

1.1 Introduction to the idea of waste heat recovery

Energy is the capability to do work and it is the basic need for the survival and growth of human life. Today world is facing energy crises as the sources of energy are limited in nature. Main sources of energy are Coal, Petroleum, Natural gas, hydroelectric power and nuclear power which grants for the energy needs of an economy. Most of the above sources of energy are exhaustible and get exhausted in few years. The trepidation of release of radioactivity into the environment in the case of an accident in nuclear power plant or from nuclear waste has strained people to think again about the use of nuclear power. In view of these problems related with conventional energy sources, the centre is now changing to conservation and efficient utilization of energy.

We know that in an integrated steel plant large quantity of heat input is required for the production of steel. This heat is obtained from the coal which is a fossil fuel and limited in nature, so it must be used judiciously and efficiently. The heat obtained from the coal in steel plants is used in Blast furnace for the production of hot metal, steel melting & casting of slabs, in soaking pits of slabbing mill and for hood annealing. Out of this heat input large quantity of heat is released in to the environment as a waste energy.

Waste heat energy could be recovered by means of a waste heat recovery system and can be used in different processes. Vapour absorption Air conditioning is one of the processes where we can use this waste heat to provide air conditioning in different areas of the steel plant.

By adopting waste heat energy recovery method the overall energy efficiency of the steel plant will improve.

1.2 Major Components of the system:

- Source of waste heat
- Waste heat recovery unit
- Vapour absorption air conditioning unit

1.3 Recovery of Waste Heat

Waste heat is a thermal energy which is produced in a process by means of exploitation of energy sources such as combustion of fossil fuels like coal, petroleum and natural gas or any other exothermic chemical reaction, and then this energy is rejected into the environment even though this energy can be reused for various useful and economic purposes. The important quality of heat is not its quantity but to a certain extent its value. The approach for the recovery this energy depends on the temperature of the waste heat gases and the economics concerned with recovery unit. Huge amount of flue gases having large amount of waste heat are produced from Boilers, Ovens, Kilns and Furnaces. If only small amount of this waste heat could be recovered then a considerable amount of primary fuel can be saved. As we know that energy lost in waste gases cannot be completely recovered. However, lot of the heat energy could be recovered and losses can be reduced by adopting following measures as given in this chapter.

1.3.1 Heat Losses (Quantity)

In every condition of heat recovery it is necessary to calculate the amount of heat energy that can be recovered and also essential to know how this energy can be utilized. Heat recovery from the annealing furnace or the entities coming out of the annealing furnace is an example of waste heat availability. The exhaust gases are coming out at 1123K at the rate of 2150 m³/hr from Annealing furnace. The total heat energy that can be recovered at 175°C from the final exhaust can be calculated as:

$$Q = V \times \rho \times C_p \times \Delta T$$

Q is the heat content in kCal

V is the flow rate of the substance in m³/hr

ρ is density of the flue gas in kg/m³

C_p is the specific heat of the substance in kCal/kg/°C

ΔT is the temperature difference in °C

C_p (Specific heat of flue gas) = 0.24 kCal/kg/°C

Heat available (Q) = 2150 × 1.19 × 0.24 × ((850 - 175)) = 431827 kCal/hr

By using a recuperator in the above process the preheating of combustion air can be done by recovering this heat energy. The total fuel saving could be 32.99% (At the rate of 1% fuel diminution for every 22°C diminution in the temperature of flue gas).

1.3.2 Heat Losses (Quality)

The heat can be released at any temperature from the cooling water to exhaust gases at high temperature from an Industrial furnace, Oven or kiln is depend on the type of process. Generally higher the temperature of the source, higher the quality of heat and economical is the recovery of the waste heat. In the study of recovery of waste heat, it is important that the recovered heat energy should be utilized. Some of the examples of use of waste heat energy could be space & room heating, preheating of combustion air, preheating of feed water for the boilers in Thermal power plants or to preheat process water. During the recovery of heat from the high temperature source cascading is required, a cascade system may be adopted to assure that the maximum waste heat energy recovery. The system in which the high temperature phase is used for air preheating and the low temperature phase is used for heating process feed water or steam production is an example of this method.

