UNIVERSITY OF NAIROBI

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IDENTIFICATION AND ANALYSIS OF ENERGY SAVING OPPORTUNITIES FOR REHEAT FURNACE AT DEVKI STEEL ROLLING MILLS

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DECLARATION

I Clement C. Lumbasi declare that this report is my original work, and except where acknowledgements and references are made to previous work, this work has not been submitted for examination in any other University.

Signature ………………….. Date……………………

Approval by Supervisors

I confirm that the study was carried out under our supervision and has been submitted for examination with our approval as University supervisors

Prof. J.A. Nyang'aya   Signature…………………..Date………….

Dr. A. Aganda   Signature…………………...Date…………

DEDICATION

I dedicate this work to my family for their continual love and unwavering support during the journey of learning.

ACKNOWLEDGEMENT

ABSTRACT

This study seeks to identify energy cost saving measures that if implemented can cut down on energy consumption. In this study, the areas identified, analyzed and evaluated for energy efficiency improvement and cost savings include; the upgrade of the damaged furnace door, proper lagging of combustion air pipes, furnace wall and recuperator and billet preheating.

The processes in steel mills will be discussed with an emphasis on energy consumption, current prevalent practices in the industry and potential measures for energy use and cost savings elaborated. The results from an energy analysis at Devki steel mills Ruiru will be presented using tables and graphs.

This study which is an energy analysis of Devki steel mills reheat furnace will be based on the following research objective; to assess the energy efficiency of reheat furnace and analyze the feasibility of waste heat recovery of reheat furnace. This will be achieved through identification and quantification of energy losses through reheat furnace efficiency calculation and the evaluation of feasibility of billet preheating by energy recovered from flue gases.

A feasibility analysis for the areas identified for improvements which are; the upgrade of the reheat furnace door, proper lagging of recuperator, furnace wall and combustion air pipes and billet preheating will be carried out. Data obtained will be analyzed and presented with suitable illustration tables, charts and diagrams which will then be benchmarked with other world class steel rolling companies. This will then be scrutinized for ways to cut energy use, reduce waste and thereby reduce production costs.

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CHAPTER 1: INTRODUCTION

1.0 DEVKI STEEL ROLLING MILLS

Devki steel rolling Mills limited was established in 1994. The company was founded by Mr. Narendra Raval. The company is located at Ruiru, off Thika super highway in Kiambu. The company imports steel bars and rolls these bars into reinforcement bars and hot rolled sections, used mainly in the construction and transport sectors.

1.1 PROCESS DESCRIPTION

According to Devki standard operation procedures for steel rolling, the company imports billets of various sizes (120mm×120mm, 100mm×100mm) according to the best price/quality availability. The billets are cut into 2m length. These billets are fed in two rows to the heating area of the reheating furnace. This furnace is a batch type furnace, where billets are heated in three sequential heating zones (preheating zone, heating zone and soaking zone). The furnace is fired using furnace oil and combustion air is pre heated using a recuperator.

The red hot billets are pushed into a conveyor channel as they are passed through the various heating zones in the furnace. The billets are thereafter taken to the roller for the rolling process. During rolling, the thickness of the billets is reduced in seven steps at eight rolling stations or sets. The rolled products are cooled down on a walking beam conveyor. Electrical air blower fans are used from the bottom side of the walking beam conveyor to achieve the fast cooling rate. The end products are cut as per customer requirements, products are stretched and twisted to achieve the correct straightness and shape (Devki production report, 2010)

1.2 ENERGY SITUATION AT DEVKI

The effective use of energy in an industry is of utmost importance, this is because energy is an integral part of the final product cost. The main objective of this study is to analyze the feasibility of waste heat recovery from reheat furnace flue gas for preheating steel billets. At Devki rolling mills, the main forms of energy used are fuel oil and electricity

Energy requirement is a quantitative measure of the total energy required for the manufacture of a product, including energy used in converting materials, providing heating for the process, conveying, lighting and so on; usually has the units of mega-joules/tone of product. Since this is related only to the number of units used in the manufacture of a particular mass of product,

it can be used to make a judgment about the energy efficiency with which a product is made. (Barret, 1996)

The table 1.0 below shows fuel consumption, production in tons and product type for August and September for the reheat furnace. This data is necessary for determining energy consumption per unit product, hence energy intensity.

Table 1. 1 Furnace fuel consumption

Date	Production today (tons)	Production to date (tons)	Running time (Hrs)	Product type	Oil consumed (lts)
01/08/13	67.195	67.195	12	Y25	3200
02/08/13	63.0565	130.2515	12	Y25	3150
03/08/13	-	-	-	-	-
04/08/13	-	-	-	-	-
05/08/13	-	-	-	-	-
06/08/13	16.376	146.625	08	Y25	2400
07/08/13	47.4815	194.109	09	Y25	2500
08/08/13	67.195	261.304	12:30	Y25	3400
09/08/13	-	-	-	-	-
10/08/13	54.8685	316.1725	12:30	Y25	3200
11/08/13	-	-	-	-	-
12/08/13	41.207	357.3795	08	Y25	2500
13/08/13	75.205	432.5845	12	Y25	3450
14/08/13	64.08	496.6685	10	Y25	2950
15/08/13	67.106	563.7705	12	Y25	3250
16/08/13	78.053	641.8325	12	Y25	3400
17/08/13	-	-	-	-	-
18/08/13	-	-	-	-	-
19/08/13	-	-	-	-	-
20/08/13	71.022	712.8455	12	Y25	3500
21/08/13	47.17	760.0155	08	Y25	2200
22/08/13	36.3225	796.378	12	Y32	2800
23/08/13	53.94	850.278	12	Y32	3000
24/08/13	-	-	-	-	-
25/08/13	-	-	-	-	-
26/08/13	-	-	-	-	-
27/08/13	38.376	888.654	11	Y16	3500
28/08/13	37.583	926.237	08	Y16	2050
29/08/13	14.742	940.979	03	Y16	1200
30/08/13	52.78	993.959	11	Y16	3050
31/08/13	24.57	1018.329	04	Y16	1650
1/09/13	-	-	-	-	-
2/09/13	57.33	57.33	12	Y16	3200
3/09/13	52.4706	109.8006	10:30	Y16	2700

4/09/13	64.155	173.9556	12	Y16	3100
5/09/13	58.24	232.1956	11:30	Y16	2700
6/09/13	15.015	247.2106	05	Y16	1200
7/09/13	63.245	310.4556	12	Y16	2600
8/09/13	-	-	-	-	-
9/09/13	64.883	375.3386	12	Y16	2700
10/09/13	-	-	-	-	-
11/09/13	33.672	408.4626	10	Y16	2550
12/09/13	30.03	438.4928	11	Y16	2200
13/09/13	35.672	474.1646	12	Y16	2250
14/09/13	47.32	521.4846	10:30	Y16	2700
15/09/13	-	-	-	-	-
16/09/13	58.058	579.5426	12	Y16	3100
17/09/13	60.97	640.5126	12	Y16	3050
18/09/13	70.07	710.5826	12	Y16	3150
19/09/13	60.06	770.6426	12	Y16	2900
20/09/13	74	844.6426	12	Y16	3300
21/09/13	61.425	906.0676	12	Y16	3200

Source: Devki steel rolling mills records 2013

Energy intensity or specific energy consumption reflects the amount of energy required per unit of output or activity (Christina et al (2003).

Therefore, the reheat furnace fuel usage for August and September is an average of 102,950 liters of furnace oil. Areas identified for improvement or energy conservation at Devki steel rolling mills include;

The upgrading of the furnace door; as seen from Fig 1.2, the reheat furnace from where the red hot billets are removed from the furnace is damaged, it cannot be closed and is therefore left open during the entire normal 12 hour cycle. The furnace door should however be left open for 30 minutes duration when the hot steel billets are extracted from reheat the furnace after every 2 hour cycle. The effect of damaged furnace door is the infiltration of cold air into the furnace, loss of heat from furnace by radiation.

Insulation; this includes insulating the furnace walls, recuperator and combustion air pipes. From Fig.1.3 showing recuperator not lagged, Fig. 1.3 and Fig.1.4 showing combustion air pipes not lagged and Fig.1.5 showing recuperator not lagged, considerable savings on fuel consumed can be made if proper lagging of the reheat furnace is done. These energy measures if implemented can improve the company's energy index.

1.3 BACKGROUND OF THE STUDY

The manufacturing sector mainly uses electricity and oil as sources of energy in its production process. The utilization of these two forms of energy, on average has been rising, resulting in increased cost in terms of energy and total production.

The manufacturing sector is the third largest energy end user in the Kenya economy (Republic of Kenya, Economic survey (2002). It is the largest user of petroleum products, after the transport sector, and the largest consumer of electricity (Republic of Kenya, Economic survey (2001)

Petroleum is Kenya's major source of commercial energy and has, over the years, accounted for about 80% of the country's commercial energy requirements. In 2006, 4.4 million cubic meters in petroleum products were sold in Kenya, of this 420,000 m^3 was kerosene and 68,000 m^3 was LPG. Total petroleum consumption in Kenya has grown from 2.6 million cubic meters in 2003 to 3.73 million cubic meters in 2006. The consumption maintains an upward trend. As of 2009, demand for petroleum products was 3,656 thousand tons. As of 2007, Kenya had one refinery, the Mombasa refinery, with a nameplate capacity of 90,000 barrels per day. Since its commission the refinery has not operated at full capacity leading to a shortage of HFO among other petroleum products and therefore ways of conserving the available energy should be considered by industrial consumers.

(https://energypedia.info/wiki/Kenya_Country_Situation).

1.4 PROBLEM STATEMENT

This study sought to Identify and analyzes possible energy saving measures: proper lagging of reheat furnace wall, lagging of recuperator and combustion air pipes and upgrading reheat furnace door at Devki steel mills, Ruiru. In the steel sector, there are many opportunities to improve energy efficiency, including enhancing continuous production process, waste energy recovery and changing from primary to secondary production routes (Bernstein et al..2007: Gale & Freund 2000).

From table 1.0, it can be seen that Devki rolling mills furnace oil consumption per ton of steel is 114 liters/ton of steel. Steel production is an energy intensive process, it takes nearly 56-66 liters of furnace oil (or 226-269 kilograms of coal) and 165-192 kilowatt hours of electricity to produce a tone of steel (http//:undpgefsteel.gov.in)

There is therefore need to investigate limiting factors and come up with energy cost saving measures for Devki steel rolling mills since the furnace oil consumption per ton of steel (114) is twice the standard consumption per ton (56-66).

Fig. 5.3 shows damaged furnace door, this is an energy cost saving opportunity. The damaged door is open during the entire normal 12 hour furnace operation cycle. However, the furnace door should only be open for 30 minutes after every 2 hour heating cycle, during this time the red billets are removed from the furnace. It should remain closed for approximately 9 hours during the normal operation cycle. This would result in substantial savings on the fuel consumed by the reheat furnace.

Fig 5.4 and Fig 5.5 show a poorly lagged recuperator, the lagging is completely worn out. This also presents an energy cost saving opportunity. A lagged recuperator would minimize heat losses by maximizing heat transfer from exiting flue gases to incoming combustion air, thereby resulting in substantial reheat furnace fuel savings.

Fig 5.4 shows combustion air pipes that are not lagged. Lagging combustion air pipes would minimize on heat loss by radiation from the hot combustion air, save on fuel consumption and present an overall reheat furnace energy cost saving.

These energy saving measures if implemented would improve the company's energy efficiency, energy intensity index and reduce the company's overall production cost.

1.5 OBJECTIVES

The objective of this research is to assess energy efficiency of the reheat furnace and analyze the feasibility of waste heat recovery of the reheat at Devki steel rolling mills limited, Ruiru.

To achieve this objective, the following steps will be followed;

1. Identification of energy losses in the reheat furnace at Devki steel rolling mills limited for energy efficiency calculation.
2. Quantification of energy losses in the reheat furnace at Devki steel rolling mills.
3. Evaluation of feasibility of preheating steel billets by energy recovered from flue gases.

CHAPTER TWO: LITERATURE REVIEW

2.0 INTRODUCTION

Improving plant energy efficiency requires monitoring, analysis and adjustments of the appropriate plant operating parameters and in some cases, plant modifications. This involves studies of plant energy distribution and the corresponding losses associated with the various uses of energy.

Energy recovery is one of the main methods of energy efficiency improvement for industry, for reduction of energy consumed. The history of waste energy recovery can be traced back to the 19th century. Development of energy recovery technology has surged; unfortunately, application of proven waste energy recovery technology has not yet been extensively implemented due to economical, societal and political barriers (Bergmeier, 2003)

From a technological point of view, as steel production needs very high temperatures, the opportunities for continuous energy efficiency improvements are more limited compared with those of production processes that require moderate temperatures, such as paper and pulp industry (Worrel et al..2001)

Steel production is an energy intensive process. It takes nearly 56-66 liters of furnace oil (or 226-269 Kilograms of coal) or 165-192 KWH of electricity to produce a tone of steel (http://undpgefsteel.gov.in).

