue gas at outlet of supply duct decreases from 240 ˚C to 157˚C, which means the temperature of the flue gas arriving in mold drying room is 157˚C and this temperature make direct contact with moist sand mold having temperature of 19˚C.the temperature of sand mold rises from 19˚C to 138˚C. Significant amount of energy is saved by the recovery of heat from exhaust flue gases. The quantity of furnace oil saved per day is around 18lt. The total cost of furnace oil saved per day is around 295birr. The economic evaluation was done based on the

simple payback period of the investment made. Almost all of these measures are low cost measures having short payback period which is estimated to be seven month (7month) after installation.

Implementing these measures the factory could use the waste energy as alternative source of energy to enhance energy saving, production capacity and also keep the safety of the worker, while this study focused on gaseous exhaust streams, it was concluded that alternate sources of waste heat can be significant. Studying the feasibility of using this waste heat recovery (WHRS) in a different flue gas temperature capacities from energy and economic Points of view are require further investigation.

7.2 RECOMMENDATION

Energy is crucial in the production of any industry. The cost of energy directly affects the price of product. This has a direct effect on the survival of the factory. Reducing the energy wastage and improving the energy wastage increase the productivity and the competitiveness of the factory.

Based on the study on this thesis, it is recommended to take the following measures in order to decrease the energy waste and cost.

- ✓ Increase awareness of energy issues and energy conservation concern within the industries and for all workers as a whole.
- ✓ Set off a new energy research and information center to get the energy capacities and use of new technology and concepts for improving the energy efficiency and conservation.
- ✓ Introduce energy management guide lines that help in Development and implementation of key process technologies that aid the reduction of energy consumption and/or energy cost.

More research and simulations should be done on modifications of this system to raise its capability and efficiency furnace so that it becomes a feasible way of gathering energy for use of waste heat as an alternative energy.

- ✓ And also improving and optimizing mold drying time below 3hr is recommended as future work.
- ✓ Pre-heating combustion air using hot flue gas by introducing recuperator is crucial for increasing furnace combustion efficiency.

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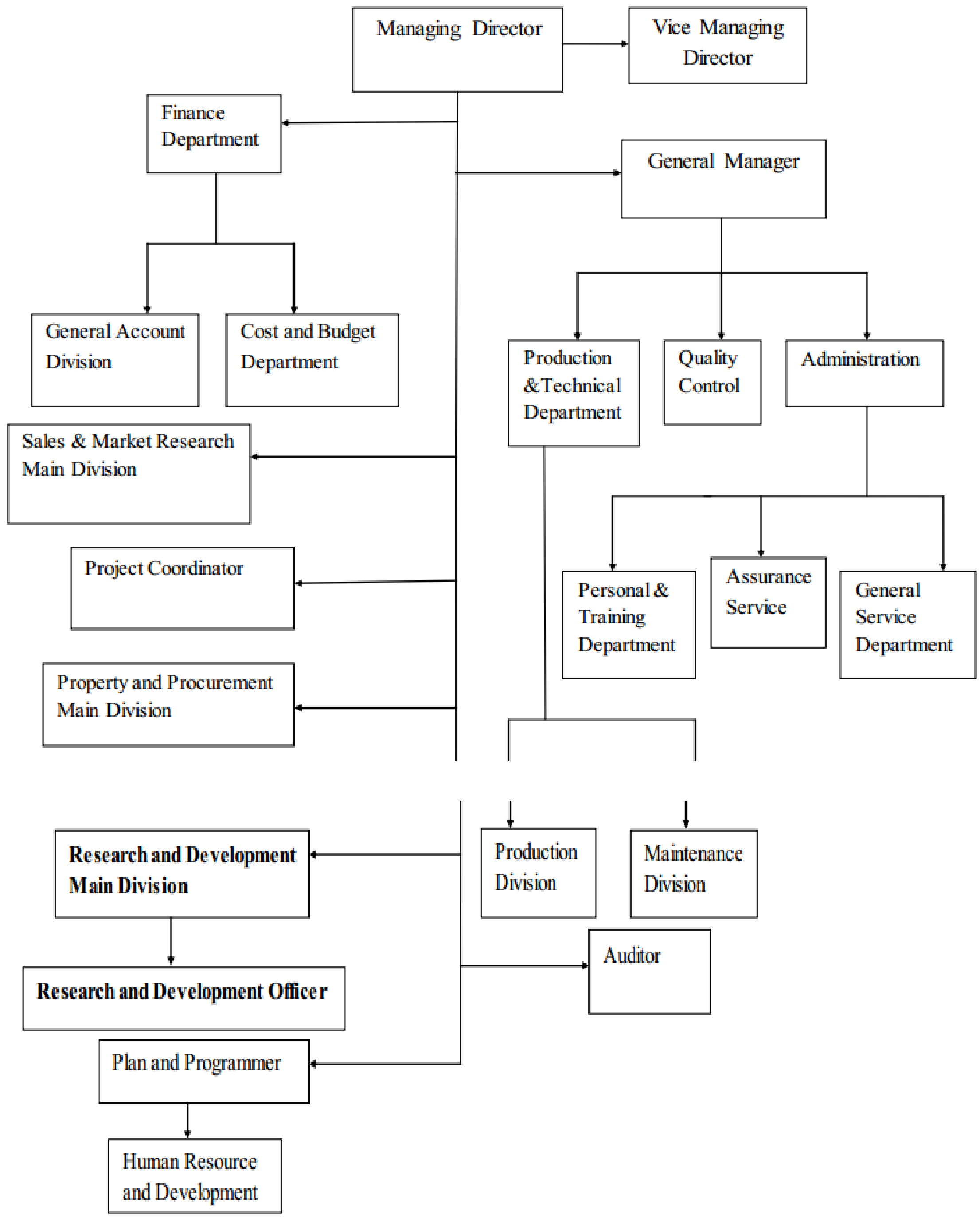
Appendix A: Organizational Structure of G-7 Trading and Industrial PLC.



Appendix B: Flue Gas Properties Calculator Soft Ware (LV software)

RESULTS	
Gas Molecular Weight	28.1544
Density, lb/ft3	0.0417
Enthalpy, Btu/lb	104.2878
Temperature, °F	464.0000
Specific Heat, Btu/lb-F	0.2640
Thermal Cond., Btu/hr-ft-F	0.0231

- ***For a temperature of flue gas at 240 ^oC (464^oF) from the above table converted as below;***

Where:

Density (p) =0.0417lb/ft^3 = 0.6679 kg/m^3

Enthalpy (H)=104.2878Btu/lb=242.6kJ/kg

Specific heat (Cp)=0.2640Btu/lb.^{o}F=1.1053kJ/kg.^{o}C

Thermal conductivity (K)=0.0231Btu/hr.ft.^{o}F

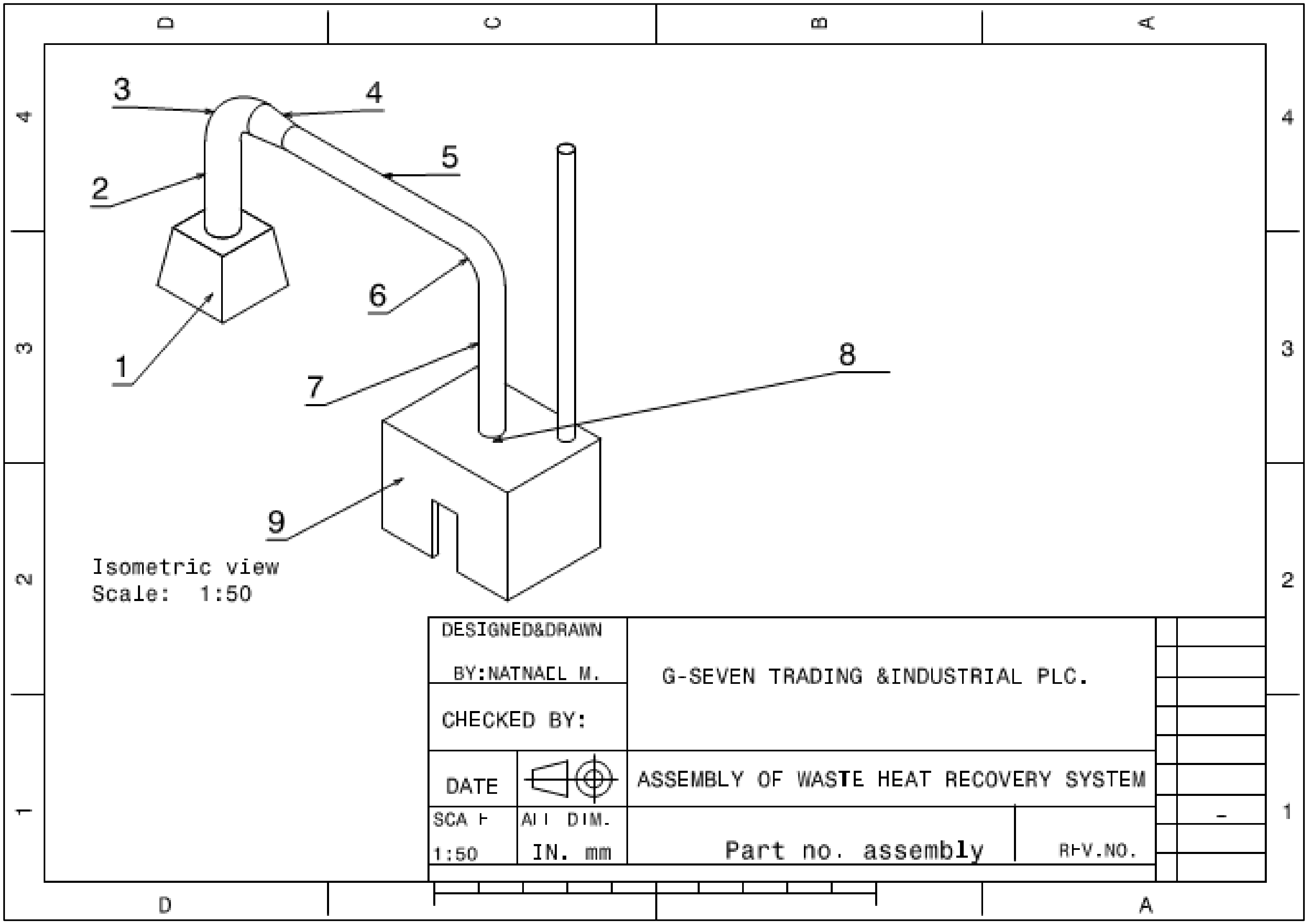
The kinematic viscosity(ν) of flue gas at temperature (t) in ^{o}C is calculated using Lauterbach Verfahrenstechnik (LV) software as:

$\nu = (0.1335 + 0.925x10^{-3}t)\ x10^{-4}\ m^2/s$ Where t - is temperature of flue gas entering to supply duct.

APPENDIX C: Detail Manufacturing Drawing For Waste Heat Recovery

BILL OF MATERIAL: For Newly Designed Supply System of Flue Gas

No.	Qty.	Part Name	Material	Type
1	1	Flue gas Harvesting Hood	Sheet Metal	Part
2	1	Vertical up ward duct for flue gas	SM	part
3	1	Elbow joint with(D=400mm)	SM	part
4	1	Reducer joint	SM	part
5	1	Horizontal supply duct	SM	part
6	1	Elbow joint with (D=300mm)	SM	part
7	1	Vertical downward supply duct	SM	part
8	4	Supply system for molds	SM	part
9	1	Mold drying Room	Bricks block	part