1.3.3 Classification & Application

During the consideration of the potential for waste heat energy recovery, it is helpful to note all the options, and grading the waste heat energy in terms of potential value as given in the following table:

S.No.	Source	Quality
1.	Heat in flue gases.	The higher the temperature, the greater the potential value for heat recovery
2.	Heat in vapour streams.	As above but when condensed, latent heat also recoverable.
3.	Convective and radiant heat lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats.
4.	Heat losses in cooling water.	Low grade – useful gains if heat is exchanged with incoming fresh water
5.	Heat losses in providing chilled water or in the disposal of chilled water	a) High grade if it can be utilized to reduce demand for refrigeration. b) Low grade if refrigeration unit used as a form of heat pump.
6.	Heat stored in products leaving the process	Quality depends upon temperature.
7.	Heat in gaseous and liquid effluents leaving process.	Poor if heavily contaminated and thus requiring alloy heat exchanger.

Table-1 Waste Heat Source and Quality

1.3.4 Heat Recovery at High Temperature

The Table-2 gives the temperatures of waste gases from different industrial process equipment in high temperature range. All of the waste heat energy in this temperature range comes from direct fuel fired processes.

1.3.5 Heat Recovery at Medium Temperature

The Table-3 gives the temperatures of waste gases from different industrial process equipment in the medium temperature range. Most of the waste heat energy in this temperature range comes from the exhaust of the directly fired process systems.

Types of Device	Temperature, °C
Nickel refining furnace	1370 –1650
Aluminium refining furnace	650–760
Zinc refining furnace	760–1100
Copper refining furnace	760– 815
Steel heating furnaces	925–1050
Copper reverberatory furnace	900–1100
Open hearth furnace	650–700
Cement kiln (Dry process)	620– 730
Glass melting furnace	1000–1550
Hydrogen plants	650–1000
Solid waste incinerators	650–1000
Fume incinerators	650–1450

Table-2 Waste heat temperature at high temperature range from different sources

Type of Device	Temperature, °C
Steam boiler exhausts	230–480
Gas turbine exhausts	370–540
Reciprocating engine exhausts	315–600
Reciprocating engine exhausts (turbo charged)	230–370
Heat treating furnaces	425–650
Drying and baking ovens	230–600
Catalytic crackers	425–650
Annealing furnace cooling systems	425–650

Table-3 Waste heat temperature at medium temperature range from different sources

1.3.6 Heat Recovery at Low Temperature

The Table-4 given below shows some of the heat energy sources in low temperature range. Within this range it is normally not practical to extract work from the source though the production of steam may not be completely excluded if there is a need of low pressure steam. Low temperature waste heat energy may be useful in a complementary means for preheating purposes.

Source	Temperature, °C
Process steam condensate	55–88
Cooling water from:	
Furnace doors	32–55
Bearings	32–88
Welding machines	32–88
Injection molding machines	32–88
Annealing furnaces	66–230
Forming dies	27–88
Air compressors	27–50
Pumps	27–88
Internal combustion engines	66–120
Air conditioning and refrigeration condensers	32–43
Liquid still condensers	32–88
Drying, baking and curing ovens	93–230
Hot processed liquids	32–232
Hot processed solids	93–232

Table 4 Waste heat temperature at low temperature range from different sources

1.4 Advantages of Recovery of Waste Heat: Advantages of waste heat recovery can be classified in two categories:

1.4.1 Direct Advantages:

Recovery of waste heat energy has a direct impact on the efficiency of the process, which can be shown by the diminution in the energy consumption by the utilities and process cost.

