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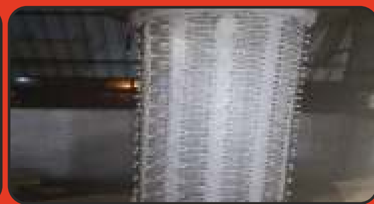

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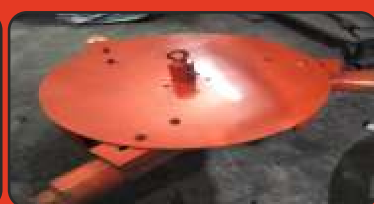

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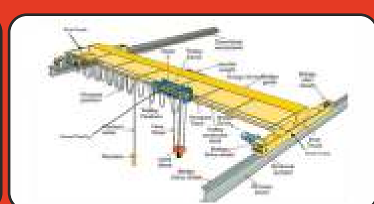

EOT Crane

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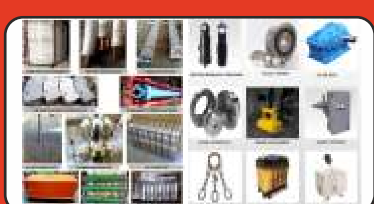
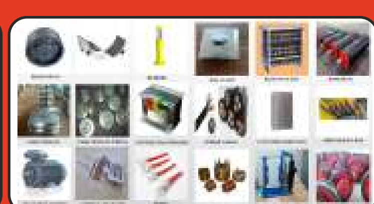

Spare Parts & Accessories

- Spare Parts & Accessories of EOT Cranes
- Spare Parts & Accessories For Induction Furnace

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WASTE HEAT RECOVERY IN STEEL INDUSTRY AND USAGE

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Introduction:

The iron and steel industry is one of the largest energy-consuming sectors globally, requiring substantial energy for steelmaking, shaping, and treating processes. A significant by product of these operations is *waste heat*, which is often released into the atmosphere without being utilized. Waste Heat Recovery Systems (WHRS) present a sustainable solution through the process of *heat integration*—reusing heat energy that would otherwise be lost. By recovering this waste heat, industries can reduce energy costs and CO_2 emissions while improving overall energy efficiency.

Understanding Waste Heat in Steelmaking:

Waste heat is an inevitable outcome of industrial processes, governed by the fundamental laws of thermodynamics. In the iron and steel sector, waste heat sources include:

- **Hot off-gases** from blast furnaces, converters, and other high-temperature units.
- **Cooling water** from processes requiring temperature control.
- **Hot intermediate products** such as those from hot rolling, forging, and other hot-working processes.

Capturing and reusing this energy can significantly improve production efficiency by reducing operational costs and enhancing productivity. Moreover, it provides an opportunity for sustainable growth, as it minimizes emissions and strengthens the industry's competitiveness in global markets.

Environmental and Economic Benefits:

Globally, more than half of the energy consumed is lost as waste heat. In industrial processes, energy losses occur via **conduction**, **convection**, and **radiation** from machinery, products, and thermal operations. Recovering this energy:

- Reduces fuel consumption.
- Lowers CO_2 emissions.
- Improves system efficiency.

According to global studies, energy-efficient processes could reduce carbon emissions by up to 44% by 2035. Common carriers of residual waste heat include:

- **Gaseous streams:** Exhaust gases, flaring gases, and low-quality steam.
- **Liquid streams:** Hot oil and cooling water.
- **Solid materials:** Hot steel and other commodities, with temperatures ranging from 50°C to over 1,000°C.

Iron and Steel Industry's Energy Profile:

Steel production is an energy-intensive process that relies heavily on electricity, coal, natural gas, and other energy sources. In 2018, the global average CO_2 emission per ton of steel produced was approximately 1.85 tons, accounting for about 8% of total global CO_2 emissions. For instance, Tata Steel Netherlands alone contributed 7% to the national CO_2 emissions.

India's steel production follows two major routes:

1. **Primary route**: The Blast Furnace-Basic Oxygen Furnace (BF-BOF) or oxygen-based route, which constitutes 44% of India's total steel production.

2. **Secondary route**: The Electric Arc Furnace (EAF) and Electric Induction Furnace (EIF), together accounting for 55% (28% EAF and 27% EIF) of steel production.

Globally, the production ratio for primary to secondary routes is 72:28, while in China, it is as high as 90:10.

Potential of Waste Heat Recovery in Steelmaking:

Waste heat recovery offers the industry an opportunity to:

- Generate electricity.
- Provide heating and cooling solutions.
- Reduce dependence on conventional energy sources.

The adoption of waste heat recovery technologies has grown significantly in the last decade, with numerous plants being established to harness off-gas energy in steelmaking processes. These systems enhance energy efficiency, promote sustainable practices, and reduce greenhouse gas emissions, thereby contributing to improved air quality.

In other words, Waste Heat Recovery Systems are integral to achieving energy efficiency and sustainability in the iron and steel industry. By effectively utilizing waste heat, industries can address the dual challenges of reducing environmental impact and enhancing economic performance, paving the way for a greener and more competitive future.

Global Focus on Waste Heat Recovery Development

Waste heat is one of the largest recoverable energy losses in modern industrial processes, offering immense potential to mitigate greenhouse gas emissions and address environmental challenges. Recognized as a significant contributor to global warming, waste heat—particularly from energy-intensive sectors such as steel, power generation, industry, transport, and buildings—presents both a problem and an opportunity. Global industry leaders are increasingly focusing on quantifying current and future waste heat emissions and identifying cost-effective strategies to harness this energy. This approach aims to reduce energy costs, improve efficiency, and tackle pressing environmental concerns.