Energy is an important factor in the steel industry. Energy improvement is an important way to reduce production costs and increase a company's earnings, especially in these times of high energy price volatility. There are a variety of opportunities available at individual plants to reduce energy consumption in a cost effective manner.

In any hot rolling process or operation, the reheating furnace is a critical factor to determine end product quality as well as the total cost of the operation. Energy use in a reheating furnace depends on production factors (e.g. stock, steel type), operational factors (e.g. scheduling) and design factors (Bosler et al,.2003).

2.1 Forms and sources of energy used in industries

Energy sources are classified into two groups — renewable and non-renewable.

Non-renewable sources - These energy sources are called non-renewable because their supplies are limited. Petroleum, for example, was formed millions of years ago from the remains of ancient sea plants and animals. We can't make more petroleum in a short time.

Non-renewable energy sources are: coal, petroleum, natural gas, propane, and uranium. They are used to make electricity, to heat our homes, to move our cars, and to manufacture all kinds of products in industries.

Renewable sources - They are called renewable energy sources because they are naturally replenished. Day after day, the sun shines, the wind blows, and the rivers flow.

Renewable energy sources include biomass, geothermal energy, hydropower, solar energy, and wind energy.

The world sources of energy used in industries can be illustrated in the table below which shows their constitution in percentage from the world's total production.

Table 2. 1 World sources of energy used in industries (2008)

Source	Percentage (%)
Oil	38
Coal	26
Gas	23
Nuclear	6
Hydroelectric	6
Solar, wind, wood, wave, tidal and geothermal	1

Source: http://www.claiborneconference.org/types-of-energy-sources/

2.2 ENERGY EFFICIENCY

Energy efficiency measures can be classified as short-term, medium-term and long-term measures according to the estimated payback period for the investment.

2.3 The Importance of Energy Efficiency

Energy is essential to economic and social development and improved quality of life. Much of the world's energy, however, is currently produced and consumed in ways that cannot be sustained, if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption, and on growing reliance on environmentally sound energy systems, particularly new and renewable sources of energy. All energy sources will need to be used in ways that respect the atmosphere, human health and the environment as a whole.

2.4 ENERGY RECOVERY

Energy recovery is one of the main methods of energy efficiency improvement for industry for reducing energy consumption. The history of waste energy recovery can be traced to the 19th century. Development of energy recovery technology has surged; unfortunately, the application of proven technology of waste energy recovery has not been extensively implemented due to economical, societal and political barriers (Bergmeier, 2003)

Waste heat recovery entails capturing and reusing waste heat in industrial processes for heating or generating Mechanical or Electrical work. Heat recovery technology frequently reduces operating costs for facilities by increasing the facility's' energy productivity.

Energy can be recovered in three forms; heat, power and fuel. Heat is used, generated and discarded in almost all industrial applications. Discarded heat can be reused in other processes or to preheat incoming water and combustion air. Power can be recovered to produce electricity by using pressure recovery turbines. By using this steam, the power output from recovery turbine can cover electricity necessary for some equipment. Until now, energy recovery in steel production has been implemented in many companies and produced significant economical and environmental benefits (Martin et al,.2000)

In a reheat furnace, the products of combustion leave the furnace at a temperature higher than the stock temperature. According to the US Department of energy, office of energy efficiency

and renewable energy, sensible heat losses in the flue gases while leaving the chimney account for 30-35% of heat input to the furnace. The higher the amount of excess air and flue gas temperature, the higher would be the waste heat availability. Waste heat recovery should be considered after other conservation measures have been taken.

The sensible heat in flue gases can be generally recovered by the following methods;

1. Charge/stock preheating
2. Preheating combustion air
3. Utilizing waste heat for other process(to generate steam or hot water by a waste heat boiler)

2.5 BARRIERS TO WASTE HEAT RECOVERY

Various barriers impact the economy and effectiveness of heat recovery equipment and impede their installation (http://www1.eere.energy.gov/industry/bestpractices/)

The cost of heat recovery equipment, auxiliary systems and design services lead to long payback periods in certain applications. Certain applications also require advanced and more costly materials (required for high temperature streams, streams with high chemical activity and exhaust streams cooled below condensation temperature). The cost of equipment also favors large scale heat recovery system applications. Operation/Maintenance Costs as a result of corrosion, scaling and fouling of heat exchanger materials leads to higher maintenance costs and lost productivity.

Temperature Restrictions; Lack of a Viable End Use in many industrial facilities for on-site use of low-temperature heat. Meanwhile, technologies that create end use options are currently less developed and costly. Material constraints and costs where high temperature materials are costly and low temperature materials experience corrosion and fouling and therefore additional costs have to be incurred for materials that can withstand corrosive environments.

Chemical Composition; Waste heat stream chemical compatibility with recovery equipment materials will be limited both at high and low temperatures. Deposition of substances on the recovery equipment surface will reduce heat transfer rates and efficiency. Streams with high chemical activity damage equipment surfaces and this leads to increased maintenance costs.

Application-Specific Constraints; Equipment designs are process specific and must be adapted to the needs of a given process e.g. feed preheat systems vary significantly between glass and blast furnaces and cement kilns. Heat recovery can complicate and compromise process/quality control systems.

Inaccessibility/Transportability; Most facilities have limited physical space in which to access waste heat streams. In many facilities, the gaseous waste streams are discharged at near atmospheric pressure (limiting the ability to transport them to and through equipment without additional energy input). It is also difficult to access and recover heat from unconventional sources such as hot solid products (like billets) and hot equipment surfaces

2.6 Factors Affecting Waste Heat Recovery Feasibility

Evaluating the feasibility of waste heat recovery requires characterization of the waste heat source and the stream to which the heat will be transferred. Important waste stream parameters that must be determined include;

- Heat quality
- Heat quantity
- Composition
- Minimum allowed temperature
- Operating schedules, availability and other logistics

These parameters allow for analysis of the quality and quantity of the stream and also provide insight into possible materials/design limitations.

Heat Quantity; Heat quantity or heat content is a measure of how much energy is contained in a waste stream, while heat quality is a measure of the usefulness of the waste heat. The quantity of waste heat contained in a waste stream is a function of both temperature and mass flow rate of the stream.

Although the heat quantity of waste heat available is an important parameter, it is not alone an effective measure of waste heat recovery opportunity. It is also important to specify the waste heat quality, as determined by its temperature.

Heat Quality; It is a key factor determining waste heat recovery feasibility. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the sink temperature.

The magnitude of temperature difference between the heat source and sink is an important determinant of waste heats' utility or quality. The source and sink temperature difference influences

a. Rate at which heat is transferred per unit surface area of heat exchanger
b. Maximum theoretical efficiency of converting thermal energy from the heat source to another form of energy (mechanical or electrical).
c. Temperature difference has important implications on selection of materials in heat exchanger design

Composition; The composition of waste heat stream affects the recovery process and material selection. The composition and phase streams will determine factors such as thermal conductivity and heat capacity, which will impact heat exchanger effectiveness. The process specific chemical makeup of waste heat stream will have an impact on heat exchanger designs, material constraints and costs.

Economies of Scale, Accessibility and Other Factors; Several factors can determine whether heat recovery is feasible in a given application. For example, small scale operations are less likely to install heat recovery, since sufficient capital may not be available and because payback periods may be long.

Operating schedules can also be a concern; if a waste heat source is only available for a limited time every day, the heat exchanger may be exposed to both high and low temperatures. In this case, it has to be ensured that the heat exchanger does not fatigue due to thermal cycling. It is important that the heat source match the schedule for heat load. If not, additional systems may be required to provide heat when heat source is not available.

Another concern is ease of access to the waste heat source. In some cases, the physical constraints created by equipment arrangement prevent ease access to the heat source or prevent the installation of any additional equipment for recovering heat. Additionally, constraints are provided by the transportability of heat streams. Heat streams in industries are often recovered since they are easily transportable, piping systems are easy to tap into and the energy can be easily transported via piping to the recovery equipment. In contrast, hot streams (like ingots, cement clinkers) can contain significant amounts of energy but their energy is not

easily accessible or transportable to recovery equipment. As a result, waste energy recovery is not widely practiced with hot solid materials. (http://www1.eere.energy.gov/)

2.7 CHARGE PREHEATING

This refers to any efforts to use waste heat leaving a system to preheat the load entering the system. Direct heat transfer between combustion exhaust gases and solid materials entering the furnace can be utilized to reduce energy consumption.

The charging of billets or slabs at elevated temperature into the reheating furnace of a hot rolling mill saves energy. It also improves material quality, reduces material losses, enhances productivity and may reduce slab stocking (Ritt, 1996)

In cases where it is not possible to hot charge the billets or slabs directly from furnace, energy can be recovered by bringing the exhaust gases that leave the high temperature portion of the process into contact with the cold billets or slabs (Bosler et al,.2003)

Load preheating is not widely used due to a variety of factors including;

- Difficulties in controlling product quality
- Issues associated with environmental emissions
- Increased complexity and cost of building furnace loading or heat recovery system

The charge is preheated by exhaust gases before being placed in the reheat furnace. The amount of fuel needed to heat the charge in the furnace is significantly reduced. (http://www.engj.org/)

2.8 DEVKI STEEL ROLLING PROCESS

The company imports billets of various sizes (120mm×120mm, 100mm×100mm) according to the best price and quality available. According to Devki company production Standard operation procedure, the billets are first cut into 2m length.

The billets are fed in two rows to the preheating area of the reheating furnace. This furnace is a batch type furnace, whereby billets are heated in three sequential zones (pre-heating zone, heating zone and soaking zone). The billets are heated up to an average discharge temperature of 1100^OC.

The furnace is fired using furnace oil and the combustion air is pre-heated using a recuperator. The red hot billets are then conveyed into a conveyor channel. The thickness of the billets is

reduced in several steps at the rolling stations or sets. Each of these roller sets is driven by motor and water cooled to prevent overheating.

The rolled products are cooled down a walking beam conveyor. End products are cut to size as per customer requirements. The products are stretched and twisted to achieve the correct straightness and shape. The Devki steel rolling section produces structural steel products including: Reinforcement bars, Hot rolled sections, angles, hollow sections among others.

2.9 FURNACE

Furnaces can be classified based on the method of generating heat; furnaces are broadly namely combustion type (using fuels) and electric type, based 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

Characteristics of an efficient furnace

Furnaces should be designed so that in a given time, as much stock as possible can be heated to a uniform temperature with the least possible fuel and labor. To achieve this, the following parameters can be considered; Determination of the quantity of heat to be imparted to the material charge, liberation of sufficient heat within the furnace to the heat stock and overcome all heat losses, transfer of available part of that heat from the furnace gases to the surface of heating stock, equalization of temperature within stock and reduction of heat losses from furnace to the minimum possible extent.

2.10 EVALUATION OF FURNACE PERFORMANCE

Thermal efficiency of a furnace is the ratio of heat delivered to the stock and heat supplied by the combustion process. The process of heating stock in a furnace results in energy losses in different areas and forms as shown in the diagram below. A large amount of heat supplied is wasted in the form of exhaust gases. (Industrial furnace, vol 1& vol 2, John Wiley & Sons-Trinks)
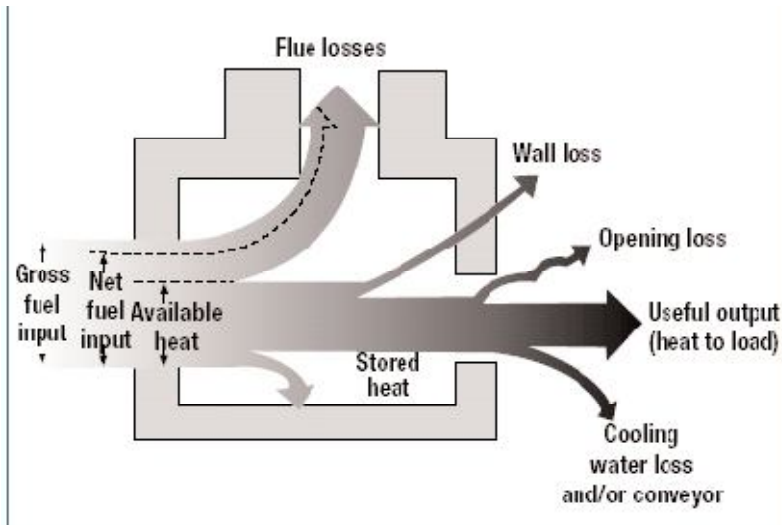
Figure 2. 1Heat losses in an industrial furnace

These furnace losses include:

Heat storage in the furnace structure; the furnace structure must be heated so that its interior surfaces are at about the same temperature as the stock. This stored heat is held in the structure until the furnace is shut down, then leaks into the surroundings. The more frequently the furnace is cycled from cold to hot, the more frequently this stored heat is replaced. Fuel is consumed with no useful output.