1.4.2 Indirect Advantages:

- a) Diminution in pollution: A number of harmful combustible waste substances such as carbon monoxide & sour gas, carbon black, oil sludge, Acrylonitrile and some other plastic chemicals etc, rejected to the environment. If these

substances are burnt in the incinerators then they fulfil dual purpose i.e. heat recovery and reduces the environmental pollution levels.

- b) Diminution in size of equipments: Recovery of waste heat reduces the consumption of fuel which leads to the diminution in the flue gas production. This results in diminution in size of all equipments for flue gas handling such as fans, stacks, ducts & burners, etc.
- c) Diminution in consumption of energy by auxiliaries: Diminution in the size of equipments gives additional advantages in the form of diminution in energy consumption by the auxiliary energy such as electricity for fans & pumps etc.

1.5 Development of a Waste Heat Recovery Unit

The understanding of the idea of heat recovery method and its working process is necessary for development of Waste heat energy recovery unit. This can be fulfilled by reviewing the process flow sheets, piping isometrics, layout diagrams, electrical and instrumentation cable ducting etc. Detail reassessment of these documents will help in identifying:

1. Energy source for waste heat.
2. Uses of recovered energy.
3. Sudden situations going on in plant due to waste heat energy recovery.
4. Space availability.
5. Some other constraints, such as dew point occurring in an equipment etc.

After the identification of the sources of waste heat energy and the feasible use of this energy, the next step is to select suitable recovery unit for the recovery of waste heat and some other equipment's to recover & utilise this waste heat.

1.6 Economic Assessment of a Waste Heat recovery Unit

It is necessary to check the economic feasibility of any system for its economic success, for this it is essential to assess the selected waste heat energy recovery system on the basis of financial analysis such as investment, depreciation, payback time, rate of return etc. Next section gives a concise depiction of general heat energy recovery devices available commercially and its industrial applications.

1.7 Devices for Recovery of Waste Heat

1.7.1 Recuperators

Recuperator is a kind of heat exchanger which is used to recover waste heat by means of indirect contact of the heat exchanging medium. In a recuperator, heat exchange takes place between the flue gases and the air with metallic or ceramic walls. Duct or tubes carry the air for combustion to be preheated; the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Figure-1

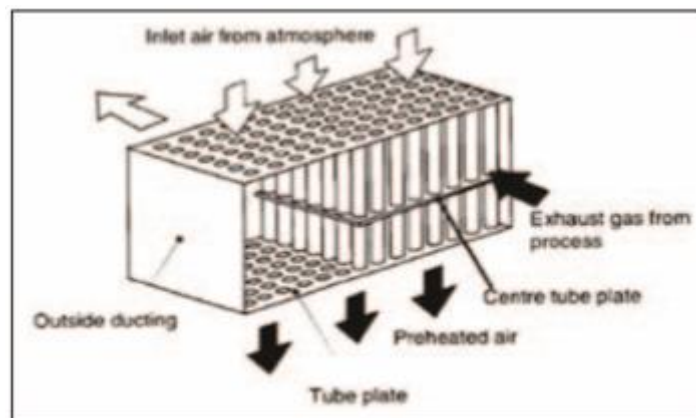


Fig-1 Waste heat energy recovery using a recuperator

1.7.1.1 Metallic Recuperator

One of the simplest structures for a recuperator is the metallic radiation type recuperator which consists of two concentric metal tubes as shown in Figure-2.

