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Current progress of process integration for waste heat recovery in steel and iron industries

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ABSTRACT

More than half of the energy consumed globally is lost as heat. Recovering waste heat can increase system efficiency, reduce fuel consumption, and lower CO_2 emissions. The iron and steel industry is one of the industrial sector's largest energy consumers. A considerable amount of waste heat is also lost during steel production, which is released into the atmosphere. Therefore, the iron and steel industry should prioritize increasing energy efficiency when saving energy. This article analyzes energy integration and application strategies for waste heat recovery throughout the iron and steel manufacturing sector. Waste heat from the iron and steel industry has shown that it can be used to provide heating, cooling, and electricity. According to a review of research studies conducted on waste heat recovery in the iron and steel sector, thermal terminal analysis, exergy analysis, and mathematical modeling techniques have proven useful in determining waste heat potential. The analyzes and information in this study can be used to fill research gaps for future studies and provide information on the potential for using waste heat in the iron and steel sector for multiple applications.

1. Introduction

With increasing concerns about global warming and fuel prices trending upward in recent decades, engineering firms are faced with reducing greenhouse gas emissions and increasing site efficiency [1]. In this framework, one of the critical areas where research has been done to cut fuel consumption, eliminate harmful emissions, and improve production efficiency is waste heat recovery technologies in industrial operations [2]. The energy produced by industrial processes but not consumed, wasted, or released into the environment is considered industrial waste heat [3]. Waste heat comes from various sources, such as heat loss through conduction, convection, and radiation from industrial products, machinery, and thermal processes [4–6].

High, medium, and low-temperature categories can be used to classify heat losses. Waste heat recovering (WHR) systems are implemented for each component of waste heat to obtain the best potential efficiency [7]. At high temperatures, WHR, waste heat is used at temperatures above 400 °C, at medium temperatures WHR between 100 and 400 °C; and at low temperatures, WHR at temperatures below 100 °C. Most waste heat generally comes from direct combustion processes in the more significant thermal potential, exhaust gases from combustion plants in the medium thermal potential, and components, products, and equipment from process plants in the low-temperature range [8]. High-value waste heat has excellent potential and is available in large quantities; it accounts for about half of all waste heat resources from heaters, boilers, and internal combustion engines in metallurgy, construction, engineering, etc. Although waste heat from chemical processes and slags represents only a tiny percentage of the energy used in the chemical industry, its exceptional waste heat potential shows that it is still important for the WHR sector [9]. Low-value waste heat, such as from lubricating oil, cooling water, and wastewater, has economic value despite having less potential than high-value waste heat [10]. An overview of various waste heat energy is presented in Fig. 1.

The backbone of the country's economy is the iron and steel sector. Iron and steel technology has advanced significantly recently, with global steel production increasing from 850 million tonnes in 2010 to 1878 million tonnes by 2020 [12]. The iron and steel industry is not only one of the highly significant sectors of the economy but is also responsible for a considerable amount of energy consumption and pollutant production. The energy consumed by the iron and steel industry accounts for 10–15 % of the globe's energy expenditure, and its CO_2 emissions account for about 7 % of all anthropogenic CO_2 emissions [13]. Table 1 shows the ranking of countries producing crude steel in 2021. China leads the way, having more than half of the world's steel. In a report by the UK parliament, in terms of gross value added, the UK steel sector contributed £2.0 billion to the UK economy in 2020. This represented 1.2 % of manufacturing output and 0.1 % of the UK

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Nomenclature

Waste heat recovery WHR
Waste heat to heat WHTH
Waste heat to cold WHTC
Waste heat to power WHTP
Rankine cycle RC
Organic Rankine cycle ORC
Steam Rankine cycle SRC
Kalina cycle KC
Heat recovery steam generator HRSG
Photovoltaic PV
Thermophotovoltaic TPV
Blast furnace gas BFG
Heat pipe heat exchanger (HPHE)
Flat heat pipe (FHP)
District cooling system (DCS)

economy. The UK steel industry comprises 1,100 companies. 33.400 jobs, or 0.1 % of all jobs in the UK, were supported by the industry in 2019 [14]. The steel industry employs some of the harshest industrial processes, including repeated heating and cooling cycles throughout the production and supply chain. But because they either allow for the reduction of iron ore to iron, alter the microstructure to improve the qualities of the finished product or soften the metal to take the correct shape, these high temperatures are crucial to the operation of the supply chain. These high-temperature processes in the heated production streams cause significant power dissipation [15]. The steel sector accounts for around 4–5 % of the world's total energy consumption; it is also one of the most energy-intensive sectors. Additionally, it significantly impacts the climate since steel manufacturing generates 1.9 tonnes of carbon dioxide every ton, which substantially leads to global warming [16].

Today, when energy conservation and pollution prevention are of the utmost significance, the recovery of waste heat from the steel-making process is a viable solution. Researchers from all over the world are consequently interested in the development of different heat recovery technologies for the iron and steel industry. According to Fig. 2, In the form of waste products, molten slag, and gas, the iron and steel sector stores high-to-low quality waste heat. The steel industry's by-product of molten slag, which accounts for 35 % of the high-quality waste heat and 10 % of the waste heat, is released at a very high temperature and transports many high-quality heats.

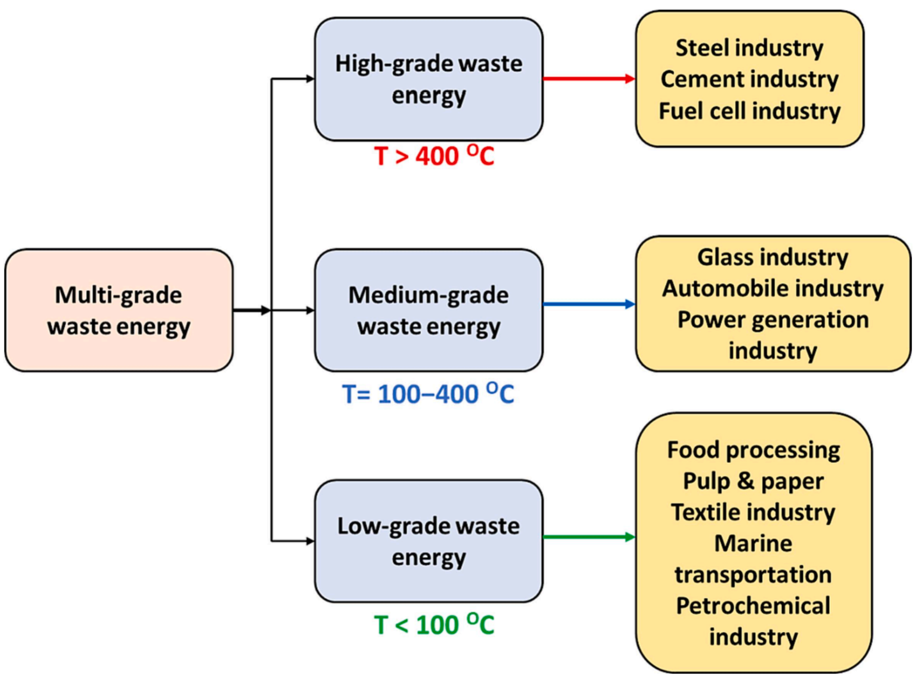

Fig. 1. Classification of industrial heat wastes [11].

Table 1
Crude steel production for 20 top countries (million tonnes) [17].

Country	Rank	Production	Country	Rank	Production
China	1	1064.8	Taiwan	11	21.0
India	2	100.3	Ukraine	12	20.6
Japan	3	83.2	Italy	13	20.4
USA	4	72.7	Vietnam	14	19.5
Russia	5	71.6	Mexico	15	16.8
South Korea	6	67.1	France	16	11.6
Turkey	7	35.8	Spain	17	11.0
Germany	8	35.7	Canada	18	11.0
Brazil	9	31.0	Indonesia	19	9.3
Iran	10	29.0	Egypt	20	8.2

The report was written to assess the knowledge and status of waste heat recovery technologies in the iron and steel industry. It aims to highlight opportunities for improving research and technological development in this research area, identifying and highlighting areas that have not yet been addressed or are of the highest priority. Therefore, the report has been written systematically to understand the problem and identify ways to improve waste heat utilization in the iron and steel industry.

Some other authors have also reviewed the waste heat recovery of the iron and steel industry. Hui Zhang et al. [19] studied the potential of molten slag, a waste of iron and steel industry at a high temperature (1400–1600 °C). The specific interest, however, was only the waste heat and recovery systems suitable to utilize waste from slag. Hussam Jouhara et al. [20] reviewed the technologies that can recover waste heat from the iron and steel industry. The reviewed technologies were

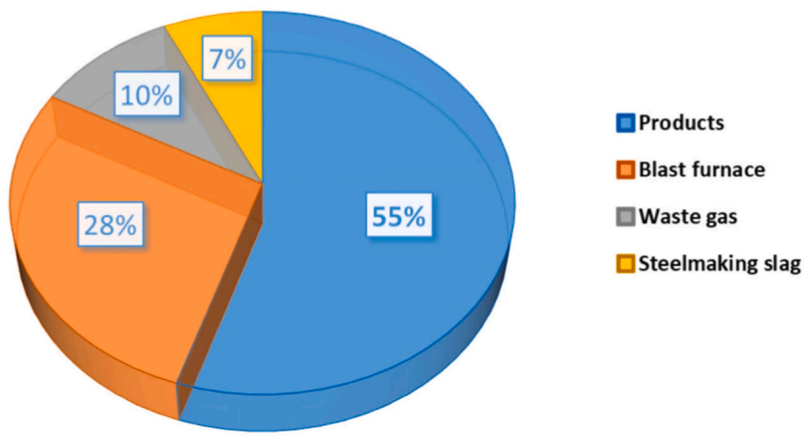

Fig. 2. Distribution of high-temperature waste heat from the steel sector [18].