Losses from furnace outside walls; caused by conduction through the walls, roof and floor of the furnace. Once the heat reaches the outer skin of the furnace, it is lost by radiation.

Heat transported out of the furnace by load conveyors or fixtures which enter the furnace cold and leave it at high temperatures draining energy from combustion gases.

Radiation losses from openings or hot exposed parts; the hot furnace surfaces radiate energy to the colder surrounding and the rate of transfer increases with the fourth power of the surface's absolute temperature. Any time there is an opening in the furnace enclosure; heat is lost by radiation, often at a rapid rate.

Heat carried by cold air infiltration into the furnace; air can infiltrate from the surrounding room if there is negative pressure in the furnace and heat carried by excess air used in the burners

2.10.1 Thermal efficiency of a furnace by direct method

According to the *bureau of energy efficiency*, furnace efficiency by direct method is;

$Efficiency = \{Heat\ in\ the\ stock / Heat\ in\ the\ fuel\ consumed\ for\ heating\ the\ stock\}$

The quantity of heat to be imparted (Q) to the stock can be found from;

Q   = $m \times C_P \times (T_1 - T_2)$ kcal/h   … (1)

Where

Q= Quantity of heat stock in Kcal

M =Weight of the stock in Kg

C_P = Mean specific heat of stock in Kcal/Kg^{O}C

T_1= Final temperature of stock desired, ^{O}C

T_2= Initial temperature of the stock before it enters the furnace, ^{O}C

Heat in the fuel consumed for heating the stock (kcal/h)

$$= \frac{GCV\ of\ fuel}{Fuel\ consumption\ rate} \ldots (2)$$

2.10.2 Furnace efficiency by indirect method

According to bureau of energy efficiency, furnace efficiency is calculated by indirect method as follows;

1. **Sensible heat loss in Flue gas**

Excess air=$\frac{O2\ \%\ \times 100}{21 - O2\ \%}$… (3)

O_2 % is the % of oxygen in the Flue gas

Theoretical air required to burn 1kg of oil= 14kg (Typical value for all fuel oil)

Total air supplied =theoretical $\times$ (1+ excess air/100)

Sensible heat loss =$m \times C_P \times (T_1 - T_2)$ kcal/h

m =actual mass of air supplied/ Kg of fuel +mass of fuel (1Kg)

2. **Loss due to evaporation of moisture present in fuel**

% Heat loss=$\frac{M \times \{584 + Cp(Tfg - Tamb)\} \times 100}{GCV\ of\ fuel}$… (4)

M- Mass of moisture in 1kg of fuel oil (0.15kg/kg of fuel oil)

T_{fg} –Flue gas temperature

T_{amb}-Ambient temperature

3. Loss due to evaporation of water formed due to Hydrogen in Fuel

% Heat loss=$\dfrac{9 \times H2\{584 + Cp(Tfg - Tamb)\} \times 100}{GCV\ of\ fuel}$… (5)

H_2-kg of H_2 in kg of fuel oil (0.1123kg/ kg of fuel oil)

Furnace efficiency= 100%-{(sensible heat loss in flue gas)+(loss due to evaporation of moisture in fuel)+(loss due to evaporation of water from Hydrogen in fuel)+(heat loss due to openings)+(heat loss through wall)}

CHAPTER 3: METHODOLOGY

3.1 Research Methods

This study utilizes a quantitative methodology employing a single multi-site case study, at Devki rolling mills and University of Nairobi mechanical engineering workshop to investigate energy cost saving opportunities in the steel rolling industry. This methodology was chosen because it was considered the best approach to answer the research question; what are the energy efficiency and cost saving opportunities in a steel rolling industry.

In this chapter, the process followed during the case study is outlined. Research tools, data collection methods are also discussed. This study is based on a practical walk through and experimentation in which energy consumption records as well as related costs are collected and analyzed.

By undertaking an energy analysis, it was possible to analyze energy consumption data to determine the feasibility of waste heat recovery to preheat billets. This research undertook the following steps;

The first step was to determine energy distribution, historical energy consumption data was collected by reviewing monthly energy bills. The next step was to identify energy losses in the reheat furnace. The structural data for the reheat furnace was measured including reheat furnace dimensions, opening areas and wall information.

The third step was the quantification of energy losses in the reheat furnace, production data was collected including Flue gas temperature, furnace temperature, discharge temperature, inside furnace temperature, opening cycle and time between charge and discharge ends during full production.

3.2 Data Collection

In this study, three data collection methods were used namely; interviews, observation and study of documentation.

3.2.1 Interviews

Following selection and contact with staff, two weeks were spent in separate weekly interviews for each section. A further two weeks were spent completing follow up visits and data collection. All staff who indicated they would like to be involved in the study was interviewed.

Interviews were used to confirm saturation of the data collected; where further interviews yielded little new knowledge until repetition from multiple sources was obtained. In this study, structured interviews were conducted with engineering staff, production staff and management. The focus of these interviews was on energy consumption, energy efficiency and cost saving measures opportunities and aspects of implementation of these measures.

The interviews entailed inviting participants to reflect on and discuss their experiences with energy management and to share the significance of these experiences to the study.

To facilitate gathering of data using this method, an open ended flexible approach to interviewing was used rather than a totally prescriptive standardized interview format. In addition to semi-structured interviewing, data was also collected through informal conversations in particular; chats with participants before and after formal interview times. Information from such conversations was written down at first opportunity, while details were still fresh.

Interview questions on staff background included;

    a. How long have staff members worked at the company
    b. Where did they work before joining the company?

Interview questions on relational factors included;

    a. Do staff members have access to energy bills?
    b. Any energy management initiative by the company
    c. Staff understanding of energy management through company trainings/seminars
    d. Any energy management professionals in the company
    e. Any energy saving measures in place/implemented
    f. Availability of resources on energy management, energy management technology

Notes were taken during interviews and field notes kept throughout the study process. This included description of settings, processes and operations and observations from social interactions. At the end of each day, after interviews and observation, using brief notes, more comprehensive notes were written.

3.2.2 Study of Documents

The study of documents involved studying Devki energy consumption records especially records on reheat furnace oil consumption, reheat furnace manual, handbooks on furnaces,

company newsletters on company prospective and development plans. Data was obtained from systematic study of the company's official and unofficial documents.

The contents of the documents were analyzed in relation to energy management and efficiency improvement data from interviews. This provided vital information on energy consumption, waste heat recovery technology and trends and the company's prospects on energy management.

3.2.3 Observation

Observation was a valuable technique and it involved extended immersion in the operations of a steel rolling mills company in order to discern trends, cycles, schedules and patterns in operations as well as decipher ways of improving on the existing opportunities to save energy.

Observations were conducted in a variety of settings within the different sections and stages of the rolling process. When interviewing was not being conducted, data was being collected from a range of planned events such as meeting, independent research and problem solving

3.3 Study area

The study is at Devki steel rolling mills reheat furnaces, the energy study will include; energy losses identification and a breakout of all energy conservation measures identified and estimated costs.

Description of the reheat furnace

Furnace dimensions

Table 3. 1 Furnace dimensions

Section	Dimensions (meters)
Furnace length	8.5
Furnace width	3.2
Furnace height	2.2
Entry door	2.2×0.30
Discharge door	0.56×0.30
Wall thickness	0.56

Source: Devki records 2012

Figure 3.1 below shows a side view of the reheating furnace at Devki steel rolling mills. Captured in this figure is the oil pre-heater, combustion air lines and furnace oil lines. This

figure shows the general layout of the furnace from the billet discharge area, next to oil pre-heater to the billet charging end.
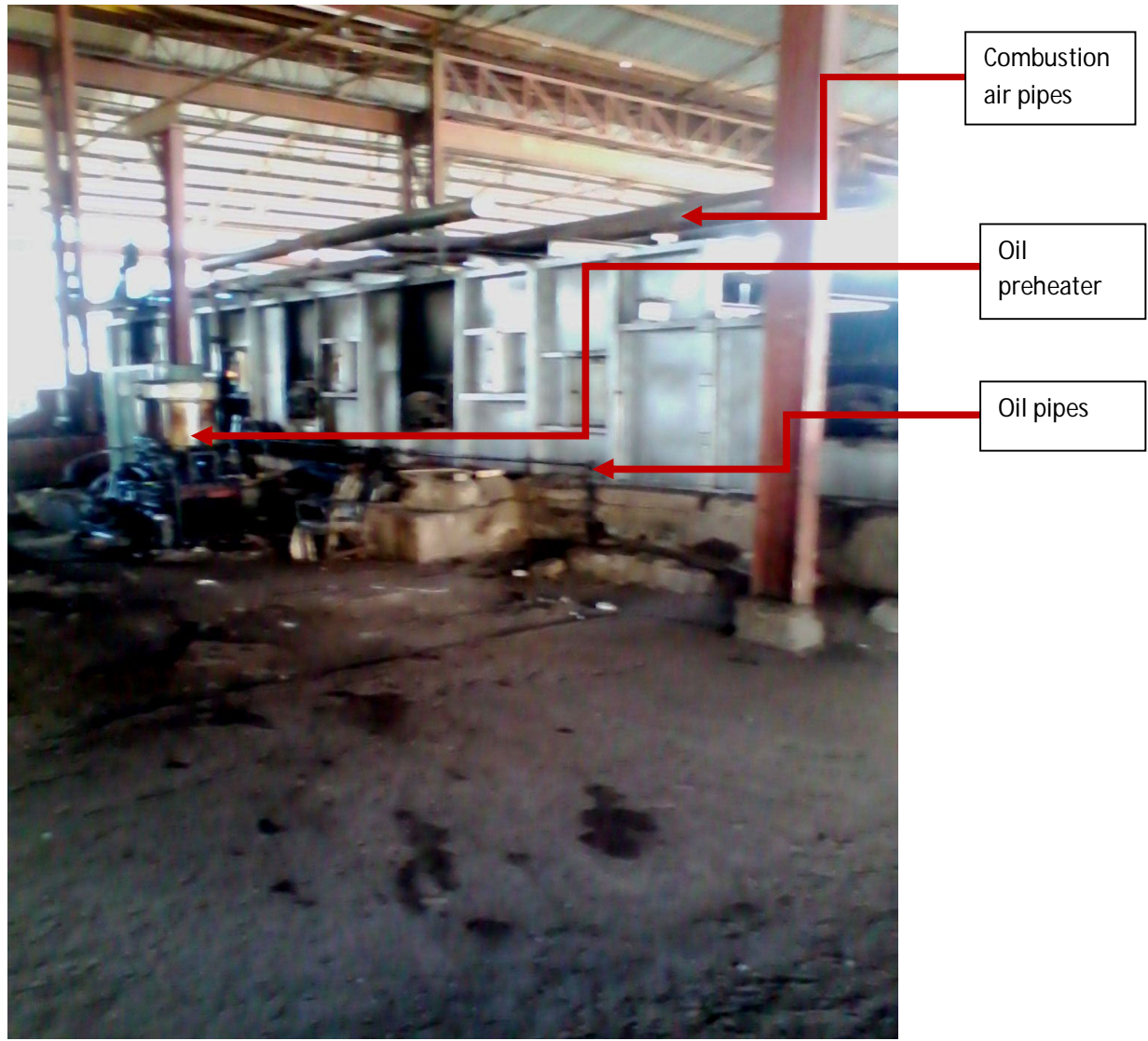

Figure 3. 1Side view of Reheat furnace

The product mass of the steel billets used in this study is as shown in the table 3.2 below

Table 3. 2 Product mass of the steel billets

Product type	Mass (Kg)
Y16	18.25
Y20	28.5
Y25	44.5
Y32	73.0

Source: Devki rolling mills records 2012

3.4 Data Analysis

This study will use descriptive analysis to analyze data. The descriptive statistics which will be used will be ☐mean☐ to indicate average performance. During analysis, emphasis will be put energy wastage in the steel rolling industry, an overview of unit operations and important process steps. Areas of material and energy use and sources of energy waste generation will be presented using pie charts and tables and analyzed using graphs and tables.

The investigations will be initiated by gathering relevant information from company records. The data to be collected in the case study plant so as to execute the audit will include:

1. Energy consumption by type of energy, by department, by major items of process equipment and by end use. (Total kilowatt hours &Total litres of boiler fuel used per month)
2. Material balance data (Production per month).
3. Energy cost data
4. Process and material flow diagrams
5. Energy efficiency improvement measures

The existing power consumption and operational records for engineering utilities will be useful in obtaining energy consumption pattern.