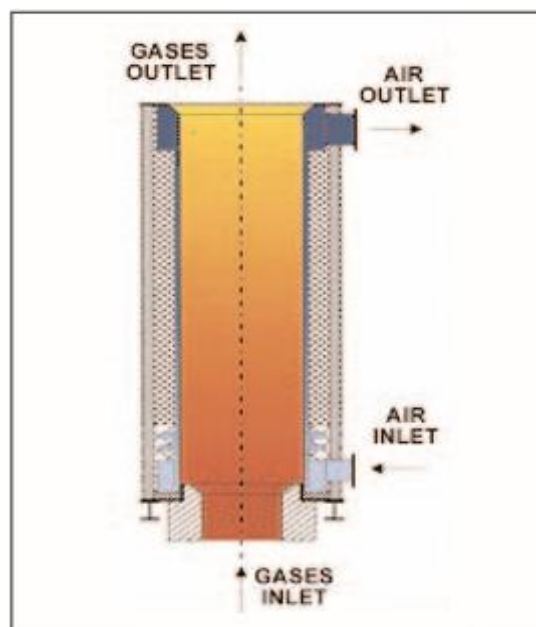


Fig-2 Metallic Radiation recuperator

Inner tube of the recuperator carries the hot exhaust gases on the other side external annulus carries the combustion air from the ambient to the air inlets of the burners. The hot gases are cooled by the incoming combustion air which then carries additional heat energy into the combustion chamber. This is energy which does not have to be supplied by the fuel, consequently reduces the fuel consumption for a given furnace loading. The reduction in fuel consumption also causes the reduction in combustion air and therefore stack losses are reduced not only by lowering the stack exhaust gas temperatures but also by rejecting smaller amount of exhaust gas in to the environment. The radiation recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer. The cold air in the annuals, however, is almost transparent to infrared radiation so that only convection heat transfer takes place to the incoming air. As given in the figure of the recuperator, the two gas flows are generally parallel, although the configuration would be simpler and the heat transfer is more efficient if the flows were opposite in direction (or counter flow). The cause for the use of parallel flow of the gases is that the recuperators serves the additional function of cooling the duct carrying the exhaust gases and consequently extending its life.

1.7.1.2 Convective Recuperator

Another common structure for recuperators is called the tube type or convective recuperator. Given in the figure-3

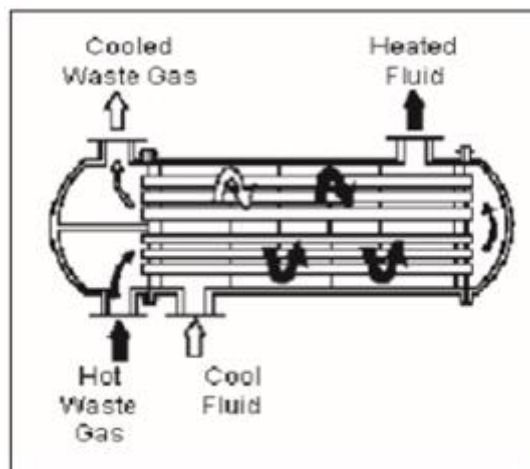


Fig-3 Convective recuperator

The hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes. If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger is termed a two pass recuperator if two baffles are used, a three pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell and tube type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area, which is possible through the use of multiple tubes and multiple passes of the gases.

1.7.1.3 Radiation cum Convective type Hybrid Recuperator

To improve the effectiveness of heat transfer, combination of radiation and convective designs is merged, with the high temperature radiation recuperator being first followed by convection type. Radiation cum Convective type Hybrid Recuperators are more costly than simple metallic radiation type recuperators, but are not as much of bulky. A Convective cum radiative Hybrid type recuperator is given in Figure-4

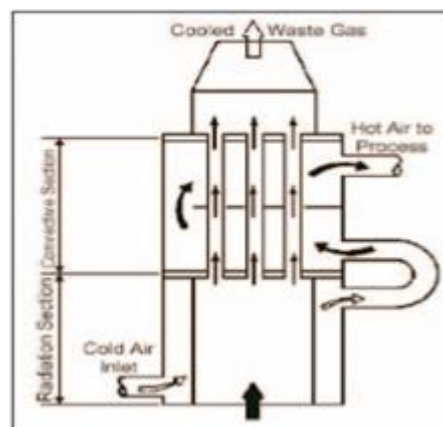


Fig-4 Convective cum Radiative recuperator

1.7.1.4 Ceramic recuperator

The major drawback on the recovery of waste heat from metallic recuperators is the short life of the liner at inlet temperatures more than 1100°C. Therefore to overcome the temperature limitations of metallic recuperators, ceramic recuperators have been developed which materials allow operation on the gas side up to 1500°C & on the preheated different kinds of short silicon carbide tubes which can be joined by flexible