Significance in the Steel Industry

The steel industry is a major source of waste heat emissions, attracting considerable global attention for its potential in energy recovery and reuse. Numerous researchers and industry experts are actively developing innovative theories, methods, and technologies to optimize material and energy flows. Notable advancements include:

- **Quenching technologies** to recover energy from high-temperature materials.
- **Evaporative uptake cooling systems** for enhanced heat recovery.
- **Heat recovery from sinter coolers**, a critical area of focus in energy optimization.

These innovations aim to enhance energy efficiency, reduce waste, and lower greenhouse gas emissions, aligning with global sustainability goals.

Sources of Waste Heat in Steelmaking

Waste heat in the steelmaking process is released as a by-product in various forms, including:

- **Combustion gases**: Discharged into the atmosphere from furnaces and kilns.
- **Heated water**: Released into the environment during cooling processes.
- **Heated products**: Exiting industrial processes at high temperatures.
- **Heat transfer from equipment surfaces**: Radiating from hot machinery and systems.

Global Trends and Developments

The drive to develop waste heat recovery systems has gained momentum worldwide, with industries investing in advanced technologies and infrastructure. International collaborations and scholarly research are paving the way for more efficient recovery methods, ensuring optimal energy use while addressing environmental challenges.

By capitalizing on waste heat recovery, the steel industry can achieve significant cost savings, reduce its carbon footprint, and contribute to a sustainable future. This global effort underscores the critical role of innovative energy management in combating climate change and fostering industrial efficiency

INDIAN STEEL INDUSTRY AT A GLANCE: 2023-24

S. No.	Type of Industry	No. of Working Units	Capacity ('000 tonnes)	Production ('000 tonnes)
I	Pellets	53	145088	96523
II	Sponge Iron	344	60520	51560
III	Blast Furnace-Hot Metals	55	95832	87045
	Pig Iron			7364
	IV Crude Steel			
1.	BOF	20	71195	61607
2	Electric Arc Furnace	39	39522	31611
3	Induction Furnace	1032	68797	51081
IV	Crude Steel (1-3)	1091	179515	144299
	V. Crude Steel to Finished Steel Equivalent			
4	Re-rolling- Non-Flat	1224	1094130	76460
	Flat			4769
5	HR Product (PM Plates & HR Coils)	24	61358	57923
V	Crude Steel to Finished Steel Equivalent (4-5)	1248	170771	139153
	VI. Value Added Steel			
6	HR Product (HR Sheets/ HSM Plates)	24	61358	3124
7	CR Product	77	32556	21737
8	GP/GC Sheets	29	11719.2	9692
9	Colour Coasted	22	4763	3063
10	Tinplate	5	1149	761
11	Pipes	159	13919	6823

The **Organic Rankine Cycle (ORC) System Technology** offers an innovative solution for waste heat recovery in the iron and steel industry. Unlike conventional systems that require complex heat recovery steam generators, the ORC system uses a dry working fluid, simplifying the recovery process. This thermodynamic process, developed by Scottish engineer William J.M. Rankine in 1859, efficiently converts waste heat into mechanical energy, which is subsequently transformed into electricity.

With its moderate technology requirements, including components such as sealing, bearings, and piping, the ORC system operates at low pressure and temperature, significantly enhancing energy efficiency. It enables the recovery of low, medium, and high-temperature heat sources, reducing carbon emissions and transforming otherwise wasted heat into valuable electricity.

The iron and steel industry, one of the most energy-intensive sectors, accounts for approximately 5% of global energy consumption. A substantial amount of waste heat is generated and often lost during production and thermal processes. Utilizing this excess heat presents a significant opportunity for energy savings, offering a cost-effective and reliable method to boost energy efficiency. By enhancing self-production of electricity, the ORC system reduces reliance on external power sources, addressing the rising electricity demands caused by industrial electrification while alleviating pressure on power grids.

In addition to economic benefits, waste heat recovery through ORC technology plays a crucial role in mitigating climate change. By significantly cutting carbon emissions, it supports the global fight against global warming. ORC technology is particularly well-suited for advancing sustainable practices in the steel sector, promoting market penetration of green technologies, and reinforcing the industry's role in the transition to a low-carbon future.

The working principle of the ORC system (illustrated in the diagram below) involves channelling waste heat to a boiler, where the working fluid is evaporated. The vapor then passes through an expansion device (such as a turbine, screw, or scroll expander) to generate mechanical energy, followed by condensation in a heat exchanger, completing the cycle. This streamlined and effective process demonstrates the potential of ORC technology to revolutionize waste heat recovery and drive sustainability in energy-intensive industries.

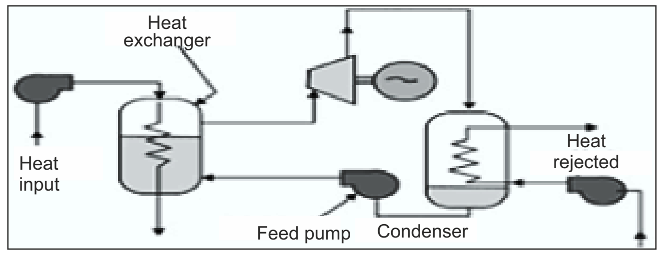

Image of Rankine Cycle

The **Press Information Bureau (PIB)**, as the nodal agency of the Government of India, plays a pivotal role in disseminating information about government policies, programs, initiatives, and achievements to the print and electronic media. According to PIB, India hosts over 900 steel plants, encompassing small, medium, and large capacity units engaged in crude steel production. Among these, only about 20 major steel producers, both in the public and private sectors, have production capacities exceeding 1 million tonnes (Mt).

