

United Nations Environment Programme













# Steel Rolling Industries (Indonesia)

in

Sponsored by

**UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)** 

A Joint Initiative of



The Energy and Resources Institute



Agency for the Assessment and Application of Technology

# Prepared by



# Energy Efficient Technologies and Best Practices in Steel Rolling Industries (Indonesia)

Prepared by



The Energy and Resources Institute New Delhi (India)

For

UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP) Bangkok (Thailand)

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Suggested format for cita	tion		
	TERI. 2014		
	Energy Efficient Technologies and Best Practices in Steel Rolling Industries		
	(Indonesia)		
	New Delhi: The Energy and Resources Institute 112pp.		
	[F10]ect Report No. 20141E04]		
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Published by			
	T E R I Press		
	The Energy and Resources Institute		
	Darbari Seth Block		
	IHC Complex, Lodhi Road		
	New Delhi-110 003		
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## **ACKNOWLEDGEMENTS**

The Energy and Resources Institute (TERI) expresses its sincere gratitude to the United Nations Environment Programme (UNEP) for providing opportunity to work in the GEF project titled "Pilot Asia-Pacific Climate Technology Network and Finance Centre in Asia and the Pacific". The focus of TERI's activities in the project was on energy efficiency in steel reheating furnaces in Indonesia.

We express our gratitude to Mr Rajiv Garg, Programme Officer (Climate Change), UNEP for his support and guidance in preparation of the manual on 'Energy Efficient Technologies and Best Practices in Steel Rolling Industries' in Indonesia. TERI is also thankful to the National Council on Climate Change, Indonesia and Agency for the Assessment and Application of Technology (BPPT), Indonesia for their valuable inputs, cooperation, and support for identification of the units for detailed assessment study in Indonesian steel rolling industries. The interactions with Center for Technology Assessment & IPR (Ministry of Industry) and other key stakeholders in Indonesia provided valuable inputs during the detailed assessment and preparation of manual.

We also take this opportunity to express our deep appreciation for the excellent support and baseline information provided by following Steel Rolling Industries in Indonesia, which was extremely useful for preparation of manual.

- PT Bhirawa Steel, Surabaya
- PT Java Pacific, Surabaya
- PT Hanil Jaya Steel, Surabaya
- PT Krakatau Wajatama, Cilegon

Last but not the least, we are also thankful to the project advisors from TERI, Mr Girish Sethi, Director and Mr Prosanto Pal for their inputs and support.



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## **ABOUT THE PROJECT**

The Asian Development Bank (ADB) and the United Nations Environment Programme (UNEP) are working in partnership with funding from the Global Environment Facility (GEF) and co-funding from the governments of Japan, Republic of Korea, Denmark and Finland, and VITO-Flemish Institute for Technological Research NV to pilot a climate technology finance center in Manila, managed by ADB, and a climate technology network secretariat in Bangkok, managed by UNEP. These pilot institutions directly address key barriers to climate technology transfer and deployment in Asia and the Pacific. The climate technology network secretariat managed by UNEP focuses on creating capacity readiness and enabling conditions for market transformation interventions in the region through fostering knowledge sharing, public-private partnerships and the development of institutional capacity and climate technology policies. The secretariat is implementing three main sets of activities:

- 1. Facilitating a network of national and regional technology centers, organizations and initiatives.
- 2. Building and strengthening national and regional climate technology centers and centers of excellence.
- 3. Designing, developing, and implementing country-driven climate technology transfer policies, programmes, demonstration projects, and scale-up strategies.

This broad range of activities will support countries in designing the technical and financial policy mechanisms for climate technology transfer and country-driven climate technology transfer initiatives. This will include development of monitoring and evaluation (M&V) tools for technology transfer policy, setting up of demonstration projects, designing strategies to scale-up environment friendly technologies, the costs of specific adaptation & mitigation measures and to advice on technology regulations and standards. This project on 'Energy Efficient Technologies & Best Practices in Steel Rolling Industries in Indonesia' primarily focuses on activity "3" i.e. country driven programmes and scale-up strategies. The overall objective of the project is to assess the potential for technology upgradation and energy saving in steel rolling industries in Indonesia. The specific objectives of the project include the following:

- Assessing the performance of steel reheating furnaces in terms of scale of operation, product types, production capacity, energy consumption and technology adopted
- Identification of energy efficient technology (EET) and best operating practices (BOP) that can be implemented to save energy and reduce GHG emissions
- Development of monitoring, reporting and verification (MRV) guidelines for reheating furnaces
- Awareness on improved technology and BOP among industry stakeholders

The industry sector in Indonesia is one of the major consumers of commercial energy. Among the industries, steel rolling is one of the most energy intensive process steps in steel making after casting which involves reheating and shaping of cast steel into desired forms. Studies conducted in steel rolling industries in Indonesia indicate substantial scope for energy saving and improvements in employed technology. Energy efficiency improvements in reheating furnaces may lead to substantial reduction in energy input cost, enhanced competitiveness, and low emissions of GHG.



## **EXECUTIVE SUMMARY**

The manual "Energy Efficient Technologies and Best Practices in Steel Rolling Industries" focuses on energy efficiency improvement options in steel rolling mills in Indonesia. It outlines technological options and practices, which may be adopted to enhance the efficiency of the existing installations as well as for augmentation of the capacities. The manual has been prepared by TERI based on the field assessment studies undertaken during September–November, 2014 in selected steel rolling mills in Indonesia. The adoption of new and modern technologies will not only help the Indonesian steel rolling industries to be competitive at global level but also help in reducing emission levels. The manual is also expected to act as a knowledge resource for the industry personnel and energy practitioners for incorporating energy efficient options in their regular operating procedures.

The total energy consumption of Indonesia in the year 2012 was about 162 million tonnes of oil equivalent. Industrial sector contributes to the final energy consumption of 29.9 per cent, closely followed by households (28.5%) and transportation (26.8%). Thus, the industry sector is one of the important consumers of commercial energy, which is mainly attributed to significant development in textile, automobiles, infrastructure, and other associated sectors. The steel industry is also one of the leading sub-sectors with expectations of increased investments and competitiveness in the coming years.

The domestic demand for crude steel in Indonesia was about 8.6 million tonnes in 2011; while domestic production was 6.01 million tonnes. Indonesia is ranked 36<sup>th</sup> in the world in terms of steel production. The per capita consumption of steel in the country has increased from 22.8 kg to 62.3 kg during the last decade (2003–2012). However, per capita consumption of the country is still lower than the per capita consumption of Asian countries (262 kg).

The downstream steel industries sector, which comprises various finishing operations, is an extremely important sub-sector, but largely remains unattended. One of the important finishing operations in steel sub-sector is steel rolling mills. There are about 72 steel mills operational in Indonesia. A detailed field assessment study in a few typical steel rolling industries (selected based on installed capacity, energy consumption, technology used, raw materials & products and location) located in Surabaya (East Java) and Cilegon (Banten) was carried out by TERI.

Steel rolling industries are highly energy intensive and the specific energy consumption of the four units that were studied was in the range of 2.36–4.37 Giga Joule per tonne. The weighted average specific energy consumption is estimated to be 3.13 Giga Joule per tonne of rolled steel for hot rolling, whereas the world average is about 2.2 Giga Joule per tonne, which indicates significant potential for energy conservation and energy efficiency improvements. Summary of the key findings from the field assessment is given below:

A wide variation in the specific thermal energy consumption was observed, which is mainly attributed to age of the furnace, technology employed, and capacity utilization.



Natural gas is the primary fuel used in the reheating furnaces across the country due to lower price in comparison with other developed countries as well as easy availability. Reheating furnaces are the major consumers of energy in the form of thermal energy, accounting for about 60–65 per cent of total energy consumption of rolling industries.

The utilities associated with reheating furnaces and rolling mills (compressed air system, process cooling system, etc.) are of conventional type and the efficiency levels were not up to the design mark. This is mainly due to lack of proper selection of equipment, over designing, absence of periodic maintenance practices, and lack of adoption/ awareness about new and energy efficient technologies. The use of modern era technologies and process automation & control system can lead to substantial reduction in energy consumption and greenhouse gas (GHG) emissions.

 $\clubsuit$  The average GHG emissions have been estimated based on the type of fuel used and its share in the total consumption. The emission level from steel rolling industries in Indonesia is estimated to be 363 kg CO<sub>2</sub> per tonne of product.

Various energy efficient technology options have been identified for reheating furnaces, rolling mills, and auxiliaries. These options are summarized below.

#### **REHEATING FURNANCE**

Recovery of heat – Regenerative burners

Becovery of heat – Self-recuperative burners

Solution technology

Hot charging of continuous cast billets

✤ New reheating furnace technology – Walking beam furnace

Solution of combustion – Oxygen level control and VSDs on combustion fans

b Improved insulation and refractories of reheating furnace

Solution of operation – Furnace pressure

Solution of operation – Temperature of material

Solution of operation – Capacity utilization

#### STEEL ROLLING MILL

- Scapacity optimization and use of energy efficient electric motors
- Improved lubrication system
- Solution Winimum waste crop length optimization
- ♥ Use of cast-in-carbide rolls
- Schuler State Anti-friction roller bearing
- Scomputerized roll pass design

#### **AUXILIARIES**

Process cooling system – Automation and control and use of Energy efficient pumps

Scompressed air – Optimum pressure, capacity utilization and prevention of leaks

- Ultra high efficiency transformers
- Quantity control of transformers
- Senergy efficient lighting

#### Energy efficiency options for steel rolling mills in Indonesia

Modern technologies such as enhanced recovery of the waste energy and optimum use of auxiliary system provide opportunities for minimizing heat input to reach up to the required temperature profiles in reheating furnaces. Along with technological advancements, adoption of control & automotive process technology and adhering to regular and preventive maintenance practices will help in improving the performance of reheating furnaces and rolling mills.

A large number of steel rolling mills in Indonesia are equipped with small and medium capacity reheating furnaces (typically up to 40 tonnes per hour). High-end technological options may not be the appropriate solution for such mills as large investment would be required resulting in high payback periods. Instead, these mills can improve the performance through adoption of energy efficient technologies and practices provided in this manual. High investment technologies such as regenerative burner technology may be suitable only for rolling industries having reheating furnaces of capacities more than 40 tonne per hour or more and utilization factor in the range of 75–100 per cent. As per the information collated during the field interaction, the number of such mills present in Indonesia is very limited.

This manual describes the general methods for energy saving as well as success stories and practical examples that can serve as reference for the industries and energy practitioners, who deal with the operation of rolling mills. The primary objective of the manual is to highlight the energy efficient technologies and best operating practices that can be adopted/ implemented to save energy and reduce GHG emissions. Also, creating awareness on improved technologies and best operating practices among industry stakeholders is one of the goals of the project.

The manual discusses both the measures, which may be retrofitted in the existing system as well as replacement options for minimizing energy consumption. The technical options are provided along with their applicability, availability, investments, energy usage, and monetary benefits. Suitable case studies have also been provided to validate the worldwide use of the suggested technologies. Special emphasis has been given in the manual on best operating practices and Operations and Maintenance (O&M) guidelines that should be followed in reheating furnaces, rolling mills, and other utilities. It is envisaged that this document will help various stakeholder industries to adopt suitable technologies and practices in their mills.

The industries in steel rolling sector will have to scrutinize the level of technology used and their specific energy consumption to assess the current level of performance. The preliminary analysis would help them to decide on the changes required to achieve optimum performance levels and remain competitive with international market. Industries may also seek the help of energy practitioners and technology suppliers for detailed plant specific performance assessment studies.

Modification in existing designs, retrofits of control and automation systems and adoption of new technologies along with improved O&M practices and monitoring can lead to a significant reduction in operating and maintenance cost of the facilities. An energy saving

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potential of 20–35 per cent exists in rolling industries of Indonesia. The realization of this potential will not only lead to reduction in energy consumption and energy costs for the mills but also contribute to the overall international goal of reducing the GHG emissions from various sources.

# **Steel Industries**



## **1.1 INTRODUCTION**

The steel sector plays a vital role for progress of Indonesia in many fields; infrastructure, goods, transportation, and even weaponry. Because of its important role, the existence of steel industry is very strategic to the prosperity of the nation. Steel industry is one of the leading sub-sectors with orientation to increase the investment and competitiveness.

The world steel market has grown in the last few decades due to development in infrastructure and other relevant sectors. The world crude steel production1 in 2012 touched 1,545 million tonnes (MT), in which Asian countries produce about 65% of the total. In 2013, the global steel production has increased by 3.5% to 1,607 MT despite tepid demand growth



Steel production - Global and Asia

in most parts of the world. The increasing growth in crude steel production is associated with high market demand especially from developing countries which resulted in higher steel prices in international market.



The domestic demand for crude steel in Indonesia was about 8.6 MT in 2011, while domestic production<sup>2</sup> was 6.01 MT. The crude steel import during the year was 2.59 MT. Construction and automotive sectors are major consumers of steel and steel products. The share of steel products about 0.39% of the total world and 0.60%

of the total crude steel produced in Asian countries. Indonesia is ranked 36<sup>th</sup> steel producer in the world however; the per capita consumption<sup>3</sup> of steel in country has increased from 22.8 kg to 62.3 kg during last decade (2003 – 2012). The per capita consumption of the country is still lower than the per capita consumption of Asian countries (262 kg).

## **1.2 SCENARIO – STEEL INDUSTRIES**

The dependence on imported raw materials is one of the factors for stagnation of

the country's steel industry which further reveals high dependency of upstream and downstream sectors of the industry. The 6.8% growth of the industry<sup>4</sup> surpassed the target of 6.1% as set in the Strategic Plan of Ministry of Industry in 2010-2014. This figure is supported by sectors that crossed the target, such as (1) food, beverages, and tobacco industry which grew 9.2% (target 7.9%), (2) textile, leather goods, and footwear industry grew 7.5% (target 3.4%), (3) cement and non-metallic mineral industry grew 7.2% (target 3.74%); and (4) base metal, iron and steel industry grew 7% (target 6.4%).

The products of steel industry from upstream to downstream consist of flat products and long products. The uppermost in the upstream industry is iron making from iron ore. The sponge iron, scarp, and hot briquette iron (HBI) are melted into steel to form slabs as the basic material for flat products and billets as the basic material for steel bars or long products. The subsequent process i.e., hot rolling is to make hot steel basic material thinner to desired forms and sizes. The hot rolling process produces hot rolled coil (HRC) and steel plates. HRC is made thinner through the cold rolling process to turn out cold rolled coil (CRC), which is used as basic material for galvanized iron sheet (GIS) and tin plate. Hot rolling process produces long products in the form of wire rods and reinforcement bars (concrete iron). Wire rods, through cold rolling are processed to produce wire and nail.

The steel industry may be classified into two categories according to product formations and types, i.e., upstream industries and downstream industries. It can also be classified into three categories namely *basic steel industries, steel smelting industries*, and *steel rolling industries*. Industries classified as upstream industries produce products, such as HRC products and CRC products. These include flat steel products, either for direct consumption according to end use or to be used by downstream industries. Upstream industries also produce non-flat steel products, such as ingot, bloom and billet (casting), sections, merchant bar and wire rod (hot rolling from ingot, bloom and billet), etc.

Most of the steel industries in the country are located in Iava Island especially in West Java, Banten, DKI Jakarta and East Java. Outside Java, some industries are located in North West Sumatera, Sumatera, South Kalimantan and South Sulawesi.



Geographical representation of steel industries



The steel industries in terms of product supply chain can be categorized into three. The first category is pellet provision industries, which is entirely dependent on the imports. The second category is the slab, billet and bloom providers, who are mostly located in Java and some parts of North Sumatra. The third category comprises steel bar, hot rolled products and cold rolled products industries, which are mostly located in Java. A typical tree of the steel industries and availability and non-availability of the various sub arms of the products are shown in figure.



A typical tree of steel industries

There are about 325 industries operating in Indonesia manufacturing different type of steel products namely direct reduction of iron (DRI), slabs, billets, HRC, CRC, and finished products. There are an estimated 72 working steel re-rolling mills, scattered across the country with an installed capacity of 12.61 MT of steel. The steel industries based on product categories are shown in table.

Sub-category	Product type	Number of industry	Capacity (MT)
Iron product	DRI	2	1.81
Semi-finished product	Slab	1	1.80
	Billet	14	5.48
Flat product	Hot rolled coil/Plate	6	3.61
	Cold rolled coil/Plate	5	1.54

Sub-category	Product type	Number of industry	Capacity (MT)
Long product	Rebar	32	3.85
	section	22	1.31
	Wire rod	7	2.30
Downstream	Finished product	236	-

Hot rolled plate, one of the strategic intermediate steel products, has experienced a significant market growth in Indonesia in the last few years. This is due to sturdy growth in demand from several related sectors, such as power generation and distribution, heavy equipment, shipbuilding and steel fabrications and structures. The market size for hot rolled plate (thickness of 20 mm and higher) has developed steadily from about 273,000 tonnes (2005) to 445,000 tonnes (2009) and rose sharply to 703,000 tonnes in 2010. The substantial growth in 2010 was driven by the strong recovery in various sectors following the global economic crisis faced in FY 2008-09. Although still importing hot rolled plate for certain types, Indonesia has been able to export it with an increasing volume over the last three years.

The rolling and forming is the process of changing the semi-finished steel into finished products, which will be used by end-users directly or to produce other advanced products. The finishing process provides required characteristics for the products which include final shape, surface finish, strength, hardness, flexibility and corrosion resistance. Rolling and forming process typically uses raw materials, such as billet, bloom, or slab. It can include hot rolling, cold rolling, forming or forging. For example, in hot rolling of steel strips, the steel plate is heated to over 1,000 °C and then passed through several sets of rollers. High pressure in rollers reduces the thickness of steel plates while increasing the width and length. The rolling process primarily uses heating furnace which is one of the major consumers of thermal energy whereas in the milling section, huge quantity of electrical energy is used for shaping the heated material to the final form.

While the rapid growth in the steel rolling sector has paved the path of the development of country, there has been substantial stagnancy in adoption of advanced technologies and gaps in the indicators of the standards of production efficiencies as compared to other leading countries in steel sector.

## **1.3 NEED & APPROACH—ENERGY EFFICIENCY**

Steel production technology exhibits deprived performance level in terms of specific energy consumption (SEC) i.e., energy required to produce one unit of steel, in heating furnaces and milling process in the country. A number of studies have shown that in most of the rolling mills, inadequate attention is paid towards energy efficiency aspect. In hot rolling operation, the reheating furnace is one of the critical sections in determining end-product quality as well as costs of the operation. Energy use in a reheating furnace depends



on production factors (for e.g. stock, steel type), operational factors (for e.g. scheduling, operation and maintenance practices), and design features.

Based on detailed assessment studies conducted, it is observed that the SEC of the rolled steel is about 3.13 GJ per tonne (FY 2013-14), ranging 2.36–4.37 GJ per tonne, whereas the world average<sup>5</sup> is about 2.2 GJ per tonne. The excessive specific energy consumption in Indonesian rolling mills shows the existence of significant energy saving potential and the need for technology level interventions.