seals placed in the air headers air side to 800°C on a more or less practical basis. Initial ceramic recuperators were made of tile and joined through furnace cement, and thermal cycling caused cracking of joints and rapid deterioration of the tubes. Initial designs had experienced leakage rates from 8% to 60%. But the new designs are reported in last two years with air preheat temperatures as high as 710°C, with lesser leakage rates.

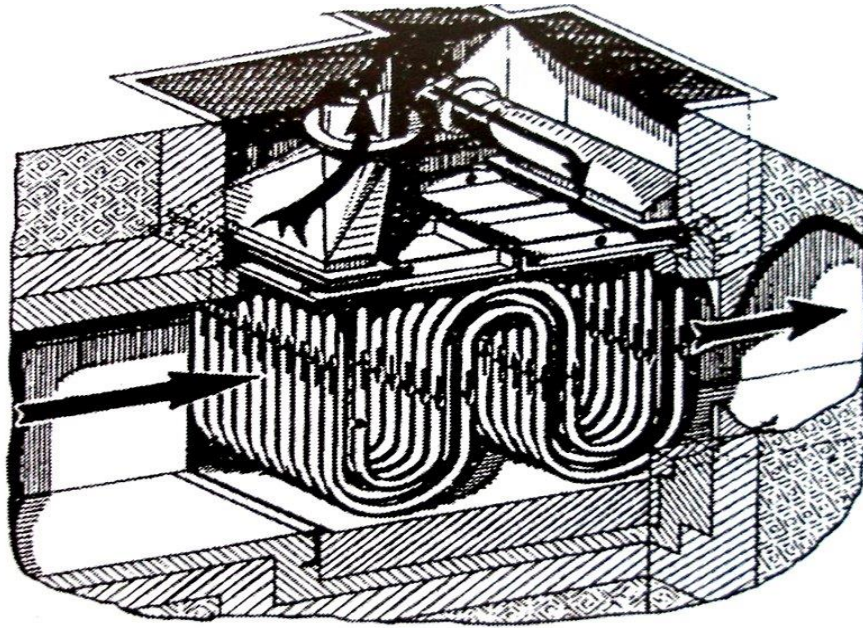


Fig-5 Ceramic recuperator

1.7.2 Regenerator

The Regeneration which is preferable for large capacities has been widely used in glass and steel melting furnaces. Important relations exist between the size of the regenerator, time between reversals, thickness of brick, conductivity of brick and heat storage ratio of the brick. In a regenerator, the time between the reversals is an important aspect. Long periods would mean higher thermal storage and hence higher cost. Also long periods of reversal results in lower average temperature of preheat and consequently reduce fuel economy.