3
4
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2
6
1
8
7
9
Isometric view
Scale: 1:50
DESIGNED&DRAWN
BY:NATNAEL M.
CHECKED BY:
G-SEVEN TRADING &INDUSTRIAL PLC.
DATE
ASSEMBLY OF WASTE HEAT RECOVERY SYSTEM
SCALE
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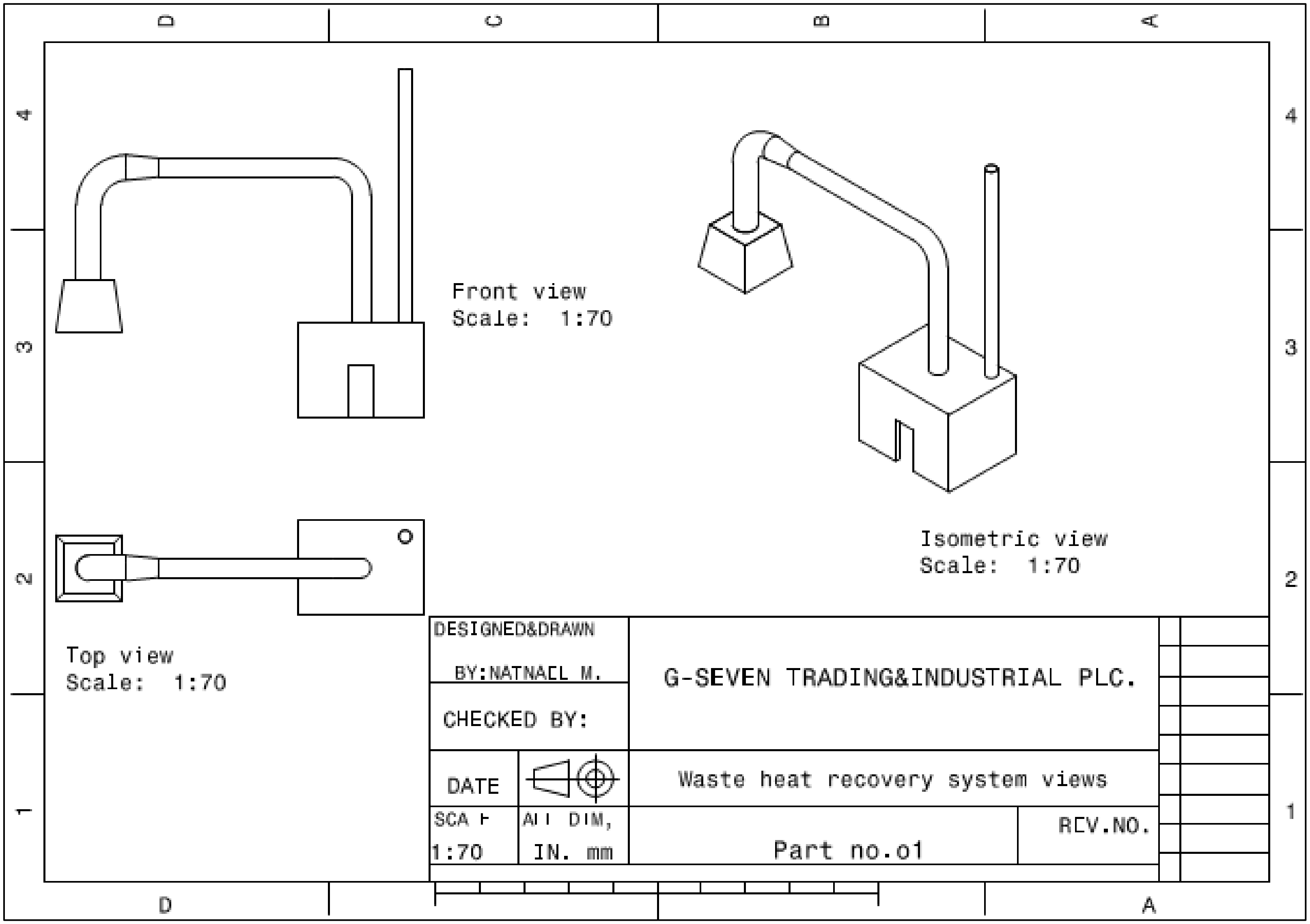
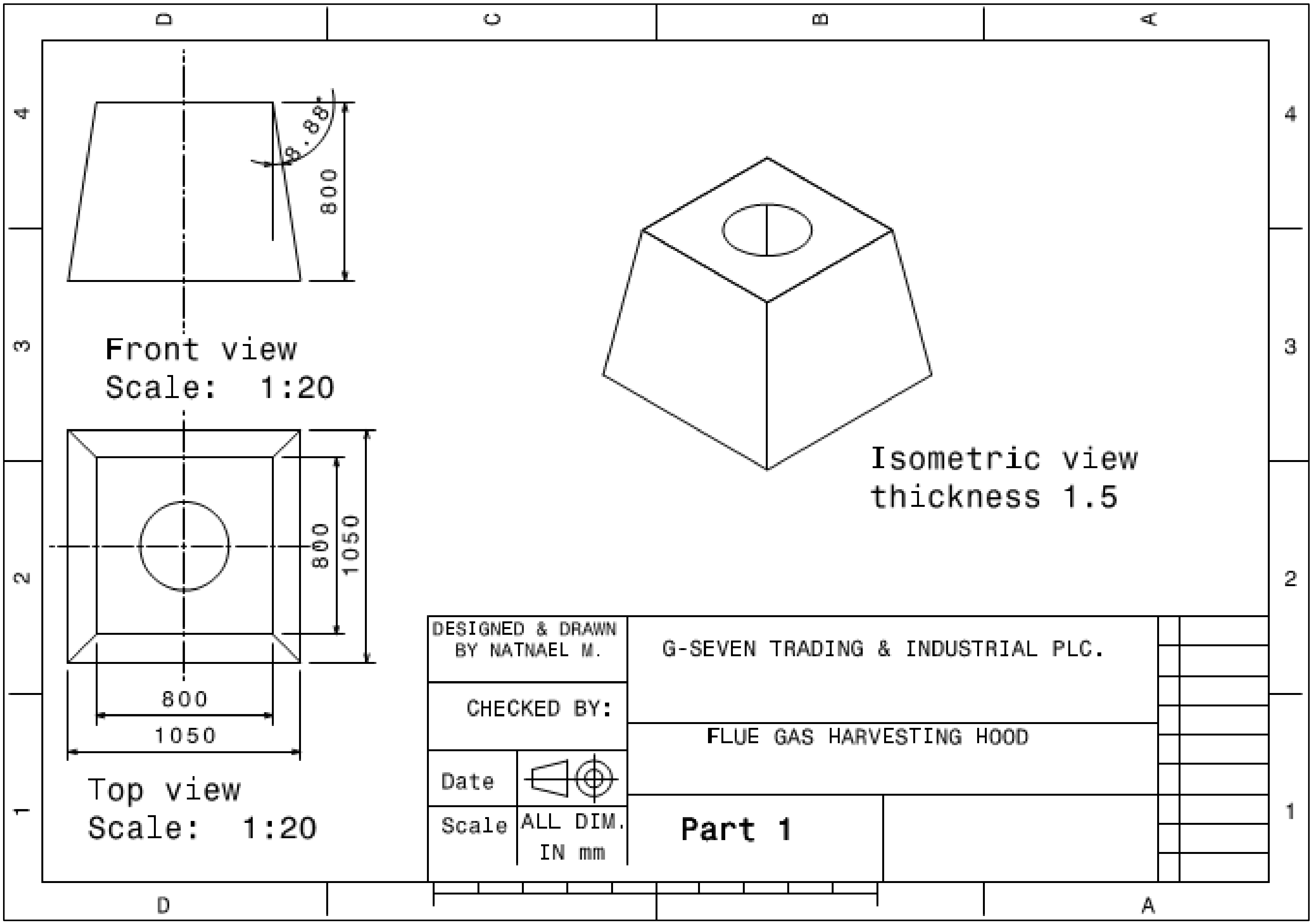
ALL DIM.
IN. mm
Part no. assembly
REV.NO.


Front view
Scale: 1:70
Isometric view
Scale: 1:70
Top view
Scale: 1:70
DESIGNED&DRAWN BY:NATNAEL M.
CHECKED BY:
G-SEVEN TRADING&INDUSTRIAL PLC.
DATE
Waste heat recovery system views
SCALE 1:70
ALL DIM, IN. mm
REV.NO.
Part no.o1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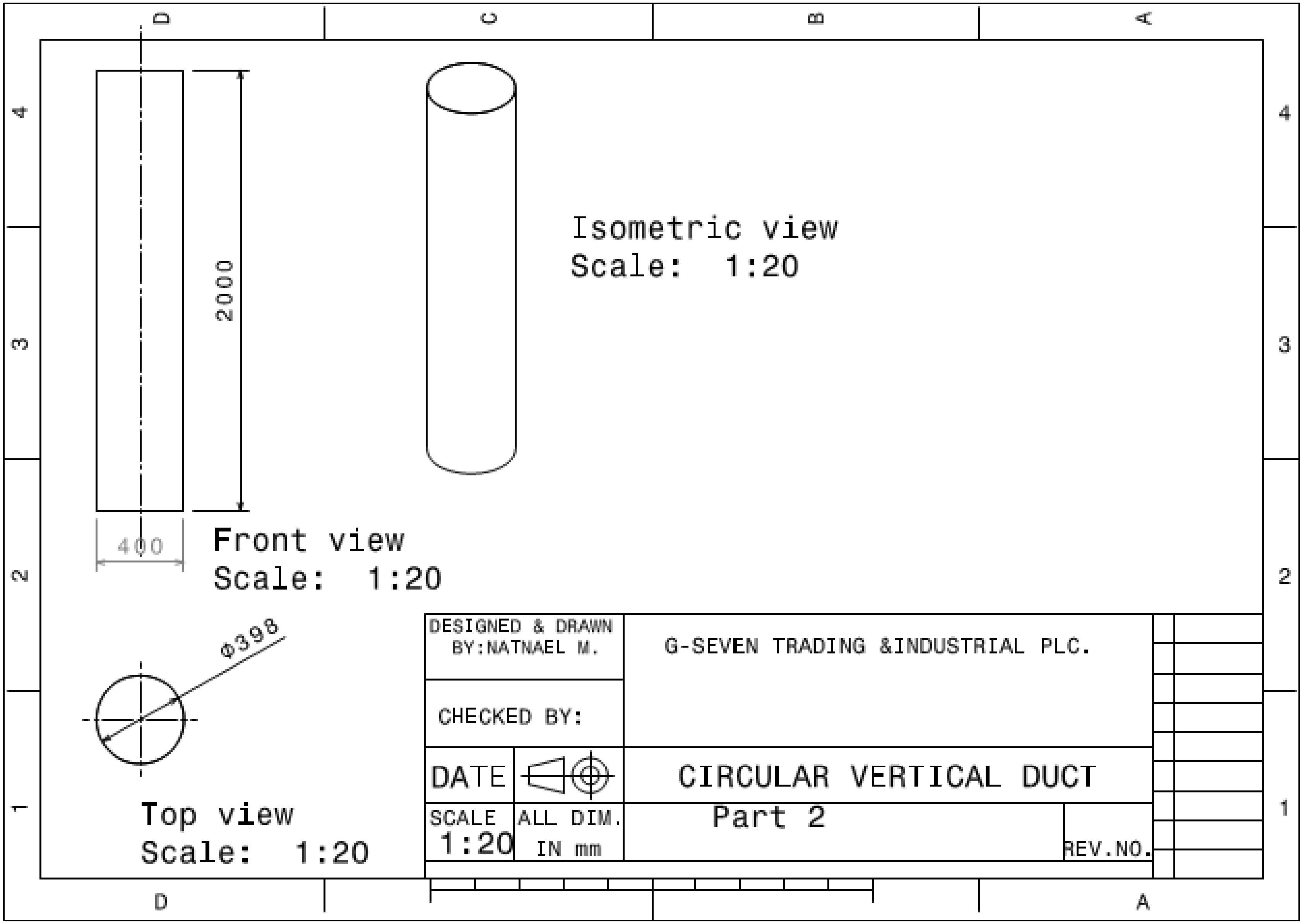
88.8°
800
Front view
Scale: 1:20
800
1050
800
1050
Top view
Scale: 1:20
Isometric view
thickness 1.5
DESIGNED & DRAWN BY NATNAEL M.
G-SEVEN TRADING & INDUSTRIAL PLC.
CHECKED BY:
FLUE GAS HARVESTING HOOD
Date
Scale
ALL DIM. IN mm
Part 1