Energy is a key factor of production for all types of rolled products manufactured. With all other operating parameters kept the same, an increase in production will generally lead to an increase in energy consumption, although most processes have both fixed and variable components in normal mode of operation. Hence, if the demand for production from the process drops, the energy intensity will increase. The demand for steel and rolled products is increasing rapidly in the country as well as in other parts of the world. The relationship between energy and production/demand, and how it performs as compared to developing countries will be influenced by several factors including:

 $\odot$ 

Average age of industry  $\odot$ 

Product quality

 $\odot$ 

- Process and technology employed Quality and type of energy used
- $\odot$ Operational and maintenance practices
- $\odot$ Quality of raw material
- The existing situation of steel industry in Indonesia clearly shows that the technologies

used for energy efficiency is still lagging compared to the world's best practices. In order to be competent with the international market, the technology upgradation and optimization of energy is a necessity for the nation. Therefore, only fundamentally new processes and the next generation steel making technologies can make a significant reduction in energy intensity in steel production. Technological advancement is one of the key approaches to achieve the goal of energy efficiency and meeting the indicators to the world average. These advancements include enhanced energy efficiency, process modernization, and better environmental protection techniques.

The manual provides the first steps which could be a constructive path for steel making and rolling industries. To understand the need of the sub-sector, it was considered important to assess the current level of resource efficiency before selection of the best technologies available globally. The priority was therefore to collect consistent facts that could be used to determine the energy efficiency levels of the industries which can be used to compare with each other and also compare the best technologies and practices adopted in the developed countries. The energy and cost optimization through technology upgradation and adopting better practices forms the core of this manual.



# Steel Rolling Process and Equipment



Most steel products from the casting operations are further processed to produce finished steel products in a series of rolling and finishing operations. It is beyond the scope of this study to outline all operations and products in detail. Instead, it focuses on two common shaping processes, hot rolling and cold-rolling. In general, rolling process includes the mechanical forces that are applied to the metal surfaces through a series of rolls to produce specific shapes and sizes by reducing the width and thicknesses. The ingot or continuous casting is hot rolled into a blooms or slabs, which are the basic structures for production of a wide range of manufactured forms. Many of these products will be the starting material for subsequent manufacturing operations, such as forging, sheet metal working, wire drawing, extrusion and machining. The chain of metal forming of rolling operation in modern manufacturing is shown in the following figure.



Rolling mill operations and product profiling

## 2.1 HOT ROLLING

The primary function of the hot rolling mill is to reheat slabs/ingots/ billets/blooms of steel close to soaking temperature point, then rolls to thinner and longer through successive rolling mill stands driven by electric motors. The steel slabs/billets are heated up to about 1,250 °C in reheating furnaces (pusher hearth/walking beam), using mainly natural gas (NG) as the primary energy source. The heated slab is rolled in a roughing stand, in which the thickness is reduced in various passes, back and forth. The length of the slab increases from 3-6 meters to an intermediate slab which is up to 80 meters long. The material is then rolled down to between 32-1.8 mm in only one pass through six stands. At the end of the hot rolling mill, the speed of the strip/rolled product is up to 120 km per hour. The speed increases after every stand and is highest at the end. A typical process flow of hot rolling is shown in the figure following this text.



Typical manufacturing process of hot rolled product (Source: Industrial Energy Technology Database)

## 2.2 COLD ROLLING

Cold mills produce rolled sheet 0.35–1.8 mm or tinplate 0.15–0.3 mm for a variety of purposes, e.g. for car bodies to tin cans. This is done by reducing the thickness of hot rolled

coil. The process begins with the removal of a thin film of iron oxide by a warm acid bath. The strip is then immediately cold rolled in the tandem mill before further oxidation can take place. To make the cold rolled steel soft and flexible, it is annealed which involves heating to about 700°C followed by slow cooling. After annealing operations, such as pickling can be carried out to improve metallurgical properties or obtain precise steel specifications for downstream processing.



## 2.3 MAJOR EQUIPMENT

Reheating furnaces are the major consumers of thermal energy and operational characteristics of the furnace play a vital role in overall milling process. The reheating furnaces are equipped with combustion equipments, such as burners and waste heat recovery systems. Other associated equipment includes charging and discharging system, such as pusher and loaders. A typical mill furnace has preheating, heating, and soaking zones to gradually increase and maintain desired temperature profile for milling process.

Cutting machines, trimming machines, and tools are used in rolling mills. Most of the rolling mills are open train, 2-high or 3-high type, with roll diameters ranging from

150 - 650 mm (maximum up to 950 mm also) in the roughing stage, with speed of 92 - 275 rpm and 1 to 8 stands. The mechanical coupling between the mill motor and rolling stands is either v-belt and pulley type or speed reduction gear type. The system has flywheel arrangements to guard against the load fluctuation.

## 2.3.1 Furnaces

The reheating furnace can be classified in a number of ways:

- Based on the method of heating, reheating furnaces can be combustion type or electric. The combustion furnace can be coal, oil or gas fired.
- Based on heat recovery mechanism, reheating furnaces can be classified as regenerative or recuperative. Presently only recuperative type of reheating furnaces are used in the country.
- Based on method of charging, reheating furnaces can be classified as batch type or continuous type. In batch furnaces, the charged material remains in a fixed position on the hearth until heated to rolling temperature. In continuous furnaces, the charged material moves through the furnace and is heated to rolling temperature as it progresses inside.
- Continuous furnaces can be further classified based on the movement of steel stock in heating zones. Most popular continuous type of furnaces include pusher, rotary hearth, walking beam, walking hearth or roller hearth type.

Most of the steel rolling industries in the country are equipped with continuous type heating furnaces. Different types of batch furnaces and continuous furnaces are described below.

## 2.3.1.1 Batch furnace

Batch type furnaces are conventional furnaces, used in steel heating in batches, also known as 'in-and-out' type furnace or 'periodic furnace'. These furnaces are capable of heating all grades and sizes of steel stock. They are used to heat a large single piece used for forging operation or heat treatment purpose or small pieces weighing 3 – 50 kg for rolling operations.

In batch type reheating furnaces used for rolling purposes, the raw material is loaded manually without any pusher (mechanical) system and then heated to the required rolling temperature. These furnaces are generally 5–10 metre long and 1–2 metre wide. In batch type furnaces, the material does not move; it lies on the hearth until it is heated to the required temperature upon which it is taken out for heat treatment or rolling purpose. Some of the disadvantages of batch furnaces include the following:

- High capital investment per unit of production
- Low hearth productivity and area efficiency

- High man hours per tonne of heated product
- Limitation of length of pieces to be heated

#### 2.3.1.2 Continuous pusher furnace

In this type of furnaces, the charge or stock is introduced at one end ('feeding or charging'), which moves through the furnace and is discharged at the other end ('discharge doors'). There exists a temperature gradient in the length of the furnace. In general, the material and combustion gases move opposite to each other. On the basis of the temperature gradient, the continuous furnace is divided into three zones or segments i.e., preheating, heating and soaking zones as shown in figure.



Three zones of a continuous type furnace

Continuous furnaces are further classified according to the following:

- Number of heating zones (one, two to five, top or top-bottom) and the method of moving of material (pusher type, walking beam type, rotary hearth type or roller hearth type).
- Based on heat recovery, the reheating furnace can be either regenerative or recuperative.

The advantages of pusher type furnaces are as follows:

- High production per unit capital investments
- High hearth area efficiency and higher specific production per unit of space utilized
- Ease of charging and discharging
- Gradual rise in temperature permits charging of all grades of cold materials
- More control of the rate of heating at all temperature levels

The disadvantages associated with pusher type furnaces are given below. However, these shortcomings do not limit the use of the continuous furnaces over the batch type.

- Limits the cross section of the charge since the contacting surface is to be square to avoid piling up inside the furnace
- No flexibility for heating efficiently small quantity or low thicknesses of steel stock



• It is marginally difficult to maintain water cooled skid and also limits the thickness of steel stock to a maximum of 300-350 mm when water cooled skids are used.

Different types of continuous steel reheating furnaces commonly used in the country as well as in other parts of the world are described below.

**Pusher type furnace:** The cold steel stock is pushed forward with the help of pushers at the charging side. These furnaces are designed for heating billets/ingots or smaller sections of blooms. The hearth of pusher furnaces used earlier was short in length and sloped downward longitudinally towards the discharge end in order to permit easy passage of steel stock through the furnace. Presently, pusher furnaces are long with hearths up to 30 metre length. The steel stock is moved forward by pushing the last piece charged with a pusher at the charging end. With each pushing of the cold steel stock against the continuous line of material, a heated piece is discharged at the discharge end through an end door upon a roller table feeding the rolling mill, or pushed through a side door to the mill roller table by suitable manual or mechanical means or withdrawn through the end door by a mechanical extractor.

In order to increase the throughput of the furnace, additional combustion zones are introduced by changing the profile of the furnace from single zone to multi-zone (two-zone, three-zone, four-zone and five -zone furnaces) and placing the burner at more than one location, for example front-fired, side-fired-bottom or top-fired furnaces.



Two-zone (top and side fired) continuous furnace

A two zone reheating furnace delivers better results for the temperature gradient than a single-zone furnace. It consists of two combustion zones, viz. soaking and heating. In these furnaces, burners are arranged as follows:

- Soaking zone Front firing
- Heating zone Top or side firing



If the heavy material is required to be heated (up to 150 mm billet size), 3 or 4 or 5 zone continuous furnaces may be employed in order to increase the total temperature level and productivity. To cater to such requirements, two or three heating zones are a norm in the furnace, with burners being mounted in each of them. This customized design makes it possible to have a higher temperature at the end of the pre-heating zone, which shortens the length of the zone and increases the total length of high-temperature zones; as a result, heating of the metal is more intensive.

**Walking beam furnaces:** Furnaces have mechanisms to transport the heating material by means of walking (mobile) beams which are called 'walking beam furnaces'. The earlier version of walking beam furnaces were designed with alloy steel walking beams which were exposed directly to the furnace heat and were also subject to heat corrosion. Hence these furnaces had limitations to operate at maximum temperatures of about 1,050 °C. The existing type of walking beam furnaces used to reheat billets, blooms and slabs are made of water cooled steel system lined with refractories so that only the refractories are exposed to heat. Alternatively, the beams and supports are constructed of water cooled pipe sections with provision on the top surfaces to keep away the hot material from direct contact with the water cooled pipes. Walking beam furnaces are usually designed with end or side charging and discharging mechanisms. The beams can be actuated either hydraulically or mechanically. Cross firing with side wall burners above and below the material stock are used. In some furnaces, the material is heated with radiant type roof burners or with burners placed in the roof and below the material.

Steel Rolling Process and Equipment



Walking beam furnaces

**Walking hearth furnaces:** These furnaces are similar to the walking beam furnaces while considering the passage of steel stock through the heating chamber. The basic difference lies in the method of conveyance i.e., steel stock rests on fixed refractory piers. These piers extend through openings in the hearth and their tops are above the hearth surface while the



material is stationary in the furnace, thus allowing heat to circulate between bottom surface of the work and hearth. For progressive movement of the material towards discharge end, the hearth is raised vertically to first contact the material and then raised further for a short distance above the piers. The hearth then moves forward to a preset distance, stops, lowers the material on to its new position on piers, continues to descend to its lowest position and moves backward to its starting position for the next stroke.

**Regenerative furnaces:** These are the modern era furnaces having high capacities based on the principles of heat recovery to a maximum limit of 1,000–1,150 °C. Regenerative furnaces have two chambers, each containing refractory material called 'the checker' (either high

alumina balls or honeycomb structure). While in one chamber, combustion gases pass through the checker and enter the furnace; in the other chamber, the checker is heated, or regenerated, with the outgoing hot exhaust gas. The furnace operates in two cycles. After each cycle (about 60 seconds), the flow is reversed so that the new combustion air can be preheated by the checker arrangement. Typical air preheat temperatures, depending on the number of ports are normally in the range of 1,000-1,150 °C.

## 2.3.2 Rolling mills

There are three types of rolling mills in common use i.e., 2-Hi, 3-Hi, and 4-Hi mills. This classification is based on the mode of arranging rolls in the housings. Typically, one 2-Hi stand consists of 2 rolls, arranged one above the other. Similarly, a 3-Hi mill has 3 rolls and a 4-Hi mill has 4 rolls. 6-Hi, 12-Hi or 20-Hi mills are also designed but only for specific use. Mills having 6 or more rolls are generally termed as cluster mills.

#### 2.3.2.1 Cross-country mill

In the cross-country mills, the roll stands are located in a scattered manner. These mills are based on the

concept of continuous rolling but the stands are placed so far apart that the piece must leave one set of rolls before entering the next. Such mills are useful for rolling sections that due to size or shape are not adaptable to loop rolling.



Regenerative furnace



A. 2-high B. 3-high C. 4-high D. 6-high E & F. Cluster



#### 2.3.2.2 Continuous mill

In order to meet high production, it is common to install a series of rolling mills one after another in tandem, i.e., in a straight line. Since a different size reduction is taken at each stand, the strip is rolled simultaneously at a number of stands. This is called a continuous mill. Reduction takes place in several passes at the same time until the piece emerges as a finished shape from the last stand.

## 2.3.2.3 Semi-continuous mill

A semi-continuous mill comprises a reversing roughing stand for reducing the piece prior to entering the continuous mill and its reduction to finished shape.

Rolling mills can also be classified based on product types as per the following.

- **Roughing or cogging mill:** Producing semi-finished products like blooms, slabs, and billets.
- Section mill: Producing various sections like heavy, medium, and light structural sections (angles, channels, etc.) rounds and square bars and other sections used in applications like windows and pilings.
- Plate and sheet mill: This includes wide and medium strip mills.
- **Tube mill:** This is used for production of both seamless and welded tubes.
- Merchant mill: This includes production of rounds, bars, etc.

## 2.3.3 Rolling mill equipment

Rolling mills consist of a number of equipments which together contributes to execute rolling process with ease and efficiency. Some of the equipment is essential to constitute rolling operation while many of them are additional equipment used to improve productivity and efficiency. The main equipment used in rolling mills is briefed below.

## 2.3.3.1 Mill housings

Mill housings are one of the most important structures of the rolling mill since they hold the mill assembly in position. Housings are elements in a rolling mill which hold chock assemblies, adjusting and other mechanisms, and retain proper positions. Thus their construction and dimensions have to take into account sizes of related elements. The forces which act on the rolls during rolling are completely transferred on to them through the nuts of the adjusting mechanism. The housing of the rolling stand requires high rigidity, sufficient strength for taking the loads, simplicity of design and minimum cost of production. One-piece cast housings of simple form (rectangular section) are used for heavy roughing mills, for e.g., blooming, slabbing, billet, and plate mills. These are called 'closed type' housing. In the mills wherein change of rolls are frequent (merchant and structural mills), sometimes the housing has a detachable top for easy removal of rolls, especially in the linear mills. Such housings are called 'open type' housings (top beams connected by bolts to the pillars).

## 2.3.3.2 Mill bearings

The load on the rolls gets transferred to the bearings and their assembly (chocks). The mill bearings can be classified into three types.

**Slider bearings:** Slider bearing may further be classified into two categories. Slider bearings with metallic bush have high coefficient of friction and comparatively low life. They are used when high temperatures and pressures prevent the use of other bearings. The non-metallic bush bearings have all the advantages of slider bearings. In addition, they are low cost and provide good bearing for rolls when the speed may vary considerably or may even reverse. Further, the coefficient of friction is also very low.

**Hydrodynamic bearings:** Hydrodynamic bearings completely enclose the roll neck and bearing surfaces are separated by a liquid film. They have a low coefficient of friction at high speeds. Also they have a very long life, and low space requirement. This has led to their extensive application as a substitute for anti-friction bearing in many non-reversing stands. However, their use is restricted to applications where speeds are relatively high and almost constant.

**Anti-friction bearings:** Include all types of bearings with rolling contact. However, only taper bearings are used in rolling mills in multiple row series. The principle advantage of anti-friction bearings is low friction and their ability to work at low speeds.

## 2.3.3.3 Rolls

Rolls are most vital part of a rolling mill. The deformation of metal work piece is directly accomplished by the rolls. The rolling stresses are first of all applied on rolls and after that transmitted to other sections of a mill. Consequently, the rolls had to be harder and more resistive to deformation than the metal under processing.



#### Configuration of roller

Further, the rolls can be classified into four categories.

**Steel rolls:** The steel rolls have carbon composition of 2–3% and are made of either cast steel or gorged steel. The rolls can be either sand cast or chilled mould cast. In some critically

cast steel rolls, the roll body is chilled cast while other portions are sand cast. Some of the steel rolls have high alloy contents.

**Iron base rolls:** The iron base has a composition of 2.5–3.5%. Different types of commonly used iron base rolls include (i) clear chill rolls, (ii) indefinite chill rolls, (iii) SG iron rolls and (iv) double poured rolls.

**Tungsten carbide rolls:** These rolls are manufactured by pressing and sintering powdered carbide. They are usually fashioned in the form of rings of relatively small diameters that may be used in association with steel arbors.

**Composite rolls:** These types of rolls consist of arbor and a ring or sleeve-type member which is shrink-fit over the arbor. These rolls have the advantage that if ring or sleeve has been worn down, the arbor may be refitted with new outer member.

Rolling mills are powered by electric drives and suitable transmission lines are necessary between them and the rolls. In general, it would consist of a shaft connecting the motors to gear box connected by couplings at both ends. The gear box provides for the speed reduction from motor speeds to the roll speed. The power is then transmitted on to the pinion box where it is distributed to a number of shafts, depending on the number of rolls to be driven.

## 2.3.3.4 Lead spindle

The lead spindle is used to connect the prime mover with the pinions and may be of universal type, either short-coupled or long with carrier bearings, depending on the position of the motor in layout. If short-coupled, standard flexible couplings can be used. The lead spindle is attached to the bottom pinion of 2-Hi mills, and to the center pinion of 3-Hi rolling mills.

## 2.3.3.5 Mill pinions

The pinions are gears serving to divide the power transmitted by the drive between the 2 or 3 rolls, driving the adjacent rolls in opposite directions. The earlier pinions had either spur teeth or a divided face and staggered spur type teeth but the present practice is to use double helical teeth. Helical gears provide smoother drive, as some parts of the teeth are in contact at all times, making the transmission of power continuous.

## 2.3.3.6 Spindles

Spindles are used to connect pinions with rolls of the mill if not a direct driven type. In direct drive case, the spindle is connected directly to the motors. Spindles are made of cast or forged steel and are fitted at each end with wobblers similar to those on the rolls or with the universal couplings, depending upon type of mill.
#### 2.3.3.7 Reduction gear boxes/reducers

The reduction gear boxes 'reducers' used in the installation having speed of motor is higher than required for rolls. Depending on the required reduction in speed, reducers can be used in 1, 2 or 3 stages.