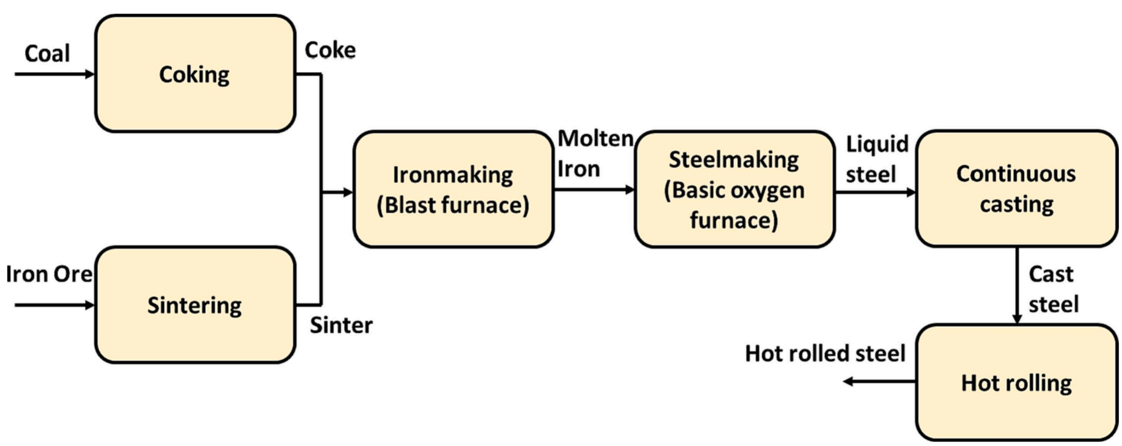

Fig. 3. Overview of steel production process.

recuperators, regenerators, furnace regenerators, and rotary regenerators or heat wheels, passive air preheaters, regenerative and recuperative burners, plate heat exchangers and economizers and units such as waste heat boilers, and run-around-the-coil. Pili R et al. [21] reviewed the waste energy utilization using the Organic Rankine cycle for power generation. The focus of the analysis was the German iron and steel industry. This review, unlike other studies, is very comprehensive and covers all aspects of waste energy utilization from the iron and steel industry, including waste energy conservation technologies, waste heat utilization integration approaches, and industrial applications.

1.1. Overview of the primary steel production process

High demand for iron ore, coke, and steel scrap, rising energy prices, and industry consolidation are forcing steel companies to develop new strategies to increase efficiency to remain competitive. Over the last decade, raw material production processes have evolved dramatically, and scrap-based production now accounts for a higher percentage of the total steel supply [22]. Sintered iron ore is treated in a blast oxygen furnace after being reduced with coke in a blast furnace to make primary steel. Conversely, secondary steelmaking entails remelting scrap in an electric arc furnace. Molten steel is continuously cast and hot rolled during core manufacturing to create a range of stock items that are sold for additional processing into commodities [23]. Fig. 3 summarizes the

Table 2
Exhaust gas temperatures from various industrial processes.

Industrial Process	Exit Exhaust T (^{O}C)	Ref.
Iron and steel making	1500–1600	[24]
Steel electric arc furnace	1400–1700	
Basic oxygen furnace	1100–1300	
Steel heating furnace	950–1050	
Coke Oven	650–1000	
Glass oven without regenerator	700–1200	[25]
Glass oven having regenerator	550–750	
Melting oven	400–700	
Ceramic kiln	150–1000	
Blast furnace stoves	250–300	[26]
Steam boiler	200–300	
Flat glass melting	160–200	
Coke oven stack gas	190–200	
Pulp drying (paper industry)	95–120	[27]
Paper drying (paper industry)	95–120	
Dry heating (textile)	80–90	[28]
Ironing (textile)	95–105	
Bleaching (textile)	60–100	
Dyeing (textile)	100–160	
Food and beverages cooking	110–120	[29]
Food and beverages pasteurizing	60–70	

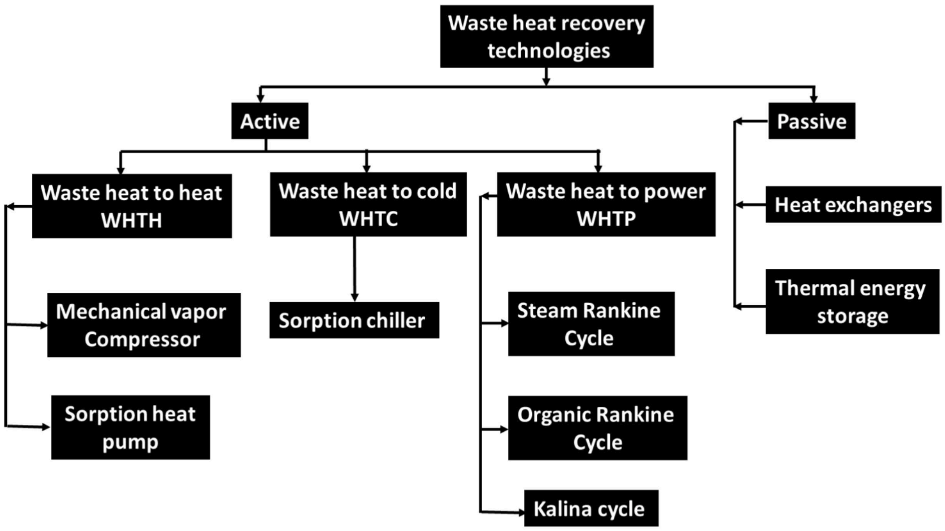

Fig. 4. Categorization of waste heat recovery technologies [33].

linkages between the stages in the significant steel supply. The iron and steel industry has some of the highest operating temperatures. Table 2 compares exhaust gas temperatures in iron and steel manufacturing with some other process industries.

Just as you cannot build a building without having solid waste, you cannot operate without waste heat. Waste heat is generated and emitted while producing goods and equipment by radiation, coolant, exhaust, or air. Although these heat flows are counted as waste, they usually have a high level of exergy and can be used for work through one of several waste heat recovery methods. This report reviews current waste heat recovery systems advances and their integration for heating, cooling, and power generation. Because it is the largest energy consumer, the research relates to the iron and steel sector. Therefore, it's crucial to use waste heat flows for a productive production process that uses less energy.

2. Waste heat recovery systems

The refluxing process waste heat from a gas or liquid can be collected and supplied into the system as an additional energy source using waste heat recovery technologies. The energy source can be utilized to produce heat, hydrogen, extra mechanical or electrical energy, or both [30,31]. An overview of the waste heat recovery technologies is presented in Fig. 4. The grade of the waste heat generally improves with available temperature; therefore, optimizing the waste heat recovery method becomes more straightforward. So it's crucial to determine how much heat can be recovered from a process with the most capability and to ensure a waste-heat recovery system works as efficiently as possible [32].

Equation (1) can be used to determine how much usable waste heat is available.

$$Q = V \times h \times C_p \times hT \tag{1}$$

Q is the heat content in Joules (J).
is the material's fluid velocity in m^3/sec
ϱ the flue gas density in kg/m^3.
C_p for the substance's specific heat in J/ (kg. K).
and ΔT is the temperature gradient.
The amount and grade of heat that can be retrieved from the operation must be considered to identify the kind and origin of waste heat and the heat recovery technologies that may be applied.

There are various heat recovery systems for capturing and recovering waste heat. These methods are most used in waste heat recovery systems with heat exchangers for energy recovery. These systems are air preheaters, regenerators, furnace regenerators, heat wheels, heat exchangers and regenerators, regeneration and recovery burners, heat pipe heat exchangers, plate heat exchangers, economizers, waste heat. A standard waste heat recovery system includes a boiler and a direct heat exchanger. A standard operating concept for all these units is the capture, recovery, and exchange of heat with the estimated energy content of the process. This section briefly reviews the technologies used for heat recovery systems.

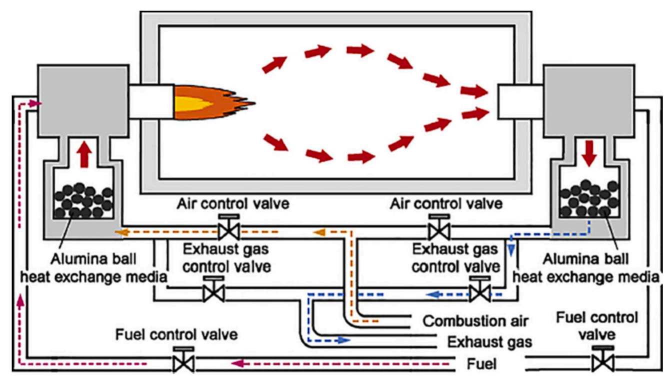

Fig. 5. Regenerative burner mechanism [36].