D
C
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400
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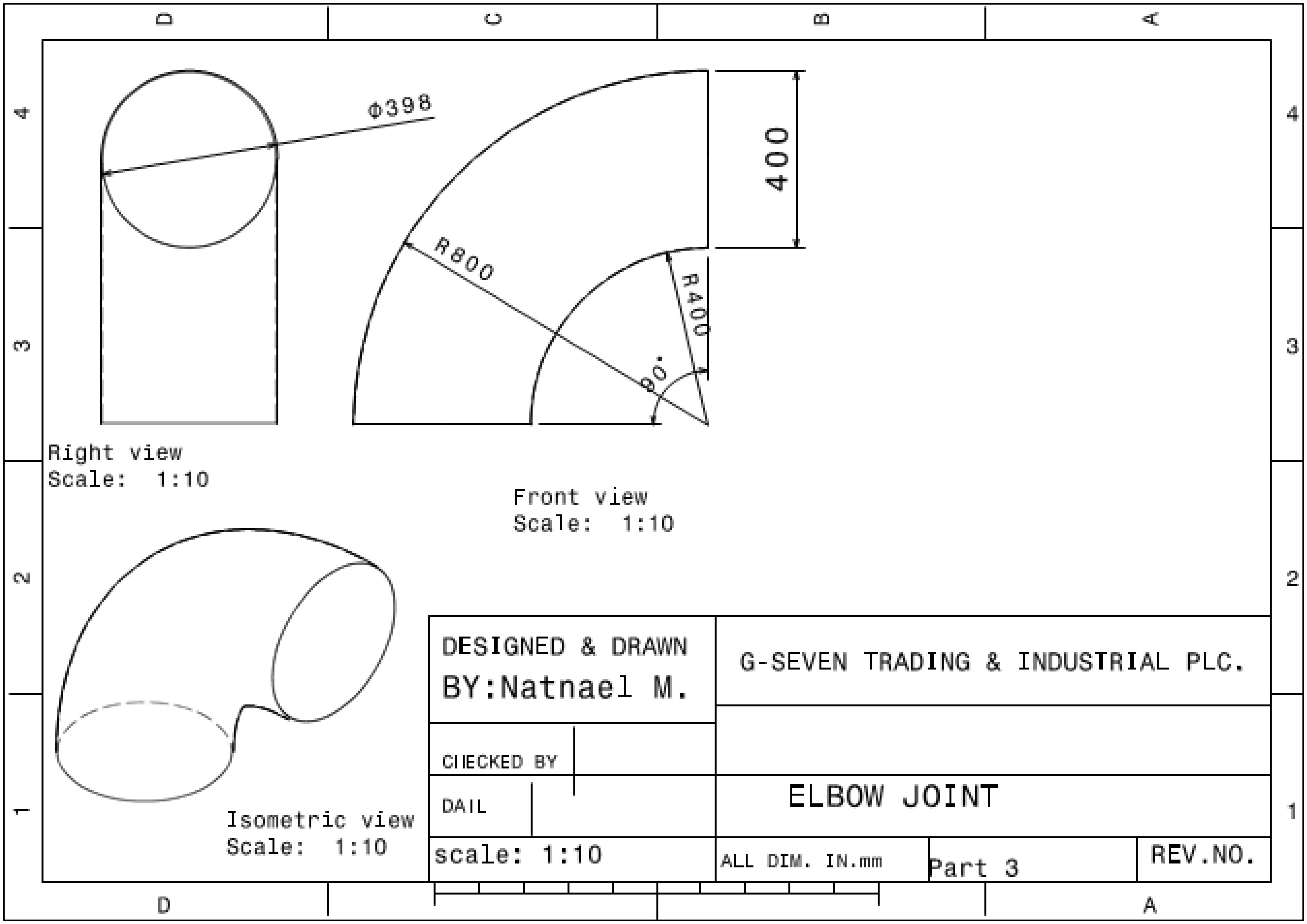
Front view
Scale: 1:20
Isometric view
Scale: 1:20
Top view
Scale: 1:20
DESIGNED & DRAWN BY:NATNAEL M.
CHECKED BY:
G-SEVEN TRADING &INDUSTRIAL PLC.
DATE
CIRCULAR VERTICAL DUCT
SCALE 1:20
ALL DIM. IN mm
Part 2
REV.NO.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1
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400
R800
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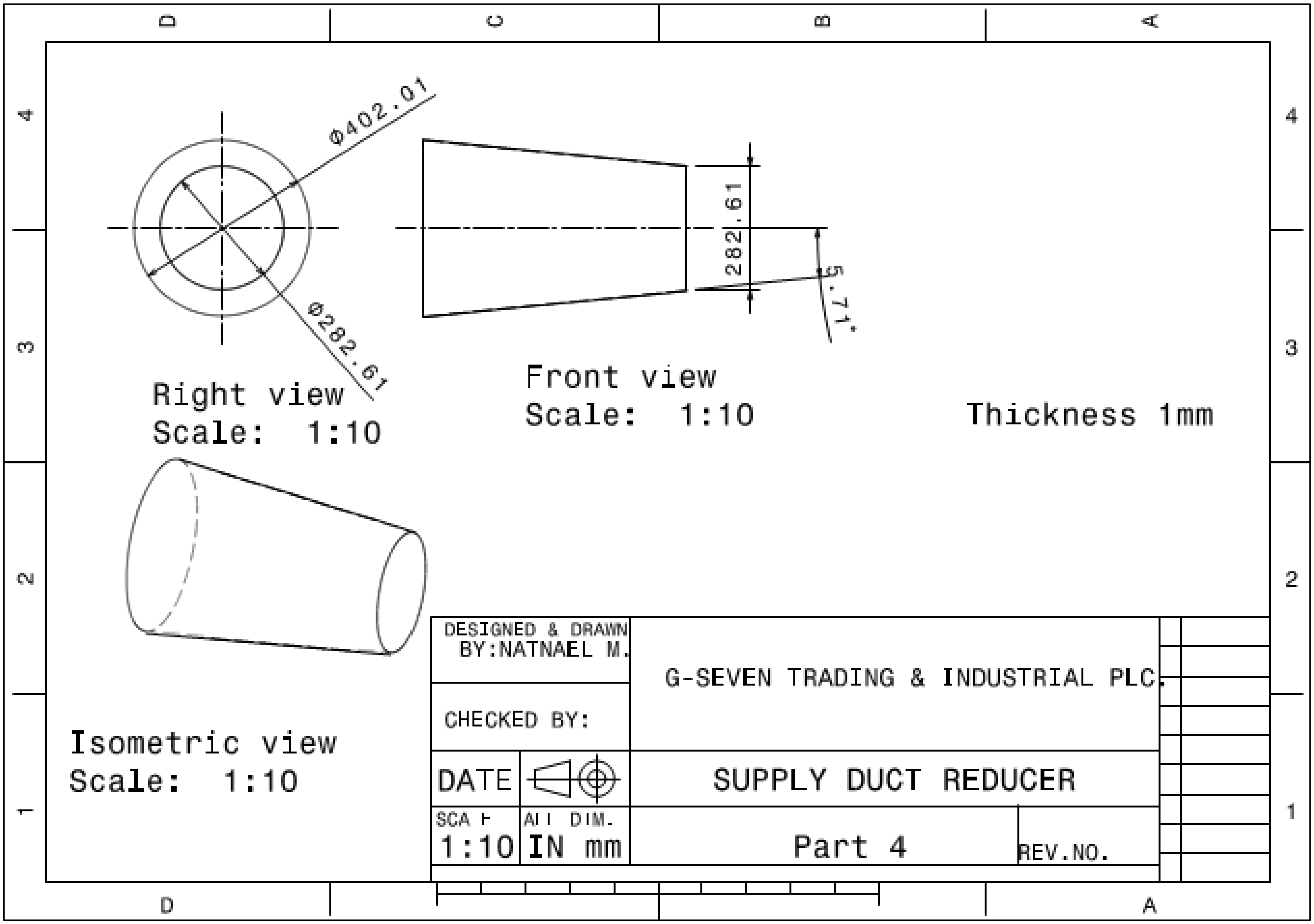
90°
Right view
Scale: 1:10
Front view
Scale: 1:10
Isometric view
Scale: 1:10
DESIGNED & DRAWN
BY:Natnael M.
G-SEVEN TRADING & INDUSTRIAL PLC.
CHECKED BY
DAIL
ELBOW JOINT
scale: 1:10
ALL DIM. IN.mm
Part 3
REV.NO.