3.5 DATA REPORTING AND MONITORING

The energy plan needs to ensure that a reporting mechanism exists to put the right information in the right hands at the right time.The objective of an energy reporting system is to measure energy consumption and compare it either to company goals or to some standard of energy consumption.

CHAPTER 4: EXPERIMENT ON PREHEATING BILLET USING FLUE GAS

This experiment was performed at Mechanical Engineering sheet metal workshop, on 15th and 22nd October 2015. The experiment involved determining the final temperature of a steel billet in a preheating box that was to be heated using flue gas of Aluminium smelting furnace.

4.1 INTRODUCTION

In a steel rolling mill, steel billets are first heated in a reheat furnace to a temperature close to the required rolling temperature so that the billets can be milled without causing any damage to the rolling machine. A typical reheating furnace has three zones; preheating, heating and soaking. After the billet is charged into a reheat furnace, the billet goes through these zones from inlet to outlet and finally reaches the target temperature before it's discharged.

Waste heat recovery involves capturing and re-using waste heat in industrial process for heating or generating mechanical or electrical work. Heat recovery technology frequently reduces energy and operating costs.

In a reheat furnace, the products of combustion leave the furnace at a temperature higher than the stack temperature. Sensible heat losses in flue gases while leaving the stack account for 30-35% of heat input to furnace. The sensible heat in flue gas can be used for charge/stock preheating.

4.1.1 Purpose; to determine the feasibility of using flue gas to preheat steel billets before they are charged into a reheat furnace

Nomenclature

T-billet temperature (^{O}C)

t- Time (S)

ρ- Density of steel

c_p- specific heat

K-thermal conductivity

The quantity of heat to be imparted (Q) to the stock can be found from;

Q   =   m$\times C_P \times$ (T$_1$-T$_2$) kcal/h   … (1)

(Natural Resources Canada, 2009a; United Nations Environment Programme, 2006)

Sensible heat loss in Flue gas

Excess air=$\frac{O_2\% \times 100}{21 - O_2\%}$... (3)

O_2 % is the % of oxygen in the Flue gas

Theoretical air required to burn 1kg of oil= 14kg (Typical value for all fuel oil)

Total air supplied =theoretical $\times$ (1+ excess air/100)

Sensible heat loss =m$\times C_P\times$ (T_1-T_2) kcal/h

m =actual mass of air supplied/ Kg of fuel +mass of fuel (1Kg)

4.2 EXPERIMENT SET UP

Apparatus

In this experiment, steel billets are placed across a rack in a preheating box, with thermocouple probes for temperature measurements touching the surface of the billets. Flue gases from a Crucible Aluminium melting furnace are tapped via a chimney and directed into the preheating box via a door as is shown in the figure below.
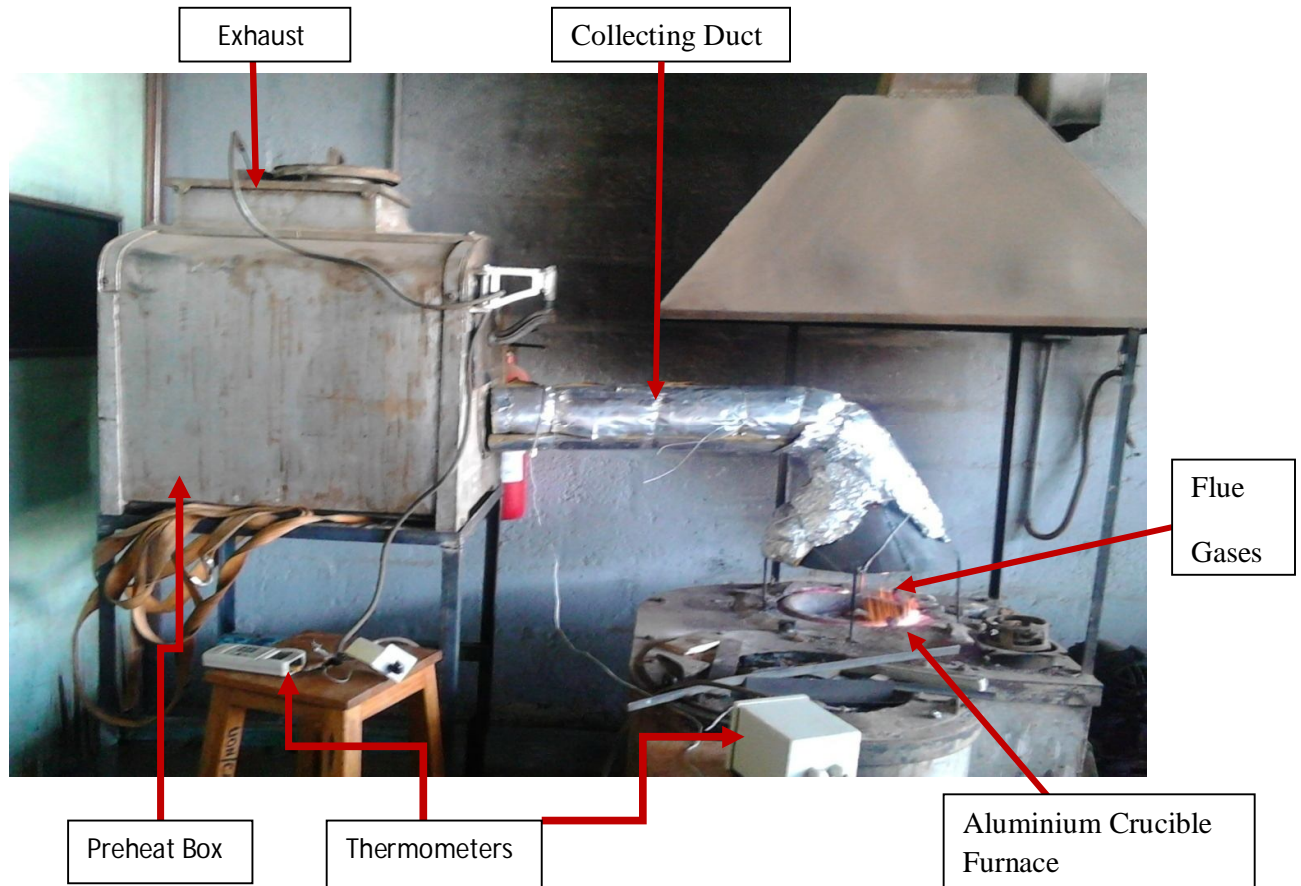

Figure 4. 1 Alignment of preheating box, collecting duct and Aluminium crucible furnace
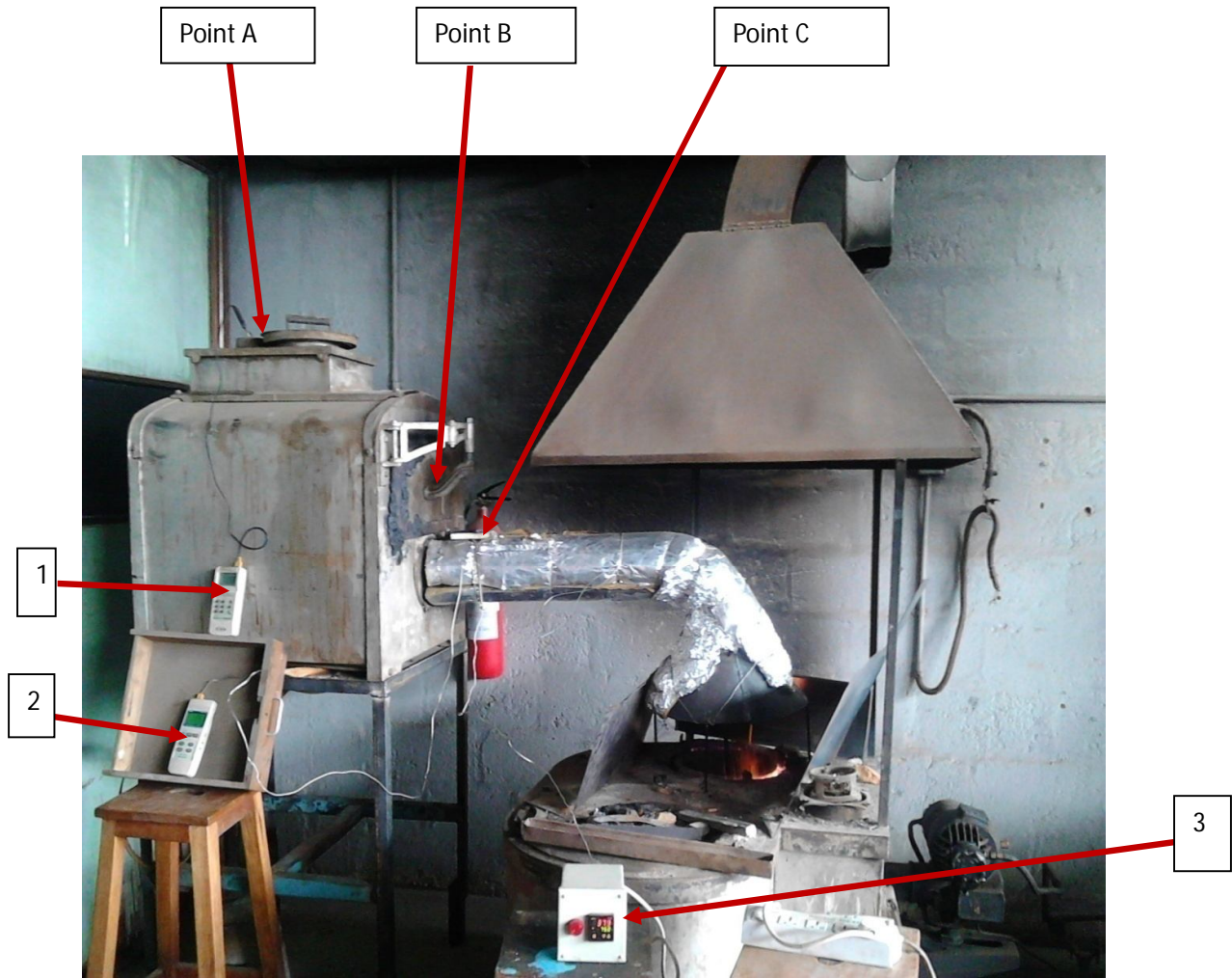
Figure 4. 2 Thermometers for temperature readings at inlet exhaust and steel billet

Preheat box Door   Chimney   Point B

Point C   Preheat box   Collecting Duct

Figure 4. 3 Parts of preheating box and collecting duct
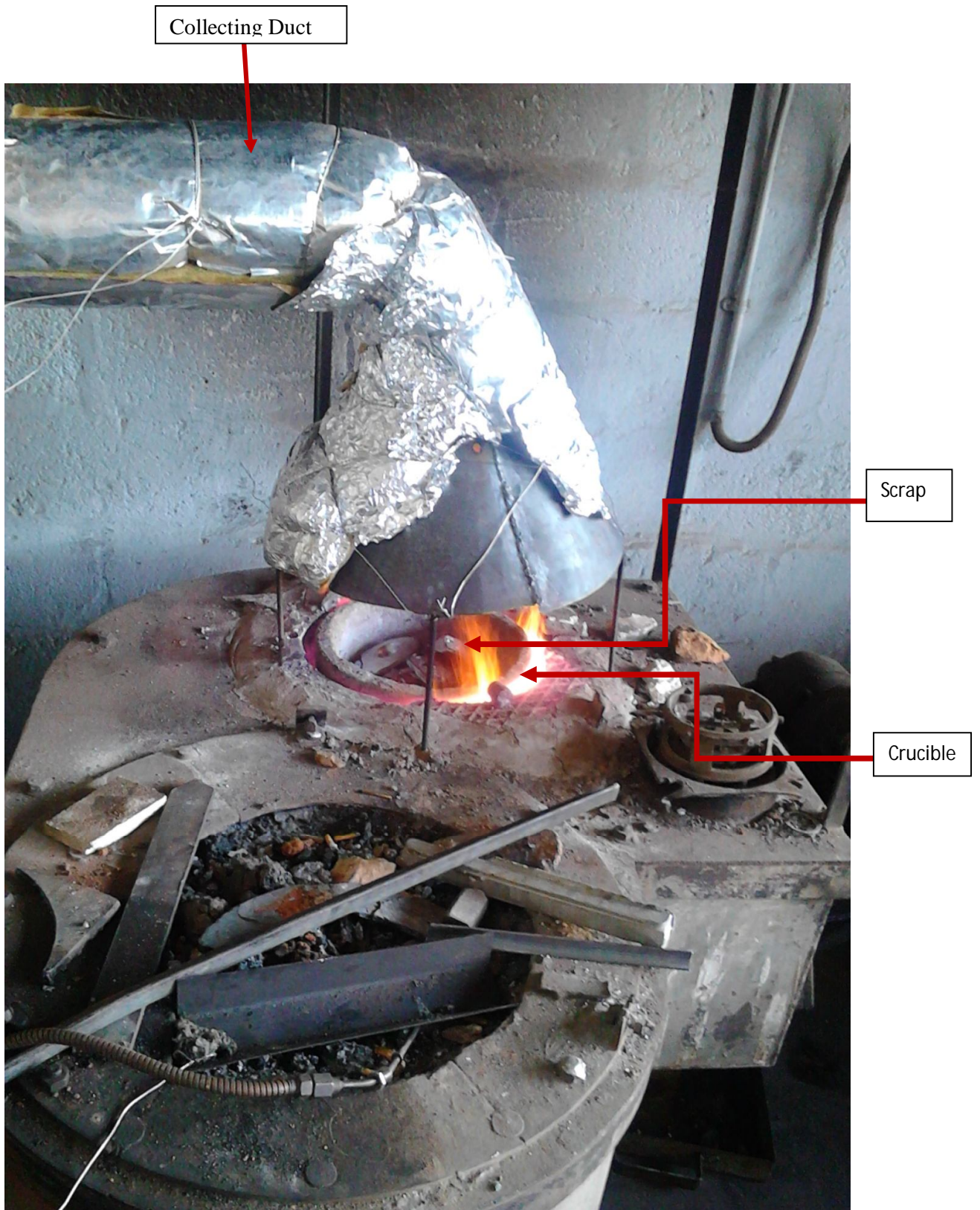
Figure 4. 4 Aluminium Crucible Furnace

4.3 EXPERIMENT APPARATUS

Preheat Box

Figure 4:3 shows the front view of preheat box used in this experiment. The sectional drawing of the preheat box is shown the attachment on the next page. The preheat box has a rack onto which the steel billets being preheated are put. From Figure 4.3, Point B on the picture shows an opening through which thermocouples are inserted to take temperature readings for the steel billets being preheated and the temperature inside the preheat box.