The steel industry holds immense potential for waste heat recovery, ranking second only to the oil and gas sector in terms of recovery capacity. This presents a significant opportunity to enhance energy efficiency and reduce emissions in one of the most energy-intensive industries.

In terms of production methods, the iron and steel industry predominantly rely on two major routes:

1. **The Blast Furnace-Basic Oxygen Furnace (BF-BOF) Route**: This conventional method involves the smelting of iron ore in a blast furnace, followed by steelmaking in a basic oxygen furnace.

2. **The Electric Arc Furnace (EAF) and Induction Furnace (IF) Routes**: These processes use recycled steel scrap and, in the case of EAFs, can also include Direct Reduced Iron (DRI) as a raw material.

By adopting advanced technologies and optimizing these production routes, the Indian steel industry can significantly improve its sustainability, contributing to national and global climate goals while enhancing its competitiveness in the global market.

Steelmaking Routes:

1. **Primary Steelmaking Route (BF-BOF):**

   The **Blast Furnace-Basic Oxygen Furnace (BF-BOF) route** is the dominant steel production method globally, accounting for 71% of total steel production. This process uses iron ore and scrap as primary raw materials.

   According to the Global Energy Monitor, there are **1,408 blast furnaces across 477 plants in 55 countries**, with a combined pig iron production capacity of **2.0 billion tonnes**. Of this, **1.45 billion tonnes are currently operational**, while **0.28 billion tonnes are under development**, and **0.23 billion tonnes are idled or retired.** These facilities represent 91% of the global BF-BOF capacity.

   A **Global Steel Plant Tracker (GSPT)** survey of crude steel plants with capacities exceeding 1 million tonnes per annum (Mtpa) identifies **553 operating plants**, producing **2,010 Mtpa** of crude steel—82% of the total global capacity of **2,453 Mtpa**.

2. **Secondary Steelmaking Route (EAF & EIF):**

   The **Electric Arc Furnace (EAF)** and **Electric Induction Furnace (EIF)** methods, which primarily use recycled steel scrap and/or Direct Reduced Iron (DRI), contribute to 29% of global steel production.

   In the secondary steel sector in India, there are approximately:

   - **344 DRI plants**
   - **39 EAFs**
   - **1,032 Ifs**
   - **1,248 steel re-rolling mills**

Together, these facilities form a significant part of the secondary steel value chain, as per TERI & GIZ (2022). Notably, India's steel production split between primary and secondary routes is **50:50**, differing from global trends.

Energy Management in the Indian Steel Industry:

Energy is a critical cost factor in the highly energy-intensive iron and steel industry. Efficiency improvements are crucial to reducing costs and ensuring predictability in operations. Indian steel plants typically have higher energy consumption rates compared to advanced countries, with specific energy consumption in the range of **35–50 GJ/tonne of crude steel (tcs)** compared to **17–25 GJ/tcs** in advanced steel plants.

For integrated steel plants in India, **energy consumption averages 6.0–6.5 Giga Calories per tonne of crude steel**, significantly higher than the **4.5–5.0 Giga Calories per tonne** observed in international plants. The higher energy consumption in India can be attributed to:

- **Obsolete technologies** and challenges in retrofitting modern systems.
- **Old shop floor practices** and operational inefficiencies.
- **Poor quality of raw materials,** such as high-ash coal/coke and high-alumina iron ore.

However, energy consumption in Indian steel plants is gradually decreasing due to:

- **Technological upgrades** and adoption of energy-efficient methods.
- **Utilization of waste heat** recovery systems.
- Use of **higher-quality raw materials** and inputs.

Energy management efforts focus on identifying and implementing conservation options, leading awareness programs, and actively monitoring energy usage. These measures aim to align the Indian steel industry with global benchmarks, reducing operational costs and contributing to sustainability initiatives.

Characteristics of Gas from Key Units:

1. Coke Oven Plant:

- **Energy Recovery:**

  Coke oven gas accounts for approximately **6.53% of the total energy input** in the steelmaking process. Utilizing the **dry quenching process**, around **24% of the energy** from coke production can be recovered.

- **Process Overview:**
  - In conventional coke production, coking coal is heated in the absence of air within coke ovens, transforming coal into coke.
  - Below the ovens, a **regenerator chamber** preheats combustion air, which is then mixed with firing gas to heat the ovens.
  - Upon completing the coking process, the hot coke (~1000°C) is quenched with water in a cooling tower to stabilize it.
  - The heat from hot coke is used to **preheat the firing gas**, improving energy efficiency.

- **Dual Benefits:**

  This method achieves significant energy savings by integrating heat recovery with coke production, enabling both cooling of hot coke and preheating of the firing gas.

2. Blast Furnace (BF):

- **Gas Generation:**

  Blast furnace gas is produced under high pressure and at a temperature of **100–150°C (212–302°F)**. This gas is utilized in a **Top-Gas Pressure Recovery Turbine (TRT)** to generate up to **35 kWh per tonne of pig iron** without burning additional fuel.

- **Composition:**
  - **Nitrogen (N_2):** 55.19%
  - **Carbon Monoxide (CO):** 20.78%
  - **Carbon Dioxide (CO_2):** 21.27%
  - **Hydrogen (H_2):** 2.76%
  - Trace amounts of **methane (CH_4)** (~0.2%) and cyano compounds (HCN, Cn_2).
  - The **CO/CO_2 ratio** ranges from **1.25:1 to 2.5:1**.