2.1. Regenerative and recuperative burners

By receiving and using the excess heat of the hot exhaust gases from the combustion chamber via heat transfer plates, regenerative and recuperative burners increase energy production. Two burners attached to the furnace that successively heat the combustion air flow constitute regenerative systems in most applications. Each burner has a separate control valve. In this method, the exhaust gasses from the furnace are directed into a container filled with refractory material, such as aluminum oxide [34]. The exhaust gasses heat the alumina medium, and the thermal energy of the exhaust gasses is captured and saved. The flue gas travels in the reverse direction when the medium is entirely heated, transferring the heat to the air approaching the burner and igniting the hot medium. The process starts over when the combustion air from the hot media warms the cooler media. This method allows the regenerative burner to decrease the fuel necessary to heat the air, increasing combustion efficiency [35]. A conventional illustration of the regenerative

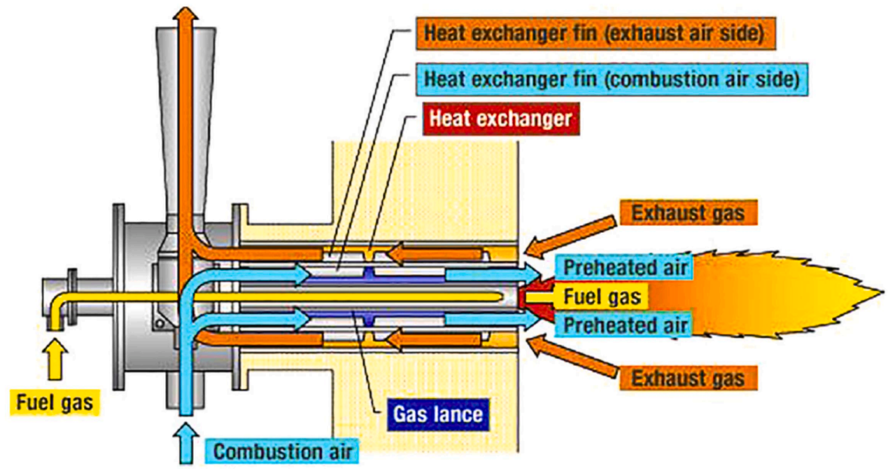

Fig. 6. Recuperative burner structure [38].

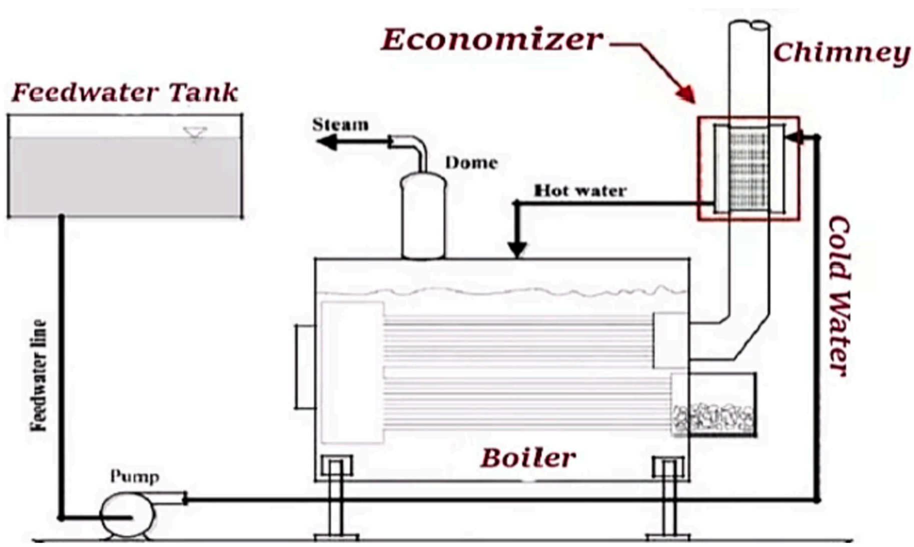

Fig. 7. Mechanism of an economizer.

burner mechanism is presented in Fig. 5.

The design of a recuperative burner has heat exchanger surfaces that utilize the energy of the hot gas as it flows through the burner body. The burner heats the combustion air before it is combined with the fuel by using the exhaust energy from the flue gas [37]. The burners are internal heat exchangers with several characteristics that provide thermal contact between the exhaust gases and the combustion air from the supplying pipe. The design transfers heat to the combustion air by absorbing waste heat and exhaust gases from the body of the burner nozzle. Additional heat is generated in the nozzle due to the increased combustion efficiency achieved by preheating the air [38]. A typical illustration of the recuperative burner mechanism is shown in Fig. 6.

Kanit Manatura et al. [39] investigated the potential of combining a regenerative burner with a recuperator for waste heat recovery in the iron and steel industry. According to readings and an assessment of energy expenditure, the recuperator system with regenerative burners consumes about 43 % less energy than the traditional recuperator system studied in the test case.

2.2. Economizers

The term "economizer," often referred to as an "exhaust heat recovery device," refers to a heat exchanger attached to the flue of a boiler. The goal is to recover heat that would otherwise be lost. Economizers can either be installed with a new boiler or retrofitted into an existing system. Actual energy savings are calculated by multiplying the mass flow rate of flue gases through a boiler stack economizer by the temperature drop of the flue gases [40]. A conventional non-condensing boiler has a flue gas temperature of 140 °C. An appropriately sized economizer condenses the flue gases and transfers the absorbed heat to the water stream, reducing the temperature of the flue gases to about 77 °C [41]. The economizer can increase the efficient regular heat efficacy of these boilers from about 80 % to about 90 %. An economizer can improve a boiler system's effectiveness by 1 % for each five °C decrease in flue gas temperature, according to Spirax Sarco [42]. This implies that the system's fuel expenditure may be decreased by 5–10 % with a repayment time of under two years. Fig. 7 shows an illustration of the economizer's working mechanism.

2.3. Waste heat boilers

A waste heat boiler is a device that converts several types of waste heat from industrial furnaces, waste incinerators, and industrial waste incinerators into usable and efficient thermal energy. This waste heat is

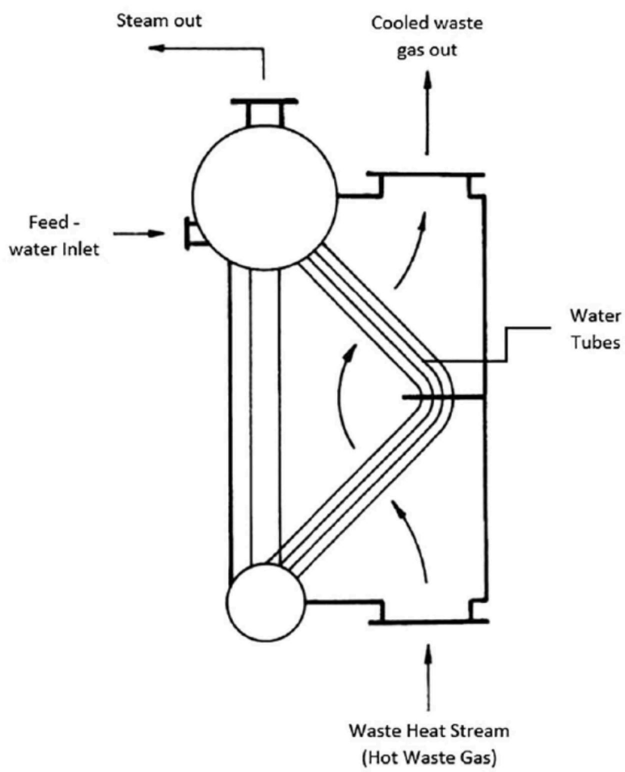

Fig. 8. Mechanism of a waste heat boiler [46].

produced while manufacturing steel, non-ferrous metals, chemicals, cement, and other materials. Waste heat boilers increase thermal efficiency, save energy, and protect the environment and other aspects of modern life [43]. The waste heat boiler for thermal afterburning is usually located after the combustion chamber. The primary function of the waste heat boiler is to generate steam from the hot combustion by-products of thermal exhaust. The industry can then use this steam in their manufacturing process, on their construction sites, in the thermal oxidizer itself, or even sell it to neighboring facilities that need it [44]. For example, it is pointed out that the heat generated during the combustion process in a coal-fired power plant can reach temperatures of up to 1000 °C after leaving the combustion chamber. In this case, installing a waste heat boiler allows the recovery and use of the exhaust heat to vaporize a liquid and produce steam, which can then be used to drive turbines and generators [45]. Fig. 8 shows an illustration of the waste heat boiler working mechanism.

2.4. Air preheaters

The primary purpose of an air preheater is to eliminate waste heat from the flue gases leaving the boiler. The air that is fed into the boiler or furnaces for fuel combustion is preheated with air preheaters, a type of heat exchanger with a tube bundle design. Typically, fuel is added to the boiler at room temperature, and for combustion to occur, the temperature of the fuel should be elevated to the level of ignition. Hot air is pumped into the furnace to burn the fuel, which improves both the combustion process and the efficiency of the boiler [47]. The temperature of the flue gases can be lowered by 20 to 22 °C, which reportedly increases the boiler's efficiency by 1 %. In addition, preheating the air facilitates the combustion of lower-quality fuels and allows for a reduction in supplemental air. Hot air can dry coal, economical movement of coal to burners, and accelerate combustion when burning pulverized coal [48]. According to Nicholson [49], there are generally 3 categories of air preheaters commonly used and categorized as

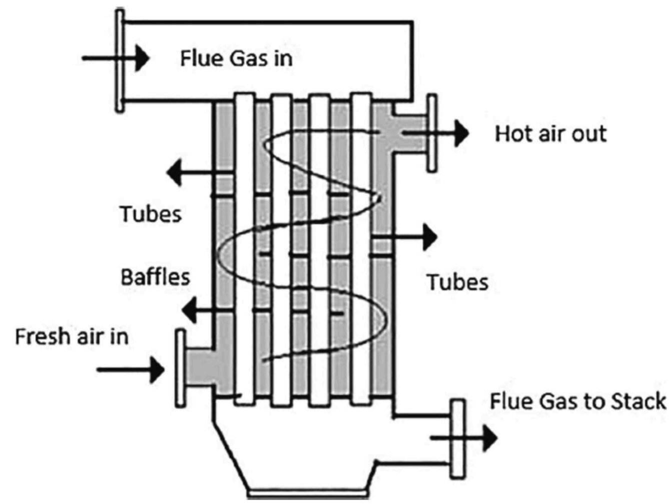

Fig. 9. Mechanism of air preheater [50].

regenerators: rotary regenerators, circular regenerators, and recuperators. Although they are designed differently and used for different reasons, these technologies operate on a similar theory as air preheaters. Fig. 9 shows an illustration of air preheater working mechanism.