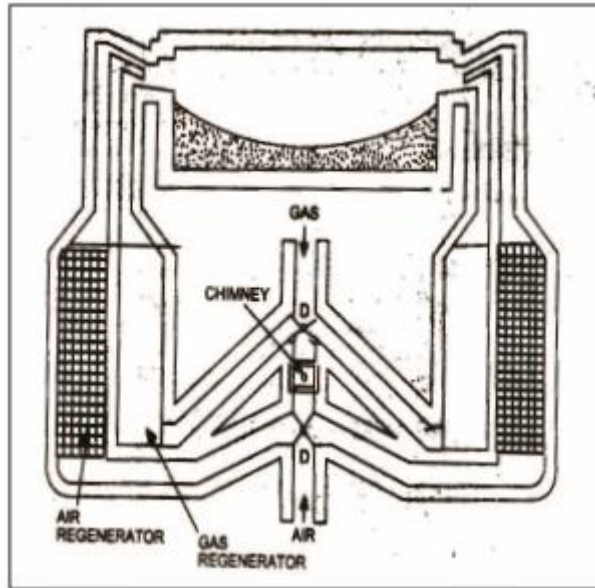


Fig-6 Regenerator

Accumulation of dust particles and slagging on the surfaces reduces the efficiency of the heat transfer as the furnace becomes old. Heat lost from the walls of the regenerator and air in leaks during the gas period and out leaks during air phase also reduces the heat transfer.

1.7.3 Heat wheels

It is also a type of heat exchanger which is used for applications in low to medium temperature waste heat energy recovery units. Figure-7 given below is illustrating the application of a heat wheel.

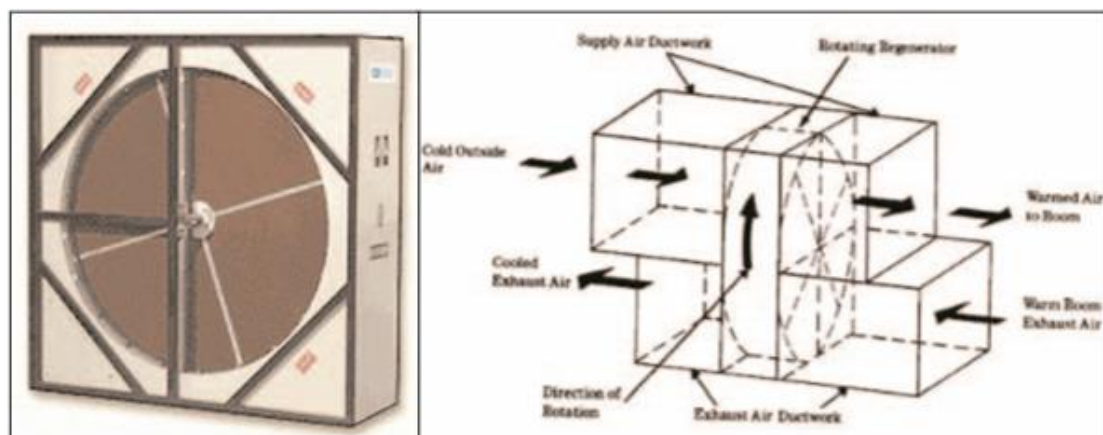


Fig-7 Heat wheel

Heat wheel is a substantial porous disk, fabricated with material having a high heat capacity which rotates between two side by side ducts (one a cold gas duct and the

other a hot gas duct). Axis of the disk is located parallel to the two ducts and placed on the partition between the two ducts. As the disk slowly rotates the sensible heat is transferred to the disk by the hot air to the cold air by the rotation of the disk. The total efficiency of the sensible heat transfer of this type of regenerator can be as high as 85%. These are being made as large as 21m in diameter with air capacities up to 1130 m³/min. One of the similar configurations of the Heat wheel is the rotary regenerator where the matrix is in a cylinder which is rotating across the waste gas and hot air currents. A heat energy recovery wheel is a rotating type gas heat regenerator which can transfer waste heat energy from exhaust to incoming gases. Its main area of application is where heat energy exchange between large masses of air and small temperature differences is required. Heating & ventilation systems and recovery of heat energy from dryer exhaust air are some typical applications of heat energy recovery wheels.

1.7.4 Heat pipe

A heat pipe is another type of waste heat recovery device which is capable of transferring heat energy up to 100 times faster than copper which is known as the best conductor of heat. Heat pipe is a heat energy absorbing and transferring device and has no moving parts and therefore needs minimal maintenance.