The steel billets to be preheated are inserted in the preheat box through the preheat box door shown in Figure 4:3. This preheat box door just like the rest of the preheat box is lagged and firmly closed during the experiment to prevent any heat loss. The chimney in Figure 4:3 is where temperature for exhaust flue gas is taken.

Collecting Duct

The collecting duct shown in Figure 4:3 taps Flue gases from the Aluminium crucible furnace to the preheat box. As is shown the above figures, it is properly lagged to minimize heat loss from the Flue gases being tapped from Aluminium crucible furnace. At Point C as is shown in Figure 4:3, a hole is drilled on the duct, at this point a probe is inserted into the duct. It is at this point that temperature of Flue gases before entry into the preheat box is taken.

Aluminum Crucible Furnace

Figure 4:4 shows the Aluminium crucible furnace used in this experiment. The crucible is filled with scrap metal during the experiment to assist in heat retention, rather than losing all the heat to Flue gases. The collecting duct is placed close to the crucible so as to trap most of the Flue gases during the experiment. Before any temperature readings are taken, the furnace has to be switched on and the entire set up of apparatus given time to warm up.

Thermocouple: Four thermocouples were required for the experiment; this is because four temperature measurements were to be recorded instantaneously. The temperature readings are taken at the entry to the preheating box, inside the preheating box, for the steel billet and for the flue gas exiting the preheating box. The four thermocouples are shown in figure 4.1

Weighing scale: It is needed for measuring the mass of steel billets placed in the preheating box.

Stop watch: Is needed for time measurements because temperature readings are taken at intervals until these readings stabilize.

4.4 EXPERIMENT PROCEDURE

The mass of the steel billets to be heated is measured using a weighing scale. The steel billets are then placed on a rack inside the preheat box. The rack is shown in the sketch showing the arrangement of the various parts of the experiment set up. The billets are placed on the rack in such a way that they do not interfere with the free flow of flue gases in the preheat box. The billets are stacked on the rack with the flue gas duct entering the preheat box slightly beneath the billets for free flow of the gases by convection as they heat the billets.

The flue gas duct is then fitted onto the preheat box via an opening beneath the preheat box door. This entry point is sealed to prevent any heat loss from this point. The flue gas duct has a hole at the top, near the entry point to the preheat box, it is at this point that temperature readings for the flue gas are taken just before the gases enter the box. Figure 4.5 shows a side view of the flue gas duct and how it is fitted to the preheat box. The flue gas duct is also shown in the sketch. Also shown in these two diagrams is the point at which flue gas temperature reading before entering the box is taken.

The four thermometer probes are then put in place and checked if they are working properly. These probes are placed on the flue gas duct, inside the preheat box, on the steel billet and at the chimney. Figure 4.5 shows the probe measuring temperature of flue gas before entry into the preheat box and figure 4.6 shows the probe for measuring temperature of the flue gas at the exit. The probe for measuring temperature inside the preheat box and the billet temperature are shown in the sketch.

Once the probes are in place and thermometers confirmed to be working properly, the level of fuel in the crucible furnace tank are measured after which the furnace is switched on. The entire set up is left to warm up as the flue gas flows through the duct and preheat box until the temperature readings inside the furnace begin to stabilize. The four temperature readings can now be taken simultaneously after five minute intervals. These readings are taken until there is no significant change in the temperature readings from the four points.

Once the temperature readings are taken, the furnace is switched off. The entire set up is left to cool. The level of fuel in the crucible furnace tank is taken, the difference between the two

readings is the fuel consumed during the experiment. With all readings noted and photos or sketches done, the set can now be dis-assembled.

Temperature Reading

In this experiment, four temperature readings are taken simultaneously namely;

1. Flue gas exhaust temperature
2. Steel Billet temperature
3. Inside preheat box temperature
4. Flue gas temperature before entry to preheat box

Figure 4:5 shows point at which temperature of flue gas before entry to the preheat box is taken. The collecting duct has a hole on its surface through a thermocouple probe is inserted and temperature readings taken.

Figure 4:6 shows point on the preheat box, at the exhaust from which Flue gas exhaust temperature readings are taken, as is shown in this figure, a thermocouple probe is inserted into the opening on the preheat box stack.

For the temperature of steel billets, a thermocouple probe is inserted into the preheat box through the opening at Point B in Figure 4:3. The probe is put on the surface of the steel billet being preheated.

For the temperature inside the preheat box, a thermocouple probe is inserted in the preheat box through the opening at Point B in Figure 4:3 and left hanging inside the preheat box.

Once the four thermocouple probes are in place and the apparatus has warmed up, the four temperature readings are taken simultaneously at intervals and these readings noted in a table. For this experiment, temperature readings were taken after five minutes intervals, these readings are taken until the temperatures stabilize.

Figure 4. 5 Flue gas Temperature at Entry to preheat box

Figure 4. 6 Flue Gas Exhaust Temperature Measurement

5.0 REHEAT FURNACE DATA

The table below shows temperature readings of various sections of the furnace carried out during the study;

Section	Readings in ^oC
Inside furnace temperature	1180
Furnace wall temperature	116.4
Temperature of red hot billet	1080
Billet temperature before heating	32
Flue gas temperature	540

Table 5. 1Temperature readings during the experiment

The combustion air temperature reading after the blower was 54.5^OC, after the recuperator, the reading was 141.2^OC and the reading was 116.8^OC just before the burner, indicating that there was heat loss along the air lines.

During this study, surface temperature of a sample of billets was taken so as to determine the average temperature of red hot steel billets from the furnace for use in calculating furnace efficiency as is shown in table 5.2 below

Table 5. 2 Temperature of sample of billets

Billet sample no.	Surface temperature (^OC)
1	1098
2	1102
3	1100
4	1099
5	1101

Source: Devki production records 2013

Furnace oil consumption

Furnace oil being one of the main energy forms used at Devki steel rolling mills, data was collected on the reheating furnace oil consumption and this is represented in table 1.2 ;

On 01/08/13; 3200 lts of oil was consumed in 12 hours;

Consumption rate $= \dfrac{3200lts}{12Hrs}$

$\qquad$ =267lts/Hr

$\qquad$ =267lts/Hr $\times 0.92$

$\qquad$ =245.64 Kg/hr

GCV of Oil 10,000 Kcal/Kg

Average O_2 % in flue gas 12%

Specific heat of Billet 0.186 Kcal/Kg/ ^{O}C

Surface temperature of roof and sidewalls 116.4 ^{O}C

Theoretical air required is 14Kg of air to burn 1 Kg of fuel

Furnace operating temperature 1180 ^{O}C

5.1 REHEAT FURNACE EFFICIENCY

5.1.1 FURNACE EFFICIENCY BY DIRECT METHOD

According to the Bureau of energy efficiency;

$Efficiency = \{ \dfrac{Heat\ in\ the\ stock}{Heat\ in\ the\ fuel\ consumed\ for\ heating\ the\ stock} \}$

The quantity of heat to be imparted (Q) to the stock can be found from;

Q $\qquad$ = $\qquad$ m$\times C_P \times$ (T$_1$-T$_2$) kcal/h

Where

$\qquad$ Q= Quantity of heat stock in Kcal

$\qquad$ M =Weight of the stock in Kg

$\qquad$ C$_P$ = Mean specific heat of stock in Kcal/Kg/^{O}C

$\qquad$ T$_1$= Final temperature of stock desired, ^{O}C

T$_2$= Initial temperature of the stock before it enters the furnace, ^{O}C

(Natural Resources Canada, 2009a; United Nations Environment Programme, 2006)

Mass of Billets (on 01/08/2013)=67.195tons for 12hours

$$M = {67195kg}/{12hrs}$$

M=5,600Kg/hr

Q=5,600Kg×0.12× (1180-32)

=771,456 Kcal/ hr=3,229,314.186Kj/hr

Heat in the fuel consumed for heating the stock (kcal/h)

$$= \frac{GCV\ of\ fuel}{Fuel\ consumption\ rate}$$

Heat input=oil consumption rate ×GCV of Oil

=245.64 kg/hr×10000 Kcal/kg

=2,456,400 Kcal/ hr=10,282,490.4Kj/hr

$$\eta = \frac{heat\ output}{heat\ input} = \frac{3,229,314.189\ Kj/hr}{10,282,490.4Kj/hr}$$

=31.4 %

5.1.2 FURNACE EFFICIENCY CALCULATION BY INDIRECT METHOD

Furnace efficiency is calculated after subtracting sensible heat loss in Flue gas, loss due to moisture in the Flue gas, heat loss due to openings in the furnace, heat loss through furnace wall and other unaccounted losses from the input to the furnace.

In order to find out furnace efficiency using indirect method, various parameters that are required are hourly furnace oil consumption, material output, excess air quality, temperature of Flue gas, furnace temperature, skin temperature and combustion air temperature. Efficiency is obtained by subtracting all losses from 100%.

The following measurements are made for doing the energy balance in the oil fired reheat furnace;

    a. Weight of stock/ Number of billets heated

    b. Temperature of furnace walls, roof using infrared thermometer

    c. Flue gas temperature

    d. Flue gas analysis

    e. Fuel oil consumption

According to the Bureau of energy efficiency;

    1. ***Sensible heat loss in Flue gas***

$$\text{Excess air} = \frac{O2\,\% \times 100}{21 - O2\,\%}$$

O_2 % is the % of oxygen in the Flue gas

Theoretical air required to burn 1kg of oil= 14kg (Typical value for all fuel oil)

Total air supplied =theoretical × (1+ excess air/100)

$$=14 \times 2.33 \text{ kg/kg of oil}$$

$$=32.62 \text{ kg/kg of oil}$$

Sensible heat loss = $m \times C_P \times (T_1 - T_2)$ kcal/h

m =actual mass of air supplied/ Kg of fuel +mass of fuel (1Kg)

  =32.62+1.0

  =33.62 kg/kg of oil

C_p =0.24 kcal/kg/ ^{O}C

Sensible heat loss=33.62×0.24× (540-32)

$$=4098.9504 \text{ kcal/kg of oil}$$

$$=4098.9504 \text{ kcal/kg of oil} \times 245.64 \text{ kg/hr}$$

$$=1{,}006{,}866.1763 \text{ kcal/ hr} = 4{,}214{,}741.814 \text{Kj/hr}$$

Oil consumption is 245.64 kg/hr

Heat input =245.64 kg/hr×10,000kcal/kg (GCV)

$\qquad$ =2,456,400 kcal/ hr=10,282,490.4Kj/hr

Sensible heat loss in Flue gas as a % heat loss to input energy;

$$\eta = \frac{4,214,741.814 \text{ kj/ hr}}{10,282,490.4 \text{ kj/ hr}}$$

$\qquad$ =40.98%

2. *Loss due to evaporation of moisture present in fuel*

According to bureau of energy efficiency;

$$\% \text{ Heat loss} = \frac{M \times \{584 + Cp(Tfg - Tamb)\} \times 100}{GCV \text{ of fuel}}$$

$\qquad$ M- Mass of moisture in 1kg of fuel oil (0.15kg/kg of fuel oil)