2.5. Plate heat exchanger

Multiple parallel plates are stacked on top of one another to form a network of passages in a plate heat exchanger—the route along which the gap between two parallel surfaces creates the fluid moves. A plate is constantly in touch with the heat source on one end and the cold fluid on the other end, thanks to intake and exit apertures at the extremities of the plates, by which hot and cold fluids alternatively flow into the heat exchanger [51]. A plate may be only a few square centimeters (100 mm × 300 mm side) or 2 or 3 square meters (1000 mm × 2500 mm side) [52]. A single heat exchanger may contain from 10 to several hundred plates, resulting in exchange sections of up to thousands of square meters. The three types of plate heat exchangers each have two single-pass configurations and one multi-pass variant. A plate heat exchanger's plates can be sealed, brazed, or welded together. A gasket, frequently formed of a polymer material, fits between the plates of a plate heat exchanger and serves as a cover and separator at the plate ends. Two stiffer compression plates on each side and fastening screws are used to secure the plates in a framework. Due to the design, the exchanger may be disassembled for maintenance. In this design, gaskets are employed to protect against thermal wear and sudden pressure fluctuations while giving the plate flexibility [53]. All plates in a brazed plate heat exchanger are combined in a vacuum furnace of copper or nickel. The design provides greater tolerance to higher pressure and temperature ranges than a gasket heat exchanger and is generally inexpensive to maintain. However, it cannot be disassembled because it is brazed, which can cause problems when cleaning or resizing is required [54]. Welded plate exchangers are considered more adaptable and resistant to temperature variations and pressure changes. This advantage is achieved by using laser welding to keep the plate packed together with welds. The higher operating temperature and pressure limitations make this heat exchanger suitable for high-performance applications [55]. Fig. 10 shows an illustration of the type of plate heat exchanger. Depending upon the application, many other heat exchanger assemblies can be utilized. Hongting Ma et al. [56] used heat pipe heat exchangers in the slag cooling process of the steel industry to recover waste heat. To improve the HPHE's ability to transfer heat, a specially designed on-line cleaning tool was developed and used. The first and second laws of thermodynamics were integrated to determine the technical specifications of a heat pipe heat exchanger. The online cleaning mechanism

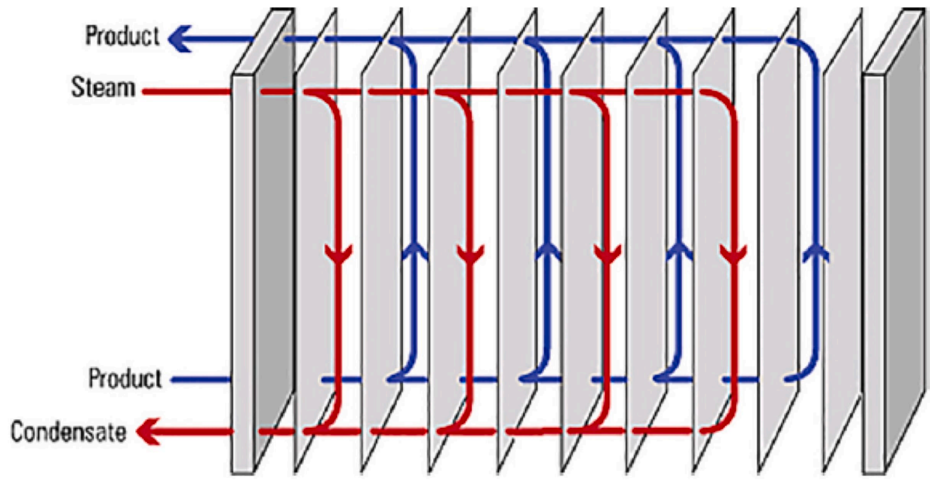

Fig. 10. Design of a typical plate heat exchanger.

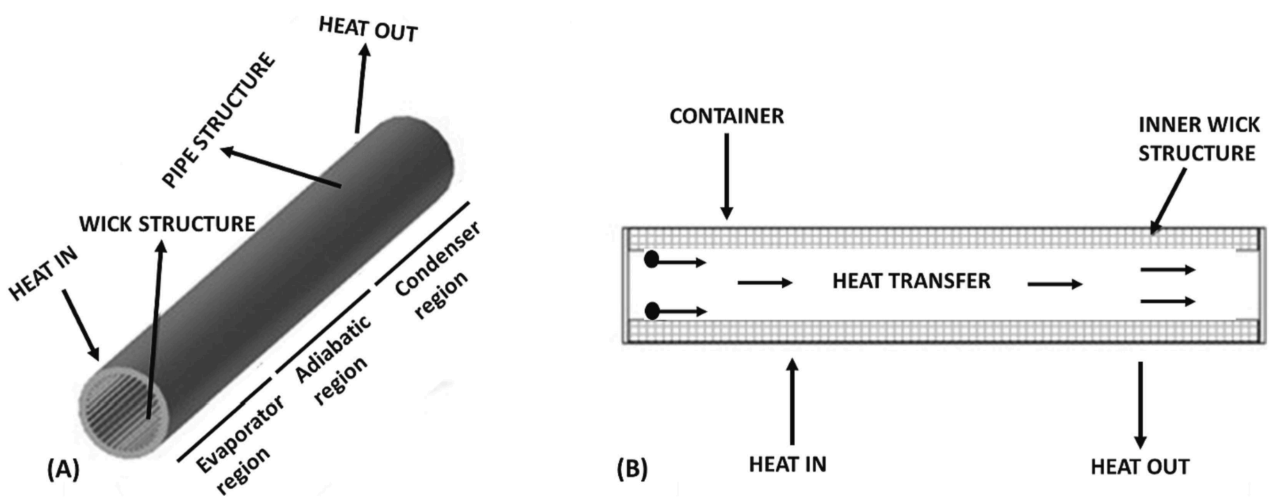

Fig. 11. Working of the heat pipe (A) – isometric view and (B) sectional view.

significantly impacted heat exchange; its use increased heat exchange rates, heat exchange coefficients, efficiency, and energy efficiency by 6.11 %, 9.49 %, 7.19 %, and 7.93 %, respectively.

2.6. Heat pipe systems

A heat pipe is a straightforward device with incredibly excellent thermal conductivity, no mechanical components, and the capacity to effectively transmit significant volumes of heat across vast distances at a steady temperature without needing external power. A small, narrow tube with a capillary inside that is filled with a little amount of liquid, often saturated water, is all a heat pipe needs to function. The system includes three parts: an evaporator at one side that absorbs heat and turns liquid into vapor; a condenser at the other side that releases heat; and an adiabatic segment in the center that allows the liquid and vapor phases of the liquid to flow in reverse through the core and wick, respectively, to complete the process with very little heat exchange from the fluid to the surroundings [57]. The operating temperature of the pipe significantly influences the working pressure and the kind of liquid inside the heat pipe. For instance, to dissipate heat from a network, the pressure in a heat pipe that uses water as the fluid should be kept at 31.2 kPa, or the pressure during which water boils at 343 K. Heat pipes can be made from a range of materials, such as aluminum, copper, titanium, and tungsten. The temperature range of the applications and the substance's appropriateness for the working fluid often decide the material chosen for heat pipes [58]. Fig. 11 shows the fundamental working principal of heat pipe.

2.7. Heat recovery steam generator

One of the key components of a gas turbine combined cycle power plant with high thermal efficiency and low carbon dioxide emissions is the heat recovery steam generator (HRSG). An HRSG is a type of heat exchanger that is particularly good at recovering heat from the exhaust gases of the gas turbine. The heat is recovered from steam, which is used as fuel for a steam turbine that generates electricity [59]. Furthermore, HRSG uses selective catalytic reduction equipment to reduce the concentration of nitrogen oxides in the exhaust gases released into the environment. They often work with a gas turbine or diesel generator to produce more energy using steam. These combined cycle power plants have excellent part-load characteristics and extremely high-power generation efficiency [60]. There are two main configurations. In a horizontal tube HRSG, the evaporator tubes are arranged horizontally. In large plants, this configuration is quite common. The flue gas path in horizontal tube HRSGs is often square. The primary heat exchanger tubes of vertical-type HRSGs are oriented vertically. These heat recovery