- **Hazards:**

  A higher percentage of CO makes the gas hazardous, and the presence of cyano gases renders BF gas highly poisonous.

- **Energy Management Factors:**

  The generation and utilization of BF gas depend on factors such as:
  - Characteristics of burden materials.
  - Flux addition in the furnace.
  - Burden distribution in the furnace stack.
  - Auxiliary fuel injection and hot blast temperature.
  - Oxygen content in the blast.

- **Chemical Oxides in BF Gas (by weight):**
  - **CaO:** 39.4%
  - **FeO:** 30.23%
  - **MgO:** 9.69%
  - **Al_2O_3:** 2.16%
  - Others include MnO, P_2O_5, TiO_2, Na_2O, and trace elements.

- **Utilization:**

  The BF gas is reused within the integrated steel plant, particularly for hot blast stoves, and its energy efficiency is critical for minimizing operational costs.

- **Energy Content and Variability:**

  The specific volume and calorific value (CV) of BF gas depend on operational parameters, including the grade of hot metal and auxiliary fuel input. Typically, CO + CO_2 constitutes **37–53%** of the total gas volume.

By leveraging heat recovery and efficient gas utilization, coke ovens and blast furnaces contribute to the overall energy optimization in integrated steel plants, aligning with sustainability goals.

Basic Oxygen Furnace (BOF) Process:

1. Process Overview:

The **Basic Oxygen Furnace (BOF)** steelmaking process involves:

- Adding a **minor quantity of steel scrap** and a **large amount of molten iron** from the ironmaking unit into the furnace.
- Introducing **fluxes** (lime or dolomite) to remove impurities.
- Injecting **99.5% pure oxygen** at supersonic speeds through a lance, initiating intense oxidation reactions at temperatures ranging from **1600–1650°C**.

2. Reactions and Heat Generation:

- The oxidation of **carbon** and **silicon** in the hot metal generates significant heat, which is sufficient to melt the scrap.
- The typical composition of hot metal includes:
  - Carbon: **4.0–4.5%**
  - Silicon: **0.6–0.8%**
  - Sulphur: **0.03%**
  - Manganese: **0.7–0.8%**
  - Phosphorus: **0.15%**
- Additional oxidation of **iron**, **manganese**, and **phosphorus** contributes to the process, though with lower energy output compared to carbon and silicon oxidation.

3. Gas Composition and Energy Value:

The BOF process generates gas with the following composition:

- **Carbon Monoxide (CO): 57%**
- **Carbon Dioxide (CO2): 14%**
- **Nitrogen (N2): 14%**
- **Water Vapor (H2O): 12%**
- **Hydrogen (H2): 3%**
- **Lower Heating Value (LHV): 7.5 MJ per normal cubic meter**.

This efficient and high-temperature process not only enables the conversion of molten iron and scrap into steel but also provides opportunities for recovering and utilizing the generated BOF gas, contributing to energy optimization in integrated steelmaking operations.

Electric Arc Furnace (EAF) and Induction Furnace Steelmaking:

1. Electric Arc Furnace (EAF) Process:

The **Electric Arc Furnace (EAF)** steelmaking process generates significant amounts of high-temperature off-gas, with temperatures reaching up to **2100°C**. These off-gases contain a high concentration of **iron oxide dust**, which has potential for industrial recovery. The EAF process is energy-intensive, relying on electric arcs to melt scrap steel and other raw materials to produce molten steel.

2. CO2 Emissions:

In terms of **CO2 emissions**, EAF steelmaking is comparatively more efficient and environmentally friendly than other methods. Specifically, **Induction Furnaces (IF)**, which are commonly used in smaller steel plants, produce only **3-5 kg of CO2 per tonne of steel**. This is significantly lower than the emissions associated with traditional **Blast Furnace-BOF (BF-BOF)** and **Electric Arc Furnace (EAF)** steelmaking, which typically have higher carbon footprints.

3. Emissions Comparison:

- **Induction Furnace: 3-5 kg CO2 per tonne of steel**
- **EAF:** Generally, produces higher CO2 emissions due to the energy requirements of melting scrap and iron.
- **BF-BOF:** The **Blast Furnace-BOF** process, which involves coke and other fossil fuels, generates substantially

higher CO_2 emissions compared to EAF and IF methods.

While both EAF and Induction Furnace methods are more environmentally sustainable than traditional BF-BOF, further improvements in energy recovery, emission control technologies, and the use of renewable energy sources in EAF processes can continue to reduce the environmental impact of steelmaking.

Sponge Iron Unit - Waste Heat Recovery:

In a **Sponge Iron Unit**, **waste heat recovery** involves capturing surplus heat generated during the production process, such as from a **gas turbine** on an offshore platform or other high-temperature sources. By utilizing this waste heat, the energy efficiency of the plant can be significantly improved, often **more than doubling** energy use efficiency. This process is commonly referred to as **waste heat recovery**.

The waste heat recovery system in a sponge iron plant typically focuses on capturing and reusing the remaining heat from **stack gases**. This waste gas, initially at temperatures as high as **994°C**, is cooled down to around **250°C** through a series of preheating and power generation stages. The system is designed to integrate the recovered heat into the sponge iron production process, thereby enhancing overall energy efficiency.

Capital Investment and Benefits:

Implementing this waste heat recovery system requires initial capital investment, but the benefits include substantial **savings in coal** and **water consumption**, resulting in increased profitability. Annual savings can amount to approximately **$1.07 million**, with the payback period for the investment calculated to be around **2.06 years**.