#### 2.3.3.8 Guides

Guides assist stock in entering and leaving the rolls. They are termed entry or delivery guides according to their location and are customarily secured to a rest or cramp bar, running in parallel with the rolls and mounted across the housings. Fixed guides are those having no moving parts and are usually cast in iron, or occasionally in bronze, to minimize dangers or preventing scratching of stock. In the simplest form, a fixed entry guide comprises two castings clamped together to form a bell-mouthed box. Roller guides have been developed to overcome the tendency of stock to scratch the stock. Such guides, which are used particularly as entry guides, incorporate one or more pairs of idle rollers profiled to the appropriate stock shape.

#### 2.3.3.9 Repeaters

Repeaters are devices used to receive the work piece as it emerges out from one stand and loop it through 180° into an adjacent stand automatically. This consists of grooved channels or troughs which guide the leading end of the stock through 180° or in some cases through an S-shaped path in forward running repeaters. The front end of the stock is driven round the repeater by the succeeding stock until it is gripped by the next stand. The speed matching between the adjacent stands



Repeaters

is usually such that the succeeding stand runs slightly slower than the balancing speed which causes the loop to grow in size. The repeating channels are designed to allow the stock to kick out on to a flat table under these conditions.

#### 2.3.3.10 Roller tables

The roller tables consist of a series of roller either driven by line shafting and bevel gears from a common drive or by individual motors. In some improved designs, the bevel gears have been replaced with spur gears. The roller tables serve to feed the rolled piece into the rolls and receive it from the rolls. Hence they operate under severe conditions of mechanical impact, repetitive short-term duty cycles and dynamic transients (acceleration and decelerations). The roller tables connect the separated stands of large and medium sized mills. There are required on majority of the mills for conveying the stock away after rolling.

#### 2.3.3.11 Tilting or lifting tables

In large 3-Hi mills, the stock has to be mechanically lifted from the pass line of the middle and bottom rolls to the higher pass line of middle and top rolls. To achieve this, the tables on either or both sides of the stand may be designed to tilt.

#### 2.3.3.12 Shears

The following different types of shears are used in rolling mills depending on applications.

**Bloom and slab shears:** There are large hydraulically or electrically-driven shears with upcutting or down-cutting blades used to crop the segregated and deformed ends of blooms and slabs, and also for dividing slabs into shorter lengths for rerolling.

**Pendulum shears:** Shears, coupled close to a stand, with blades supported in a frame free to move in pendulum fashion are used to cut moving stock, such as deformed back-ends disappearing into the following stand.

**Flying shears:** All the shears that cut moving stock could be termed flying shears, but the term is particularly used to describe the shears following continuous billet mills where stock must be divided at the emerging speed (about 600 ft/min) into lengths of 30–40 ft.

**Crop and cobble shears:** In rolling mills, crop shears are located ahead of repeating trains to remove the deformed or split front ends of stock after roughing. They are usually arranged to remove the first few inches of the stock, but they can also be set in continuous motion to divide stock into short lengths for clearance when the front end has cobbled further down the train.

**Snap shears:** Automatic repeaters are frequently equipped with snap shears which are pneumatically operated to snap closed and stay closed until reset. They are useful for taking back end samples of repeated stock or for preventing the remaining stock feeding a cobble further down the train.

#### 2.3.4 Mill motors and auxiliary drives

Rolling is a continuous process and main mill stand drive motors are exposed to high stresses. Any unscheduled stoppage or failure of equipment and drive leads to significant loss of energy, production, and time. Therefore the drive system for main and auxiliary equipment is one of the critical utilities to undertake periodic operational and maintenance practices. Drive used for these are known as primary auxiliary drives. Secondary auxiliary drives are used for



Mill motors and auxiliary drives

driving fans (furnace combustion system), cooling water pumps, and lubrication system. In multi-stand continuous hot rolling mill, the power and speed of motors must be selected to suit the rolling schedule.

The motors used in rolling mills can be broadly classified into two types, AC motors and DC motors. AC motors are generally used where the stand is to operate at constant speed in one direction, whereas for variable speeds and reversible drives, DC motors are generally used. AC motors used are further classified into (i) synchronous, (ii) squirrel cage and (iii) wound rotor motors.

Similarly, DC motors can be classified into three categories (i) shunt wound, (ii) series wound and (iii) compound wound motors. It should be noted that each of these motors has characteristics that make it suitable for a specific application. The cost of each type is also different and is one of the main factors determining the type to be used.

## 2.3.5 Centralized oil lubrication system

The centralized oil lubrication system helps in automatic lubrication of gears of gear box, pinion box, etc. The lubricating oil is filtered, cooled, and re-circulated in a closed loop.

## 2.3.6 Cooling water system

Cooling water system helps in cooling of mill stand rolls, bearings, etc. The water is cleaned, cooled to ambient temperature and re-circulated in a closed loop.

## 2.3.7 Power supply, distribution, instrumentation, and control system

- The mill's electrical power supply and distribution system mainly includes transformers circuit breakers, high tension capacitor banks, and control panels.
- Variable Voltage Variable Frequency (VVVF) drives for regulating the speed of AC motors particularly in finishing mills is the latest trend.
- PC-PLC instrumentation and control system for automation of front and end cropping shears, TMT water-cooling system, flying shear, etc. with valve actuators.





# Energy Performance and Indicators

Indonesia ranks 21<sup>st</sup> in primary energy consumption<sup>6</sup> at the global level. The consumption of final energy<sup>7</sup> for period 1971 to 2012 witnessed significant growth, i.e., about 24 times

from 6.78 Mtoe in 1971 to 162.0 Mtoe, an annual average growth of 8.05%. In 1971, industry sector contributed about 26% of the final energy consumption and ranked three after transport and residential. However, the final energy consumption during the year 2012 was dominated by industrial sector [29.9%], followed by households [28.5%], and transportation



Share of energy consumption by different sub-sectors

[26.8%]. The change in consumption was attributed to government efforts encouraging development of large industries in order to support the growing economy.



Fuel types used in industry sub-sector

The breakup of final energy usage in industrial sector shows that electricity accounts for about 10.8% (2012) of primary energy consumption. The total energy consumption by steel rolling sub-sector (2013) is estimated to be 385,000 toe based on the energy and production profile collected during the detailed assessment study.

The GHG emissions<sup>8</sup> of the country were reported to be 490 million tonne of  $CO_2$  (MtCO<sub>2</sub>) and the emission by steel rolling industry was about 1.81 million tonnes of  $CO_2$ .

#### 3.1 SPECIFIC ENERGY CONSUMPTION

The primary energy sources used in hot rolling mills may be categorized into two parts, the first part includes the energy used for rising the temperature of the feed to desired value (generally 1150 – 1300 °C) i.e., reheating furnace and the other part is the energy required for formation and shaping of hot product. Most of the reheating furnaces in the country operate on natural gas, whereas electricity is the primary energy source for milling and auxiliary operations. Some of the units also use liquefied petroleum gas (LPG) or high speed diesel (HSD) to cater to backup power requirements. The consumption of LPG and HSD are generally insignificant in steel rolling sector.

Specific energy consumption is the term used for evaluation of the performance of rolling mill. To assess the performance of different operations of a steel rolling mill, SEC (energy input per tonne of product) is divided into two parts. The first is the 'specific thermal energy consumption' (NG, LPG, oil and coal) which may be defined as the thermal energy used to increase the temperature of metal (GJ per tonne of product). The second part is the energy used in milling and other auxiliaries (including the auxiliaries of reheating furnace) associated with the process i.e. 'specific electricity consumption' (kWh per tonne of product).

#### 3.1.1 Specific thermal energy consumption

The reheating furnace is the primary consumer of thermal energy. The specific thermal energy consumption of furnaces of different types and capacities were analyzed to prepare a baseline and assess the potential for technology upgradation and energy efficiency

improvements. The average SEC (thermal) of the sample furnaces was estimated to be 1.76 GJ per tonne of product. A wide variation in the SEC (thermal) was observed, which is mainly attributed to the age of the furnace, technology employed, and utilization. SEC capacity (thermal) of the furnaces (3, 4)



PH – Pusher Hearth, WB – Walking Beam

and 5) was found to be lower than the average SEC, which is mainly due to age of furnaces. These furnaces are comparatively new and have been equipped with better control and waste heat recovery system. The furnace – 6 was commissioned in the year 2012; however, the SEC was found to be higher because of the poor capacity utilization (about 30%) and absence of the waste heat recovery system.

## 3.1.2 Specific electrical energy consumption

The rolling mill and associated axillaries of the milling unit have energy intensive equipment, and consume large amounts of electrical energy. In rolling mill, the largest consumption of electricity is bar mill. The



SEC (electrical) PR – Plain Round, TB – TMT Bar, SS – Special Section

specific energy consumption is dependent on diameter/dimensions of the final product. The lesser the diameter, more is the power consumption and vice-versa. The specific electrical energy consumption of rolling mill (of different product types and dimensions) was analyzed to prepare baseline and improve the SEC. The average SEC (electrical) of the sample mills was estimated to be 125 kWh per tonne of product (1.4 GJ per tonne).

#### 3.1.3 Specific energy consumption (overall)

The overall specific energy consumption of the sample rolling mills shows significant variations. Based on detailed assessment study, the average total primary energy requirement is estimated to be 3.13 GJ per tonne rolled steel (FY 2013–14) for hot rolled product whereas the world average<sup>9</sup> is about 2.20 GJ per tonne. The average



Overall specific energy consumption

greenhouse gas emission for rolled steel is estimated to be 352 kg of CO<sub>2</sub> tonne of product.

## **3.2 HEAT BALANCE OF REHEATING FURNACE**

Heat balance of the reheating furnace is a mean to determine the thermal efficiency of the system and compare the relative heat losses. By making comparison with an identical process, areas of inefficiency can be identified, where a change in operational control or equipment could lead to improvement in thermal efficiency of the furnace.

Heat input	Heat output	
1. Combustion from fuel at regenerative burners	1. Sensible heat in billet	
2. Combustion from fuel at ordinary burner	2. Sensible heat of flue gas from regenerative burners	
3. Preheated air by recuperator	3. Sensible heat of flue gas of ordinary burner	
4. Sensible heat of air inlet	4. Heat loss in wall	
5. Sensible heat of scale formation	5. Heat loss from opening	
	6. Sensible heat into scale	
	7. Other losses	

The assessment of the heat loss profile based on measurements and analysis of the data collected from representative industries. The major heat losses include dry flue gas losses (37–59%) and losses due to hydrogen in fuel (12–15%). The average efficiency of the furnace

is estimated to be 34% (22–46%). The heat losses clearly indicate significant potential to reduce the consumption of energy resources as well as scope to improve the competitiveness of the Indonesian steel sector.

In addition to the reheating furnaces, there are other energy intensive areas that have also shown significant potential for optimization of energy use. These include electrical drives



Heat losses in reheating furnace

associated with mills and utilities, process utilities, (such as compressed air system and process cooling water system) and electrical distribution system.

#### **3.3 ASSESSMENT OF FURNACES**

This section describes the basic methods and techniques used to quantify heat losses from reheating furnace and the methods to conduct performance assessment of typical furnaces. The operators and supervisors may use this methodology to conduct the performance assessment of the furnace periodically. The performance assessment of furnace and associated equipment should be conducted at normal plant load operation. Ideally, all heat added to the furnaces should be used to heat the load or stock. In practice, however, a lot of heat is lost in several ways.



Heat losses in reheating furnace

Solution Flue gas losses: Part of the heat remains in the combusted gases inside the furnace. This loss is also called flue gas loss or stack loss.

Some moisture in fuel: The fuel usually contains some moisture and some of the heat input is used to evaporate the moisture inside the furnace.

Hydrogen in fuel which results in loss due to formation of water.

Solution of the second second

Surface skin/surface losses: Heat is conducted through the roof, floor, and walls and emitted to ambient air once it reaches the furnace skin or surface.

There are a number of other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include the following:

**Stored heat losses:** When the furnace is started, the furnace structure and insulation are also heated up. This heat leaves the structure when the furnace is shut down. Therefore, this type of heat loss increases with the number of times the furnace is turned on and off.

**Material handling losses:** The equipment used to move the stock through the furnace, such as conveyor belts, walking beams, bogies, etc. also absorb heat. Every time equipment leaves the furnace they lose the heat absorbed. Therefore, the heat loss increases with the mass and type of equipment and the frequency by which they enter and leave the furnace.

**Cooling media losses:** Water and air are used to cool down equipment, bearing and rolls, but heat is lost because these media absorb heat.

**Incomplete combustion losses:** Heat is lost in case the combustion is incomplete, resulting in unburnt fuel or particles, leading to loss in potential heat available in fuel.

**Loss due to formation of scales**: The scale formed on heat transfer surfaces resist and reduce the effective heat transfer.

Furnace efficiency is calculated after subtracting the various heat losses from total heat input. In order to find out furnace efficiency using the indirect method, various operating parameters must be measured, such as fuel consumption rate, material output, excess air quantity (flue gas analysis), temperature of flue gas, temperature of furnace at various zones, and others. Data for

some of these parameters can be obtained from production records while others must be measured with special monitoring instruments.

Parameters	Preferred sample points	Instruments required
Flue gas analysis – 1 (percentage $O_2$ , CO and temperature)	Before recuperator/Air preheater	Flue gas analyzer
Flue gas analysis – 2 (percentage $O_2$ , CO and temperature)	After recuperator/Air pre heater	Flue gas analyzer
Furnace hearth pressure in heating zone	Near charging end and side wall over the hearth	Low pressure ring gauge
Furnace soaking zone temperature	Soaking zone and side wall	Digital temperature indicator with Pt/ Pt-Rh thermocouple
Billet temperature	_	Infrared pyrometer or optical pyrometer



Flue gas analyzer



Temperature indicator



IR Temperature indicator



## **3.4 FURNACE PERFORMANCE CALCULATION**

The efficiency of a furnace increases when the percentage of heat that is transferred to the feedstock inside the furnace increases. The efficiency of the furnace can be calculated by two methods, (1) direct method and (2) indirect method; both are explained in the following sections. The tools used to calculate the performance of a reheating furnaces using direct and indirect method is given below.

## 3.4.1 Direct method

The efficiency of a furnace can be determined by the ratio of the amount heat absorbed by the feedstock and the total amount of the energy supplied.

Thermal Efficiency of Reheating Furnace =  $\frac{Q = m \times C_P (t_1 - t_2)}{Quantity of fuel X Calorific value of fuel}$ 

Where,

Q = Quantity of heat of stock (kCal)

m = Weight of the stock (kg)

C<sub>p</sub> = Specific heat of stock (kCal/kg °C)

t<sub>1</sub> = Final temperature of stock (°C)

t<sub>2</sub> = Initial temperature of stock (°C)

Parameters	Unit	Value
Average fuel consumption	SCM/Hour	1,270
Average rate of production	kg/hour	45,099
Initial temperature of feed	oC	35
Final temperature of billet	oC	1,148
Heat capacity of feed	kCal/kgoC	0.108
Total heat in product	kCal/Hr	5,421,055
Total heat input to furnace	kCal/Hr	11,290,813
Efficiency of furnace	%	48.0

## 3.4.2 Indirect method

The furnace efficiency can also be determined using indirect method. In this, the heat losses are subtracted from the heat supplied to the furnace. The formulae and assumptions to be considered to estimate the efficiency by indirect method is provided below.

3.4.2.1 Heat loss in flue gas

Excess air (EA) =  $\%O_2 / (21 - \%O_2)$ Mass of air supplied =  $(1 + EA/100) \times$  Theoretical air

% Heat loss in flue gas =  $\frac{m \times C_p \times \Delta T \times 100}{GCV \text{ of fuel}}$ 



Where,

m = Weight of flue gas (air + fuel) (kg)

C<sub>p</sub> = Specific heat of flue gases (kcal/kg °C)

 $\Delta T$  = Temperature difference between flue gas and ambient (°C)

3.4.2.2 Heat loss from moisture in fuel

% Heat loss from moisture in fuel =  $\frac{M x \{584 + C_p (T_f - T_{amb})\} x 100}{GCV \text{ of fuel}}$ 

Where,

M = kg of moisture in 1 kg of fuel oil

 $T_f = Flue gas temperature (°C)$ 

T<sub>amb</sub> = Ambient temperature (°C)

GCV = Gross Calorific Value of fuel (kCal/kg)

3.4.2.3 Heat loss due to hydrogen in fuel

% Heat loss due to hydrogen in fuel =  $\frac{9 \text{ x H}_2 \text{ x } \{584 + C_p (T_f - T_{amb})\} \text{ x 100}}{\text{GCV of fuel}}$ 

Where,

 $H_2 = kg \text{ of } H_2 \text{ in } 1 \text{ kg of fuel oil}$ 

3.4.2.4 Heat loss due to openings in furnace

% Heat loss from openings in furnace = (Black body radiation factor x emissivity x factor of radiation x area of opening) x 100 Quantity of oil x GCV of oil

The factor of radiation through openings and the black body radiation factor can be obtained from standard graphs. These include the following:

- Factor of radiation
- Black body radiation at furnace temperature (kCal/kg/cm<sup>2</sup>/hr)
- Area of opening (cm<sup>2</sup>)
- Emissivity of the surface



Black body radiation at different temperatures (Source: BEE India)

Radiation factor for heat release through openings relative to perfect black body (Source: BEE India)

#### 3.4.2.5 Heat loss through skin

The quantity of heat loss from surface of furnace body is the summation of natural convection and thermal radiation. This can be calculated from surface temperatures of furnace. The temperatures on furnace surface should be measured at as many points as possible and weighted average should be used. If the number of measuring points is

too small, the possibility of error may be large. The quantity of heat release from a reheating furnace is calculated with the following formula:

$$Q = a x (t_1 - t_2)^{5/4} + 4.88E \left[ \left( \frac{t_1 + 273}{100} \right)^4 - \left( \frac{t_2 + 273}{100} \right)^4 \right]$$

Where,

- Q = Quantity of heat release  $(kCal/W/m^2)$
- a = Factor regarding direction of the surface of natural convection ceiling
- t<sub>1</sub> = Temperature of external wall surface of the furnace (°C)
- t<sub>2</sub> = Temperature of air around the furnace (°C)
- E = Emissivity of external wall surface of the furnace



Quantity of heat release at various temperatures (Source: BEE India)

The first term of the formula represents the quantity of heat released by natural convection and the second term represents the quantity of heat released by radiation. The total heat loss is derived by multiplying the heat loss (kCal/m<sup>2</sup>/hr) with total surface area.

% Heat loss through furnace skin = Quantity of fuel X GCV of fuel

Total heat losses will be the sum of the losses calculated using the described method and formulae and the furnace efficiency by indirect method can be summarized as follows:

Furnace Efficiency (%) = 100 - Total losses

Heat loss (%)	Value
Sensible Heat Loss in Flue Gas	37.4
Loss Due to Evaporation of Moisture in Fuel	0.1
Loss Due to Evaporation of Water Formed due to Hydrogen in Fuel	12.7
Heat Loss due to Openings	0.1
Radiation Heat Loss from Surface of Furnace	3.6
Total heat losses	53.8
Efficiency of the furnace	46.2

The critical factors, which affect the efficiency of a reheating furnace, are listed below.