D
C
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A
4
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2
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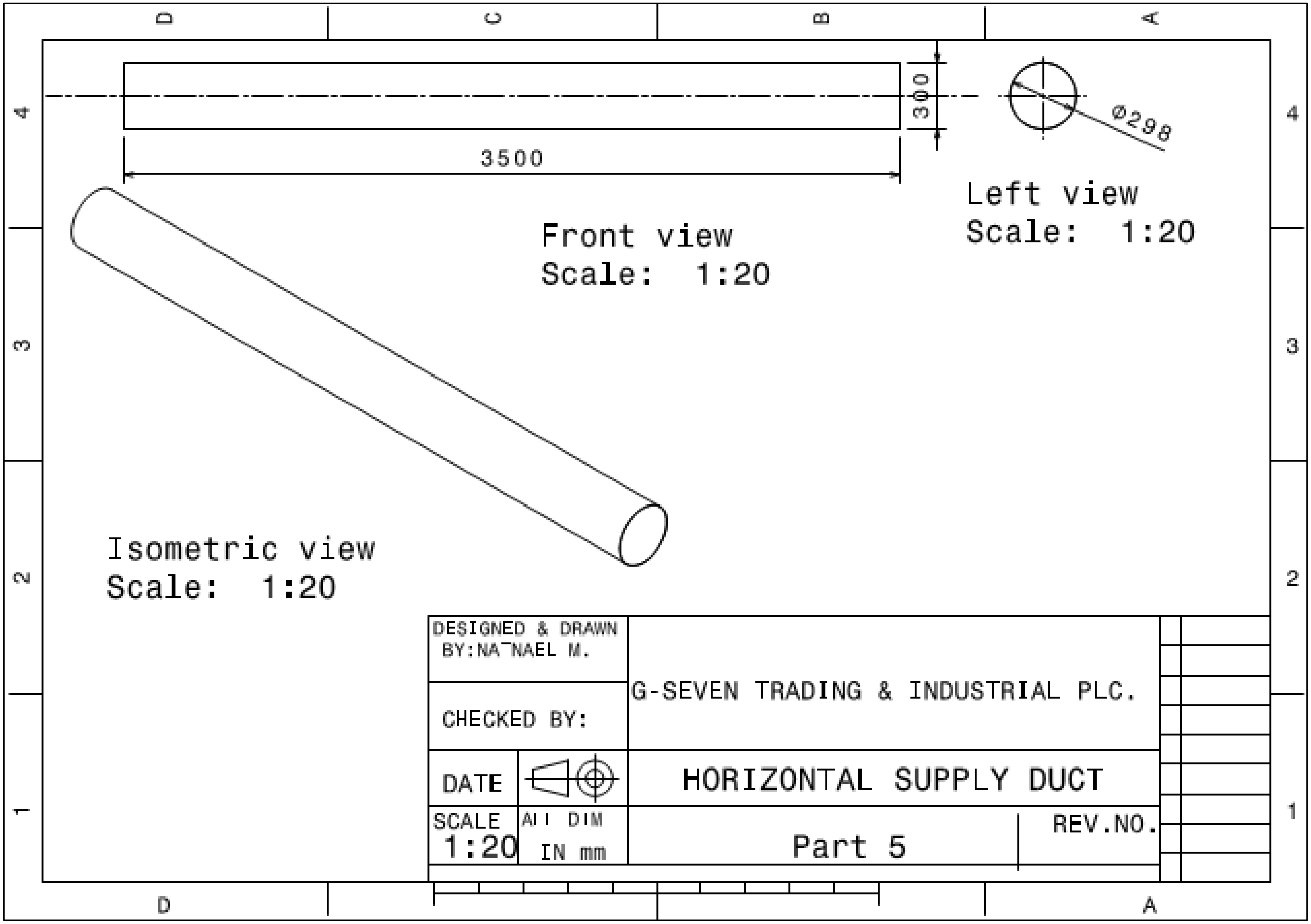
Ø282.61
282.61
5.71°
Right view
Scale: 1:10
Front view
Scale: 1:10
Thickness 1mm
Isometric view
Scale: 1:10
DESIGNED & DRAWN BY:NATNAEL M.
G-SEVEN TRADING & INDUSTRIAL PLC.
CHECKED BY:
DATE
SUPPLY DUCT REDUCER
SCALE
1:10
ALL DIM.
IN mm
Part 4
REV.NO.