T_{fg} –Flue gas temperature

T_{amb}-Ambient temperature

$$\% \text{ Heat loss} = \frac{0.15 \times \{584 + 0.45(540 - 32)\} \times 100}{10,000}$$

$\qquad$ =1.22%

3. *Loss due to evaporation of water formed due to Hydrogen in Fuel*

According to bureau of energy efficiency;

$$\% \text{ Heat loss} = \frac{9 \times H2\{584 + Cp(Tfg - Tamb)\} \times 100}{GCV \text{ of fuel}}$$

H_2-kg of H_2 in kg of fuel oil (0.1123kg/ kg of fuel oil)

$$\% \text{ Heat loss} = \frac{9 \times 0.1123 \times \{584 + 0.45(540 - 32)\} \times 100}{10,000}$$

=8.21%

4. *Heat lost through to openings*

Heat loss through openings consists of heat loss by direct radiation through openings and the heat loss caused by combustion gas leaks through openings. The heat loss from an opening can be calculated using the following formula;

According to bureau of energy efficiency;

$$Q=4.88\times (\frac{T}{100})^4\times a\times A\times H$$

Where;

T: absolute temperature

a-factor for total radiation

A-area of opening

H-time (Hr)

$$Q= \{4.88\times (\frac{1180+273}{100})^4\times 0.67\times (0.5\times 1)\} \times 2$$

=145,732.72Kcal/hr=610,037.18Kj/hr

% Heat loss through openings=$\dfrac{610,037.18kj/hr}{10,282,490.4Kj/hr}$

=5.93%

Heat escapes through openings by radiation. This can also be calculated by computing black body radiation at furnace temperature and multiplying these values with emissivity (usually 0.8 for furnace brick wall) and the factor of radiation through openings.
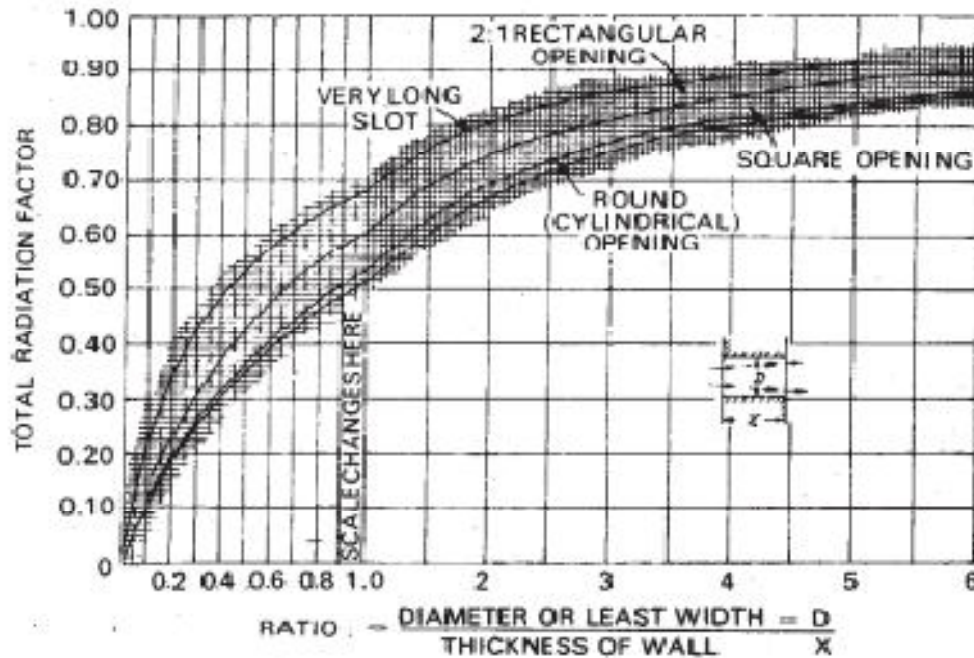
Furnace thickness (X) =560mm- Billet extraction outlet

Dimension of extraction side=1m×1m

Quantity of radiation heat loss from opening is calculated as follows;

The shape of opening is square and $\dfrac{D}{X}=\dfrac{1}{0.56}=1.8$

Figure 5. 1 Factor for Determining the Equivalent of Heat Release from Openings to the Quantity of Heat Release from Perfect Black Body

Factor of radiation (Ref to fig. 5 for determining equivalent of heat release from openings to quantity of heat release from perfect black body) is 0.67

Black body radiation corresponding to $1180^{O}C$ is $=22.0Kcal/cm^{2}/hr$ (Refer to fig on black body radiation)

Area opening $=100cm\times100cm= 10,000cm^{2}$

Emissivity $=0.8$

Total heat loss $=22\times 10,000 \times 0.62 \times 0.8$

$=109,120Kcal/hr=456,776.32$

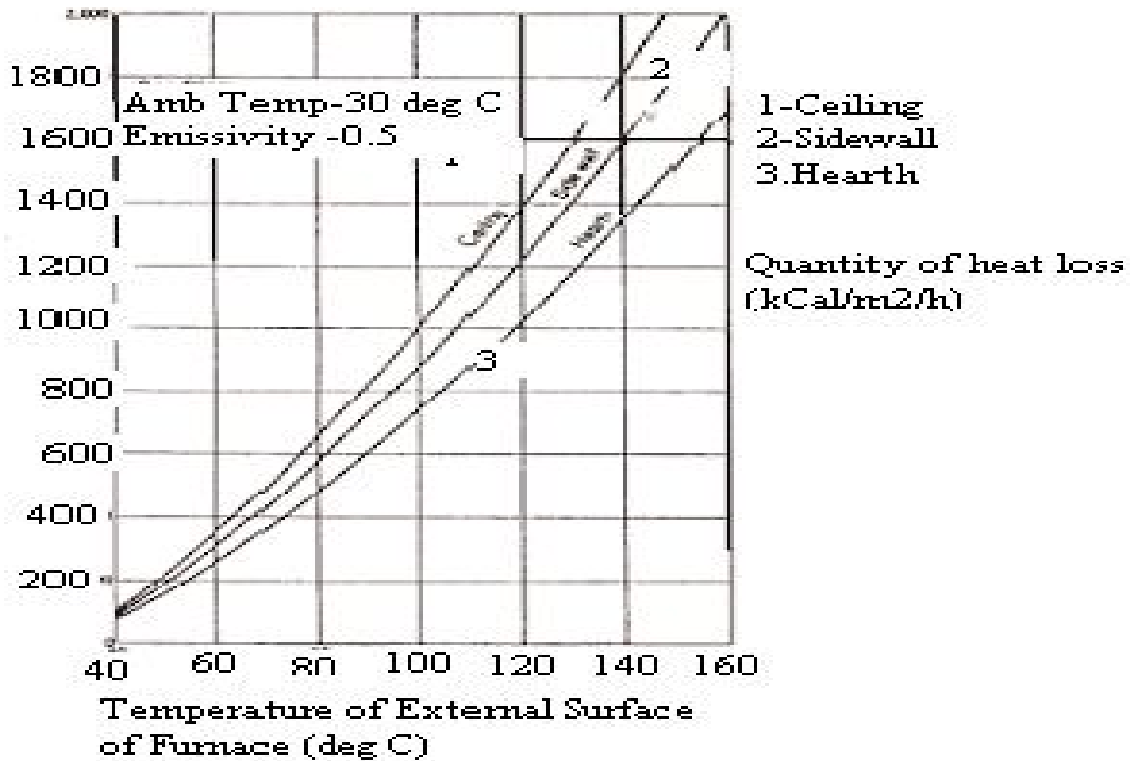$$\text{Heat loss through openings}=\dfrac{456,776.32}{10,282,490.4}$$

$$=4.4\%$$

5. *Heat loss through furnace walls*

Heat loss through roof and sidewalls;

Total average surface temperature $=116.8^{\mathrm{O}}C$

Heat loss at $116.8^{\mathrm{O}}C$ referring to the figure below is 1020Kcal/m ^{2}hr

Figure 5. 2 Quantity of Heat Release at Various Temperatures

Total are of roof and sidewalls= $\{(8.2\times3.2)\times2+(8.2\times3.2)\}$ =62.32m^2

Heat loss=1020Kcal/m ^{2}hr$\times$62.32m^2

$$=63{,}566\text{kcal/hr}=266{,}087.276\text{Kj/hr}$$

% Heat loss through furnace wall$=\dfrac{266{,}087.267Kj/hr}{10{,}282{,}490.4Kj/hr}$

$$=2.59\%$$

Alternatively;

According to bureau of energy efficiency;

Quantity of heat release from reheating furnace is calculated with the following formula

$$Q = a \times (T_1 - T_2)^{5/4} + 4.88E \times \{(\frac{T1+273}{100}) \, 4 \, - \, (\frac{T2+273}{100}) \, 4$$

Where;

Q-quantity of heat released

a: factor regarding direction of surface of natural convection, ceiling=2.8, sidewalls=2.2, hearth=1.5

T_1-temperature of external wall surface of the furnace (^{O}C)

T_2-temperature of air around the furnace (^{O}C)

E-emissivity of external wall surface of the furnace

The first term of the formula above represents the quantity of heat release by natural convection, and the second term represents the quantity of heat release by radiation.

Sensible heat loss in Flue gas	40.98%
Loss due to evaporation of moisture in fuel	1.22%
Loss due to evaporation of water from hydrogen in the fuel	8.21%
Heat loss due to openings	4.3%
Heat loss through furnace wall	2.59%
Total losses	57.3%
Furnace efficiency	100%-57.3%
	=42.7%

Table 5. 3 Furnace Efficiency

HEAT BALANCE TABLE	
HEAT INPUT	HEAT OUTPUT

ITEM	Kj/hr	%	ITEM	Kj/hr	%
Combustion heat of fuel	10,282,490.4	100	Quantity of heat in steel		42.7
			Sensible heat in Flue gas	4,214,741.814	40.98
			Moisture loss in fuel	125,446.38	1.22
			Hydrogen loss in fuel	844,192.46	8.21
			Heat loss due to openings	456,776.32	4.3
			Heat loss through furnace wall	266,087.267	2.59
Total		100	Total		100

Table 5. 4 Heat Balance

5.2 GENERAL ENERGY EFFICIENCY IMPROVEMENT MEASURES IN THE REHEAT FURNACE

Typical energy efficiency measures for the reheat furnace are;

1. Complete combustion with minimum excess air
2. Operating at the desired temperature
3. Reduction of heat losses from furnace openings
4. Minimum refractory losses
5. Waste heat recovery from flue gases

5.2.1 Prevention of Heat Loss through Openings

Heat loss through openings consists of the heat loss by direct radiation through openings and the heat loss caused by combustion gas leaks through openings.

If the furnace pressure is slightly higher than outside (as in case of reheat furnace) during its operation, the combustion gas inside ma blow off through openings and heat is lost with that.

Furnace doors that are damaged can be a source of considerable leakage of air into or gas out of the furnace. These should be replaced by doors with tight fitting seals. Further

improvement would result from installing power operators on the doors to minimize the time they are open as well as make it easier for operators.

From furnace efficiency calculations by indirect method;

Heat loss through openings Q=610,037.18 Kj/Hr

M-oil consumption (Kg/Hr)

5.2.3 Upgrading furnace door

Savings from upgrading furnace door

Since heat loss through opening is equal to heat from fuel used to generate this heat;

$Q \times \eta = Heat\ input\ from\ fuel$

$$610,037.18 \text{ Kj/Hr} \times \eta = \left\{ M \times \frac{10,000 Kcal}{Kg} \times 4.186 \right\} kj/Hr$$

$$M = \frac{610,037.18 kj/Hr \times \eta}{\left\{ \frac{10,000 Kcal}{Kg} \times 4.18 \right\} Kj/Hr}$$

$= \{14.59 \times \eta\}$ Kg/Hr

$\quad = \{15.69 \times \eta\}\ Lts/Hr$

Furnace doors should be open for 30 Minutes during extraction of red hot steel billets in a two hour cycle, in a normal 12 Hour day the furnace doors should remain closed for approximately 9 Hours.