- Under loading of furnace due to poor hearth loading and improper production scheduling
- Improper design
- Use of inefficient burner system
- Insufficient draft/chimney
- Absence of waste heat recovery system
- Absence of instruments and controls
- Improper operation and maintenance
- Dry flue gas loss
- Improper insulation/refractories

## **Energy Conservation and Technology Options**



This section provides detailed assessment of appropriate energy efficient (EE) technologies that would lead to improvement in the performance of reheating furnaces and other associated equipment in steel rolling industries. In the rolling process, reheating furnaces account for about 60–65% of the total primary energy consumption in the form of thermal energy. Hence the reheating furnaces are one of the focus areas for application of new and efficient technologies. The efficiency of reheating furnaces depends not only on its design parameters but also on operation and requirements for uniform heating.

## 4.1 REHEATING FURNACE

The basic concepts of energy conservation in reheating furnaces include optimization of combustion, rationalization of heating and cooling, minimization of structural heat losses, and recovery of waste heat in flue gases.



Characteristic diagram of energy optimization, maintenance practices, and control system

The following section provides an overview of technologies that can play a vital role to optimize energy consumption, temperature profile and other operational aspects to improve the quality of the end product.

## 4.1.1 Regenerative burner system

In order to mill steel bar/billet into steel rod, the material is heated up to 1,250 °C. In most of the reheating furnaces in the country, centralized recuperators (to preheat the combustion air) are in use to recover the waste heat from flue gases. The preheating temperature of the combustion air was observed to be 50% (maximum up to 425 °C) of the flue gas temperature and is always less than the flue gas exit temperature to the environment. The lower rate of

#### ADVANTAGES

Secause of the low temperature flue gases, additional waste heat recovery system is not required

Sequence the two sequences of two sequen

 $\clubsuit$  Reduction in emissions (CO<sub>2</sub> and NOx.).

Selame temperature in chamber of reheating furnaces can be increased

High level heat can be kept in chamber of reheating furnaces

Radiation heat transfer efficiency in furnace chamber can be increased

heat recovery from the flue gases is mainly attributed to limitations of centralized recuperator system, such as material of construction and economic effective area of heat transfer.

The heat loss profile of reheating furnaces shows that the flue gas alone is carrying about 50–60% of the total heat input; there is a huge potential to recover the heat available in flue gas which may be further utilized to preheat the combustion air. The high efficiency regenerative burner is a new approach to minimize the energy used in reheating furnaces having exhaust gas at high temperature during the heating process of steel. The regenerative burner technology may rise the preheat air temperature up to 900–1,000 °C (for 1,250 °C furnace temperature).

Regenerative combustion technology allows regenerator in burners to accomplish heat exchange between flue gas and combustion air and achieve the effects of high thermal

efficiency, reduction in operating cost and low emissions. Regenerator is fabricated using special ceramic material, which is characterized as large surface for heat exchange, better heat conductivity and heat resistance as well as high thermal efficiency. Regenerative burners are installed on both sides of furnace in pairs. For any pair of burners, regenerative



while one burner is in firing mode, the other is absorbing heat from the flue gas. After a fixed time interval, burners are switched so that the firing one changes to absorption mode and vice versa. This cycle is repeated constantly.

The high temperature flue gas flows into the regenerator chamber from top and leaves from the bottom. The heat available is absorbed and stored in regenerator. Therefore, when

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the flue gas leaves from bottom, its temperature reduces significantly. On other hand, opposite side burner is in firing mode. The combustion air enters the regenerator chamber from bottom and leaves from the top. During this process, the regenerator releases heat to preheat the combustion air to a high temperature.

The results from measurements and energy balance analysis indicate that



Effect of air preheating in regenerative burner

regenerative burner system consume energy approximately 30% less than the conventional recuperative system. The cost benefit analysis for typical furnace<sup>10</sup> used in the sample industries shows a simple payback period of about five years (table). The payback period is largely dependent on the capacity of the furnace. The regenerative burner technology has proven significant reduction in operating cost (up to 40–50% of the total input energy) and attractive payback periods.

Parameters	Values
Capacity of furnace (tonne per hour)	120
Fuel used	Natural Gas
Existing energy consumption (GJ per torune of material)	2.4
Potential for reduction in fuel consumption (GJ/tonne of material)	1.17
Approximate benefits (million Indonesia rupiah per year	13,132
Investment for regenerative burner system (million Indonesian rupiah)	53,550
Other associated investment and O&M cost (million Indonesian rupiah)	9,903
Simple payback period (years)	4.8

Note: Payback period was found higher in the selected furnance because of the poor capacity utilization



Investments, O&M, and payback with regenerative burner

#### 4.1.2 Self-recuperative burner system

As discussed in the previous section, there are several limitations of the centralized recuperator system. In order to maximize the heat recovery available in the flue gases, an alternate technology is self-recuperative burner system. This system includes a recuperator

an integral part of the burner, which preheats the incoming combustion air. It uses the waste heat from the flue gases to preheat combustion air. After entering the burner, the combustion air flows into the gap between air guide tube and inside the recuperator towards burner tip. A part of combustion air is fed into the inside of the



burner, where it combusts in the first combustion stage. The rest of the combustion air flows out through the gap between the combustion chamber and the recuperator head at high



Performance of self-recuperative burner

speed before combustion takes place in the second stage, resulting in reduced emissions. The hot flue gases, flowing in the opposite direction, leave the furnace chamber on the outside of the recuperator. Heat exchange takes place between hot flue gases and cold combustion air through the recuperator wall. This mechanism leads to а high air preheat temperatures enhanced thermal and efficiencies. The maximum achievable air preheat temperature in self-recuperative burner system is up to 700°C, depending on the type of

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application. The typical<sup>11</sup> performance indicators and associated parameters for a self-recuperative burner are shown in the table below.

Parameters	Unit - 1	Unit - 2
Capacity of furnace (tonne per hour)	15	120
Fuel used	Natural gas	Natural gas
Existing energy consumption (GJ/tonne of material)	2.18	2.4
Potential for reduction in fuel consumption (GJ/tonne of material	1.09	0.91
Approximate benefits (million Indonesia rupiah per year)	4,100	10,100
Investment for self-recuperative burner system (million Indonesia rupiah)	9,900	35,600
Other associated investment and O&M cost (million Indonesia rupiah)	1,700	5,400
Simple payback period (Years)	2.8	4.0

The cost benefit analysis for typical furnace used in the representative industries as shown in the table indicates a significant energy saving potential by replacing inferior performing centralized recuperator with self-recuperative burner system; whereas Unit - 2 in the table, shows the benefits of self-recuperative burner system in the furnace which does not have waste heat recovery mechanism.

The typical<sup>12</sup> furnace capacity, estimated investment towards the self-recuperative burner system (equipment and installation costs), operation & maintenance cost and the envisaged cost benefits are shown in figure. As shown, the



Investments, O&M, and payback with self-recuperative burner

payback period is largely dependent on the capacity of the furnace. The suggested burner technology has proven significant reduction in operating cost (up to 50% of the total input energy) and attractive payback periods.

## 4.1.3 Oxy-fuel combustion system

Combustion is a chemical process in which a substance (fuel) reacts rapidly with oxygen (oxidizer) and releases heat. The fuel can be a solid, liquid or gas. Combustion is all about fuel, oxygen, and ignition. Air contains only 21% oxygen, the remaining 79% is nitrogen. In combustion processes, nitrogen does not take part in the combustion, but has to be heated up, consuming unnecessary additional energy. Oxy-fuel combustion refers to the practice of replacement of ambient air as the source of oxidizer for combustion with industrial grade oxygen (typical purity 99.5%, maximum moisture up to 50 ppm). In this system, there is no requirement for large burners or combustion air ducts, often requiring electrical

blowers. Oxy-fuel burners are compact and easy to retrofit in an existing furnace, either for boosting or for full 100% oxy-fuel application.

The advantage of replacing air with industrial grade oxygen is the elimination of nitrogen ballast. Reduction of nitrogen combustion in allows for higher flame temperature and combustion efficiency as lower combustion gas volume reduces the amount of heat taken from the flame and lost to the exhaust. The benefits of using oxy-fuel as compared to air-fuel combustion are as follows:



Energy saving potential with oxy-fuel burner

- Reduced energy consumption and emissions
- Increased heating rate resulting in higher production (with no increase in furnace temperature set point)
- Reduced scale formation

In addition to these benefits, oxy-fuel combustion may result in lower capital investment (*however an oxygen generator must be installed to supply oxygen*) as compared to other combustion technologies of improving efficiency, such as recuperator or emissions control equipment etc. Also, in some cases, conversion to oxy-fuel combustion has resulted in less scale loss due to better control and shorter heating time.

Some of the studies<sup>13</sup> have shown that in a reheating furnace maintained at about 1,150 °C, the heat energy required for the furnace load of 1.06 GJ is about 2.58 GJ in the case of conventional burner system. However, similar heat requirements can be achieved



by supplying only 1.58 GJ of heat to the furnace using oxy-fuel burner system. This shows that there is a significant potential for reduction in total heat requirement up to 40% by replacement of conventional burner system with oxy-fuel burner system.

Heat requirement: Oxy-fuel burner vs conventional burner

#### 4.1.4 Top-and-Bottom firing system

In conventional pusher type reheating furnaces, burners are located at the top, which is more suitable for feedstock having small cross sections whereas to maintain the uniform temperature in feedstock with higher cross sections, top firing arrangement may result in

improper heating and soaking. This burner arrangement may lead to higher retention time, low productivity as well as higher energy consumption and less yield. The top-and-bottom firing arrangement provides heat input into the furnace from both ends, creating uniformity of heating of feed stock. Some of the advantages of top and bottom firing are:



• Faster heating of feedstock

Top-and-Bottom firing system

- Lower temperature differences within feedstock and reduced residence time
- Lower scale loses thus improved yield
- Reduced specific energy consumption and low emissions

#### 4.1.5 Hot charging of continuous cast billet

Almost all the rolling mills in the country have the feedstock charged at ambient temperature. Some of the reasons why these mills are not using the hot charge material include (i) improper layout of melting shop and rolling shop, (ii) processing of imported material, and (iii) lower rolling capacities. Hot charging is the process of heating slabs prior to charging them into the reheating furnace of the hot mill. Charging slabs at elevated temperatures into the reheating furnace of the hot rolling mill will save substantial energy as differential temperature of the charge will be significant than the existing practices. The higher charged temperature requires lower heat input in furnace resulting in energy savings. In addition, hot charging mechanism improves the material quality, reduces material losses, enhances productivity<sup>14</sup> (up to 6%) and may reduce slab stocking.

The layout of the plant will influence the feasibility of hot charging because the caster and reheating furnace should be located in proximity to one another to avoid a long, hot connection pathway between them. However, even if a facility would prefer to adopt hot charge, the ability to do so is limited. When the melt shop or the rolling mill has services interrupted, the entire facility operations are disrupted if there is no longer a break period between the melting and rolling operations. This can offset the advantages of energy savings.



Hot charging and conventional charging layout

Actual energy savings with hot charging is highly dependent on plant layout and capacities; however, some of the success stories have shown the potential energy savings up to 0.06 GJ per tonne of hot charged steel. The estimated investments are approximately 0.25 million IDR per tonne of material or higher depending on the plant layout and distance between the melt shop and rolling section.

#### FACTS

<sup>t</sup>→ Hot charging has been adopted by some steel makers with the use of the developed techniques for preventing temperature drop in feedstock by continuous casting, heat control techniques, and perfect conveying technology.

 $\stackrel{\text{ts}}{\Rightarrow}$  In Japan, 3 – 4 steel making facilities are using hot charging even though melt shop and rolling section are separated by about 300 meters or more.

#### 4.1.6 Walking beam furnace

The heating strategies have major influence on both the quality of reheated feed and the amount of fuel used in the reheating. A traditional, non-optimized heating system may seem sufficient under steady state conditions, but does not provide optimal quality and cost performance during interruption in process, variations in product grades, dimensions and targeted dropout temperature. A walking beam furnace represents the state-of-the-art of efficient reheating furnaces. The basic operating principle of these furnaces is given below.

- Feedstock is placed on stationary ridges
- Walking beams are raised from the bottom to raise feedstock
- Walking beams with the feedstock are moved forward



Walking beam furnace

- Walking beams are lowered at end of the furnace to place stock on stationary ridges
- Feedstock is removed from furnace and walking beams return to furnace entrance

Walking beam furnace systems are capable of processing both symmetrical and nonsymmetrical parts and can have capacities up to 350 tonne per hour. Temperatures in walking beam furnaces were limited to 1,000 °C but existing furnaces are able to reach 1,100–1,150 °C. Other advantages of the walking beam furnace are as follows.

- Overcomes many of the problems associated with pusher hearth furnaces, i.e., skid marks, stock pile-ups, charge and discharge.
- Possible to heat bottom face of the stock resulting in shorter stock heating times and furnace lengths and thus better control of heating rates, uniform stock discharge temperatures, and operational flexibility.

In some of the implementations, substantial savings in fuel and electricity consumptions were realized by installing a walking beam furnace and employing stateof-the-art combustion control system.

WCI Steel (USA) had installed a walking beam furnace along with state-of-the-art combustion control system. The use of walking beam furnace has resulted in a reduction in electricity usage by 25% per tonne of production and overall 37.5% reduction in fuel consumption per tonne produced compared to pusher-type furnaces.

(Source: WCI Steel, Inc. \$36 Million Walking Beam Slab Reheat Furnace Project)

#### 4.1.7 Oxygen level control and VSDs on combustion fans

More the air is used to burn the fuel, more is the heat wasted in heating air. Air, slightly in excess of ideal stoichiometric (or theoretical) fuel to air ratio is required for complete combustion and to reduce NOx emissions;



Excess air vs dry flue gas loss

it is dependent on the type of fuel. However, excess air beyond the optimum range (*an efficient natural gas burner however requires* 2–3% *excess oxygen, or* 10–15% *excess air in the flue gas, to burn fuel without forming carbon monoxide*) may substantially decrease combustion efficiency as it leads to generation of excessive waste gases. The effect of excess air level and flue gas temperature on dry flue gas losses is shown in the graph (Source: Detailed field *assessment studies in reheating furnaces in Indonesia, UNEP* 2014).

Controlling oxygen levels and using Variable Speed Drives (VSDs) on combustion air fans associated with reheating furnaces help in optimizing combustion in the furnace. The use of VSDs on combustion air fans in reheating furnace also helps to control oxygen levels, especially during variation in furnace production rate. The fuel and electricity savings in reheating furnace through optimization of excess air level depend on load factor of the furnace and the control strategies applied. A second



method to control the oxygen levels is to increase oxygen content of the combustion air (the oxygen enrichment technique). The reduction in exhaust gases can lead to substantial amount of fuel savings.

A successful case study<sup>15</sup> shows that implementing a VSD on combustion fan of a walking beam furnace resulted in 48% reduction in the fuel consumption, however energy savings can vary widely depending on specific installations. With a conservative estimate of 10% savings, an energy saving of up to 0.33 GJ per tonne of product may be achieved.

#### 4.1.8 Centralized and high efficiency recuperator

The quantity of heat taken away from a reheating furnace by high temperature flue gases

is quite large. This can be reduced by adopting two methods, one is to reduce the volume of exhaust gas, and the other is to reduce the temperature of exhaust gas. The former is optimization of air-fuel ratio (*section 4.1.7*). The second method is through recovering waste heat available in outgoing flue gas. One of the conventional, economical, and convenient methods is use of centralized recuperator system for preheating of combustion air.

Recuperator is a mechanical device in which heat exchange takes place between the flue gases and the combustion air through metallic or ceramic walls. Ducts or tubes carry the air for combustion for preheating whereas the other side contains the waste heat (flue gas) stream. There are many types



Convection recuperator (tube heat exchanger)

of the waste heat recovery recuperator depending on the application. The most common types of recuperator include metallic radiation recuperator, convection recuperator, hybrid recuperator, and ceramic recuperator.

The most commonly used recuperator in reheating furnace is convection type. Convection recuperator (also referred to as 'flue' or 'canal' recuperator) is tubular heat exchangers that utilize convection heat transfer to preheat combustion air for the purpose of saving fuel. By recovering heat from the hot waste gas exiting the furnace and transferring it to combustion air feeding the burners, fuel usage can be reduced up to 25%. Flue gas temperatures entering convection recuperator are usually in the 800–1,100 °C range and combustion air preheat temperatures are usually in the 425–650 °C range. Some of the other applications of convection recuperator include the following:

- Steel soaking pits
- Steel anneal and pickle lines
- Steel galvanizing lines
- Direct reduced iron furnaces
- Aluminum de-lacquering systems

- Aluminum heat treat furnaces
- Ceramic and refractory kilns
- Thermal oxidizers
- Waste incinerators
- Aluminum melting furnaces

## 4.1.9 Improved insulation and refractories of reheating furnace

The efficiency of a furnace is directly dependent of the method of combustion and heat stored within the furnace structure. Apart from the dry flue gas losses, a substantial amount (3–5%) of heat is also lost from furnace walls and material discharge doors. The heat loss from a reheating furnace structure can be divided into (i) radiation loss through openings and surface of the furnace body, (ii) cooling loss through water cooled skid pipes, (iii) heat accumulation loss to internal insulation and supports composing the furnace body. The heat accumulation loss can be ignored for a continuous operation furnace having minimal change in the operating temperature.

Improvement in the radiation heat loss from furnace surfaces can be achieved by reinforcing its insulation. This includes (i) covering of internal wall surface with ceramic fibre insulation, and (ii) covering external wall surface with ceramic fiber or rock wool insulation.

The temperature gradient i.e., difference between the hot face temperature (*hot face temperature is the temperature of the refractory surface in contact with the flue gas or heated combustion air*) and surface temperature will be a critical factor for reduction in heat loss by reinforcement of insulation. The hot face temperature is used to determine refractory or insulation thickness and heat transmitted. The design temperature is used to specify the service temperature limit of refractory materials.

A case study of heat loss from a furnace wall having standard composition walls of a reheating furnace exclusively made of fired bricks of 460 mm thickness is compared with a



Effect of insulation in a furnace: Heat loss vs surface temperature

furnace wall reinforced with a ceramic fibre of 50 mm thickness on the internal wall surface of the furnace as shown in the figure. Replacing conventional insulating materials with ceramic low thermal mass insulation materials can reduce heat losses through furnace walls. The potential energy savings for insulating a continuous furnace were estimated to range from 2–5%, or approximately 0.16 GJ per tonne of product. However, the capital investment required for reinforcement of insulation may be higher indicating long payback period.

## 4.1.10 Energy efficient reheating furnace (existing furnaces)

The energy efficiency schemes which were discussed and analyzed in previous section are useful for new and retrofitting options in pusher hearth and walking beam furnaces. Some of the schemes are also applicable for batch type reheating and annealing furnaces. The schemes may be appropriately introduced to make the existing furnace 'energy efficient'. An energy efficient furnace mainly comprises improvements or technologies for energy saving and includes the following:

- Enhancement of WHR
- Precise combustion control system
- Optimum furnace pressure mechanism
- Optimum hearth load (increase of the furnace length)
- Improvement of thermal insulation performance



A typical system diagram of an energy efficient reheating furnace with various energy saving schemes is shown below.