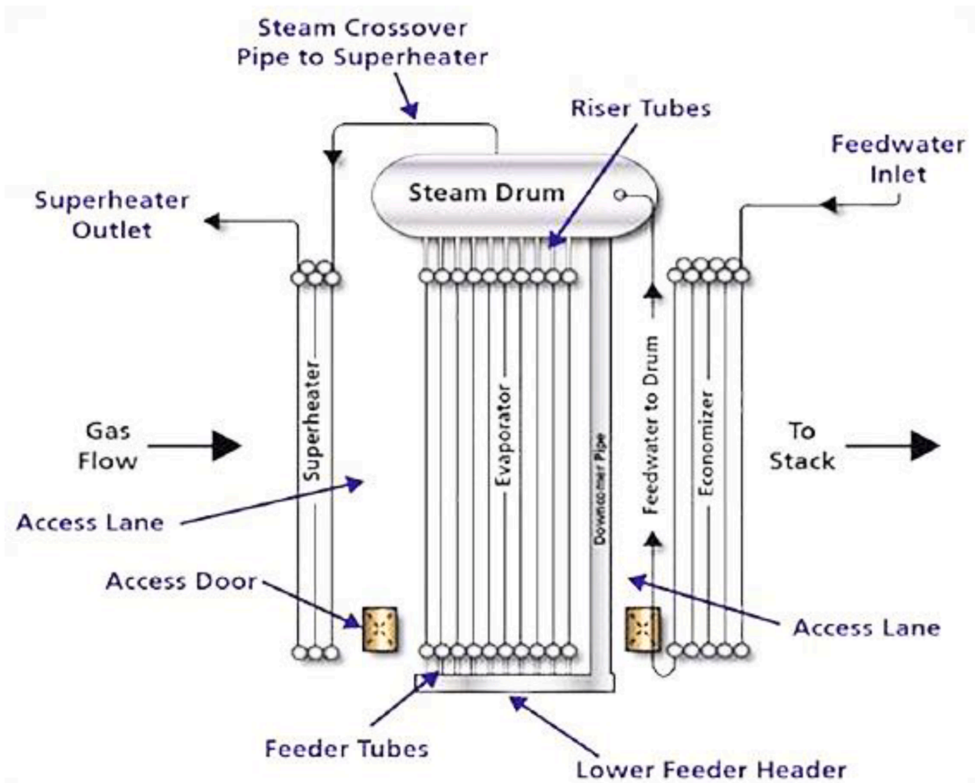

Fig. 12. Representation of a heat recovery steam generator [64].

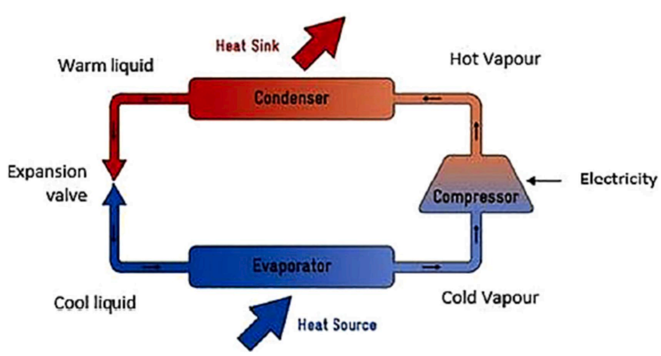

Fig. 13. Working principal of heat pumps [69].

systems are common in smaller units and often have a much greater height than a wide height [61]. It comprises of numerous considerable heat recovery components, including an evaporator, a superheater, an economizer, and a steam drum. It is claimed that system efficiencies of up to 75–85 % can be achieved when an HRSG generates steam [62]. The system consists of a steam drum and an evaporator section to convert water to steam. When the steam temperature rises above the saturation point, it is superheated. The steam drum is located above the evaporator, which is located between the economizer and the superheater. The steam required by the turbine is generated in the evaporator and then enters the steam drum and superheater. The steam generated during operation is then fed into a thermodynamic cycle to produce electricity and increase the productivity of the plant [63]. Fig. 12 shows the representation of heat recovery steam generator.

2.8. Heat pumps

A heat pump can convert a low-temperature waste heat stream into usable high-temperature heat. The mechanical heat pump is the most common of the many types of heat pumps that exist. Its working fluid, called "refrigerant," is compressed and expanded to produce heat. Evaporator, compressor, condenser, and expansion device are the four essential parts of a heat pump as shown in Fig. 13. A thermodynamic device that extracts heat from a heat source and transfers it to a heat sink with a minimum expenditure of energy [65]. There are three heat pumps: air-to-air heat pumps, water-to-air heat pumps, and geothermal heat pumps. Heat pumps extract heat from the air, water, or earth. When it comes to cooling or heating a space, heat pumps can be a more practical option than furnaces and air conditioners [66]. By transmitting the heat from a heat source to an evaporator to heat the refrigerant at minimal pressure, a heat pump employs a refrigerant cycle to create warm air and/or water. It works with similar principles as air conditioners and freezers. It is transported to a compressor where it is compressed into a high-level pressure, high-level temperature gas that may be transferred to a heat exchanger [67]. Heat pumps are advantageous for small-temperature waste heat recovery because they may raise the temperature and quality of waste heat. This was shown, for instance, in research by Baradey et al. [68] where it was found that the heat pump offered roughly 2.5 to 11 folds more useable energy relative to other waste heat recovery systems being used to generate a similar amount of heat.

2.9. Direct electrical conversion

Some systems can produce electricity right away from waste heat so that the heat does not first have to be converted into mechanical energy to generate electricity. These systems are sometimes more convenient than the other thermomechanical methods [70].

2.9.1. Thermoelectric generation

Thermoelectric generators can be used for thermoelectric conversion. Thermoelectric generators and solid-state semiconductor devices convert a temperature gradient and heat flux into a valuable direct current power source. Semiconductor thermoelectric generators use the

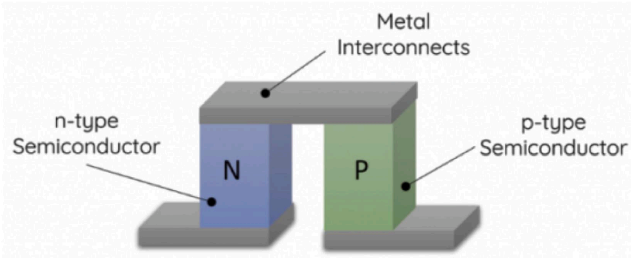

Fig. 14. Thermoelectric generator couple [74].

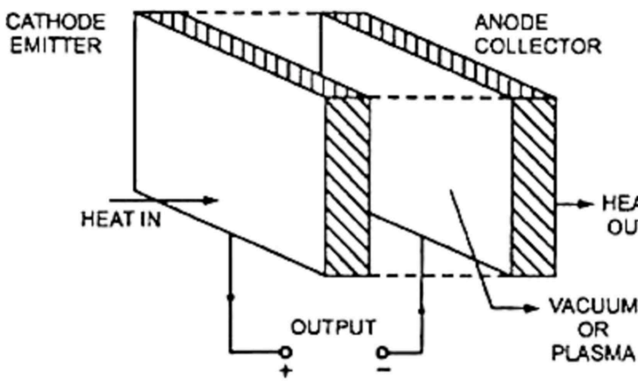

Fig. 15. Working mechanism of thermionic convertor [78].

Seebeck effect to produce voltage. The voltage generated drives the electric current, which generates usable power at a load. A thermocouple is the essential component of a thermoelectric generator [71]. A p-type semiconductor and an *n*-type semiconductor are mixed to form a thermocouple. A metal strip electrically connected in series connects the semiconductors. The semiconductors are sometimes called pellets or thermocouples [72]. The basic configuration of thermoelectric generation is shown in Fig. 14. In a study by Takashi et al. [73], waste heat was recovered by installing a thermoelectric generator system in the continuous casting plant of East Japan Works. At a slab temperature of about 915 °C and a slab width of 1.7 m, the thermoelectric production system generates a power of about 9 kW.

2.9.2. Piezoelectric power generation

Directly converting thermal energy into electricity at low temperatures can be done by piezoelectric power generation. Thin-film membranes make piezoelectric heat recovery devices that transfer ambient vibrations, such as oscillating gas expansion, into electricity. The limited efficacy, relatively high impedance, the requirement for long-term endurance, and the highly high cost of these systems prevent them from being used for effective energy recovery [75].

2.9.3. Thermionic power generation

Thermionic power converters, also known as thermionic generators, use thermionic emission to convert heat directly into electricity without first converting it into another form of energy. There are two electrodes in a thermionic converter. One of them is heated to the point where it can act as a "hot plate" or thermionic electron emitter. Because it captures the released electrons, the other electrode is called the collector and is used at a much lower temperature. Although a vacuum is occasionally present, the area between the electrodes is often filled with low-pressure gas or vapor. Waste heat energy sources can be used to generate thermal energy. Like how steam particles are released when water is heated, a hot plate releases an electron. The circuit can be closed by connecting the two electrodes to an external load – in this case, a resistor – and allowing the released electrons to flow to the collector [76,77]. Fig. 15 shows the working mechanism of the thermionic power converter.

Table 3
Waste heat outputs from the iron and steel industry [83].

Operation	Heat Type	Temperature (°C)
Sintering	Sinter flue gas	350–370
	Stack exhaust	300–400
	Sinter	700–800
Coking	Flue gas	250–270
	Coke	1000–1150
	Coke oven gas	650–1000
Iron making	Blast furnace slag	1450–1550
	Blast stove exhaust	200–300
	Blast furnace gas	200–500
	Cooling water from blast furnace	35–50
Steelmaking-Basic Oxygen Furnace	Basic oxygen furnace slag	1400–1800
	Linz-Donawitz gas	1600–1800
Steelmaking- Electric Arc Furnace	Exhaust gases with recovery	200–210
Casting	Steel latent heat	1200–1250
	Steel	1250–1650
Hot rolling	Hot rolled steel	800–1000
	Reheat exhaust	700–750

2.9.4. Thermophotovoltaic generator

Like solar panels, these devices immediately convert radiation into electricity. These systems use a radiator, a radiation filter, and a photovoltaic (PV) cell to generate electricity from a heat source and have proven potential to provide a novel technique for waste heat recovery [79]. The system uses a transmitter that produces electromagnetic waves when warmed by the heat source. Before the radiation being transformed into electric power by the PV cell, the spectrum filter makes sure that only radiation waves with the proper frequency to fit the PV cell are communicated. According to research, a TPV device's efficiency can vary depending on the radiation and heat transfer produced by the emitter and how the generator is arranged [80]. Alina et al. [81] reported on developing, measuring, and experimental demonstration of high bandgap tandem TPV cells with efficiencies greater than 40 %. The dual-junction TPV cells are designed for emitter temperatures between 1900 and 2400 °C and are made of III -V materials with band gaps between 1.0 and 1.4 eV.