Key advantages of this system include:

- **Utilization of waste heat** trapped in stack gases.
- Significant **reduction in water consumption**, contributing to more sustainable operations.
- Unlike older waste heat recovery systems (such as waste heat boilers), this system does not require high temperatures, making it more efficient for recovering heat from low-quality sources.
- The **gas-solid heat exchanger** in the system ensures that the stack gas temperature is reduced to **140°C**, which is sufficient to lower the gas density and enable it to be effectively captured and utilized in the recovery process.

Overall, the waste heat recovery system in sponge iron units enhances energy efficiency, reduces operational costs, and contributes to a more sustainable production process.

Waste Heat Sources in the Iron & Steel Industry:

The iron and steel industry generate significant amounts of waste heat during various stages of production. These waste heat sources can be broadly classified as follows:

1. **Hot Off-Gases**: These gases are produced in processes such as coke ovens, blast furnaces, and electric arc furnaces (EAF).
2. **Cooling Water**: Water used to cool equipment or products in the plant often exits at higher temperatures.
3. **Hot Intermediate Products**: These include products like billets, blooms, slabs, and forgings, which are heated during hot working processes such as rolling and forging.
4. **Hot Slags**: Waste materials from processes like the blast furnace (BF), basic oxygen furnace (BOF), and electric arc furnaces (EAF/EIF).
5. **Waste Heat Categories**: The waste heat generated can be categorized into three types based on temperature:
   - **Low-Temperature (<200 °C)**
   - **Medium-Temperature (200–500 °C)**
   - **High-Temperature (>500 °C)**

Waste Heat Recovery Systems & Technologies:

Waste heat recovery (WHR) systems in the steel industry are essential for improving energy efficiency. These systems are generally classified into two main categories:

1. Steam Control:

- This method manages heat fluctuations without requiring a thermal energy buffer. It involves regulating heat flows using valves and control mechanisms.
- **Technical Options for Steam Control**:
  - **Heat Source By-Pass**: Redirecting excess heat to prevent fluctuations.
  - **Heat Source Dilution**: Mixing excess heat with cooler substances to control temperature.
  - **Fluid Flow Control**: Managing the flow of fluids to maintain stable temperatures.

2. Thermal Energy Storage (TES):

- **TES** systems efficiently handle thermal fluctuations by storing excess heat for later use.
- **Types of TES**:
  - **Sensible Heat Storage (SHS)**: Involves storing heat in substances that change temperature without changing phase. Common methods include **hot water tanks** and **molten salts**.
  - **Latent Heat Storage (LHS)**: Involves using materials that store heat during phase changes (e.g., from solid to liquid). Common LHS materials include **paraffin**, **salt hydrates**, and **fatty acids**. LHS is commonly used as a buffer for thermal fluctuations, particularly in the recovery of energy from EAF off-gases.

Waste Heat Recovery in the Steel Industry:

- **Hot Stoves**: These devices supply hot blast to the blast furnace by preheating combustion air and fuel. Heat from the BOF gas, which contains high concentrations of carbon monoxide, can also be recovered for energy use.
- **Heat Recovery from BOF Gas**: Like coke oven gas and blast furnace gas, BOF gases offer opportunities for recovering chemical energy and sensible heat. However, the recovery process can be costly due to the presence of various metals (e.g., iron, zinc, lead) and potentially hazardous substances.

Waste Heat Recovery Technologies:

- **Economizers**: These are water-to-air heat exchangers that capture heat from boiler flue gas to heat water, which is then circulated through the system. Economizers are a simple, yet effective form of waste heat recovery.

High-Temperature Waste Heat Sources:

- **Coke Oven Gas**: Produced in coke ovens, this high-grade heat source offers substantial energy recovery potential.
- **Converter Gas**: Generated during steel refining in the BOF.
- **Electric Furnace Gas**: Generated in electric arc furnaces.
- **Heating Furnace Flue Gas**: Emissions from heating furnaces.

Medium-Temperature Waste Heat Sources:

- **Blast Furnace Gas**: A major waste heat source from blast furnaces.
- **Sintering Flue Gas**: Emissions from the sintering process.
- **Exhaust Gas from Primary After Flue**: Waste heat produced during the cooling of gases after combustion.

Low-Temperature Waste Heat Sources:

- **Waste Steam**: Low-temperature steam from various plant operations.
- **Hot Water**: Water that has been heated during industrial processes.

- **Low-Temperature Flue Gases and Materials**: These include gases and materials with lower temperatures but still offer potential for heat recovery.

In the iron and steel industry, recovering waste heat from various sources can significantly enhance energy efficiency and reduce operational costs. By implementing appropriate **waste heat recovery systems** like **steam control** and **thermal energy storage**, the industry can utilize even low-temperature waste heat effectively. Though high-temperature waste heat sources such as **Coke Oven Gas** and **Blast Furnace Gas** are the most valuable, medium and low-temperature sources also provide opportunities for significant energy recovery.

Heating Furnace in Steel Rolling Mills & the Importance of Waste Heat Recovery:

In steel rolling mills, billets are introduced into the heating furnace at one end, referred to as the **"Charge End."** As shown in the diagram (Figure 2), these billets are pushed onto the furnace hearth by a **push machine**, which directly contacts the billets through a ram. The billets then pass through three distinct zones of the furnace: the **pre-heating**, **heating**, and **soaking** zones. In these zones, the billets are gradually heated to the desired temperature. Upon reaching the end of the soaking zone, the billets are discharged by an **ejector** for further deformation processes.