Energy efficiency options in existing reheating furnaces Source: Japanese Technologies for Energy Savings/GHG Emissions Reduction: 2008 Revised Edition

Advance WHR system may also include latest technologies, such as regenerative burner, and self-recuperative burner. The energy efficient furnace uses ceramic fibre as furnace wall material, instead of conventional refractory bricks or insulating bricks, resulting in reduced furnace wall loss. The combusted gases at high temperature flow in preheating zone to heat steel products thus by increasing the furnace length; the feed material can be preheated adequately. Also, installation of the combustion control system enables optimum combustion (such as heat pattern control, waste gas  $O_2$  control, furnace pressure control etc.) in conformity with heating requirements. These performances lead to significant reduction in specific fuel consumption of reheating furnaces.

## 4.2 ROLLING MILL

Primarily electrical energy is used to fulfill the size and shaping operation in a rolling mill. The potential energy saving measures applicable for rolling mill section are described below.

## 4.2.1 Energy efficiency drives for rolling mills

Motor systems, which include motor driven units, such as rolling mills, pumps, conveyors, fans, and material handling equipment consume substantial amount of energy used in

steel rolling mills (about 40–45% of the total primary energy consumption of rolling mill). A profile of energy use and associated energy losses for motor systems in iron and steel industry<sup>16</sup> is shown in the figure. About 70% of the energy input to motor-driven systems is lost due to system inefficiencies.

Rolling mill applications demand high precision and high overload ability. They are characterized by quickly changing loads, rapid alternation between driving and braking actions, constant torque in a wide speed range

nd he m nd ly nd

Distribution

Energy use profile of a motor system

and large torque steps. High efficiency drives are the most suitable solutions in metal industries. With the use of accurate controlling and energy efficient drives, the industry can optimize production cost, minimize maintenance, enhance reliability, and ensure

quality of end product. Energy efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy efficient motors can also stay cooler, may help reduce facility heating loads, and have higher service factors, longer bearing life, longer insulation life, and less vibration.

Solution Case studies show that high efficiency motors may save upto 2% of the electricity consumption in rolling mills (de Almeida and Fonsesca, 1997). Although the payback period for energy efficient drives may be longer due to high initial investments, the advantages include low maintenance cost and reduced emissions.

## 4.2.2 Improved lubrication systems (hot strip mill)

High roll loads of steel lead to increased roll wear and high energy consumption. In addition, specific combinations of rolling loads and speeds can cause stands to vibrate which leads



Roll force reduction with improved lubrication system

to a special type of roll banding and increased wear of the equipment. These problems can be addressed by the use of improved lubrication system.

With the installation of improved lubrication package, surface defects and roll wear may be reduced. The application of lubrication media onto the work rolls significantly reduces rolling friction. This solution is typically used in mill stands that are subject to the high thermal stresses. Improved lubrication system having a special nozzle arrangement with an optimized design applies the mixture to the strip, ensuring uniform distribution and minimum consumption of lubricant. The roll-cooling system remains switched on as in normal operation, so there are no scheduling restrictions due to thermal load. Key benefits of the improved lubrication system include:

- Improved surface quality of product
- Extended mill availability
- Increased mill performance
- Extended mill capability
- Lower energy consumption resulting in reduced cost and emissions

Implementation of improved lubrication system in EKO Stahl hot strip mill<sup>17</sup> (Bösler et al., 2003) has shown reduction in specific electricity consumption upto 4 kWh per tonne of product.



An indigenous hot roll lubrication technology was developed by Steel Authority of India Limited (SAIL), and demonstrated in two steel plants in India. The results showed that a reduction in power consumption or rolling load of the order of 15-25% has been achieved. The specific

SEC for strips: Lubricated vs non-lubricated

power consumption profile for different strip thickness before and after implementation is shown in the figure.

A new method for lubricating the work rolls during hot rolling has been successfully tested on the finishing mill of ArcelorMittal Dunkerque<sup>18</sup>. The technology sprays low quantities of non-emulsified natural oil without additives onto the work rolls using air atomization, lowering the rolling forces by up to 20% and increasing efficiency of use of oil by about 50% in comparison with emulsions.

Parameters/ Lubrication method	Stirrer emulsion	Static tube emulsion	Pure oil box	Pure oil air atomized
Lowering of mill force (%)	14.3	10.5	20.5	21.0
Burn out time (roll turns)	7	7	5	5
Oil flow rate ml/min/nozzle	55	10	11	8

Due to the higher lubrication efficiency of atomized pure oil, a significant energy saving and longer campaigns between roll changes can be obtained as well as a lower environmental impact on disposal and lower consumable costs. Another positive effect is that low pressure roll cooling water sprays do not influence the lubrication properties as an oil film initially forms on the dry roll and cannot be washed away.

## 4.2.3 Crop length optimization

Failure to improve yield and quality in steel rolling mills can lead to significant production losses. While the steel mills are grappling with methods to improve the yield which are cost effective, one of the yield improvement methods that is effective, low cost and gives fast return of investment is crop cut optimization. Crop end control technique can reduce crop end losses by over 50% and thus improve the yield of the



Crop length optimization

rolling mill by upto 3%. Laser and non-contact devices are used to measure the position of head, and pattern software (centralized control based system) is used to classify the shape of the system. These systems often include adaptive functions for tuning and input from the operator manual offset. The automation of existing shear would result in reduction in crops up to 100 mm and would require an investment of about 50 million IDR.

## 4.2.4 Use of cast-in-carbide rolls

Cast-in-carbide (CIC) rolls merge excellent pass form wear resistance with strength and toughness in the roll body, which is an optimized combination of cemented carbide and

ductile iron. The composite design of CIC rolls means that cemented carbide takes care of the rolling, while torque transmission is handled by the ductile cast iron. In order to improve productivity, CIC rolls offer two distinct advantages.

- Pass life up to 20 times than conventional cast iron rolls, which heavily influence downtime costs.
- Easy to mount with a safe procedure.

Rolling speed, minimized roll wear, and overall availability are the key factors in improving mill productivity. CIC rolls are one of the appropriate solutions to handle these requirements.



Cast-in-carbide rolls

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Tungsten carbide rolls are produced by a powder metallurgical process. By contrast, steel rolls are produced by traditional casting or forging techniques. Tungsten carbide rolls are actually made of 'cemented carbide', that is, a carbide material (in this case tungsten) and a binding material, such as cobalt metal powder that helps to 'cement' the powder metal together.

The benefits of using tungsten carbide rolls are given below.

 Tungsten carbide rolls can last up to 50 times longer than conventional, hardened steel rolls.

Parameters	Cast iron	Cemented	
	rolls	carbide rolls	
Down time (Hours per year)	450	36	
Lost production (tonne per year)	45,000	3,600	
Extra production (tonne per year)	2.00	> 40,000	

- Increases the tooling life before regrinding, lasting up to 10 times longer than conventional rolls.
- Solves excess wear problems on any roll section of the mill.
- Fewer changeovers due to excessive lower wear on hardened steel rolls.

## 4.2.5 Anti-friction roller bearing

Bearings are at the heart of almost every piece of industrial equipment. Properly maintained, the bearings lead to extended operating life and boost equipment performance. Anti-friction bearings minimize friction by removing any possible sliding between bearing surfaces and replacing all contacts with rolling interfaces. A hydrodynamic or hydrostatic fluid film is used in anti-friction roller bearing to carry loads with reduced friction. It utilizes a separator to space the hardened rolling elements apart. These bearings are more desirable than plain bearing due to their lower friction and reduced lubrication requirement. However, the life of anti-friction bearing is limited by the fatigue life of the material they are made of and the type of lubricant being used. The advantages of the anti-friction roller bearing include lower power consumption, reduced roll jumping, and better product quality.

#### 4.2.6 Computerized roll pass design

Shape rolling is widely used in material processing of structural and mechanical parts as it possesses good mechanical properties and high productivity. However, due to involvement of complicated mechanics in shape rolling, it has made the process design an art of experience. Therefore, it is very common to trust expert decision in process design, particularly for complicated shapes. In general, for simple shapes, empirical relationships using computerized numerical controls (CNC) can considerably reduce such an experience oriented design procedure. The primary objectives and advantages of the roll pass design are:

• Production of correct profile within tolerance limits with good surface finish (free from surface defects).

- Maximum productivity at lowest cost and optimum energy utilization.
- Minimum roll wear and easy working.

#### CHARACTERISTICS OF A GOOD ROLL PASS DESIGN

♦ To ensure the minimum expenses in terms of energy, power, and roll consumption

by To create a simple and convenient work culture at stand, minimizing the manual operation and to introduce the automation of technological process

by To optimize the number of passes required for rolling to reduce the total rolling time cycle, with minimum time spent for changing and adjusting of rolls

## **4.3 OTHER UTILITIES**

#### 4.3.1 Monitoring and control of process cooling water system

The process cooling water systems are key enablers of steel rolling processes. Maximizing cooling system performance serves to realize primary business goals, such as production throughput and yield, energy and water conservation, and environmental compliance. Under inadequate control, the cooling water system can lead to significant difficulty to

the process, resulting in loss of productivity, increased cost of cleaning and protective chemicals, increased energy and maintenance costs and a reduction in service life.

Although regular checks are made to determine water quality compliance with and prescribed operating conditions, these checks can be infrequent enough to allow corrosion, fouling and scaling to get out of control. To avoid issues



Monitoring and control

due to unbalanced process cooling water parameters, the monitoring and control based automation of the process cooling water system is the most appropriate and cost-effective approach, which will enable the following.

- Provide minimum cost of operation for water, chemical, and maintenance
- Ensure optimum and reliable system performance
- Ensure high product quality and reduced forced outage

#### 4.3.2 Energy efficiency in pumps

Pumps are used widely in steel industry to provide cooling and lubrication services, transfer fluids for processing and provide motive force in hydraulic systems. In steel rolling sector, pumps represent 5–10% of the electricity used in utilities. Pump reliability is very important—often critically so. In cooling systems, pump failure can result in equipment overheating and considerable damage in product quality.

Inefficient operation of pumping system can be caused by a number of problems, such as improper pump selection, poor system design, excessive wear-ring clearances, and wasteful flow control practices. Indications of inefficient system operation include high energy costs, excessive noise in the pipes and across valves, and high maintenance

requirements. Each pump has a best efficiency point (BEP) at which its operating efficiency is the highest and its radial bearing loads are lowest (except for pumps with concentric case designs). At its BEP, a pump operates most cost-effectively in terms of both energy efficiency and maintenance. Operating а pump at a point well away from its BEP may accelerate wear in bearings, mechanical seals and other parts. In practice, it is difficult to keep



Best efficiency point in pump operation

a pump operating consistently at this point because systems usually have changing demands. However, keeping a pump operating within a reasonable range of its BEP lowers overall system operating costs.

Another critical criterion to maintain the efficiency of pump is speed. The pump speed is usually an important consideration in a system design. It is perhaps best determined by evaluating the effectiveness of similar pumps in other applications. In the absence of such experience, pump speed can be estimated by using specific speed which can be used in two different references—impeller specific speed and pump suction specific speed.

The energy efficiency methods which can be used to maintain the efficiency in pumps without replacement are given below.

**Impeller trimming:** Impeller trimming refers to the process of machining the diameter of impeller to reduce the energy added to the system fluid. By overly conservative design practices or changes in system loads, it can be a useful correction to pumps that are oversized for their application. The industry may consider trimming of impeller while any of the following conditions occur

of the following conditions occur:

- Many system bypass valves are open, indicating that excess flow is made to system equipment
- High levels of noise or vibration indicate excessive flow
- Excessive throttling is needed to control flow through the system or process
- A pump is operating far from its design point.



Effect of impeller trimming

Trimming an impeller changes its operating efficiency, and the non-linearities of the affinity laws with respect to impeller machining complicate predictions of pump performance. Consequently, impeller diameters are rarely reduced below 70% of their original size.

**Adjustable Speed Drives:** Centrifugal pumps are often operated over a wide range of conditions. For example, many process cooling systems experience variable loads caused by changes in ambient conditions, product shape and size and production demands. To accommodate demand changes, flow can be controlled by any of these four methods—

bypass lines, throttle valves, multiple pump arrangements or pump speed adjustments. The pump characteristics and loss in power due to throttling and bypass mechanism is shown in the figure.



#### Pump characteristic curve

To maintain the desired flow rate efficiently, speed adjustment is the most efficient means of control. Reducing the pump speed means less energy is imparted to the fluid and



less energy needs than the throttling or bypass method. There are two primary ways of reducing the pump speed: using multiple-speed pump motors and using adjustable speed drives (ASDs). The ASDs allow pump speed adjustments to be made over a continuous range, avoiding the need to jump from one to another. ASDs speed control pump speeds using different types of mechanical and electrical systems.



Mechanical ASDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical ASDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs adjust the electrical frequency of the power supplied to a motor to change the speed.



 Using the cooling water flow control system, pump energy savings of upto
5.0 million kWh per year were realized in a steel mill coiling temperature control.

Pump speed adjustments are not appropriate for all systems. However, in applications with high static head, slowing a pump could induce vibrations and create performance problems that are similar to those found when a pump operates against its shutoff head. It is suggested to provide the pump design specifications and operating parameters to the ASD supplier before selection of technology.

**Energy efficient centrifugal pump:** Centrifugal pumps handle high flow rates, provide smooth, non-pulsating delivery, and regulate flow rate over a wide range without



Characteristic curves for centrifugal pumps

damaging the pump. Centrifugal pumps have few moving parts, and hence the wear caused by normal operation is minimal. They are also compact and easily disassembled for maintenance. The design of an efficient pumping system depends on the relationship between fluid flow rate, piping layout, control techniques, and pump selection.
Before selection of a pump, it is necessary to examine its performance curve, which is indicated by a head—flow rate or operating curve. The curve shows the pump capacity (flow rate) against total developed head. It also shows the design efficiency, required input power, and suction head requirements (net positive suction head requirement) over a range of flow rates. Pump curves also indicate pump size and type, operating speed and impeller size. It further shows the best efficiency point (BEP). The pump operates most cost effectively when the operating point is close to the BEP.

To minimize energy consumption, the pump should be selected in such a manner that the system curve intersects the pump curve within 20% of its BEP. The impeller of the pump should be selected in the mid-range; it can be trimmed or replaced to meet higher or lower flow rate as per requirements.

### 4.3.3 Cooling water flow control (hot strip mill)

In hot strip mill, a number of run-out table pumps feed cooling water to the header tank, which supplies laminar flow to the cooling tubes. The constant water level in the header tank produces a constant pressure at the flow control valves and allows desired flow control. If the flow entering the header tank is higher than the required, the surplus water overflows into the scale water pit thus wasting pumping energy.

To recover the waste energy due to overflow of the water, an automatic cooling water flow control system may be installed, which will use the existing control information and predictive information from mill models. This automated flow control unit will regulate the speed of integrated VFD associated with pump set, and operates as follows:

calculate required flow based on logic.

 $\odot$ 



The automation system will Source: TMEIC Corporation Energy Savings

- The controller will receive the required cooling water flow data from feedback system, mill setup, and piece tracking models.
- The controller will predict the quantity of water using the feedbacks and determine the speed of feed pumps.
- To avoid the idle running during a roll change, the run-out table feed pumps will be either stopped or slowed down.

**Energy Conservation and Technology Options** 

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### 4.3.4 Energy efficiency in compressed air system

Compressed air is used widely in steel rolling industry and is often considered the 'fourth utility' at many facilities. It is further extremely inefficient at part load. Improving

and maintaining compressed air system performance requires only addressing not individual components, but also analyzing both the supply and demand sides of the system and how they interact. Various energy saving opportunities optimize to the compressed air use and electricity consumption are as follows:



Supply and demand sides of compressed air system

**Review air demand:** Before taking initiatives to improve the compressed air system, it is necessary to determine the air demand or requirements of the manufacturing facility. To obtain demand profile, the air delivery from compressor section must be measured at various points over a period of time (to take care of load variations). It is also necessary to monitor system pressure and power consumption at the same points and time in order to see how the flow, pressure, and power consumption change over time. This profile should be obtained over a typical production cycle so that demand on compressed air system can be seen at all stages.

The air compressors provided in rolling industries mainly use load/unload mode (online/ offline control) of operation. During unload condition, it keeps the motor running continuously, but unloads the compressor when the discharge pressure is adequate. Unloaded power consumption of air compressor is significant of their full load power demand (screw: 30–40% and reciprocating: 15–20%), while producing no useful compressed air output.

To minimize the electricity consumption during unload, variable speed option is an appropriate solution. VSD enabled compressors should be considered for trim (or swing) duty as they are typically the most efficient control mechanism to cater to partial loads. Capable of supplying a constant pressure through a wide control range, energy consumption and flow of a VSD compressor is almost directly proportional to the speed. This can result in energy savings over comparable fixed speed units when compressors are partially loaded.

**Pressure profile:** Higher the generation pressure of compressed air, higher will be the power consumption. Different tools and process operations require different pressures. Required pressure levels must take into account system losses from dryers, separators, filters, and piping.

### A rule of thumb, for every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow.

There is also another penalty for higher-than-needed pressure. Raising the compressor discharge pressure increases the demand of every unregulated usage, including leaks, and open blowing.

### Set pressure = maximum pressure required at end use + minimum pressure drop

**Compressed air system leaks:** Compressed air leaks can be a significant contributor of wasted energy in a compressed air system, and in some instances lead to productivity losses. It is not unusual to encounter 20–40% of a compressor's output as air leaks in typical industrial facilities. Although leaks can occur in any part of the distribution system, the most common areas/points of leaks include couplings, hoses, tubes, fittings, pipe joints, quick disconnects, filters, regulators, lubricators, condensate traps, valves, flanges, packing, thread sealants, and points of use devices.

Leakage rates are a function of the supply pressure in an uncontrolled system and increase with higher system

Pressure (psig)	Office Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.3	1.2	4.8	19.2	76.7	173
80	0.33	1.3	5.4	21.4	85.7	193
90	0.37	1.5	5.9	23.8	94.8	213
100	0.41	1.6	6.5	26.0	104	234
125	0.49	2.0	7.9	31.6	126	284

pressures. They are also proportional to the square of the orifice diameter (refer table). Proper installation and preventive (detection and repair) maintenance of compressed air distribution network and associated system can reduce leaks to less than 10% of a plant's compressed air generation.

In addition to being a source of wasted energy, leaks can also be reasons to other operating losses. There is a strong 'cause and effect' relationship between the number and magnitude of air leaks with the overall compressed air system pressure. For example, lower air pressure can affect air tools and equipment by reducing the mechanical output and decreasing the productivity.

An ultrasonic leak detector is probably the most appropriate equipment to detect air leakages. An ultrasonic sensor focuses on the ultrasonic elements in the noise. Because ultrasound is a short wave signal, the sound level will be loudest at the leak site. These detectors are generally unaffected by background noises in the audible range because these signals are filtered out.