D
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4
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2
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300
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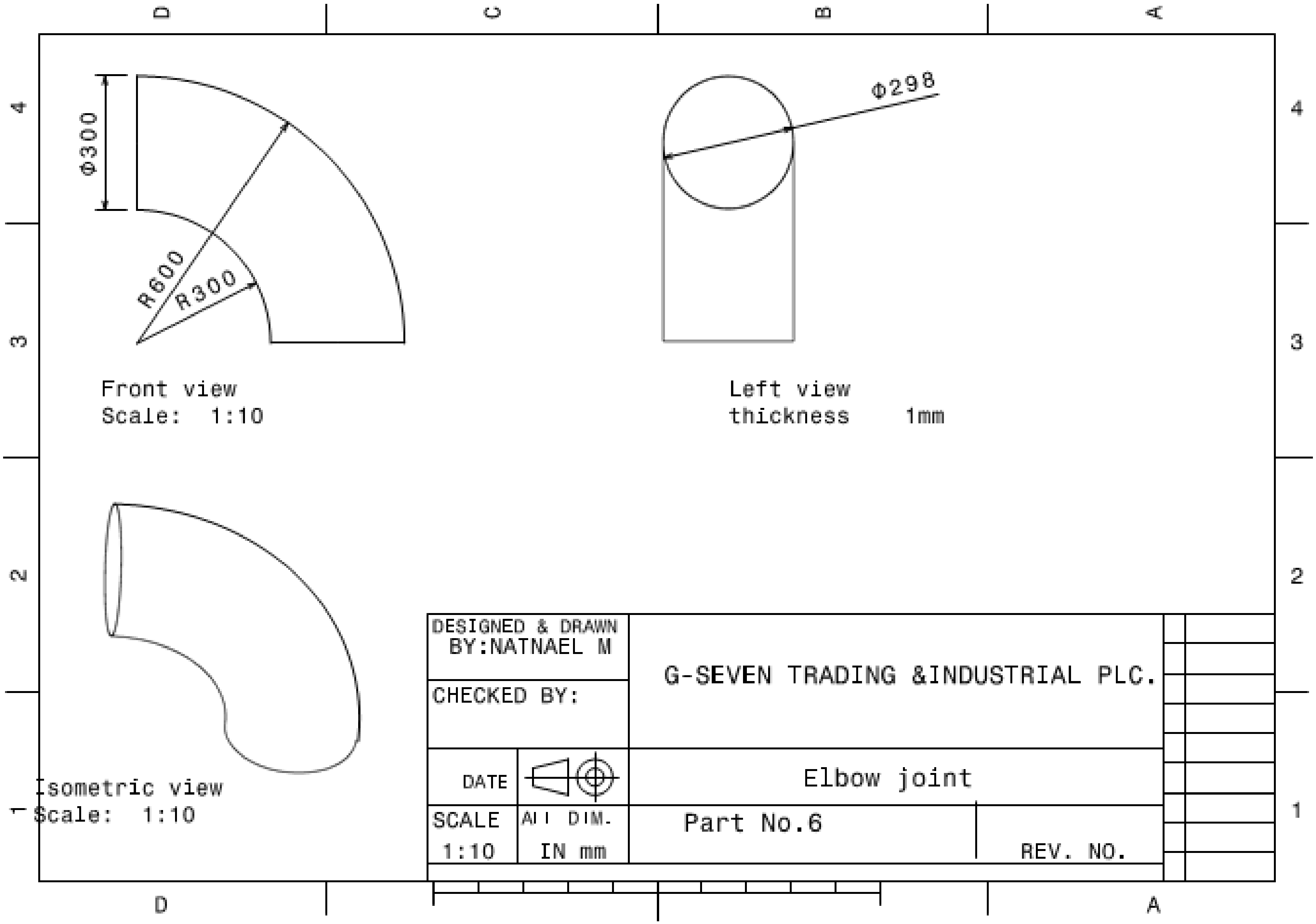
3500
Left view
Scale: 1:20
Front view
Scale: 1:20
Isometric view
Scale: 1:20
DESIGNED & DRAWN BY:NA¯NAEL M.
CHECKED BY:
G-SEVEN TRADING & INDUSTRIAL PLC.
DATE
HORIZONTAL SUPPLY DUCT
SCALE 1:20
ALL DIM IN mm
Part 5
REV.NO.


D
C
B
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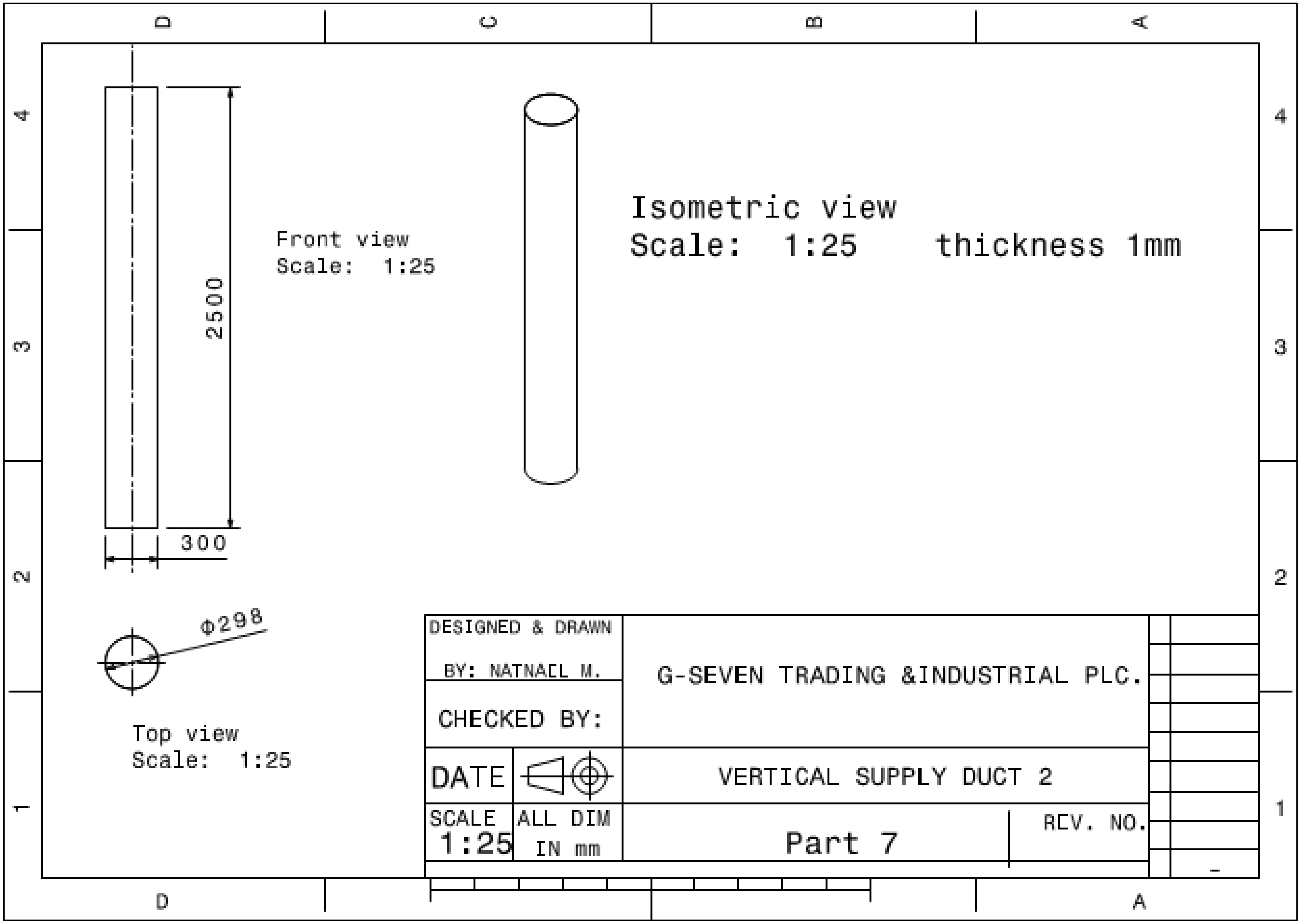
4
3
2
1
Φ300
R600
R300
Φ298
Front view
Scale: 1:10
Left view
thickness 1mm
Isometric view
Scale: 1:10
DESIGNED & DRAWN
BY:NATNAEL M
G-SEVEN TRADING &INDUSTRIAL PLC.
CHECKED BY:
DATE
Elbow joint
SCALE
1:10
ALL DIM.
IN mm
Part No.6
REV. NO.