3. Integration of waste heat recovery and applications

Waste heat is thought to be used after the leading energy has been fully utilized. By-product gas and waste heat are significant sources of secondary energy that are produced throughout the steel-making operations. Therefore, recovery technologies should also be evaluated compared to those employed to save primary energy. Such sources might be converted into steam or even other energy-producing forms, like electricity, heating, and refrigeration outputs, to meet the energy requirements of the iron and steel industries.

Waste heat may be recognized by segmenting the temperature distribution into low, medium, and high sources. Iron slag, steel slag, and high-temperature water are examples of high-temperature liquids; high-temperature sintering materials, high-temperature coke, and high-temperature steel are examples of high-temperature solid waste heat sources. High-temperature sources typically have temperatures above 500 °C. These include high-temperature coke oven gas, Linz-Donawitz gas, electric furnace gas, and flue gas from heating furnaces. The typical temperature range for medium-grade heat sources, such as BFG and sinter flue gas, is between 150 °C and 500 °C. Waste steam, hot water, all types of low-temperature flue gas, and low-temperature materials are low-quality heat sources that typically have a temperature of

Table 4
Overview of heat recovery for heating applications in the iron and steel industry.

Recovery technique	Process	Heat recovery technology	Benefit	Ref.
Regenerator and recuperative	Coking	Regenerative and recuperative burners enhance energy economy by including heat exchanger plates to capture and recycle the waste heat of the hot exhaust gas out from the coking operation.	Regenerators and recuperative are frequently used to produce steam for power production or heat recovery because they are good at retrieving heat from low to high-temperature exhaust gases	[20]
Regenerator	Iron making	To get over the drawbacks of burning highly lean gases, three cutting-edge preheated fuel gas burner techniques have been formed: dual regenerative air–fuel, oxy-fuel, and flat-flame burners.	Without natural gas enrichment, the average operating temperatures of the reheat furnaces (1350 °C) were achieved by preheating the BFG with the waste heat content of the flue gas stream, keeping NOx emissions below the European regulation limit.	[94]
Recirculation	Sintering	A recirculating system returns exhaust gas cooled by heat exchange to the cooler and then reuses it as a cooling gas for the sinter when exhaust heat is recovered from the colder exhaust gas. For this reason, recirculation systems are more effective than non-recirculation systems.	It is possible to convert up to 60 % of the waste heat from the sinter cooler into steam or electricity. Moreover, with this system, the waste heat of the boiler, which has a temperature of about 180 °C, will be reused in the cooler and not discharged into the atmosphere.	[95]
Waste heat boiler	Steel making	To raise the temperature of the input products to the working temperature of the processes in the supply chain, 9.7 GJ/t is required out of a total net energy consumption of 17.3 GJ to produce one ton of hot-rolled steel. So, it has been retrieved using the application of a waste heat boiler.	A system-wide pinch analysis determined a maximum energy saving for heat recovery of 4.3 GJ/t. Case A saves 2.5 GJ/t by integrating process heat recovery throughout the supply chain, while Case B saves 3.0 GJ/t by recovering heat from hot steel streams.	[15]
Heat pipe (radial)	Coking	The 4.3 m high coke oven of a domestic company was successfully operated with the eccentric radial heat pipe. The main machinery ran stably, produced enough steam to meet the requirements, and provided good pressure control at the bottom of the furnace stack.	This technology can produce saturated steam as a by-product while fundamentally solving the problem of direct flue gas emissions. Flue gas heat was recovered cost-effectively to minimize steel consumption per ton of steam through optimized selection and rational design.	[96]
Heat pipe exchanger	Steel making	An experimental plant for waste heat recovery was built to investigate the characteristics of a heat pipe heat exchanger (HPHE) used to recover waste heat in a slag cooling process in the steel industry.	The ideal mass flows for wastewater and cold water are calculated to be 1.40 and 2.90 m3/h, respectively. In addition, the research in this study has supported the effects of on-line cleaning systems on heat transfer and fouling cleaning.	[82]
Flat heat pipe exchanger	Cooling process of steel wires	A new heat recovery system based on a flat heat pipe (FHP) heat exchanger is designed, fabricated, and tested. The FHP system comprises an upper and a lower tube header connected by stainless steel heat pipes. The thermal performance of the FHP has been studied both in the laboratory and in an industrial plant.	The FHP recovered a heat output of about 5 kW in laboratory tests. Since the device is one meter long and the production line is 70 m long, about three-quarters of a megawatt, can be recovered in such an industrial plant. In the industrial experiments, much larger heat recovery could be achieved, on the order of 10 kW.	[97]

less than 150 °C [82]. Waste heat sources from the iron and steel industry are summarized in Table 3.

Slag is a byproduct of the processes used to make iron and steel. Typically, between half a ton and a ton of slag is produced for every ton of rolled steel or iron. Reportedly, 1.9 billion tonnes of steel were produced worldwide in 2016, suggesting that at least 1 billion tonnes of slag are produced annually. Slag production is enormous, so it needs to be managed properly. The simplest and most common option for managing slag is landfilling. However, costs continue to rise as land space becomes scarce and environmental regulations become more stringent [84]. Slag is an unavoidable byproduct of steel production. Slag is produced during iron and steel production in two ways: Iron slag (blast furnace slag) and steel slag (oxygen slag and electric arc furnace slag). The manufacturing processes and the feedstock's composition influence the slag composition [85]. Slag can also be utilized in various other applications, such as the cement industry, catalysts, water treatment, and gas treatment [86].

Iron and steel production's waste heat recovery ability is mainly concentrated in the medium–high temperature range. Due to filthy and low-grade waste heat, recovery methods encounter difficulties and limitations. However, waste heat energy from the iron and steel industry can be used for three main purposes: heating, cooling, and direct power generation. Each of these approaches to use has its advantages and limitations.

3.1. Integration of waste of recovery for heating

Heat exchangers have been most examined in the iron and steel industry field of waste heat utilization. Heating and preheating are performed using recuperators, regenerators, and heat pipes [87]. Types of recuperators include simple radiation, convection, tubular heat, mixed radiation, and convection. These types are based on how the heat is transferred. Usually, high-temperature heat is transferred, which comes from ceramic or metallic materials [88]. Coke ovens used to preheat hot blasts and blast furnaces for iron production are usually equipped with regenerators. Regenerative furnaces consist of two grate chambers, one containing the refractory material. The grid is heated or "regenerated" with the hot exhaust gases exiting the furnace in the other chamber as the combustion gases flow through in the first chamber. The flow is reversed, and the furnace runs alternately, allowing the heat exchanger to heat the fresh combustion air [89]. As a typical heat exchanger in steel mills, waste heat boilers are used to recover heat from medium to high-temperature waste gases. The steam they produce can either be used to generate electricity or fed back into the system for energy recovery [90]. Coke dry quenching, in which hot coke is quenched with inert gases, allows the sensible heat of the coke to be recovered and used to generate steam in a boiler further downstream [91]. The passive gas-to-gas air preheater for low to medium temperatures, which may be roughly classified into the plate type and the heat pipe, is yet another heat recovery device. The most prevalent form of the plate contains several parallel plates for the passage of both hot and cold gas [92]. It is particularly encouraging that heat pump systems may draw heat from a variety of sources of heat. For instance, a crusher and screening plant, district heating for plant areas and offices cooling water in the iron and steel sector that might be utilized as coke's antifreeze [93]. Table 4 shows an overview of heat-to-heat integration studies in iron and steel industry.

3.2. Integration of waste of recovery for cooling

Radiant energy, cooling fluid, hot exhaust gases, and other forms of energy can be used to absorb waste heat. This waste heat energy can be used for work because it is rich in useful energy. The iron and steel industry, one of the most energy-intensive industries, accounts for about 4–5 % of total global energy consumption [19]. Just as waste heat can be

Table 5
Case studies for waste heat to cooling technologies.

Waste heat type	T (^{O}C)	Cooling cycle	Working pair and 2nd cycle	Research results	Ref.
Exhaust gas	350	Absorption	NH_3-H_2O/ Kalina cycle	It is proposed to use a combined cooling and absorption cycle. The exergy efficiency is 37.3 %, and the total thermal efficiency of the process is 24.2 %.	[103]
Exhaust gas	450	Absorption	NH_3-H_2O/ Kalina cycle	Ammonia-water cycle is proposed for the simultaneous generation of electricity and cooling. The cogeneration system reduces energy consumption by 18.2 %.	[104]
Hot water	140	Absorption	NH_3-LiBr-H_2O/ Organic Rankine cycle	The system achieves a thermal efficiency of 38 % and an energetic efficiency of 26 %, which means that it can cover the entire space cooling demand of the building (45.6 kW)	[105]
Hot water	>70 °C	Absorption	NH_3-LiBr-H_2O/ Organic Rankine cycle	According to the simulation results, the combined cycles' output power and thermal efficiency increased by 5 % and 1.5 %, respectively.	[106]
Flue gases	250 °C	Adsorption	Silica gel + H_2O	Two systems are cascaded to generate 3 MW of electricity and 0.05 MW cold.	[107]

used for heating, it can also be used for cooling. Another area where low-quality heat recovery is being studied is thermally driven cooling. Due to its operating concept, the comparatively low temperature of the waste heat source is further utilized compared to the power generation cycle. To achieve a cooling effect, various thermal cycles such as the absorption cycle and the adsorption cycle can be used [98]. An absorption process works on the principle of separating and recombining two liquids (refrigerant and absorbent) to produce a cooling effect. Lithium bromide cycle or ammonia-water absorption refrigeration systems are the two most common types. In the first cycle, water serves as the absorbent, while ammonia-water solution serves as the refrigerant. In the second cycle, lithium bromide serves as the absorbent and water as the refrigerant. Ammonia-water vapor absorption technology is preferred by most industrial chillers for the reasons mentioned below [99]:

- Ammonia is very soluble in water.
- Ammonia water absorption chillers operate under positive pressure, minimizing maintenance issues and increasing the machine's durability.
- Extreme weather conditions won't affect an ammonia-water absorption chiller (high condensation and low evaporation temperature).
- Condenser is compatible with air cooling (zero water consumption).