Steel mills, particularly in integrated operations, have multiple opportunities for **high-temperature heat recovery**. In integrated mills, waste heat can be recovered from various processes, including **coke ovens**, **blast furnaces** used for iron production, and **basic oxygen furnaces (BOF)** used for steel production. Waste heat recovery in **rolling mills** plays a crucial role in reducing overall energy consumption and lowering fuel costs. The waste heat recovery system captures the heat generated during the rolling process and returns it to the system, creating an additional energy source. This recovered energy can either **offset the demand** for an existing **fired or electric heating system** or be used to generate electricity using technologies such as the **Organic Rankine Cycle (ORC)**.

Waste Heat Recovery Methods:

Some of the most common methods of recovering waste heat in steel rolling mills include:

- **Preheating combustion air**: Waste heat is used to preheat the air required for combustion processes, improving fuel efficiency.
- **Steam generation**: Waste heat is utilized to produce steam, which can be used for various heating and power-generation applications within the mill.
- **Water heating**: Waste heat can also be used for heating water, which can be used in cooling systems or other processes.
- **Load preheating**: The waste heat is used to preheat the billets or other materials before further processing, reducing the need for additional heating during production.

The Role of Rolling Mills in Steel Production:

In rolling mills, steel products are shaped and sized using a variety of shaping and finishing techniques. Slabs are first heated to extremely high temperatures in the **reheating furnace**, and then they are rolled into their final shape using either **hot rolling** or **cold rolling** processes. Specific products, such as reinforcement bars and steel plates, are produced through **hot rolling**, while products like automotive steel or steel for appliances require both **hot** and **cold rolling** processes.

However, both **hot rolling** and **cold rolling** processes demand high energy inputs, leading to significant operational costs. The **cold rolling** process requires more mechanical force, which results in higher energy consumption. In contrast, the **hot rolling** process requires less mechanical force but incurs substantial energy costs to heat the metal to high temperatures, often near eutectic points.

Data from large integrated steel plants show that the **hot strip rolling process** is the **third-largest energy consumer** in the steel production cycle, after iron and steelmaking. Given this high energy demand, implementing efficient waste heat recovery systems can help reduce overall energy consumption, lower costs, and improve the environmental footprint of steel production.

Moreover, the efficient recovery and utilization of waste heat in steel rolling mills can significantly contribute to reducing energy consumption and improving operational efficiency. By incorporating waste heat recovery technologies, such as **preheating combustion air**, **steam generation**, and **load preheating**, steel mills can lower fuel consumption, reduce operational costs, and even generate additional electricity. As the third-largest energy consumer in steel production, optimizing energy use in the **hot strip rolling process** is a key area where waste heat recovery can yield substantial benefits.

Reheating Furnaces:

Key to Energy Efficiency and Product Quality in Hot Rolling Operations

Reheating furnaces play a critical role in determining both the **cost** and **quality** of the final product in any **hot rolling operation**. The energy consumption of a reheating furnace is influenced by several **production factors**, such as the type of steel and the size of the stock, as well as **operational factors**, including scheduling and furnace design. According to the International Energy Agency (IEA, 2007), the global primary energy requirements for hot rolling are typically in the range of **2 to 2.4 GJ/t**, while for cold rolling, it averages between **1 to 1.4 GJ/t**. Upgrading existing furnaces presents an opportunity to reduce energy consumption and improve overall efficiency.

Process Control in Hot Strip Mills:

1. **Improved Hot Strip Mill Process Control:** Enhancing **process control** in hot strip mills can lead to substantial **indirect energy savings** by reducing oxygen rejects. The primary goal is to monitor and control oxygen levels to optimize the combustion rate in the furnace, thereby improving productivity and minimizing downtime. For example, a system installed in a mill in **Belgium** led to a reduction in oxygen rejects from **1.5% to 0.2%** and a decrease in downtime from over **50%** of the time to just **6%**. This improvement also contributed to a reduction of **15.1 kg of CO2 per ton of rolled steel**.
2. **Oxygen Level Control and Variable Speed Drives (VSDs) on Combustion Fans:** To optimize combustion efficiency in the furnace, **oxygen levels** must be carefully regulated, and **Variable Speed Drives (VSDs)** should be used on **combustion air fans**. Excessive airflow can reduce combustion efficiency, leading to unnecessary waste gases and higher energy costs. Maintaining the correct **fuel-to-air ratio** is essential for maximizing energy efficiency. Using VSDs on the combustion air fans can help maintain optimal oxygen levels, resulting in potential **energy savings of around 10%** (or **0.33 GJ/t** of rolled steel) and a reduction in **CO2 emissions** by **16.6 kg per ton of rolled steel**.
3. **Pressure Control for Furnaces:** Reheating furnaces typically have multiple **apertures**—such as extraction ports, raw material charging ports, and cracks in the furnace ceiling and sidewalls—that can lead to unnecessary heat loss. If the furnace pressure is too high, heat can escape, and if the pressure drops, cold air will be drawn into the furnace, which increases **fuel consumption**. **Furnace pressure control technology** aims to maintain a constant, **optimal pressure level**, minimizing energy consumption. This technology is especially beneficial for **industrial furnaces**, including rolling mill reheating furnaces, where maintaining steady internal pressure is essential for energy efficiency.

4. **Regenerative Burners for Reheating Furnaces:** **Regenerative burners** are advanced heat recovery systems designed to capture and reuse waste heat from furnace exhaust gases to preheat the combustion air. These systems feature **dual heat-recovery generators**, with one side collecting exhaust heat while the other combusts fuel. The burners switch roles periodically to maximize heat recovery.