It consists of three elements a capillary wick structure, a sealed container, and a working fluid. Capillary wick of the heat pipe is integrally fabricated into the inner surface of the tube and sealed under vacuum. The heat energy supplied to the external surface of the heat pipe which is in equilibrium with its own vapour as the container tube is sealed under vacuum. The heat energy supplied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantly. Vapour thus produced absorbs the latent heat of vaporisation and this part of the heat pipe becomes an evaporator area. The vapour then moves to the other end of the pipe where the thermal energy is removed causing the vapour to condense into liquid again, hence giving up the latent heat of condensation. This part of the heat pipe works as the condenser area. The condensed liquid then flows back to the evaporator area. The figure of a Heat pipe is given below

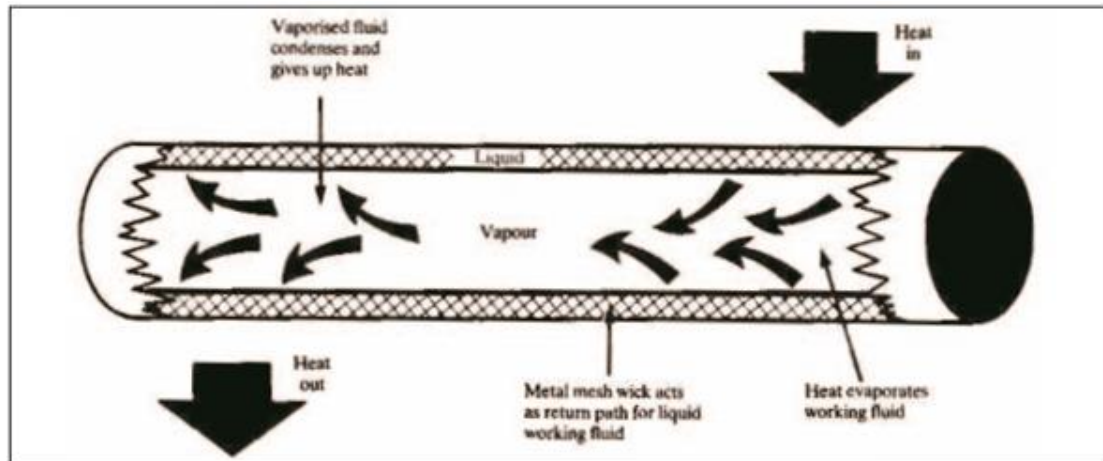


Figure-8 Heat pipe

1.7.4.1 The Advantage & Performance of a Heat pipe

A Heat pipe is a lightweight and compact heat energy recovery device and virtually it does not require any mechanical maintenance because it has no moving parts to wear out. A heat pipe does not need input power for its operation and is free from lubrication systems and cooling water. Heat pipe also reduces the fan power requirement and increases the overall thermal efficiency of the system. This type of heat recovery systems are capable of operating at 315°C with 60% to 80% heat energy recovery capability.

1.7.4.2 Heat Pipe Applications

The heat pipes are used in the following industrial applications:

1. Process to Process: It is a kind of heat exchanger that recovers the heat energy from the exhaust of the process and transfers this energy to the incoming process air. The incoming air thus become warm and can be used for the same process or any other processes and reduces process energy consumption.
2. Process to Space Heating: It is a kind of heat exchanger that transfers the heat energy from process exhaust for building heating. The preheated air can be blended if required. The requirement of additional heating equipment to deliver heated make up air is drastically reduced or eliminated.
3. HVAC Applications:
 - A) Cooling: In cooling purpose heat pipe heat exchangers pre cools the building makeup air in summer and thus reduces the total tonnage of refrigeration, apart from

the operational saving of the cooling system. The heat energy is recovered from the cool exhaust and transferred to the hot supply make up air.

b) Heating: In the heating the above process is reversed during winter to preheat the makeup air.