Adsorption refrigeration is an environmentally friendly cooling method powered by low-value heat sources such as recovered waste heat. The energy needed for the cooling process in an absorption chiller comes from a heat source [100]. Two coolants are used in the system; the first coolant performs evaporative cooling before being absorbed by the second coolant; heat is needed to return the two coolants to their initial state [101]. Currently, the only commercial device with a desorption temperature as low as 55 °C is a silica gel-based water adsorption chiller [102]. Table 5 lists studies and examples of thermally driven refrigeration systems commonly used in the steel and iron industries.

3.2.1. *District cooling system (DSC) using waste heat*

A variety of industrial activities usually generates waste heat. Radiant energy, cooling fluid, hot exhaust gases, and other forms of energy can be used to absorb waste heat [108]. This waste of heat energy can be used for work because it is rich in useful energy. The iron and steel industry is one of the most energy-intensive industries, accounting for about 4–5 % of global energy consumption. Waste heat utilization has excellent potential in the iron and steel industry [109,110]. The two main classifications of DCS are decentralized and centralized. Decentralized DCS is suitable for large-scale regions; the energy conversion equipment is in almost every building before being distributed to other buildings. The energy conversion technologies are located outside the buildings, and the required energy then flows toward the buildings through the DCS network, using a centralized DCS, which is suitable for more small capacities [111]. In the iron and steel industry, the building temperature requirements can be met by running DSC using waste heat streams.

3.3. *Integration of waste heat recovery for power generation*

When no heating, cooling, or other requirements are met, electricity-generating technologies are still considered the primary energy conversion technologies for low-value heat recovery [112]. When it comes to varying heat source temperatures, thermally driven power generation technologies have a variety of thermal cycles. A typical thermodynamic cycle that converts waste heat to mechanical energy is the Rankine cycle. Power plants that run on coal or nuclear energy often use the Rankine cycle, also known as the Rankine steam cycle. In this mechanism, fuel generates heat in a boiler and turns water into steam, which expands through a turbine to do useful work. Through this thermodynamic cycle, heat is converted into mechanical energy, which is often converted into electricity through electrical generation. Fig. 16 shows the working principal of the Rankine cycle [113]. The stages of the Rankine cycle, as shown in Fig. 16, and their associated stages are Pump: a pump is used to compress the fluid to high pressure. Boiler: When the compressed liquid is heated to its final temperature, the boiling point, a phase transition from liquid to vapor occurs. Turbine: Steam expansion in the turbine, and condenser: The steam condenses in the condenser, where the waste heat is transferred to the eventual heat sink [114].

When using a low-temperature heat source, the organic Rankine cycle and the Kalina cycle perform better than the Rankine cycle. The organic Rankine cycle is like the Rankine steam cycle but uses an organic medium such as refrigerant or hydrocarbons instead of water as the working fluid [116]. In the Kalina cycle, an ammonia-water mixture is used as the working fluid to increase the thermodynamic efficiency of the system and provide greater flexibility under different operating conditions. Depending on the application, the Kalina-Cycle can increase the efficiency of power plants by 10 to 50 % compared to the Rankine-Cycle [117]. In addition, technologies for direct power generation from

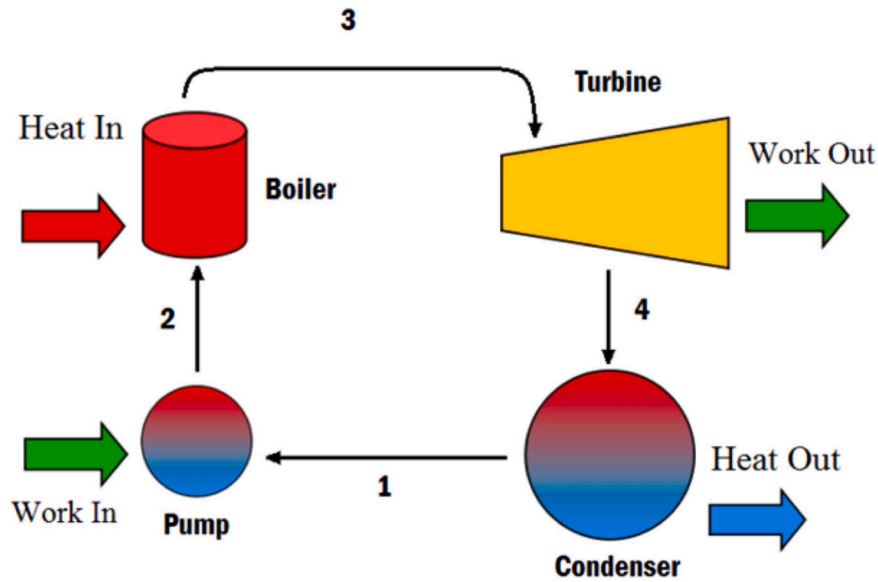

Fig. 16. Working principle of the Rankine cycle [115].

Table 6
Waste heat to power generation technologies [122].

Power generation cycle	Type of thermal source	Average temperature (^{O}C)	Thermal efficiency (%)
Rankine cycle	Furnace exhaust	350–500	25–40
Kalina cycle	Furnace and boiler exhaust	100–450	20–35
Organic Rankine cycle	Boiler or furnace exhaust	100–300	5–10
Thermophotovoltaic	Casting process waste	900–1600	2–8

heat are currently being explored, such as thermophotovoltaic systems. A photovoltaic cell, like a solar cell tuned to the spectrum irradiated by the hot object, forms the basic components of a thermophotovoltaic system. The efficiency of thermophotovoltaic systems is often low because they operate at lower temperatures than solar cells [118–120]. Table 6 lists the many aspects of waste heat recovery cogeneration cycles, including the type of heat source, temperature range, and thermal efficiency. Bradley Orr et al. [121] demonstrated the potential of producing power from waste heat using thermoelectric generators. It was found that the waste heat recovery system of a 500 MW gas turbine power plant could provide 5.9 MW of electricity.

4. Application of heat integration in steel and iron industries

It is important to remember that the integrated steel mill is a complex network of entities exchanging materials and energy. Considering the conditions of the iron and steel sector, the sources of waste heat are distributed among different units. This would make it difficult to use the resources of a particular industrial area. Therefore, appropriate energy conversion technologies must be present not only in a single unit but also at the systemic level. A systems approach is required to increase overall site efficiency and create an ideal thermal mass network.

The iron and steel industry has used general system optimization techniques to achieve energy and material efficiency while avoiding sub-optimization. The standard optimization approaches include mathematics programming, exergy analysis, and pinch analysis. Pinch analysis is a technique for reducing energy consumption in industrial processes by determining the minimum amount of energy consumed while still being thermodynamically feasible, then optimizing heat recovery systems, energy supply strategies, and process operating conditions to achieve these goals. Johan Isaksson et al. [123] performed a pinch analysis for reducing energy consumption in chemical reactions by determining the minimum amount of energy that can be consumed while still being thermodynamically feasible, and then optimizing heat recovery systems, energy supply strategies, and process operating conditions to achieve these goals. This study shows that pinch analysis is effective for several subsystems, especially for the coke oven gas cleaning system. Carl-Erik Grip et al. [124] conducted a pinch analysis study for the location of the Lulea Integrated Steel Mill. The coke plant and the steelmaking facility each have three tiers of prospective upgrades. According to the study's findings, pinch analysis is a useful technique for concentrating energy savings on areas like the coke plant's gas-cleaning region, where thermal energy fluxes predominate the local energy system. The research also made a case for a connection between both the energy systems in the coke plant and the methods utilized to make iron and steel. Kazuo Matsuda et al. [125] investigated a major steel mill to a complete concept of pinch analysis using a "Total Site Profile (TSP) Study." It was also demonstrated that, despite the very high efficiency of the plant's various process systems, the application of this strategy would significantly impact energy savings. In the past, steel mills have not effectively used waste thermal energy below 300 °C. However, analyzing TSP made it possible to identify the location and amount of this heat, which allowed the development of energy-saving strategies.