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### 4.3.6 Energy efficiency in distribution transformers

After transmission and distribution of electrical energy, facility level distribution transformers represent the next highest source of energy losses. Distribution transformers are relatively easy to replace and manage (in comparison with other technologies used in industrial facilities), and the efficiency can be easily measured and sustained. Taking life cycle cost into account, installation of high efficiency transformers is an economically sound investment despite higher initial cost. Other benefits include reduced emissions, improved reliability, and potentially longer service life.

Ultra-high efficiency transformers: Transformers are continuous operating system for any facility and therefore reduction in losses is a matter of importance. The development in transformers in last decade has led to the appearance of ultra-high efficiency transformers, which have lower energy losses as compared to conventional transformers. To reduce the iron losses (no-load losses), following iron core material technologies have been developed.

- High-orientation silicon steel sheet
- Laminated iron core of thinner silicon steel coil material
- Magnetically segmented silicon steel coil sheet
- Amorphous iron cores

With the use of efficient iron core materials, a no-load loss reduces considerably in comparison to transformers using conventional core material. Other advantages of ultrahigh efficiency transformers include no fire risk, no risk of escape of pollutants or fire-hazardous substances, long lifetime, high mechanical strength, and reduced emissions.



Efficiencies of ultra-high efficiency transformers Source: Japanese Technologies for Energy Savings/ GHG Emissions Reduction: 2008 Revised Edition



No-load and load losses in transformers Source: Japanese Technologies for Energy Savings/ GHG Emissions Reduction: 2008 Revised Edition

**Power management system** / transformer quantity controller: There are two types of transformer losses, i.e., no-load loss and load loss (copper loss). The no-load losses are certain amount of losses regardless of the existence of load on the transformer. If there are one or more transformers with same primary and secondary voltage, the total losses may be optimized by shifting the load of low load transformer to other transformer.

To achieve the maximum benefits of parallel transformer system, PLC-based power management system (PMS) may be adopted. The transformer can be operated with highest possible efficiency when the no-load loss and the load loss become equal. Therefore, if

one or more transformers are operated in parallel and if the load is fluctuating, PMS controls the losses by adhering characteristic to efficiency of each transformer and automatically controls the number of transformers and the combination of the transformers required according to the load fluctuation.



Parallel operation of transformers Source: Japanese Technologies for Energy Savings/ GHG Emissions Reduction: 2008 Revised Edition

### 4.3.9 Lighting system

In steel rolling facilities, energy consumption for illumination also has considerable share. Typical method to optimize energy use in lighting may be upgradation of existing system or adoption of new and efficient technologies. The use of automation in the existing facility may save up to 50% of energy use by providing the right amount of light. These control

system can also help to provide safer, more productive work environment. High efficiency lamps and ballasts, new and efficient light technologies (LED, induction lamps, compact fluorescent lamps etc.) and use of reflectors may lead to significant reduction in operational cost.

Product	The initial purchase cost for the lighting system	Beyond first cost, compare performance: service life, lumen maintenance, and color rendering and stability
Energy	Annual operating hours multiplied by electrical cost	Consider product wattages as well as light output & lamp performance
Maintenance	Includes manpower and relamping costs	Longer-life lamps that maintain colour stability and lumen output can reduce maintenance
Disposal	The end-of-life cost, including disposal and recycling of lamps, ballasts and fixtures	Another area where longer-life lamps benefit industrial facility owners, by reducing waste and cost

**Lighting control:** Quality lighting is an important aspect in steel rolling industries, and is often an ignored area. Light control has the ability to regulate the level and quality of light in a given space for specific tasks or situations. The lighting control systems include timerand inverter-based dimmer control systems to optimize the use of daylight operation.

Optimum control of task specific lighting not only enhances the comfort level of work stations but it also helps to save energy by using light when and where it is needed most.

**High efficiency lighting:** Recent technological advancements have introduced a new era of energy efficient lighting products. Replacement of the existing lighting with most

Lamp type	Lumens per watt	Rated life (hours)	Color rendering index, CRI	Color temperature, °K
T8 high-performance fluorescent with electronic ballasts	86 - 96+	24,000 to 42,000+	80 to 85	3,000 to 6,500
T5 with electronic ballasts	86 - 96+	30,000 to 40,000	80 to 85	3,000 to 5,000
T5HO with electronic ballasts	86 - 96+	30,000 to 40,000	80 to 85	2,700 to 5,000
Compact fluorescent lamps (hard-wired)	43 - 71	6,000 to 12,000	80 to 85	2,700 to 5,000
LED replacement lamps	50 - 100+	25,000 to 50,000+	80 to 90+	2,700 to 6,000+
LED, new fixtures	Up to 100+	50,000 to 100,000	80 to 90+	2,700 to 6,000+
Electronic HID	60 - 80	20,000	65 to 90	2,900 to 4,000
Induction (filament less)	60 - 75+	100,000	80 to 90+	3,000 to 4,000+

advanced light sources and fixtures may save upto 50% on lighting energy use, while benefiting from the best in lighting quality. Energy efficient lighting offers additional benefits, such as reduced load on air conditioning and ventilation system, better life and is compatible with advance control and automation.

# 5

# Best Operating Practices and O&M Guidelines



The 'best operating practices' (BOPs) is framed with an objective to support optimizing operating parameters and specific energy consumption close to the design level. Critical

and energy consuming equipment/system/ process are discussed in this chapter. It provides a summary of applicable BOPs which can be followed by the steel rolling industries.

The purpose of this guide is also to provide the Operations and Maintenance (O&M)/plant maintenance team and energy practitioner, with useful information about O&M management, technologies, energy efficiency, and cost-reduction approaches.

The guiding principle of 'preventive' and 'predictive' maintenance is the regular and



systematic application of engineering knowledge and maintenance attention to equipment and facilities to ensure proper functionality, optimize the performance, and reduce the rate of deterioration. It encompasses regular examination, inspection, lubrication, testing and adjustments of equipment without prior knowledge of equipment failure. These maintenance practices also provide framework for all planned maintenance activity, including the generation of planned work orders to correct potential problems identified during the inspections. Adoption of these practices in a rolling industry would lead to a proactive environment, optimizing equipment performance and life.



A total proactive maintenance programme is essential for efficient, reliable, and safe production process. Benefits are direct and substantial, includes the high product quality, long machine life, avoidance of work stoppage, and high safety.

The essential requirements for proactive maintenance practices are:

- Commitment and leadership
- Compliance and discipline
- Process level intervention to perform regular maintenance checks
- Best operational practices must be instituted to enable the facility to achieve an efficient production system to deliver quality and on time product.

### **5.1 REHEATING FURNACES**

Reheating furnaces are important segment in steel rolling mills accounting for about 60–65% of energy consumption. Various operating parameters, such as furnace temperatures, draft, retention time, and material arrangement, etc. may vary with the type of furnaces used for reheating the feedstock. Best operating practices are employed to reduce SEC level of a reheating furnace. The operating parameters of reheating furnace along with associated auxiliaries must be maintained appropriately close to design/ standard values. BOPs have significant influence on energy use and changes in operating practices within the limitations of furnace design and associated equipment may help in reducing specific energy consumption.

Monitoring of operating parameters and periodic maintenance are essential elements for achieving optimum performance and energy use. It is significant to monitor the performance of furnace parameters in order to identify the need for careful attention for maintenance which can help to sustain efficient use of energy. In addition to regular maintenance and fine-tuning/calibration of associated control system, it is also recommended to undertake rigorous monitoring of furnace on a regular basis. The plant may prepare schedule for examining the set points and calibration of the furnace control system as well as the auxiliaries. The recommended period for the calibration is generally 6–12 months depending on the sensitivity of the system/sensors used and the level of the periodic maintenance schedule adopted. Such type of practices would help operator/supervisor to analyze the specific energy use and also indicate the deteriorations or improvements in performance. This section provides the O&M practices essential to be followed and BOPs that are applicable for different types of reheating furnaces.

### 5.1.1 Air-to-fuel ratio

A ratio control technique/practice can play an important role in optimum and profitable operation of reheating furnaces and similar processes. The air-to-fuel ratio in the combustion zone directly impacts fuel combustion efficiency and emissions. A requirement for ratio control technique implementation is that both the fuel supply rate and combustion air flow rate are measured and available as process variable indicators. A typical air to fuel ratio control system is shown here.

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Typical air-to-fuel control system Source: Japanese Technologies for Energy Savings/GHG Emissions Reduction: 2008 Revised Edition

In the combustion process, air-to-fuel ratio is generally expressed on a mass basis. The maximum useful heat energy is derived by supplying combustion air (stoichiometric or theoretical) that properly matches with the flow rate of fuel to the burner. The fuel flow rate is adjusted to maintain temperatures in different furnace zones. The combustion air flow rate is simultaneously adjusted by a flow fraction controller to maintain the optimum air-to-fuel ratio. The chemical equation for the combustion of fuel is shown below.

$$\begin{aligned} \text{Fuel} + \text{Air} &= \frac{\text{Useful}}{\text{Heat}} + \text{CO}_2 + \text{H}_2\text{O} + \text{CO} + \frac{\text{Unburned}}{\text{Fuel}} + \frac{\text{Waste Heat}}{\text{in Stack}} \\ \end{aligned}$$

$$\begin{aligned} \text{CO}_2 - \text{Carbon dioxide} \\ \text{CO} &- \text{Carbon monoxide} \\ \text{H}_2\text{O} - \text{Water} \end{aligned}$$

Air is mainly composed of oxygen  $(O_2)$  and nitrogen. Oxygen combines with carbon in the fuel in a highly energetic reaction called combustion and forms carbon dioxide  $(CO_2)$ , which is the common greenhouse gas (GHG) produced from the complete combustion of hydrocarbon fuel. Water vapour is also a normal product of hydrocarbon combustion.

The relationship between the air-to-fuel ratio and wasted heat energy provides a basis

for control system design. In most of the cases, real combustion processes have inadequate mixing of air with fuel. Also, the gases tend to flow so quickly that the air and fuel mix have limited contact time in the combustion zone. As such, if air is fed in exact theoretical or stoichiometric proportion to the fuel, it will still lead to incomplete combustion. Automatic burner assembly generally performs in a manner similar to the graph. The cost associated with operating at increased air-to-fuel ratio is the energy wasted in heating additional air volume. Yet,



Flue gas constituents

if the air-to-fuel ratio is decreased, losses due to incomplete combustion and emission will increase rapidly.

### TOO LITTLE AIR INCREASES POLLUTION AND WASTES FUEL

<sup>th</sup> If the air-to-fuel ratio is too small, there will not be enough oxygen available to completely convert the hydrocarbon fuel to carbon dioxide and water. Too small air-tofuel ratio leads to incomplete combustion of fuel. As the availability of oxygen decreases, noxious exhaust gases including carbon monoxide will be formed first. As the air-tofuel ratio decreases further, partially burned and unburned fuel may appear in the exhaust stack, often revealing itself as smoke and soot.

b Incomplete combustion also means wasting expensive fuel. Fuel that does not burn to provide useful heat energy, including carbon monoxide that could yield energy as it converts to carbon dioxide, literally flows up to exhaust stack as lost profit.

### TOO MUCH AIR WASTES FUEL

<sup>th</sup> The issue that makes operation of a combustion process so interesting is that if feed air to the combustion zone is high (if the air-to-fuel ratio is too high), waste of fuel occurs, though in a wholly different manner. Once enough oxygen is available in the burn zone to complete combustion of fuel, it would have addressed the pollution portion of combustion chemistry equation. However, any air fed to the process above and beyond that amount becomes an additional process load to be heated.

<sup>t</sup>→ As the air-to-fuel ratio increases above the required level for complete combustion, the extra nitrogen and unnecessary oxygen absorb heat energy, decreasing the temperature of flame and gases in combustion zone. As the operating temperature drops, less extraction of useful heat energy occurs for intended applications.

For any particular burner assembly, there is a targeted air-to-fuel ratio to balance competing effects to minimize total losses and thus maximize efficiency. As the graph suggests (*note that there is no scale on the vertical axis*), a gas or liquid fuel burner generally balances losses by operating in the range of 105–120% of the theoretical air (*commonly referred to as operating with* 5–20% excess air).

### 5.1.2 Furnace pressure

Reheating furnaces are characterized by a large number of apertures, for example, raw material charging ports, extraction ports, and cracks in the furnace ceiling and side walls. Flame erupts through these apertures and external air is sucked into the furnace to a greater or lesser degree depending upon the pressure within the furnace.

Furnace draft, or negative pressure, is created in furnaces when high temperature gases are discharged at a level higher than the furnace openings (*commonly known as the chimney effect*). The negative pressure in a furnace that operates at a fixed temperature changes with the heat input rate or mass flow of flue gases moving through the stack. This negative pressure causes ambient air to infiltrate into the furnace. This air is heated to the flue gas temperature before leaving the furnace through the stack, resulting in wastage of

energy and reduced efficiency. The level of air infiltration can be minimized by reducing or eliminating openings and areas of possible air leaks or by controlling pressure in the furnace.

On other hand, the positive pressure levels must be controlled in the reheating furnaces to ensure fuel efficiency, environmental effects, reduced possible structural damage and further to avoid back pressure, which could interfere with the flow of fuel and combustion air. The relationship between internal furnace pressure and heat losses<sup>19</sup> through these apertures is shown in the figure below. Survey Furnace atmosphere depends on feed material compositions and operating parameters.

 $\stackrel{\text{tb}}{\Rightarrow}$  Atmosphere inside furnace would contain gases possessing oxidizing atmosphere, such as O<sub>2</sub>, CO<sub>2</sub>, SO<sub>2</sub>, and water vapour.

 $\stackrel{\text{ts}}{\rightarrow}$  It is necessary to operate the furnace at minimum possible excess air condition (in the range of 105–120% of the theoretical air).

<sup>th</sup> If there is no free oxygen, the furnace atmosphere always contains much of  $CO_2$  and  $SO_2$ , and oxidation is enhanced in the presence of sulphur contents.

### FURNACE DRAFT OPTIMIZATION

Senergy saving: Positive pressure eliminates cold air infiltration, which reduces fuel consumption.

Simproved product quality: Process heating equipment with regulated pressure control will help maintain more uniform temperature in the furnaces and avoid cold and hot spots, which can further improve product quality.

Solution Maintenance savings: Prevents flow of flue gases through cracks and doors in process heating equipment, which can minimize corrosion and crack enlargement.

Semission reduction: Improved combustion control can reduce emissions.



Source: Japanese Technologies for Energy Savings/ GHG Emissions Reduction: 2008 Revised Edition

Furnace controllers pressure regulate and stabilize the pressure in the working chamber of process heating equipment. Pressure controllers use pressure gauge in furnace chamber/ duct and regulate airflow to maintain a slightly positive pressure in the furnace chamber. Airflow can be regulated by varying the speed of fans or adjusting damper settings. Pressure controllers can be either manual or automatic. An operator/ supervisor typically use a dial on a control panel to set the pressure in a

manual system. An automatic system has a feedback loop and continuously monitors and regulates the pressure through an electronic control system.

### 5.1.3 Optimum reheating temperature

While selecting the heating temperature for semi-finished products prior to rolling, attempt should be made to obtain a fine-grained structure in the metal along with the requisite mechanical properties in the rolled product. A reduction of the heating temperature by about 100 °C decreases unit fuel consumption by 9–10%. However, lowering the heating temperature may increase the rolling forces and moments, and hence increase the load on the electric drive motors, i.e., it will have the overall effect of increasing the mechanical

and electrical loads on the main components of the mill, thereby increasing energy consumption and wear of the equipment. Since there mill are many permutations that arise from the combination of rolling equipment, temperature, steel grade, desired end shape, water cooling temperature etc., it is considered difficult to address the specific energy gains that can be made by varying heat levels. As a result, under certain conditions total unit energy consumption may not decrease with a decrease in



Optimum furnace and billet temperature profile

heating temperature (even without allowance for the losses associated with electric power generation). Therefore, any changes to the heating temperature should be first examined using a systems approach.

Type of furnace	Operating temperature (*C)
Slab reheating furnaces	1,200
Rolling mill furnaces	1,200
Bar furnace for sheet mill	800
Bogie type annealing furnaces	650-750

It is necessary to operate the furnace at its optimum temperature to achieve the desired metallurgical properties of the material. Operating at too high temperatures causes heat loss, excessive oxidation, de-carbonization,

and stress on refractories. Automatic control of the furnace temperature is preferred to avoid human error. Operating temperatures of various furnaces are given in the table.

### 5.1.4 Optimum capacity utilization

The capacity utilization (commonly known as 'loading') of a reheating furnace is one of the key factors affecting the furnace efficiency. The loading of a furnace includes preparation of material to feed, amount of material placed in the furnace, arrangement inside the furnace, and the residence time inside the furnace.

### 5.1.4.1 Optimum loading

If the furnace is under loaded, the proportion of heat taken up by the stock is smaller, resulting in a lower efficiency. On the other hand, overloading may lead to the stock which is not heated to the desired temperature within given retention time. The natural tendency of an overloaded furnace is to run colder than optimal, unless the temperature is set artificially high. This causes the burners to operate at higher than normal firing rates, which increases combustion gas volumes. Higher gas flow rates and shorter residence time of gas will lead to poor heat transfer, resulting in higher temperatures of flue gases. Increased volumes of higher temperature flue gases lead to sharply increased heat losses. Overly ambitious production goals might be met, but at the cost of excessive fuel consumption. The optimum loading of the furnace is the amount of charge at which the furnace will operate at maximum thermal efficiency, i.e., the amount of fuel per kg of material is lowest. The optimum load is generally obtained by monitoring and recording of the weight of stock in each hour, the time taken to reach the right temperature and the amount of fuel used. The furnace should be loaded to the optimum load at all times, although in practice this may not always be possible.

### 5.1.4.2 Optimum arrangement of load

The feedstock on the furnace hearth should be arranged in such a manner that:

- ☑ It receives maximum amount of radiation from the hot surfaces of the heating chambers and flames
- ☑ Hot gases are efficiently circulated around the heat receiving surfaces of the materials

Stock should not be placed in the following positions:

- In the direct path of the burners or where impingement flame is likely to occur
- In an area that is likely to cause a blockage or restriction of the flue system of the furnace
- Close to any door openings where cold spots are likely to develop

### 5.1.4.3 Optimum residence time

The retention time of the furnace requires close monitoring of time taken to reach to set temperature and total resident time of feedstock inside the furnace. The optimum residence time of the load when the fuel consumption is kept at a minimum and product quality is

at best of the set temperature, if the load only remains inside the furnace until it has the required physical and metallurgical properties.

Sometimes the charge and production schedule does not correspond with the capacity of the furnace. If this is the case then,

- Load is higher or lower than optimum load.
- ☑ Residence time is longer or shorter than ideal residence time. Excessive residence time will increase oxidation of material surface which can result in increased rejections. The rate of oxidation is dependent upon time, temperature as well as free oxygen content.
- E Temperature is increased to make up for shorter residence time. The higher the working temperature, the higher is the loss per unit of time.