Furnace fuel savings when furnace doors are open during billet extraction are thus;

Fuel savings/Day= $\{M \times \eta \times Hours\ furnace\ doors\ are\ closed\ in\ a\ day\}$

Where;

     M-oil consumption/Hr

Fuel savings/Day=$15.69 \times \eta\}\ Lts/Hr\ \times 9$

    =141.19 Lts/Day

Annual Fuel savings=Fuel savings/Day$\times 5D/Wk \times 4Wks/Mo \times 12Mo/Yr$

        =141.19Lts/Day$\times \eta \times 240Days/Yr$

$$=33,886.45 \text{ Lts/Yr}$$

Fuel Cost savings

1 Litre= Kshs. 69

Annual fuel cost savings=cost/lt× *litres of fuel saved*

$$=\text{Kshs. } 69 \times 33,886.45 Lts/Yr$$

$$=\text{Kshs. } 2,338,165.16$$

Cost of upgrading door

Material cost

Half tone chain block –Kshs. 15,000

Cost of 4mm Mild steel sheet plate – Kshs. 10,000

Ceramic bricks $9\square \times 4\square \times 3\square$

Cost of bricks- Kshs. 150 each piece

Bricks needed for discharge door upgrade -80

Total brick cost =80×Kshs. 150

$$=\text{Kshs. } 12,000$$

Total material cost= Kshs. 37,000

Labor cost= Kshs. 25,000

Labor and Material cost=Kshs. 62,000

Total project cost (C$_p$) $= \dfrac{175 \times Kshs 62,000}{100}$

$$=\text{Kshs. } 108,500$$

Annual savings (S$_a$) =Kshs. 2,338,165.16

Payback period (P$_p$) = $^{Cp}/_{Sa}$

$$= \frac{Kshs.108,500}{Kshs.2,338,165.16}$$
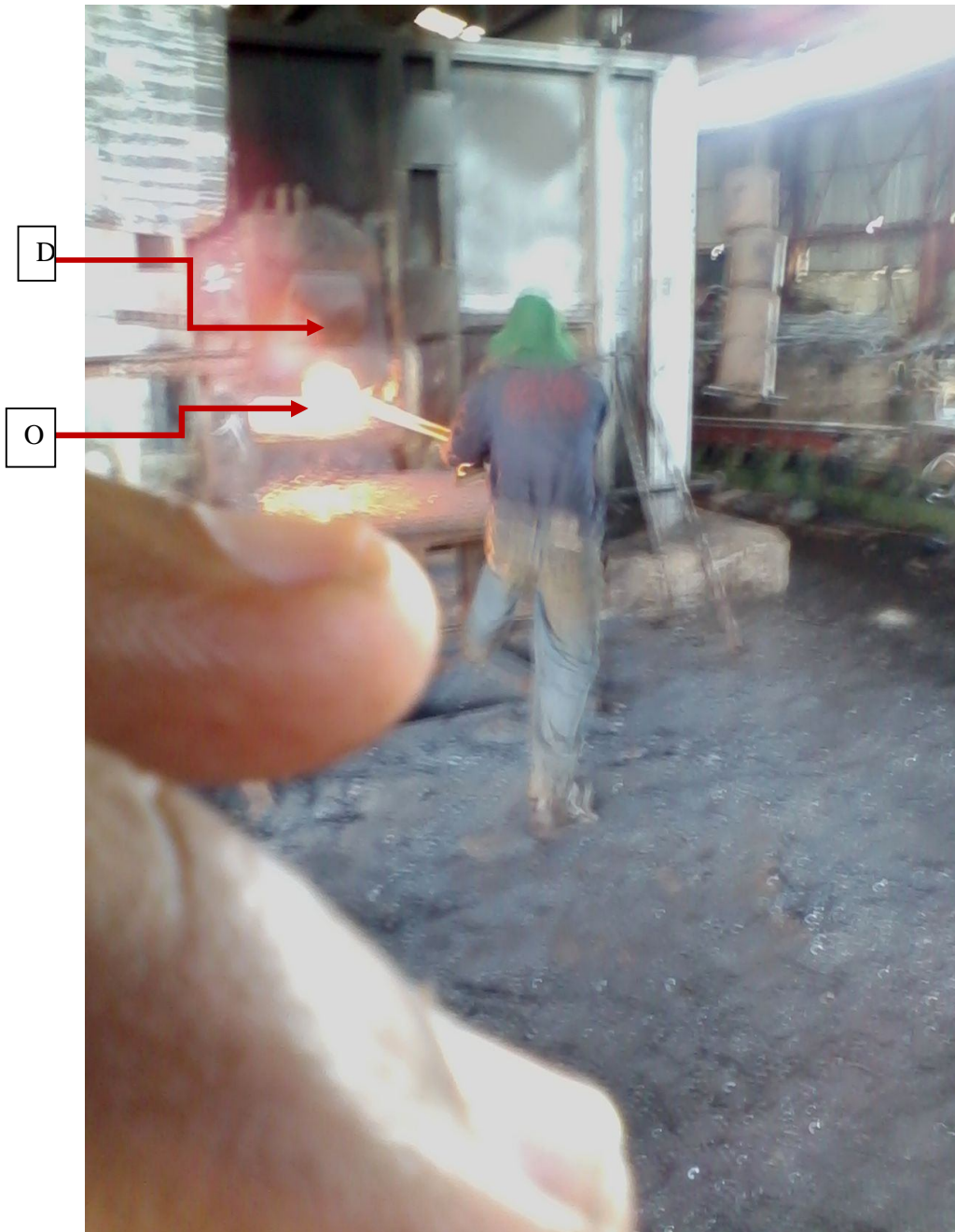
P_p=0.04 years

   =1 month

Figure 5. 3 Damaged furnace door

In Fig 5.3 above, O represents the opening, and D is the damaged furnace door to be upgraded

5.2.2 Re-insulate Furnace Enclosure

The appropriate choice of refractory and insulation materials goes a long way in achieving fairly high fuel savings in industrial furnaces. The heat loss from furnace walls affects fuel economy considerably. The extend of wall losses depend on;

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1. Emissivity of wall
2. Thermal conductivity of refractory
3. Wall thickness
4. Whether the furnace is operated continuously or intermittently

Heat losses can be reduced by increasing the wall thickness, or through the application of ceramic fiber blanket. Refractory brick is used for furnace lining. However, if the furnace is rebuilt, it is economical to use ceramic fiber blanket insulation. If refractory brick is required to withstand rough handling, an outer layer of ceramic fiber can be used. Since ceramic fiber is a better insulation material than refractory brick, care should be taken to ensure that the inner layer of refractory is not overheated, since its average temperature will be higher.

Outside wall temperatures and heat losses of a composite wall of a certain thickness of fiber brick and insulating brick are much lower, due to lesser conductivity of insulating brick as compared to a refractory brick of similar thickness.

In actual operation in most furnaces, the operating periods alternate with idle periods. During off period, he heat stored in the refractories during the on period is gradually dissipated mainly through radiation and convection. In addition, some heat is abstracted by air flowing through the furnace. Dissipation of stored heat is a loss, because the lost heat is again imparted to the refractories during the heat 'on□ period thus consuming extra fuel to generate that heat. Furnace walls built of insulating refractories and cased in a shell reduce the flow of heat to the surroundings.

5.2.3 Heat loss from un-insulated combustion air pipes

Preheated air temperature (after recuperator) $=141.2^{o}$C

Preheated air temperature (before blower) $=141.2^{o}$C

Heat loss Q=MC$_P$Δθ

$=$33.62Kg/Kg of oil$\times \dfrac{1.00464 Kj}{Kg} oil \times \{141.2 - 116.8\} \times 245.64 Kg/Hr$

$=$202,440 Kj/hr

Annually$= 202{,}440 \text{ Kj/hr} \times 12 Hr/D \times 5D/Wk \times 4Wk/Mo \times 12Mo/Yr$

$=$583,027,200 Kg of oil

$$Fuel\ savings=\frac{583,027,200\ \text{Kg of oil}}{(10,000\times4.186)}$$

$$=13,928\text{Kg of oil}=\frac{(13,928\times1000)}{930Kg/M3}\text{Lts}=14,976\text{Lts}$$

$$Cost\ savings=Fuel\ saved\ (Lts)\times\ fuel\ cost\left(\frac{Kshs}{Lt}\right)$$

$$=14,976\text{Lts}\times Kshs\ 69/Lt$$

$$=\text{Kshs } 1,033,370$$

Project cost

Cost of 20 4mm stainless steel sheets= Kshs 200,000

Cost of 20 rolls of Glass wool =Kshs 240,000

Labor cost =Kshs. 30,000

Labor and Material cost= Kshs. 470,000

$$Project\ cost=\frac{175\times470,00}{100}=\text{kshs. }822,500$$

P_P **(Payback period)** $=\dfrac{project\ cost}{annual\ savings}=\dfrac{822,500}{1,033,370}=10\text{ months}$

Figure 5.4 below shows the recuperator and combustion air lines that are not lagged. The parts on the figure are;

R-recuperator

L-combustion air pipes
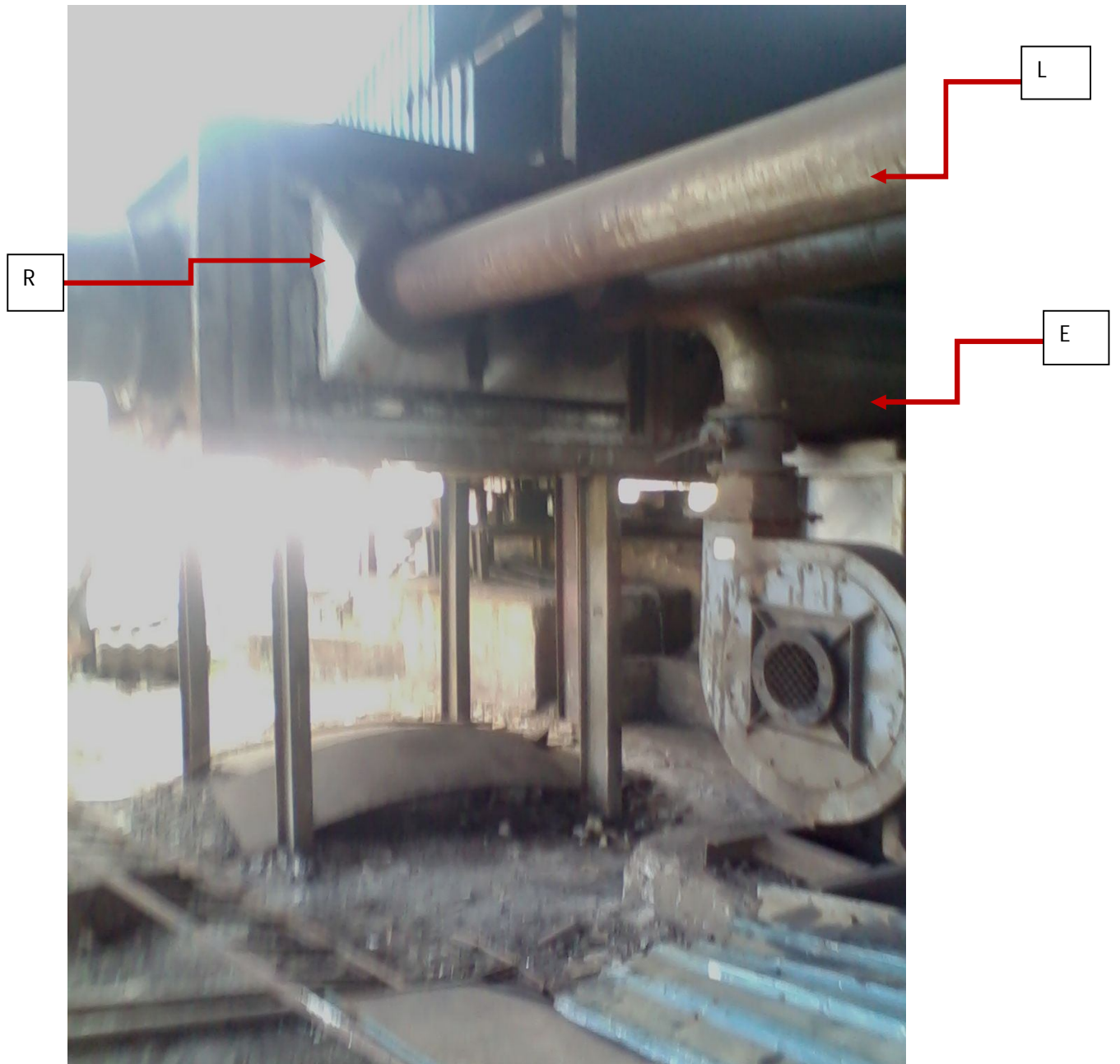
E-exhaust pipe from reheat furnace

Figure 5. 4 Recuperator and combustion air lines

5.2.4 INSULATING FURNACE WALL

From calculations on reheat furnace efficiency, heat loss through furnace walls is 266,087.276Kj/Hr.