Ningwen Xu et al. [126] conducted a pinch analysis on liquid slag. At 1450 °C, a significant volume of liquid slag is generated in the iron and steel sector, and its efficient recovery is a key step in lowering energy usage. When designing the slag granulator system, the waste heat recovery system was optimized using the pinch analysis approach to analyze the design system data. The supply system may be built to give the minimal heating and cooling heat of 20895.74 kJ/s and 1108.75 kJ/s, respectively, to satisfy the goal of energy savings and consumption reduction. Abrar Inayat et al. [127] performed a case study of building cooling requirements using an absorption chiller and waste heat from a cast iron plant in Sharjah, United Arab Emirates. The heat integration technique was used in conjunction with pinch analysis and the problem

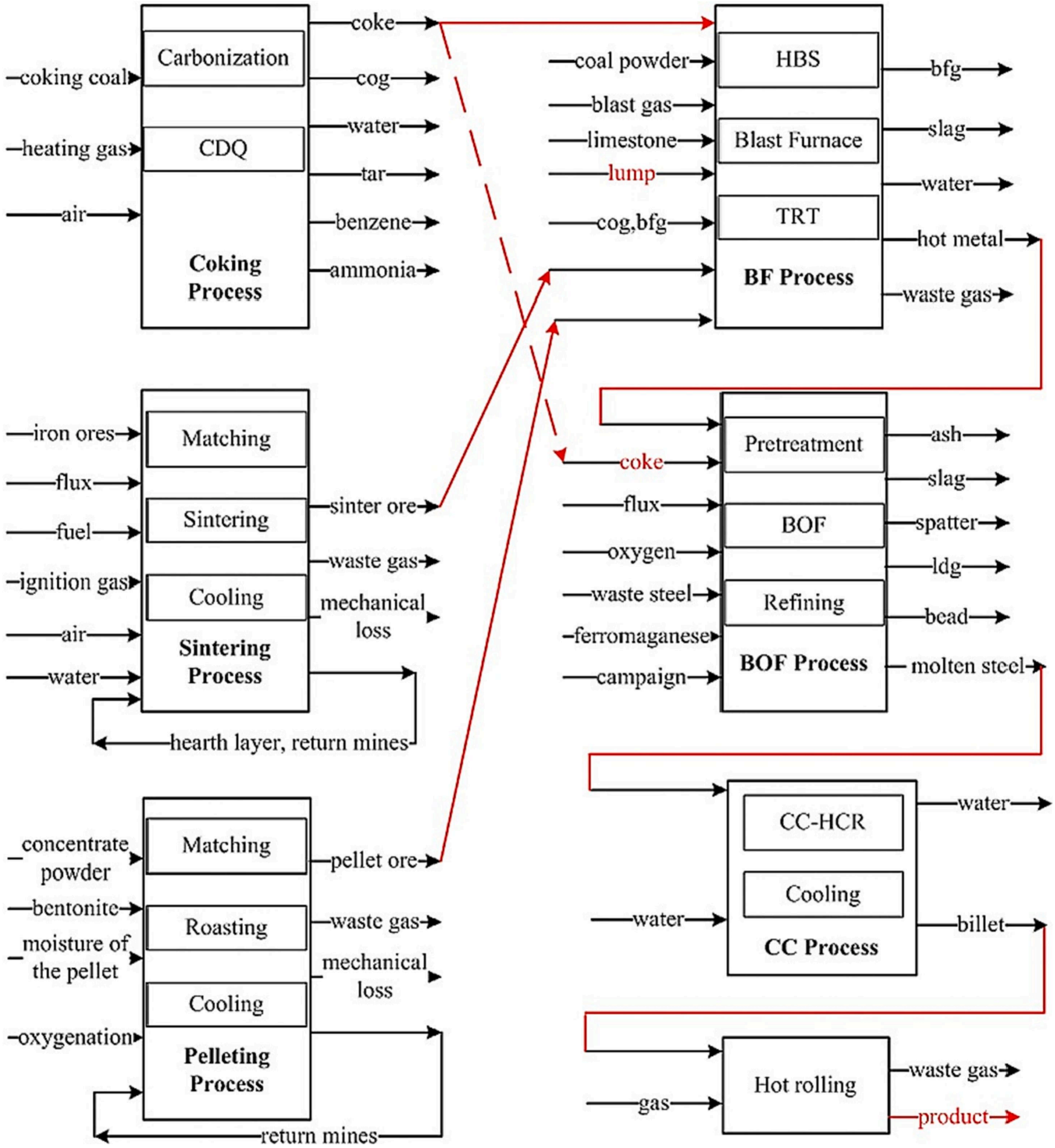

Fig. 17. Mass-thermal network of iron and steel industry [134].

table algorithm to determine the minimum hot and cold-water supply. 8,793 W and 1,600 W were projected as the minimum hot and cold supplies. At 30^{O}C, the pinch point was detected with an energy recovery rate of more than 80 %. Tianyi Yan et al. [128] conducted a mixed-integer linear programming model based on the theories of exergy and energy level to solve the illogical energy distribution and excessive energy waste in the iron and steel sector steam system. The findings indicate that the steam system has an energy efficiency of 74.065 %. After optimization, the iron and steel industry's energy consumption drop by 84.30 MJ t^{-1}-CS^{-1}, the steam system's energy efficiency rises by 10.568 %, and the energy waste potential of hot rolling and sintering is identified. Kadir Yılmaz et al. [129] evaluated both conventional and increased exergy in an existing steam power plant utilizing the exhaust gases produced in iron and steel production facilities. The study's findings demonstrate that the system's traditional and increased energy efficiencies are 60.7 % and 83.7 %, respectively. The system's progress capability is evaluated to be 24.8 % (low) and 74.5 % (high), respectively, as is the interface between its parts. Qi Zhang et al. [130] presented the combined model includes long-distance iron and steel production with coking, sintering, iron, steel, and hot rolling processes, as well as a complicated energy network that includes steam, electricity, and byproduct gases. The results show that compared to the original data, the total optimal site *SEC*, and the total site DCE have decreased by 14.07 % and 6.65 %, respectively. The analysis also shows that most factors have a relationship between energy consumption and CO_2 emissions in terms of co-efficiency. Ismael Matino et al. [131] showed an analysis to optimize the use of by-products in an integrated steel plant in Italy, paying particular attention to internal recycling during the palletization process. The study shows that a certain scenario can minimize environmental impacts and costs and produce high-quality pellets with a certain "winning formula" (65 wt% BOF slag, 27 wt% BOF sludge, 1 wt% dolomite, 7 wt% cement). These preliminary results suggest that good byproduct management could offer significant benefits to companies by helping to achieve the "zero waste" goal. Haining Kong et al. [132] presented a distribution of byproduct gases is optimized using a dynamic mixed integer linear programming (MILP) model for multi-period optimization. The case study shows how well the proposed strategy reduces the total cost. Compared to the previous model, a total of 5 % less of the total cost is spent. Evaluations of the sensitivity of electricity and fuel oil prices are also performed.

Yan Liu performed a numerical study to evaluate the cascading use of waste heat in the sinter cooling bed [133]. Using Computational Fluid Dynamics, a two-dimensional unstable mathematical model is created to represent the three-dimensional uniform flow and heat transfer in the sinter cooling bed. This significantly reduces the computational time. The results indicate that increasing the height of the sinter cooling bed, the speed at which the trolly moves, and the sinter heat flux increases both the quantity and quality of waste heat recovery. In addition, it was found that the amount and quality of waste heat in the sinter cooling bed would not increase simultaneously with different allocations of cooling air flow.

The core principle of mass thermal network optimization in all related studies, which typically consists of five steps, seeks to locate the most significant energy potential and construct economically optimal networks that connect usable utilities and supply systems. First, data collection takes place. This step collects information on all facilities and activities, including each utility's respective volume, temperature and pressure, hot and cold vapors, the distance required for heat transfer, and all other factors. The next step is to identify all energy sources and sinks so that the exergy indicator can show the energy potential. The final phase is to establish a link between the origin and other utilities, including potentially new exploitable utilities. The fourth phase is to determine the maximum potential. The last phase is designing the best energy recovery and reuse networks. In this technique, multi-objective optimization based on mathematical programming is considered.

4.1. Mass thermal network in the iron and steel industry

Many plants in the steel industry with several utilities and various chemical and thermal processes convert raw materials into goods. These processes together form the mass-thermal network, a sophisticated production system. The network, which is the basic element of the entire system, has a considerable number of parameters and interactions. The typical mass network of the iron and steel industry consists of several important energy-saving technologies used in each unit. Mass networks aim at continuous and compact production to reduce energy demand and consumption [134]. A complex mass-thermal network of the iron and steel industry is shown in Fig. 17.

5. Conclusion and outlook

The iron and steel industry is one of the most important economic sectors, but it also consumes a lot of energy and causes a high environmental impact. The iron and steel industry consumes about 10 to 15 % of the world's energy, and its CO_2 emissions account for about 7 % of total anthropogenic CO_2 emissions. Waste heat recovery systems are introduced according to the three main categories of heat loss – high temperature, medium temperature, and low temperature. Regarding applicability and effectiveness, essential variables such as quality, quantity, and type of heat source greatly influence the choice of heat recovery methods and techniques. This review focuses on the performance and operation of waste recovery technologies, including waste heat boilers, recuperators, regenerators, combustion regenerators, rotary regenerators or heat wheels, passive air preheaters, regenerative and recuperative burners, plate heat exchangers, and economizers. Next, the possibilities of waste heat for heating, cooling, and power generation are discussed in detail concerning the iron and steel industry. It is shown that energy and cost savings can be achieved with each technology. It has also been shown that most research studies use a combination of pinch analysis, exergy analysis, and mathematical modeling to identify and optimize energy waste. This review is the first to provide a systematic approach to a comprehensive algorithm of the knowledge of waste heat recovery technology in iron and steel plants. It is suggested to escalate the research focus on the practical implementation of waste heat recovery studies in the iron and steel industry. For future studies, it is expected that more case studies should be done on local iron and steel plants and industries where waste heat recovery technologies are ignored/or not implemented.

CRediT authorship contribution statement

Abrar Inayat: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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