D
C
B
A
4
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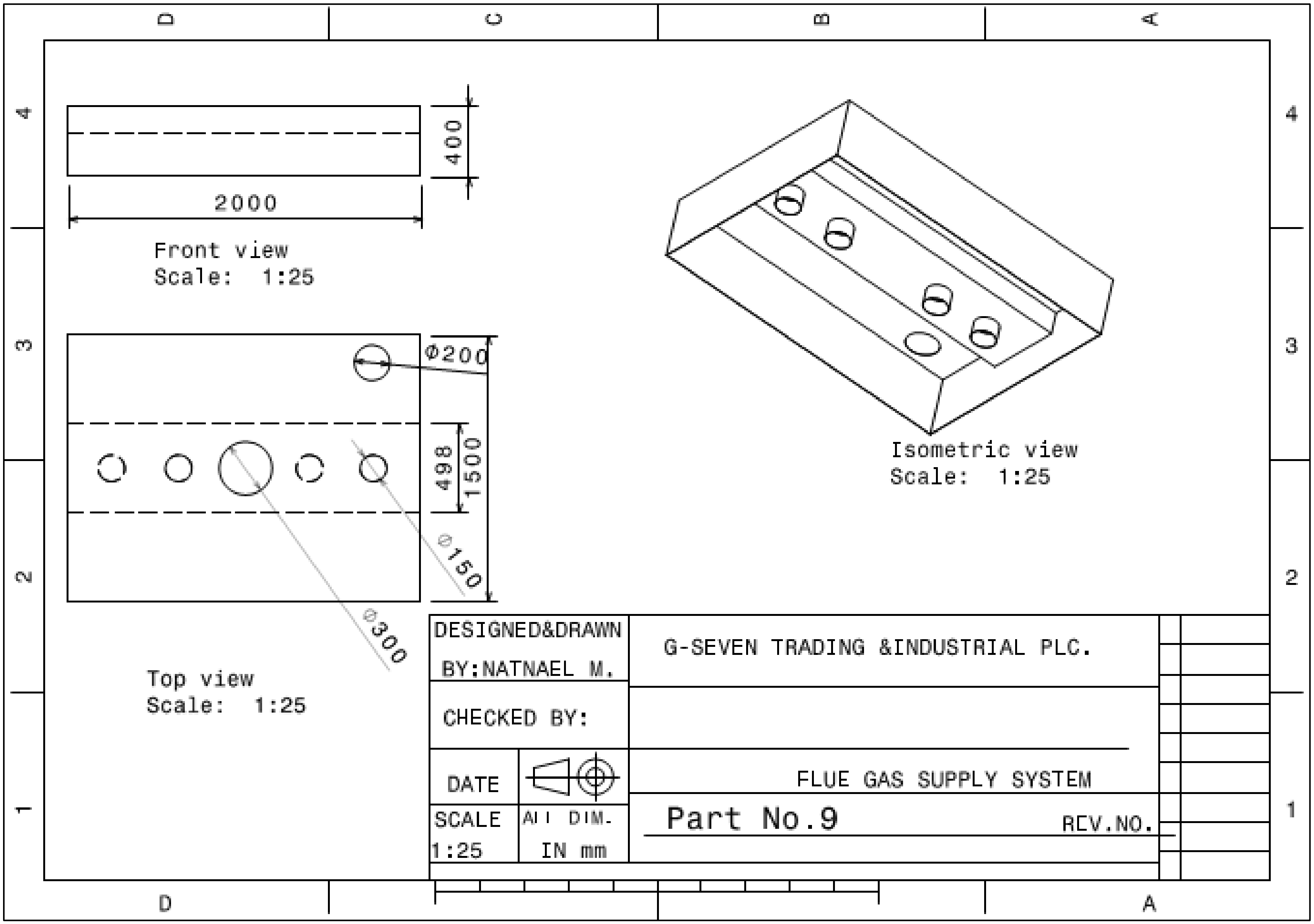
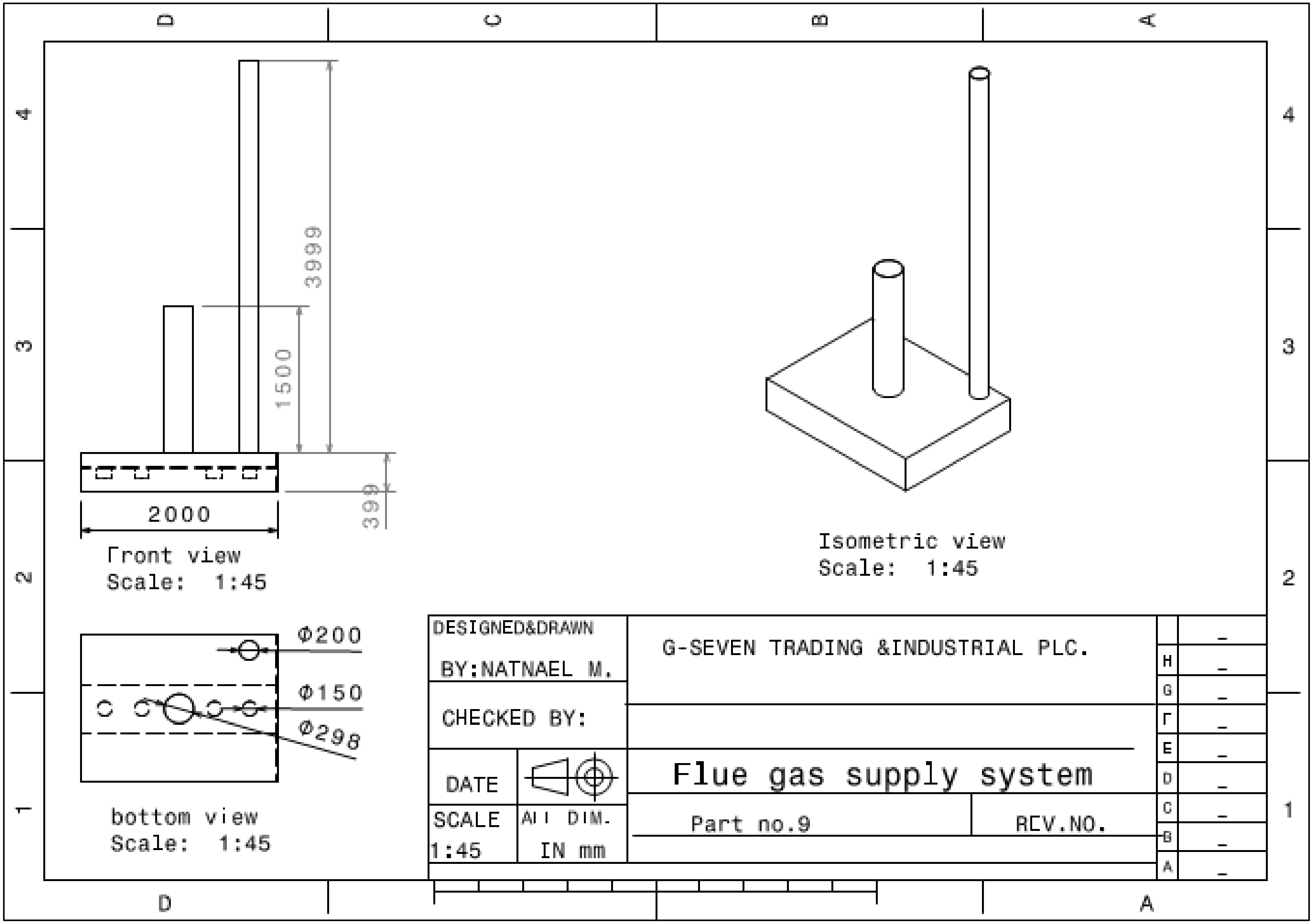
2500
300
Front view
Scale: 1:25
Isometric view
Scale: 1:25 thickness 1mm
Φ298
Top view
Scale: 1:25
DESIGNED & DRAWN
BY: NATNAEL M.
CHECKED BY:
G-SEVEN TRADING &INDUSTRIAL PLC.
DATE
VERTICAL SUPPLY DUCT 2
SCALE
1:25
ALL DIM
IN mm
Part 7
REV. NO.