   The use of **regenerative burners** in reheating furnaces can significantly reduce energy consumption. For instance, applying regenerative burners to a **110 t/h billet reheating furnace** (operating at **1050°C**) can decrease energy use by **0.18 to 0.21 GJ/t of steel** compared to conventional furnaces. This results in **annual energy savings** of approximately **9.3 to 11.6 GWh**. Furthermore, regenerative burners can lead to a **50% reduction in NOx emissions** during high-temperature combustion and help lower **CO2 emissions**, making them an effective solution for improving both energy efficiency and environmental performance.

The implementation of advanced technologies such as **oxygen level control**, **VSDs on combustion fans**, **furnace pressure control**, and **regenerative burners** can significantly improve the **energy efficiency** of reheating furnaces in steel mills. These upgrades not only **reduce energy consumption** but also **lower CO2 emissions** and **improve operational efficiency**. By adopting these innovative solutions, steel producers can achieve **cost savings**, enhance product quality, and contribute to **sustainable practices** within the industry.

Importance of Recovering Waste Heat in the Iron & Steel Industry

In the iron and steel industry, more than half of the energy consumed is lost as waste heat. Industrial processes, especially those in energy-intensive sectors like steel production, generate vast amounts of heat. This wasted energy, if not captured and reused, is released into the environment, contributing to energy inefficiency and CO2 emissions. Waste heat, typically lost through conduction, convection, and radiation from machinery and thermal processes, can be recovered to improve system efficiency, reduce fuel consumption, and lower emissions.

Global Energy Loss and Waste Heat Recovery

Estimates suggest that implementing energy-efficient processes in energy-intensive industries could reduce global carbon emissions by 44% by 2035. Waste heat can be found in gaseous streams (such as exhaust gases and flaring gases), liquid streams (e.g., hot oil and cooling water), and solid products (such as hot steel), spanning temperatures ranging from 50°C to over 1000°C. Recovering this heat not only contributes to energy efficiency but also helps in reducing operational costs and environmental impacts.

In the steel industry, which is one of the largest global energy consumers, a significant amount of energy is lost during production. For instance, in 2018, every ton of steel produced emitted an average of 1.85 tons of CO2, accounting for approximately 8% of global CO2 emissions. Waste heat recovery systems, which can utilize heat from sources such as Electric Arc Furnaces (EAF), Basic Oxygen Furnaces (BOF), sinter coolers, and reheating furnaces, are vital to improving energy efficiency in steelmaking. The heat from off-gases in steel production processes has increasingly attracted attention due to its potential in reducing fuel use and emissions.

Energy Recovery Systems in Steelmaking

The development of effective waste heat recovery plants requires detailed knowledge of various components such as the water-steam cycle, EAF processes, dedusting systems, and the end users of the recovered heat. Waste heat recovery is especially promising in high-temperature processes, such as those in EAFs and BOFs, where substantial amounts of energy can be captured and redirected for use in heating, cooling, or even electricity generation.

Reheating furnaces, integral to steel production, often lose large quantities of heat into the environment. By recovering this heat, significant reductions in energy consumption can be achieved, while also lowering emissions. Advances in technologies, such as regenerative burners, recuperators, and rotary heat exchangers, have been explored for this purpose, with many steel plants adopting these systems in recent years to enhance their overall energy efficiency.

Technologies for Waste Heat Recovery in Steel Mills

In rolling mills, technologies like recuperators, regenerative burners, and heat recovery steam generators are commonly used to capture and reuse waste heat. These technologies can recover heat from the gas emissions, and some, like regenerative burners, use this recovered heat to pre-heat combustion air, further improving fuel efficiency.

Other techniques, such as direct and indirect contact condensation recovery, membrane condensation, and the use of heat pumps, are also being explored. Emerging technologies for direct heat-to-power conversion, such as thermoelectric, piezoelectric, and thermionic power generation, offer promising avenues for utilizing waste heat that would otherwise go unused.

Optimizing Heat Recovery in Rolling Mills

During the steel shaping process in rolling mills, the temperature of the gases above the steel ingot or slab typically ranges from 1250°C to 1350°C, dropping near the surfaces of the slabs to between 600°C and 900°C. This temperature gradient offers significant opportunities for heat recovery. Reheating furnaces, where slabs are heated to temperatures of 1200–1250°C, are critical points for waste heat recovery, as they are responsible for removing casting dendrite structures and dissolving alloying elements.

In other words, Waste heat recovery in the iron and steel industry is essential for improving energy efficiency, reducing fuel consumption, and mitigating CO2 emissions. By harnessing waste heat from high-temperature processes and utilizing advanced recovery technologies, steel producers can achieve substantial energy savings and make significant progress toward sustainability. Continued research and adoption of emerging heat recovery technologies will be key to maximizing energy efficiency in the industry and addressing the global challenges of climate change.

Disadvantages of Waste Heat Recovery:

While waste heat recovery offers substantial energy-saving potential, its implementation poses several challenges. A thorough understanding of the waste heat generation source, equipment specifications, and the corresponding water-steam cycle is essential. Additionally, the composition, temperature, and characteristics of the waste heat source must be carefully assessed. Significant waste heat can be recovered from sources such as Electric Arc Furnaces (EAF) and Basic Oxygen Furnaces (BOF), as well as from other industrial units like Sinter Coolers and Reheating Furnaces. However, designing an effective waste heat recovery system requires exploring various options for utilizing the recovered energy, as this directly impacts the economic feasibility of the system and its installation.

The initial capital investment required to implement a waste heat recovery system can be considerable, and in some cases, it may outweigh the benefits derived from the recovered heat. Moreover, much of the waste heat is of low quality (lower temperature), which means that the heat exchangers needed to capture significant quantities of this energy are typically large, further increasing the capital cost.