All the mentioned factors may result in fuel wastage and sometimes affect the product quality also. Therefore, coordination between the furnace operator, production and planning personnel is essential. Optimum utilization of furnace can be planned at design stage, by selecting the size and type (batch, continuous) that best matches the production schedule.

### 5.1.5 Summary of operation aspects in reheating furnaces

The following list summarizes the operational aspects that can affect the energy use in the reheating furnaces. This section is not intended to cover all eventualities, but to act as a checklist that highlights the critical points.

### 5.1.5.1 Flue gas characteristics

The optimum excess air level to be maintained for different fuel types and burners/furnaces is given in the table.

Fuel	Type of Furnace or Burners	Excess Air (% by wt.)
Pulverized coal	Eater-cooled (slag-tap/ dry-ash removal)	15-20
	Partially water-cooled (dry-ash removal)	15-40
Coal	Spreader stoker	30-60
	Water-cooler vibrating-grate stokers	30-60
	Chain-grate and traveling-grate stokers	15-50
	Underfeed stoker	20-50
Fuel oil	Oil burners, register type	15-20
	Multi-fuel burners and flat-flame	20-30
Natural gas	High pressure burner	10-20

### 5.1.5.2 Damper position and furnace pressure

Setting of damper position is very important in furnace operation. To maintain optimum furnace pressure, the damper must be gradually opened from close position till the smokes or flames coming out from side window and doors stop. At this position, if

Damper position	Furnace pressure and its effect		
Eully open	<ul> <li>Negative furnace pressure</li> </ul>		
runy open	<ul> <li>Air enters from all openings (i.e. air infiltration)</li> </ul>		
	· Leads to cooling down of furnace or uneven heating		
	<ul> <li>Higher specific energy consumption</li> </ul>		
P. Bardand	Positive pressure		
Pully closed	<ul> <li>Smoke and flames come out of furnace doors</li> </ul>		
	<ul> <li>Damage to furnace refractories and structure</li> </ul>		
	<ul> <li>Increased heat losses through furnace structure</li> </ul>		
	<ul> <li>Slightly positive furnace pressure positive</li> </ul>		
Optimum position	<ul> <li>No air infiltration</li> </ul>		
	Minimum heat losses		

a thread/ light cloth/ fine dust is made to fall near furnace door, it would fly away from the furnace and not inwards. This is the optimum position of a damper.

### CHECK LIST

Scheck the concentration of oxygen in flue gases, which is an indication for excess air level for combustion of fuels. If the level is high, check for air infiltration

Scheck the level of carbon monoxide in flue gases which indicates combustion efficiency or the unburnt that affect thermal efficiency of furnace

Solution State State

b The burners are not over-rated and should be able to operate at low fire condition throughout the production campaign

✤ There is adequate mixing of air and fuel at the burner

Scheck pre-heated air temperature which indicates the condition of recuperator and cleaning requirements.

### 5.2 ROLLING MILL

The rolling mill operation can be divided into following major activities which include raw material preparation, planning of production, rolling mill set-up and operation & maintenance (O&M). The standard operating practices (SOP) applicable for rolling mills are discussed in this section.

### 5.2.1 Rolling supervision and section control

The important aspects that should be considered in rolling supervision include the following:

 Maintain the uniform heating of billets along their length and crosssection; corrective action must be taken in case of nonuniform temperatures observed.



**Uneven Crop Length** 

**Optimum Crop Length** 

• The length of end cuts

i.e., crops must be adjusted to the minimum so that the purpose of cutting the ends to prevent splits is achieved while maintaining the yield to maximum. Optimization of crop length can be achieved through shear automation and would lead to an increase in mill yield upto 3%.

- The root cause of a 'miss-roll' must be attended before starting the rolling process to ensure the proper mill setting and mill available hours.
- The supervisory monitoring should be provided to observe changes in billets/ ingots being rolled. These include the following:
  - Size of rolled product coming out of any pass is larger than normal.
  - EX Billets have any fins or overfilling of pass; each and every pass in rolling operation is important and must deliver exact size of the product. Hence, it is important to ensure no fins formed on the product caused due to overfilling of the pass or flattened sides due to under-filling.
  - Difficulties for intermediate product to enter next pass.
  - ☑ Loose guide or guard; guide rolls should be set at the exact position/width that allows smooth entry without any chance for the feed tilting or hitting the roll pass shoulders
  - ✓ End cuts are clean
  - ✓ Front and back end difference in unit weight is as minimal as possible; profile dimensions of products emerging from roughing, intermediate and finishing mills pass should be measured on a random basis after cooling the products and comparing with requirement.

### 5.2.2 Standard O&M practices

The key components of O&M practices to be adopted for optimum yield and efficient operation of a steel rolling mill include 'preventive' maintenance and 'predictive' maintenance. Preventive maintenance includes oiling and greasing and cleaning whereas the following activities are suggested under the predictive maintenance:

- Visual inspection
- Inspection of bolts for looseness/corrosion and tightening/changing
- Condition monitoring of various critical sections/parts and taking necessary maintenance and repair activities to avoid unscheduled breakdown and enhance reliability:
  - ☑ Monitoring the vibration level of bearings of all rotating equipment like gear box, motors, pinion box
  - Checking the performance of electric motor with respect to current drawn, power consumed, speed, and condition of insulation
  - Proper alignment of all shafts, couplings, bearings. Advance technique of *laser alignment* is available for accurate alignment of all rotating parts/equipment

- ☑ Inspection of belt tension of electrical drives and keeps the appropriate tightness by tightening or changing the belt
- ☑ Periodic testing of lubricant used and use of proper grade of lubricants
- ☑ Use the thermal imager to check all critical parts for overheating due to malfunctioning including motors, bearings, and so on.

### 5.2.3 Preventive maintenance programme

It is essential to develop and implement a preventive maintenance programme for a mill to avoid poor quality and higher unscheduled stoppage problems. The benefits of such programme include quick changeovers, reduced down time and scrap, longer tooling life, and higher quality end product.

Areas	Activities
Lubrication of mill component	<ul> <li>Mills should be lubricated according to a daily or weekly schedule with the frequency (determined by date).</li> <li>Tube, pipe and roll-form mills should be greased according to a schedule based on service time (such as hours).</li> <li>Provide an hour meter on the power side of the mill to count down when the mill is running, not sitting idle.</li> <li>Tailor the specific needs based on factors, such as mill configuration and operating environment.</li> <li>Use high-quality, high-temperature grease for lubrication. Also, high quality oil is recommended for those applications requiring oil, such as gear boxes and oilers.</li> <li>Be sure all grease fittings are serviceable and the component or bearing is taking grease. Apply grease sparingly.</li> <li>Mill components should be greased every 100 hours.</li> <li>The list of mill components requiring lubrication are: <ul> <li>Driven stand bearing blocks (inboard and outboard)</li> <li>Side pass rolls</li> <li>Entry guide, seam guide, Turks head</li> <li>Drive shaft universals joints (W style mills)</li> <li>Upper lead screws for top shaft adjustment</li> <li>Coolant tank support rollers</li> <li>Run out table rollers</li> <li>Looper or floop accumulators (including pinch roll drive systems)</li> <li>Payoff reel bearings (greaseable style)</li> <li>Auxiliary equipment</li> </ul> </li> </ul>
Weld rolls	<ul> <li>Two-roll, ERW design welders should be lubricated every 100 hours.</li> <li>Three, four, or five-roll high frequency design welders should be lubricated every 12 hours.</li> </ul>
Gear boxes	<ul> <li>Check oil level every 100 hours.</li> <li>Check for oil leaks every 100 hours (repair any leaks, as needed).</li> <li>Change oil in gear boxes every 2,500 hours.</li> </ul>
Driveline couplings	Grease every 2,500 hours.

Areas	Activities
Cut-off presses	<ul> <li>Grease lube points every 100 hours (lube points are located on the ram swing arms, crankshaft bearings, sections of the accelerator system).</li> <li>Check oil level every 100 hours, or as required, based on usage (some reservoirs might require refilling before 100 hours).</li> <li>Inspect all oil lines to ensure that each line is <ul> <li>Properly connected to its connection point and the connection is not leaking</li> <li>Not plugged and oil is flowing through the line.</li> </ul> </li> </ul>
Hydraulic accelerator systems	<ul> <li>Check oil level every 100 hours.</li> <li>Check for oil leaks every 100 hours.</li> <li>Change oil and filters every 2,500 hours.</li> </ul>
Clean up	<ul> <li>Plant shutdowns are especially good times to clean the entire mill. The mill should be cleaned before any maintenance work is initiated.</li> <li>A detailed inspection of a clean mill will make maintenance work much easier to perform compared to a mill that is not clean before maintenance activities.</li> </ul>

### 5.2.4 Predictive maintenance programme

Predictive maintenance generally known as condition based maintenance and proactive maintenance management is a system of choice for steel industry to achieve higher machine reliability and in turn to be cost competitive in the market. It encompasses instrumentation, engineering, information technology, and management. This programme is a process aimed at detecting a machine condition that will eventually lead to failure and then estimating the amount of time before failure occurs. The following are the test/analysis to be performed to achieve the machines/process feeble point before any fault occurs.

Testing/Analysis	Activities
Vibration test	<ul> <li>Vibration analysis is used primarily with rotating equipment to find problems, such as out-of-balance, looseness, misalignment, gear teeth defects, bearing defects, and system resonance.</li> <li>The root cause (when vibration reaches a certain level than base line) for high vibration should be analyzed and corrective action plan should be drawn.</li> </ul>
Ultrasound	<ul> <li>Use ultrasound primarily for leak detection, particularly for air leaks and detect the cavitation problems in hydraulic pumps.</li> <li>Loose connections in junction boxes and bus bars can also be monitored for the sounds of arcing.</li> </ul>
Oil and wear- particle analysis	<ul> <li>Conduct oil analysis periodically to determine the condition of lubricants</li> <li>Wear-particle analysis to be conducted to determine the condition of equipment based on the concentration of wear particles in the lubricant.</li> </ul>
Thermography	<ul> <li>Thermography is to be used in the process having high temperature applications. This technique should also be used to find electrical components that are hotter than normal. Such a condition usually indicates wear or looseness.</li> <li>Other areas to be covered in predictive maintenance are the monitoring of outdoor wiring, such as overhead transmission lines, which wear due to environmental conditions.</li> </ul>

### **5.3 OTHER UTILITIES**

### 5.3.1 Compressed air system and distribution network

The delivery pressure of compressors is generally 1.1 kg/cm<sup>2</sup> (100 kPa) or higher. Compressed air systems are usually designed to operate within a fixed pressure range and to deliver a volume of air that varies with system demand. Compressed air needs are defined by air quality, quantity, and pressure level required by the end use points. Analyzing needs carefully will ensure that a compressed air system is configured properly.

**Air quality:** The quality of compressed air is determined by dryness and contaminant level permissible at end use and need is to be accomplished using drying and filtering equipment.

Quality	Applications
Plant Air	Air tools, general plant air
Instrument Air	Laboratories, paint spraying, powder coating,
	climate control
Process Air	Food, pharmaceutical, electronics etc.

The higher the quality, the more is the cost to produce air. Typical air quality for various industrial applications is shown in the table. High quality air usually requires additional equipment, which not only increases initial capital investment, but also makes the overall system more expensive to operate in terms of energy consumption and maintenance costs.



**Intake air:** The air entering compressor should be as cool as possible to maintain the specific power consumption at design because cold air is denser than warm air. The colder the incoming air, the more the air molecules there are, so that more air is compressed for each revolution of the air

Effect of intake air temperature on performance

compressor. Also the cooler the incoming air, the lesser the requirements for intercooling and after cooling. The compressor room should also be cleaner and cooler for optimum compressor operation.

### For about 4 °C rise in intake air temperature, the power consumption increases by about 1% for the same air delivery.

**Generation pressure:** System pressure is monitored and control system decreases the compressor output when the pressure reaches a preset level. Compressor output is increased again when the pressure drops to a lower value than the preset. The difference between these two pressure levels is called the control range. Depending on pressure requirement at utilization end, the control range can be anywhere from 0.15–1.5 kg/cm<sup>2</sup>. To optimize the generation cost of the compressed air selection of appropriate capacity and

reduction in delivery pressure are two critical parameters.

A rule of thumb for systems in the 7.0 kg/cm<sup>2</sup> range is for every 0.15 kg/cm<sup>2</sup> increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow.

Raising the compressor discharge pressure increases the demand of every unregulated usage, including leaks, open blowing,



Power consumption vs delivery pressure

etc. Although it varies from plant to plant, unregulated usage is commonly as high as 30–50% of air demand.

**Prevention of leakages:** Compressed air system leak repair programme is very important for maintaining the efficiency, reliability, stability, and cost effectiveness of compressed air system. One of the best practices to avoid the losses due to leakages in compressed air distribution network is leak prevention activities. There are two basic types of leak repair activities, the 'leak tag' and 'seek and repair'. The 'seek and repair' is the simplest method which allows the team to find the leaks and repair them immediately. The 'leak tag' involves the tagging the identified and logging for repair at a later time. Both the activities may be undertaken during the preventive maintenance practices and/or the plant may regularly conduct the leakage test to identify the activities to be performed to repair the leak.

**O&M practices and schedule:** Most of the steel rolling industries in the country use lubricant-injected rotary compressor. The general O&M practices and the schedule to perform the practices in lubricant-injected rotary compressor are given in the table.

Period	Activities
Periodically/ Daily (8 Hours Maximum)	<ul> <li>Monitor all gauges and indicators for normal operation</li> <li>Check lubricant level and top off as necessary</li> <li>Check for lubricant leaks</li> <li>Check for unusual noise or vibration</li> <li>Drain water from air/ lubricant reservoir</li> <li>Drain control line filter.</li> </ul>
Weekly	Check safety valve operation
Monthly	<ul> <li>Service air filter as needed</li> <li>Wipe down entire unit to maintain appearance</li> <li>Check drive motor current at full capacity and design pressure</li> <li>Check operation of all controls</li> <li>Check operation of lubricant scavenger/return system and clean as necessary.</li> </ul>

Period	Activities
Half-yearly or every 1,000 Hours	<ul> <li>Take lubricant sample</li> <li>Change lubricant filter. Manufacturers may recommend changing the lubricant filter within the first week of operation to rid the system of foreign particles which may have been collected during initial assembly and start-up.</li> </ul>
Annually/ Periodically	<ul> <li>Go over unit and check all bolts for tightness</li> <li>Change air/lubricant separator</li> <li>Change air filter</li> <li>Lubricate motors as per manufacturer's instructions</li> <li>Check safety shutdown system. Contact authorized service person.</li> </ul>

### 5.3.2 Motor maintenance

Electric motors fail for a variety of reasons. Certain components of motors degrade with time and operating stress. Electrical insulation weakens over time with exposure to voltage unbalance, over and under-voltage, voltage disturbances, and temperature. Contacts between moving surfaces cause wear. Wear is affected by dirt, moisture, and corrosive fumes and is greatly accelerated when lubricant is misapplied, becomes overheated or contaminated, or is not replaced at regular intervals. When any components are degraded beyond the point of economical repair, the motor's economic life is ended. An electric motor performs efficiently only when it is maintained and used properly. Electric motor efficiencies vary with motor load; the efficiency of constant speed motor decreases as motor load decreases. Below are some general guidelines for efficient operations of electric motors.

**Turn off unneeded motors:** Locate motors that operate needlessly, even for a portion of the time they are on and turn them off. For example, there may be multiple HVAC circulation pumps operating when demand falls, cooling tower fans operating when target temperatures are met, ceiling fans on in unoccupied spaces, exhaust fans operating after ventilation needs are met.

**Sizing motors:** It is necessary to assess the actual loading of existing motors especially when replacing motors. Many motors operate most efficiently in the range of 75–85% of full load rating. Under-sizing or over-sizing will lead to operate at reduced efficiency.

**Replacement of motors versus rewinding:** Instead of rewinding small motors, consider replacement with an energy efficient version. For larger motors, if motor rewinding offers the lowest life-cycle cost, select a rewind facility with high quality standards to ensure that motor efficiency is not adversely affected.

**Preventive and predictive maintenance:** These maintenance procedures involve a sequence of steps to be used to prolong motor life or foresee a motor failure. Predictive maintenance programmes for motors observe the temperatures, vibrations, and other data to determine a time for overhaul or replacement of the motor. Preventive maintenance takes steps to improve motor performance and to extend its life. Common preventive tasks

include routine lubrication, allowing adequate ventilation, and ensuring the motor is not undergoing any type of unbalanced voltage situation etc.

Most motor cores are manufactured from silicon steel or de-carbonized cold-rolled steel, the electrical properties of which do not change measurably with age. However, poor maintenance can cause deterioration in motor efficiency over time and lead to unreliable operation. The general O&M practices and the schedule to perform the practices in electric motor is given in the table.

Period	Activities
Periodically/ Change in duty cycle	<ul> <li>Turn off/sequence unnecessary motors</li> <li>Complete overall visual inspection to be sure all equipment is operating and safety systems are in place</li> <li>Check load conditions to avoid the over or under loading conditions due to change in duty cycle or associated load profile</li> <li>Check for alignment of the motor and the driven equipment. Improper alignment can cause shafts and bearings to wear quickly, resulting in damage to both the motor and the driven equipment</li> </ul>
Weekly	Check condition of motor through temperature or vibration analysis and compare to baseline values
Monthly	<ul> <li>Assure that all bearings are lubricated as per the manufacture's recommendation</li> <li>Check packing for wear and repack as necessary. Consider replacing packing with mechanical seals.</li> <li>Aligning motor coupling allows for efficient torque transfer to pump</li> <li>Check and secure all motor mountings</li> <li>Tighten connection terminals as necessary</li> <li>Remove dust and dirt from motor to facilitate cooling</li> </ul>
Annually/ Periodically	<ul> <li>Ensure that supply wiring and terminal box are properly sized and installed</li> <li>Inspect regularly the connections at the motor and starter to be sure that they are clean and tight</li> <li>The life of the insulation in motor would also be longer; for every 10°C increase in motor operating temperature over the recommended peak, the time before rewinding would be needed is estimated to be halved.</li> <li>Over- or under-voltage situations can shorten the motor life through excessive heat build -up</li> </ul>

### 5.3.3 Cooling towers

Cooling towers are used to cater to the process cooling requirements in steel rolling industries to reject the heat conveyed from rolling and furnace components. Cooling tower maintenance must be an ongoing effort which otherwise may result in system degradation, loss of efficiency and potentially serious health issues. The common causes of poor performance of cooling towers include the following:

**Scale deposits:** Water evaporates from the cooling tower leaves scale deposits on the surface of the fills (heat exchange media). Scale build-up reduces heat transfer area and acts as a barrier to heat transfer from the water to the air.

Clogged spray nozzles: Algae and sediment collected in the water basin as well as excessive

solids in process water can clog the spray nozzles. This causes uneven water distribution over the fill, resulting in uneven airflow through the fill and reduced heat transfer surface area.