2000
400
Front view
Scale: 1:25
Φ200
498
1500
Φ150
Φ300
Top view
Scale: 1:25
Isometric view
Scale: 1:25
DESIGNED&DRAWN
BY:NATNAEL M.
G-SEVEN TRADING &INDUSTRIAL PLC.
CHECKED BY:
DATE
FLUE GAS SUPPLY SYSTEM
SCALE
1:25
ALL DIM.
IN mm
Part No.9
REV.NO.


3999
1500
399
2000
Front view
Scale: 1:45
Isometric view
Scale: 1:45
Φ200
Φ150
Φ298
bottom view
Scale: 1:45
DESIGNED&DRAWN
BY:NATNAEL M.
CHECKED BY:
DATE
SCALE
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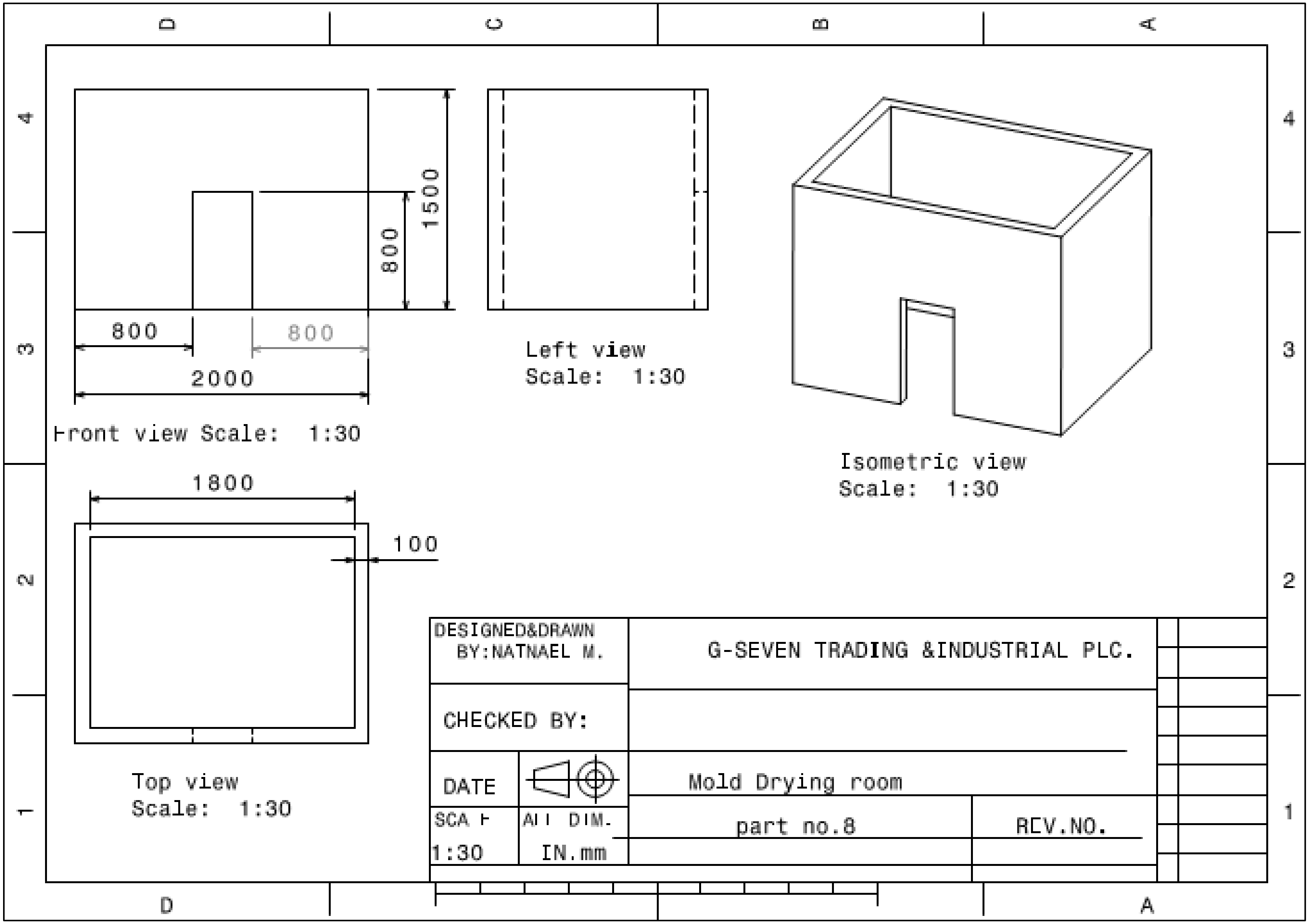
ALL DIM.
IN mm
G-SEVEN TRADING &INDUSTRIAL PLC.
Flue gas supply system
Part no.9
REV.NO.


800
800
2000
800
1500
Front view Scale: 1:30
Left view
Scale: 1:30
Isometric view
Scale: 1:30
1800
100
Top view
Scale: 1:30
DESIGNED&DRAWN
BY:NATNAEL M.
G-SEVEN TRADING &INDUSTRIAL PLC.
CHECKED BY:
DATE
Mold Drying room
part no.8
REV.NO.
1:30
IN.mm