Q_{WLoss} =266,087.276Kj/Hr= *heat from fuel*

Heat input (from fuel) =Heat loss through furnace walls

$$\left\{ M \times \frac{10,000 Kcal}{Kg} \times 4.186 \right\} kj/Hr = 266,087.276 Kj/Hr \times \eta$$

$$M = \frac{266,087.176 kj/Hr \times \eta}{\left\{ \frac{10,000 Kcal}{Kg} \times 4.18 \right\} Kj/Hr}$$

=6.366Kg/Hr

=6.845Lts/Hr

Annual fuel savings;

$$=6.845 \text{Lts/Hr} \times \frac{12 Hrs}{Day} \times \frac{5 Days}{wk} \times 4 wks/mo \times 12 mo/yr$$

=19,713.21 Lts

Fuel Cost savings

1 Litre= Kshs. 69

Annual fuel cost savings=cost/lt× *litres of fuel saved*

$$=\text{Kshs. } 69/Lt \times 19,713.21 \ Lts$$

$$=\text{Kshs. } 1,360,211.50$$

Material cost

Cost of 4mm Mild steel sheet plate= cost of plate×No. of plate

$$=30 \text{ plates} \times \text{Kshs. } 10,000/\text{plate}$$

$$=\text{Kshs. } 300,000$$

Cost of ceramic bricks= cost/brick× *No. bricks*

$$= 15,000 \times Kshs. 150$$

$$=\text{Kshs. } 2,250,000$$

Labor and material cost= 3,350,000

Total project cost (C_p) =Kshs. 3,350,000

Payback period (P_p) = $^{Cp}/_{Sa}$

$$= \frac{Kshs \ 3,350,00}{Kshs. 1,360,211.50}$$

Payback period (P_p) =2.5 years

5.2.5 LAGGING RECUPERATOR

Savings from recuperator

Newly installed recuperator preheats air to 300°C

Currently the preheater preheats air to 141.2^{O}C

Heat savings with new recuperator;

$Q=MC_P\Delta\theta$

$$=33.62\text{Kg/Kg of oil}\times \frac{1.00464Kj}{Kg}oil \times \{300-141.2\} \times 245.64Kg/Hr$$

=1,317,521.65 Kj/Hr

Annual savings=1,317,521.65 Kj/Hr$\times 12Hr/D \times 5D/Wk \times 4Wk/Mo \times 12Mo/Yr$

=3,794,462,362 Kj

$$\text{Fuel savings}=\frac{3,794,462,362 \text{ Kj}}{(10,000\times4.186)Kj/Kg}$$

=90,646.5Kg=97,469 Lts

Annual cost savings= Fuel saved (Lts)$\times fuel\ cost(\frac{Kshs}{Lt})$

=97,469 Lts$\times Kshs\ 69/Lt$

=$Kshs$6,725,385

Project cost

Cost of 6 4mm stainless steel sheets =Kshs 60,000

Cost of 800 ceramic bricks=Kshs 120,000

Material cost =Kshs. 180,000

Labor cost =Kshs 50,000

Labor and Material cost =Kshs 230,000

$$\text{Project cost}=\frac{175\times230,000}{100}= \text{kshs 402,500}$$

$P_P={}^{Cp}/_{Sa}$

$$=\frac{402,500}{6,725,385} = 1 \text{ month}$$

Figure 5.5 show the recuperator with its lagging completely worn out.

R-recuperator; in this figure

R

Figure 5. 5 Recuperator not lagged

5.3.2 Billet preheating

Data from experiment

The experiment start time was 1035 AM and stop time 1500 PM.

Ambient temperature 27.6 $^\circ$C

Measurement	Value
Length	0.225m
Width	0.0813m
Height	0.025m
Mass	4kg

Table 5. 5 Billet measurements

TEMPERATURE READINGS

TIME	INLET TEMPERATURE ($^\circ$C)	BILLET TEMPERATURE ($^\circ$C)	EXIT TEMPERATURE ($^\circ$C)	INSIDE TEMERATURE ($^\circ$C)
1145	406	156.4	194	296.2
1150	407	157.9	202.4	299.8
1155	409	160.2	205.3	318.2
1200	410	162.6	208.1	325.6
1205	414	164.7	211.3	336.8
1210	419	167.4	213.7	337.2
1215	421	170	216.5	344
1220	422	171.9	218.9	347.2
1225	423	173.5	220.3	352.1
1230	425	175.6	223.7	355.4
1235	426	177.1	225.2	356.6
1240	426	178.6	227.3	358.2
1245	427	180.0	229.2	361.5
1250	429	181.5	231.1	362.8
1255	430	183	231.9	363.4
1300	430	184.3	234.1	365.5
1305	430	185.4	235.5	370.3
1310	431	186.7	237.2	371.6
1315	432	188	238.2	373.4
1320	432	189.3	241.2	376.1
1325	432	190.1	242.6	378.5
1330	435	191.9	243.9	380.7
1335	435	192.9	245.5	381.8
1340	435	194.1	247.5	381.6
1345	435	195.0	247.6	384.3
1350	436	195.8	249.7	385.3
1355	437	197.3	251.9	387.6
1400	437	198.3	254.4	387.8
1405	437	199	254.6	391.2

1410	439	200.2	255.1	393.2
1415	440	201.2	257.6	394.6
1420	440	202.3	257.6	395.2
1425	439	203.2	258.7	395.8
1430	439	203.7	260.7	396.2
1435	440	204.6	260.9	396.4
1440	440	205.6	262.3	397.3
1445	440	206.4	262.5	397.7

Table 5. 6 Preheating Box Temperature Readings

5.4 Analysis

Graph of temperature against time

Since heat quality is the main factor in determining the feasibility of recovering heat from a waste heat stream and having determined by experimentation that steel billet can be preheated by flue gases from ambient temperature of 27.6^0C to a temperature of about 206.4^0C, this is applied to the case study performed at Devki mills.
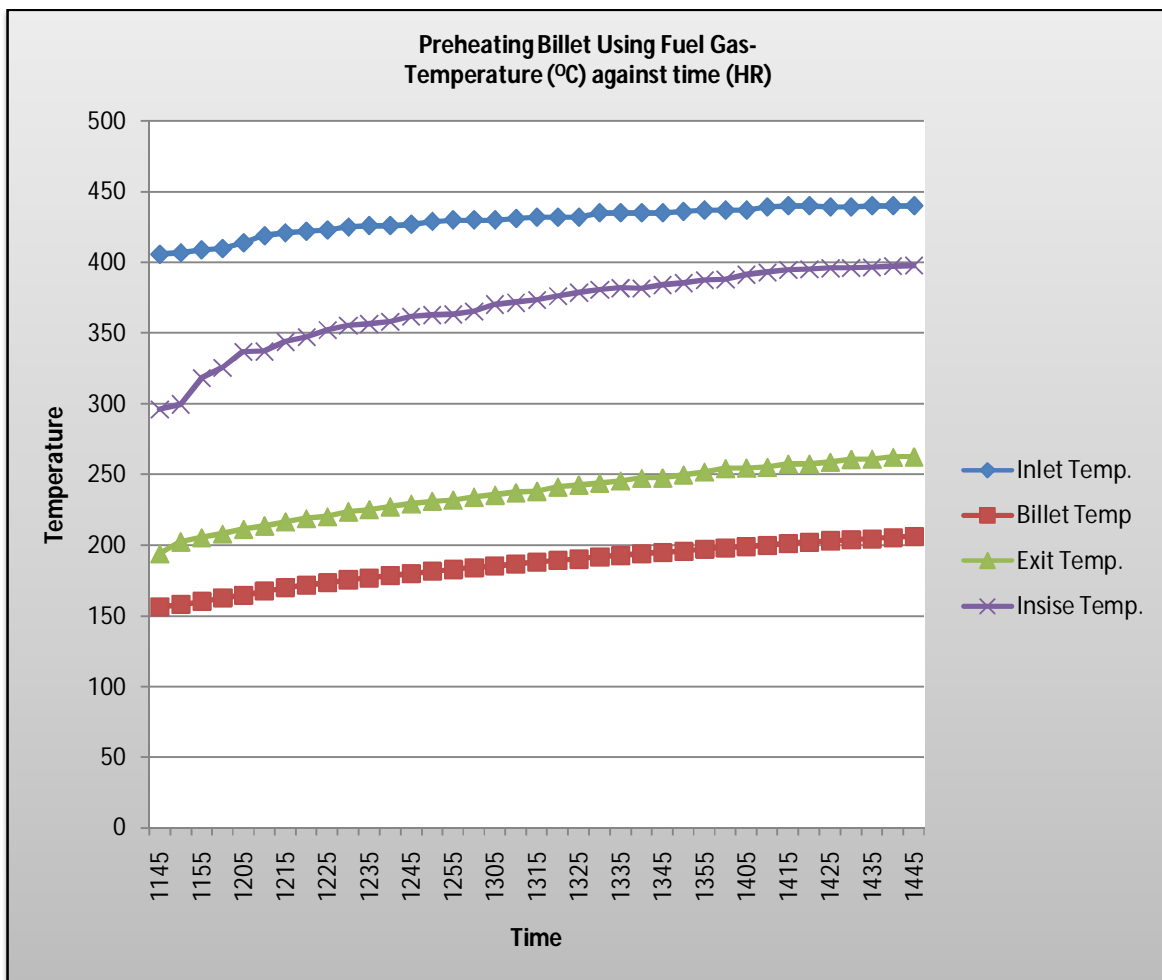

Figure 5. 6 Graph of Preheating Box Temperature (^{O}C) against time (Hrs)

5.1.1 Billet preheating

Billets are heated from ambient temperature to target temperature of 1100^0C. This section explores the feasibility of recovering waste heat from Flue gases for preheating billets. From reheat furnace efficiency calculations for Devki steel mills, heat loss by flue gases is 4,214,741.814 Kj/Hr, this energy can be recovered.

Amount of recoverable heat

This is calculated by the following equation;

Q_R =   m$\times$ C$_P\times \Delta$T

Where,

Q_R-amount of recoverable heat

M-average annual production

From Table 1:0 Production (tons/day), the average annual production can be determined as follows;

M=67,195 Kg$\times \dfrac{5d}{Wk} \times 4Wks/Mo \times 12Mo/Yr$

  =16,126,800 Kg

C_P=0.12Kcal/Kg/^{0}C$\times 4.186Kj/Kcal$

  =0.5023 Kj/Kg/^{0}C

Flue gas temperature a 440^0C; preheating billets from ambient temperature of 27.6 ^{0}C to 206.4^0C, the amount of recoverable heat;

Q= m$\times$ C$_P\times \Delta$T

  =16,126,800Kg$\times$0.5023 Kj/Kg/^{0}C$\times$ (206.4 ^{0}C$-$27.6 ^{0}C)

  =1,448,367,905 Kj

Annual fuel saving

Q_R=1,448,367,905 Kj=M$_{fuel}\times$GCV$_{fuel}$

1,448,367,905 Kj= M$_{fuel}\times$(10,000Kcal/Kg$\times 4.186Kj/Kg$

$$M_{fuel} = \frac{1{,}448{,}367{,}905 \text{ Kj}}{41{,}860 \; Kj/Kg}$$

$=34{,}600$ Kg$=\dfrac{34{,}600 Kg}{930 \; Kg/M3}=37{,}204$ Lts

Fuel cost savings=Annual fuel savings×Fuel cost

$\qquad$ =37,204Lts×Kshs. 85/Lt

$\qquad$ =Kshs 3,162,365

Energy saving measure	Annual fuel saving (Lts/yr)	Cost saving (S_a) Kshs	Project cost (C_P) Kshs	Payback Period $PP = {}^{(CP)}\!/_{(Sa)}$	Feasibility (Y/N)
Insulate combustion air lines	14,976	1,033,320	822,500	10 months	Y
Insulate furnace walls	19,713	1,360,211	3,350,000	2.5 years	Y
Upgrade furnace door	33,887	2,338,165	108,500	1 month	Y
Billet preheating using flue gas	37,204	3,162,365			
Insulate recuperator	97,496	6,725,385	253,750	1 month	Y

Table 5. 7 Summary of the Energy saving opportunities for the Reheat furnace

CHAPTER 6: CONCLUSIONS

Several energy efficiency and cost saving measures were analyzed including; proper lagging of combustion air pipes, proper lagging of recuperator, proper lagging of furnace and billet preheating. In addition, this study also analyzed the feasibility of these measures.

Several measures were found feasible including;

The insulation reheat furnace combustion air pipes that would result in annual fuel savings of 14,976 Litres with an annual cost saving of Kshs 1,033,320. This measure has a simple payback period is 10 months and is therefore feasible.

The insulation of the reheat furnace walls, this would result in annual fuel savings of 19,713 Litres translating to an annual cost saving of Kshs 1,360,211. The simple payback period for this measure is 2.5 years.

Upgrading furnace door that was damaged and thus left open during the entire operation cycle, this would result in annual fuel savings of 33,837 Litres and an annual cost saving of Kshs 2,338,165 annual savings.

The Insulation of the recuperator, this would result in annual fuel savings of 97,496 Litres with an annual cost saving of Kshs 6,725,385 annual. The simple payback period for this measure is 1 month and it is therefore feasible.

Billet preheating using flue gas from ambient temperature to 206.4 ^{O}C, this would result in an annual fuel savings of 37,204 liters and an annual cost saving of Kshs 3,162,365.

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