**Poor air flow:** Poor air flow through cooling tower reduces heat transfer rate from water to air. It can be caused by debris at the inlets or outlets of the tower or in the fill. Other possible causes of poor air flow includes loose fan and motor mountings, poor motor and fan alignment, poor gear box maintenance, improper fan pitch, damage to fan blades or excessive vibration.

**Poor pump performance:** Proper water flow is important to achieve optimum heat transfer. Loose connections, failing bearings, cavitation, clogged strainers, excessive vibration and non-design operating conditions result in reduced water flow, reduced efficiency and premature equipment failure.

The following are the key O&M practices to be adopted to achieve the efficient operation of cooling towers.

Period	Activities
Daily	<ul> <li>Inspect and remove any accumulated debris before starting the cooling tower.</li> <li>Before starting the fan motor, check the tightness and alignment of drive belts, tightness of mechanical hold-down bolts, oil level in gear reducer drive systems, and alignment of couplings.</li> <li>Blowdown water rate from the cooling tower should be adjusted to maintain between two to four concentrations of total dissolved solids (TDS).</li> </ul>
Monthly	<ul> <li>Check cooling water to avoid formation of algae and increase in TDS level. Use the water treatment chemical addition as recommended by water treatment agency after the testing of the water quality.</li> </ul>
Half yearly	<ul> <li>Balance water flow as per the guidelines provided by the manufacturer to ensure even distribution of hot water to all areas of the fill material. Poorly distributed water may also lead to air bypass through the fill and loss of performance.</li> </ul>
Annually/ Periodically	<ul> <li>To avoid the hotspots, infrared thermal imager should be used for accurate, non-contact assessment of temperatures. It should include key parts, such as bearing and electrical contact assessments on motor and fan systems as well as belt and other drive systems.</li> </ul>

### 5.3.4 Efficient pumping system operation

There are a number of operational measures that can be adopted for proper pump operation and control. The most prevalent O&M recommendations having the greatest energy impacts and life of the system includes the following.

**Eliminating flow control valve:** In conventional general practices, the flow is controlled by closing or opening the discharge valve (this is also known as 'throttling' the valves). While this method reduces the flow, it does not reduce the power consumption, as the total head (static head) increases. This method increases vibration and corrosion and thereby increases maintenance costs of pumps and potentially reduces their lifetime. It is always recommended to use the variable speed tools to control the flow. **Eliminating by-pass control:** The fluid flow can also be regulated by installing a by-pass control system, in which the discharge of the pump is divided into two flows going into two separate pipelines. In other words, part of the fluid is pumped around for no reason, and thus is energy inefficient. Because of this inefficiency, this option should therefore be avoided.

**Impeller trimming:** It is one of the methods to reduce the flow permanently. Changing the impeller diameter gives a proportional change in the impeller's peripheral velocity. Changing the impeller diameter is an energy efficient way to control the pump flow rate. However, this method required some of the preliminary consideration which includes the following:

- Not suitable for varying flow patterns.
- Impeller should not be trimmed by more than 25% of the original impeller size.
- The balance of pump has to be maintained, i.e., the impeller trimming should be the same on all sides.
- Changing the impeller itself is a better option than trimming, which however is expensive and sometimes the next smaller impeller is too small.

The following are the key O&M practices to be adopted to achieve the efficient operation of pumps.

Period	Activities
Daily	<ul> <li>Turn off/sequence unnecessary pumps</li> <li>Complete visual inspection to ensure that all equipment is operating and safety systems are in place</li> </ul>
Monthly	<ul> <li>Assure that all bearings are lubricated as per the manufacturers' recommendation</li> <li>Check packing for wear and repack as necessary. Consider replacement packing with mechanical seals.</li> <li>Aligning the pump/motor coupling allows for efficient torque transfer to the pump</li> <li>Check and secure all pump mountings</li> </ul>
Annually/ Periodically	<ul> <li>Inspect bearings and drive belts for wear. Adjust, repair or replace as necessary</li> <li>Checking the condition of the motor through temperature or vibration analysis assures long life</li> </ul>

### 5.3.5 Illumination system

Illumination system is one of the areas which do not have significant share of energy consumption in steel rolling mills. However, adoption of best practices is required to maintain the better work environment and other safety aspects. Following are the key operation and maintenance practices necessary for efficient and preferred lux level as per task.

• Use of appropriate selection of lamps and luminaire from the time of designing and commissioning.



- Establish schedules for re-lamping, cleaning, recalibration, and reevaluation of the lighting system.
- The ballasts and lighting controls must be specified for factory pre-set to the extent possible.
- Some lighting equipment is designed for specific task which may be sensitive to orientation, such as spotlight, wall washers, and occupancy sensors. A 'pre-application diagram' can be specified or requested prior to installation.

Some maintenance items, such as swirling lamps or inoperable ballasts obviously require immediate attention and repair. To maintain the desired properties of the illumination system, following are the key O&M practices to be adopted.

Period	Activities
Need-based/ One-time analysis	<ul> <li>Identify areas where day lighting controls could be used</li> <li>Identify areas where local automatic controls could be used</li> </ul>
Monthly	<ul> <li>Inspect fixtures to identify inoperable or faulty lamps or ballasts. Burned out lamps may damage ballasts if not replaced.</li> </ul>
Half yearly	<ul> <li>Inspect fixtures and controls to identify excessive dirt, degraded lenses, inoperable or ineffective controls</li> <li>Measure light levels compared to tasks needs in typical spaces. Identify areas for reduction or increase in illuminance</li> </ul>
Annually/ Periodically	<ul> <li>Lamps and fixture reflective surfaces should be cleaned periodically for maximum efficient delivery of light to the space</li> <li>Clean surfaces allow maximum distribution of light within the space</li> <li>For larger facilities consider group re-lamping</li> </ul>

# **Measurement and Verification**

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This chapter provides guidelines and procedures for quantifying savings resulting from energy efficient equipment and improved operation and maintenance projects implemented. This manual is intended for maintenance and production managers and contractors implementing performance contracts at steel rolling facilities.

The measurement and verification (M&V) of energy performance improvements in reheating furnace and associated system of a steel rolling mill are important to determine and report on the results of implemented energy conservation measures or projects. The quality of the information and indicators considered is particularly important for M&V consultants in order to assure the credibility of reported energy performance.

### 6.1 RECOMMENDED M&V FRAMEWORK

The steel rolling sector is highly diverse in terms of size, deployment of technologies, and range of products. Project stakeholders are concerned to have admittance to a variety of information relevant to implemented energy performance improvement measures. However, it is important to enable comparisons between reports of various projects and stakeholders. The suggested minimum or basic M&V reporting measures are provided below with a clarification thereon.

### 6.1.1 Measures to be reported

The first step in the M&V process is to identify and define data to be reported. Key measures to be reported include (1) energy consumption (both pre- and post-energy efficiency project implementation), (2) type of energy consumed, and (3) date and time of energy performance improvement.

The M&V process should allow for values or trends for major but relevant variables. For example, if the baseline is normalized for production, the M&V process may report energy savings despite an absolute increase in energy consumption.

- Energy GJ, toe, kWh (*The unit of measurement is not critical; it can always be converted*).
- Energy forms—natural gas, diesel, furnace oil, solid fuel (biomass, coal, coke etc.), electricity, etc.
- Date and time of event is also one of the critical measures to be captured to estimate the period of evaluation
- Product—bar, rod, sheet, strip, etc.
- Production tonne, kg, number of billet, etc.

Category	Examples
Environmental measures	Air, water, and atmospheric impacts
Social measures	Health benefits
Economic measures	Job creation
Financial measures	Project payback, internal rate-of-return, and return-on- investment
Location, sector, or initiative measures	National, regional, and local impacts
Project stage measures	Funding approval stage, baseline stage /M&V plan and performance
Engineering measures	Energy demand or consumption, technology feasibility, and equipment efficiency

The reporting measures may differ from 'project to project' and with the objective of the implementation. However, the reporting measures can be categorized into different groups to highlight the essential co-benefits as well.

### 6.1.2 Reporting format and period

The reporting format is a key focus in order to ensure that the correct M&V measures are considered during the implementation. The M&V reporting format is based on the period of time in which measurements are considered. The assessment date is defined as the end of the assessment period, which can be considered on a monthly, yearly, year-to-date, or inception-to date basis. In order to develop an acceptable M&V report, evaluator must indicate the most applicable assessment period.

### 6.1.3 Data quality definition

The quality of M&V reporting should maintain the maximum possible accuracy level, reliability, and cost of the system adequate to the stakeholders involved. All reported performance should be conservative in nature (i.e., performance improvements should never be overstated). It will assure all stakeholders that the reported performance is meaningful. Also, the reported performance should always be stated with a statistical relevance. Statistically, performance with '±7.5%' accuracy (or precision) and 80% confidence is recommended, but this may change depending on project specific conditions. (*These statistical measures are directly related to the accuracy of measurements performed and the sample size used*). Following are the main features that must be achieved in order to assure the reported energy performance and the credibility of the reported measures:

- Measurement equipment errors can be due to calibration issues, inexact measurements, or improper meter selection installation or operation.
- Modelling is important to manage due to difficulties in finding mathematical forms that fully account for all variations in energy use. Modelling errors result from inappropriate functional form, improper inclusion of irrelevant variables, or exclusion of relevant variables.
- Sampling can introduce errors that result from the variation in values within the population (biased sampling). Sampling should be performed in either a physical sense by designating a certain number or percentage of physical energy consuming items (e.g., lighting fixtures) or a temporal sense by defining a number of measurements taken per unit of time (e.g., instantaneous measurement only once per hour).
- The interactive effects of actions implemented within the system (measurement) boundary but affecting the larger organizational boundary may not be fully included in a performance computation methodology. For example, changing a lighting system to be more efficient will have a measurable effect on the HVAC system. If the

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measurement boundary encompasses the lighting system only, the effect on the HVAC system must be considered separately.

- Estimation of parameters can also be performed using an M&V retrofit option, rather than measuring all parameters. In other words, performance is determined by partial short-term or continuous energy use measurements, separate from the overall facility energy use (with some stipulations). For example, reheating furnace pre- and postretrofit efficiencies are measured and operating hours are stipulated or based on meetings.
- Uncertainty management refers to managing the data quality to a level where the results would be acceptable. Models may be developed and used to establish optimal measurement samples against the benefits generated.

### 6.1.4 M&V costs

The cost of the system adopted for monitoring and reporting purpose should not be more than the 5–10% of cost incurred towards the technology or retrofit project. M&V costs are usually directly related to the quality and amounts of data available to be used. However, more data does not always imply substantially better results.

Measurement errors and cost limitations may result in uncertainties which need to be considered. With due regards to the M&V objective and the intended use of the results, there is a compromise between uncertainty levels and M&V costs, as decreasing the uncertainty would bring about more measurement requirements with more data, which ultimately results in more expensive M&V. The exact quantification of uncertainty may not be required if achieving it is prohibitively expensive in relation to the value of the energy performance measure.

### 6.2 M&V APPROACH

The level of required M&V along with the associated costs is a deciding factor in which M&V approach to be considered. Some of the known M&V approaches that can be used to develop appropriate methodologies to quantify energy performance with a specific level of certainty and confidence are shown in the table.

M&V approach	Typical performance calculations	Typical applications
Key parameter measurements Performance is determined by partial short-term or continuous field measurements (i.e., metering) of only key parameters of the applicable system energy use, separately from the rest of the facility.	Engineering calculations using short-term or continuous measurements and stipulations.	Oxygen level control and VSDs on combustion fans, installation of automation and control system, improved insulation, crop length optimization etc. is measured and operating hours are stipulated or based on discussions.

M&V approach	Typical performance calculations	Typical applications
All parameter measurements Performance is determined by short-term or continuous field measurement (i.e., metering) of the applicable system energy use, separately from the rest of the facility.	Engineering calculations using short-term or continuous measurements.	Regenerative/ self-recuperative burner, energy efficient drives in rolling mills, lubrication system etc. energy use is determined by short- term or continuous measurements of applicable systems.

These approaches will require different data measurement requirements, which will have different cost implications. In some instances the stakeholders may be willing to accept a higher degree of uncertainty by discounting performance in order to lower the overall cost of M&V. Since conservative reporting is mandated, the only way to accept higher uncertainty is to discount the performance figures. In addition, M&V data quality is highly dependent on measurement timing and measurement duration. The measurement methods that can be used to address any of the M&V approaches can be categorized into the following groups.

Measurement method	Description	Applicable implementations	Type of projects	Typical cost of M&V (% of ECM Costs)
Spot measurement	Measurements are taken when and where appropriate. Operational factors, such as operating hours must be stipulated to arrive at accurate results.	Implementations with a constant load (e.g., lighting, electric motor replacements, and insulation).	Small projects, fast- track projects, projects where installation verification is most important, and projects where stakeholders are willing to assume some performance risk.	1–5%; primarily dependent on the quantity of measurement points and type of measurements required.
Continuous measurement	Measurements are taken continuously throughout the term of the contract at the equipment or system level.	Variable load projects, projects with equipment and systems that can be isolated, or projects where few measurement points are needed (e.g., reheating furnace, process control system, air compressor).	Large projects that can absorb the higher M&V cost, projects with time available for baseline measurement, projects where owner and stakeholders are <i>not</i> willing to assume performance risk, or projects with operational reasons to collect data that were not previously collected (e.g., for improved quality control).	3–10%; primarily dependent on the quantity and type of system(s) to be measured and the duration of metering and analysis.

Measurement method	Description	Applicable implementations	Type of projects	Typical cost of M&V (% of ECM Costs)
Utility bill comparisons	A versatile high-level M&V approach where all ECMs within a metered building or group can be measured and analyzed by using current and historical utility meter/sub-meter data.	Any measures within a metered facility, or group. Individual ECMs implemented cannot be reported on, but reporting can be done at facility level.	Projects where energy performance improvement is projected to be greater than 10–20% of baseline energy use, aggregation of various ECMs within a metered building or group, fast-track projects, or projects where stakeholders are <i>not</i> willing to assume performance risk.	1–10%; primarily dependent on the quantity and complexity of parameters analyzed.

To validate the measurements taken by means of these approaches, periodic audits and data reconciliation must be commenced. These audits can be performed either as a single, post-installation verification, or as a post-installation verification with regular interval verifications following completion of energy efficient retrofitting to evaluate project sustainability and persistence of performance improvements.

Baseline adjustments may also occur due to future changes within the facility and can "re-open" the M&V process, which may result in additional energy performance improvements. To promote transparency, such adjustments should be pre-established and incorporated into the M&V plan whenever possible.

## Annexures



### LIST OF ABBREVIATIONS

AC	Alternating Current
ASD	Adjustable Speed Drives
BEP	Best Efficiency Point
BOP	Best Operating Practices
BPPT	Badan Pengkajian dan Penerapan Teknologi
CIC	Cast-in-carbide
CNC	Computerized numerical controls
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CRC	Cold Rolled Coil
DRI	Direct Reduction of Iron
EA	Excess Air
EE	Energy Efficiency
EET	Energy Efficient Technology
EMS	Environment Management System
ft	feet
FY	Fiscal year
GCV	Gross Calorific Value
GEF	Global Environment Facility
GHG	Greenhouse Gases
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Giga Joule
HBI	Hot Briquette Irons
HRC	Hot Rolled Coil
IDR	Indonesian Rupiah
kg	kilogram
km	kilometre
kVA	kilovott ampere
kW	kilowatts
kWh	kilowatt hour
LPG	Liquefied Petroleum Gas

M&E	Monitoring and Evaluation
M&V	Measurement and Verification
mm	millimetres
MRV	Monitoring, Reporting and Verification
Mol	Ministry of Industry
MT	Million Tonnes
MtCO <sub>2</sub>	Million Tonnes of Carbon Dioxide
Mtoe	Million Tonnes of Oil Equivalent
MtPa	Million Tonnes per Annum
NCCC	National Council on Climate Change, Indonesia
NG	Natural Gas
02	Oxygen
O&M	Operation and Maintenance
PLC	Programmable Logic Controller
PMS	Power Management System
R&D	Research and Development
Rp	Indonesian Rupiah
SCM	Standard Cubic Meter
SEC	Specific Energy Consumption
SO <sub>2</sub>	Sulphur dioxide
SOP	Standard Operating Practices
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
TMT	Thermo-Mechanically Treated
toe	tonnes of oil equivalent
TPH	Tonnes per Hour
TPD	Tonnes per Day
TPY	Tonnes per Year
UNEP	United Nations Environment Programme
VFD	Variable Frequency Drives
VSD	Variable Speed Drives

### **UNIT CONVERSION TABLE**

### Energy

Unit	hp	kW	kJ	Btu	kCal	toe
hp	1.0	0.746	2686	2544	642	6.41 X 10⁵
kW	1.341	1.0	3600	3412	860	8.60 X 10⁵
kJ	3.72 X 10 <sup>-4</sup>	2.78 X 10 <sup>-4</sup>	1.0	0.948	0.239	2.39 X <sup>-8</sup>
Btu	2.19 X 10 <sup>-4</sup>	2.93 X 10 <sup>-4</sup>	1.055	1.0	0.252	2.52 X 10 <sup>-8</sup>
kCal	1.56 X 10 <sup>-3</sup>	1.16 X 10 <sup>.</sup> 3	4.187	3.965	1.0	1.00 X 10 <sup>-7</sup>
toe	15590	11630	4.19 X 10 <sup>7</sup>	3.97 X 107	1.00 X 10 <sup>7</sup>	1.0

### Thermal Conductivity

Unit	Btu/h-ft- F	Btu-in/h-ft <sup>2</sup> - F	W/m– C	kcal/h-m- C
Btu/h-ft-F	1.0	12.0	1.72958	1.48816
Btu in/h-ft <sup>2</sup> -F	0.0833	1.0	0.14413	0.124013
W/m-C	0.57818	6.9381	1.0	0.860422
kcal/h-m-C	0.671971	8.06365	1.16222	1.0

### **Coefficients of Heat Transfer**

Unit	Btu/h-ft <sup>2</sup> - F	W/m²– C	kcal/h–m <sup>2</sup> – C
Btu/h-ft <sup>2</sup> -F	1.0	5.67446	4.88243
W/m <sup>2</sup> -C	0.17623	1.0	0.86042
kcal/h-m <sup>2</sup> -C	0.20482	1.16222	1.0

### Pressure

Unit	pascal (Pa)	pound per square inch (psi)	bar (bar)
pascal (Pa)	1.0	1.45 X 10 <sup>-4</sup>	1.0 X 10 <sup>-5</sup>
pound per square inch (psi)	6894.7	1.0	0.06895
bar (bar)	100000	14.50	1.0

### Lengths

1 ft	= 0.3048 m	= 12 in	$1 \text{ ft}^2$	$= 0.09290 \text{ m}^2$	= 144 in <sup>2</sup>
1 m	= 3.28084 ft	= 39.37008 in	1 m <sup>2</sup>	= 1550 in <sup>2</sup>	= 10.7639 ft <sup>2</sup>

Areas



### **PROJECT PARTNER ORGANIZATIONS**

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