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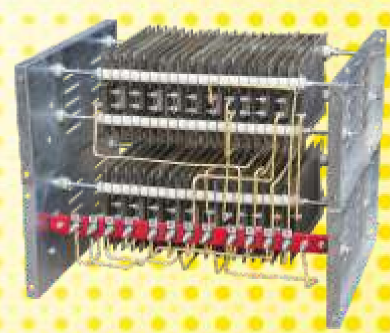

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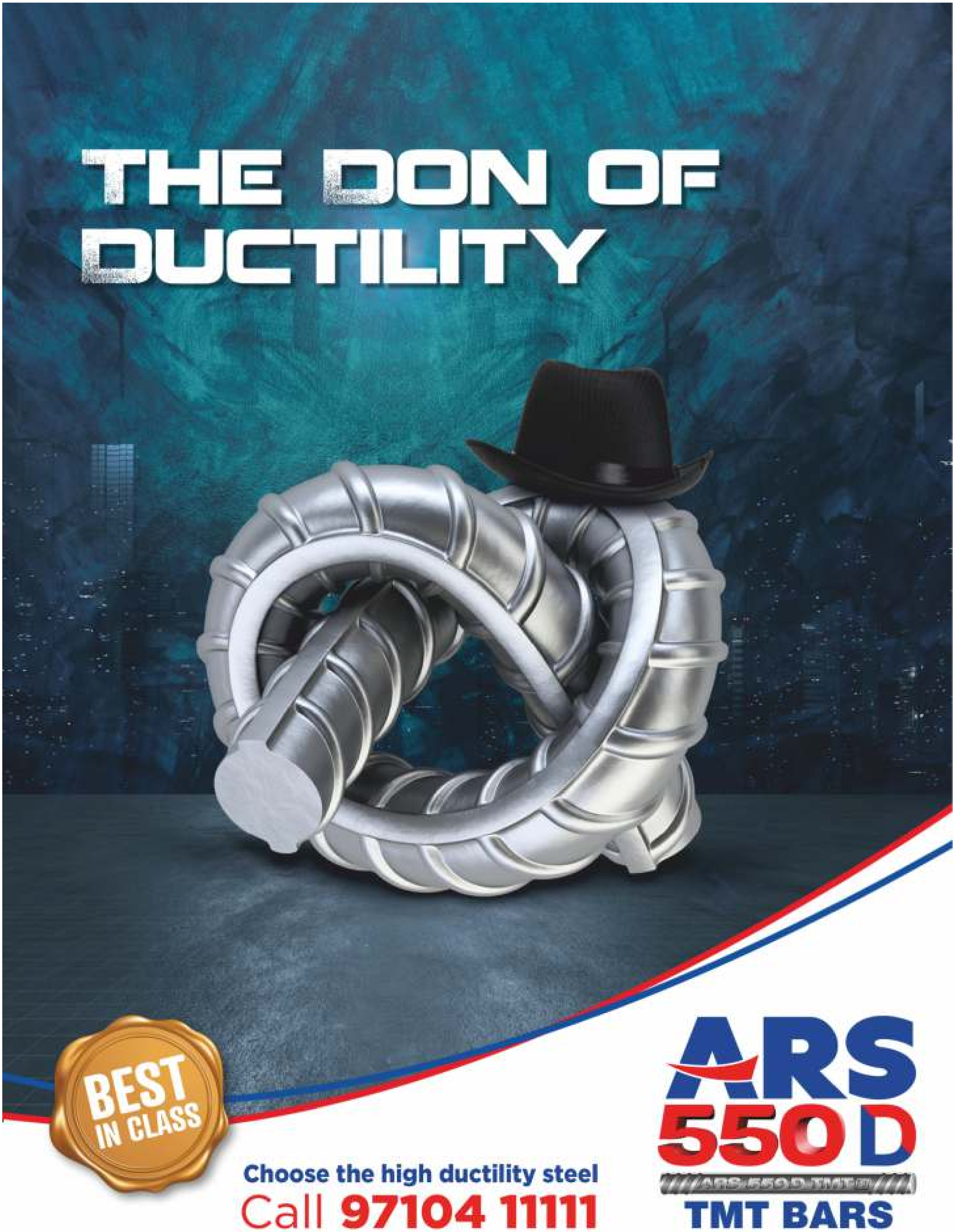
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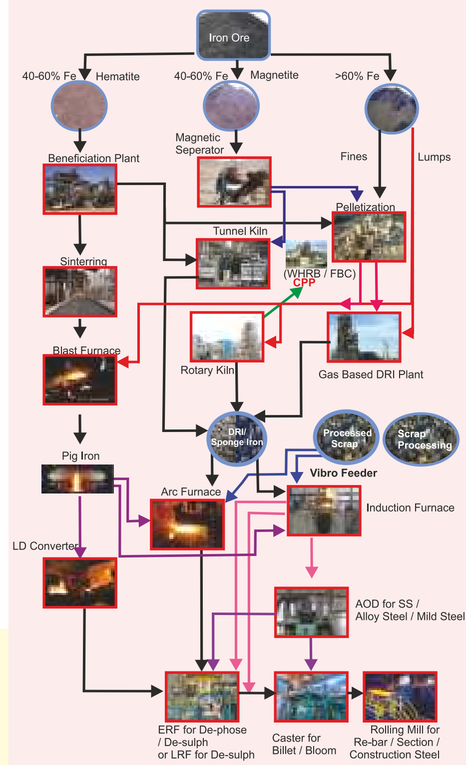

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