Some of the other industrial applications of Heat pipe are:

- Preheating of combustion air in Ovens, Boilers or Kilns.
- Heating, ventilating and Air conditioning systems.
- Recovering waste heat energy from furnaces.
- Reuse of waste heat of furnace as heat source for other oven.
- Reheat the ambient air for hot air driers.
- Recovering the waste heat energy from catalytic deodorizing equipment.
- Air conditioning of closed rooms with outside air.
- Boiler feed water preheating with waste heat energy recovery from flue gases in the heat pipe economizers.
- Curing, Drying and baking ovens.
- Reclamation of waste steam.
- Reverberatory furnaces and Brick kilns.

While doing an exhaustive literature review, I came across many new developments in the field of Recovery of Waste Heat. Here I intend to present few of all the literatures that have been studied. The literature consist research papers mainly from the Recovery of waste heat from different sources and its application in various processes. The literatures based on different technologies for efficient recovery of waste heat and different processes for its utilization. Energy and Thermal analysis of different cycles in which waste heat can be utilised are also reviewed. There is some of the most influential material with observations and conclusions are given below:

According to the studies conducted in 2014 by Dongxiang Wang, Hao Peng and Xiang Ling

- Ligament Mode Disintegration of Liquid Film at the Rotary Disk Rim in Waste Heat Recovery Process of Molten Slag
- As we know that the blast furnace slag is rich in high temperature waste heat, however, most of the slag sensible heat is wasted in the current “wet granulation” method. Dry granulation method based on rotary disk atomizer has received growing attention. However, the waste heat recovery efficiency of this method is mainly determined by the slag particle size.
- In this study, a simple model is proposed to characterize the ligament mode disintegration of liquid slag film at the rotary disk rim.
- The results indicated that the ligament number increases with increasing rotational speed, slag density and slag tapping rate but decreases with increasing viscosity and surface tension.
- The Sauter mean diameter of the droplet increases with increasing viscosity and surface tension but decreases with increasing rotational speed and slag density. Compared with density and rotational speed, increasing of viscosity, surface tension and slag tapping rate results in slight increases of the Sauter mean diameters.
- The results in this study can be applicable for characterizing the dry granulation of slag by rotary disk in the waste heat recovery process of molten slag in a wide range of operation condition.

According to the studies conducted in 2013 by Hui Zhang, Hong Wang, Xun Zhu, Yong Jun Qiu, Kai Li, Rong Chen and Qiang Liao

- A review of waste heat recovery technologies towards molten slag in steel industry.
- Molten slag exhausted with critically high temperature of about 1450–1550 C is a potential resource of energy and raw materials. Water quenching is a traditional heat recovery technology, which uses cold water to cool down slag so as to achieve the desired glassy by products. However, this technology consumes a huge amount of water and fails to recover the sensible heat of slag.
- To save energy and reduce water consumption, some other heat recovery technologies have thus been proposed. Generally, current heat recovery technologies can be classified into physical and chemical methods. Regarding the physical methods, mechanical crushing, air blast and centrifugal granulating process, etc. are widely investigated. With respect to chemical methods, methane reforming reaction and coal gasification process, etc. are proposed.
- Unfortunately, all these methods cannot fulfill the sustainable requirement. This paper aims to review the proposed granulation and heat recovery technologies. Their working principle, current research status, challenges and future prospects are presented.
- The waste heat recovery and utilization technologies, which give consideration to both heat recovery rate and cooled slag particles with high quality and high additional value, will be a key to achieve sustainable development for the iron and steel industry.

Onder Kaska in 2013, in his Energy and Exergy analysis of an organic Rankine cycle for power generation from waste heat recovery in steel industry concluded that

- The energy and exergy efficiencies of the evaporator pressure, condenser pressures, superheating and sub cooling of the system are 10.2%; 48.5% and 8.8%; 42.2%, respectively.
- He quantified the components with greater exergy destructions to lower one and can be listed as evaporator, turbine, condenser and pump. And observed

that the evaporation pressure has significant effect on both energy and exergy efficiencies.

- He also performed pinch point analysis to determine effects of heat exchange process, in the evaporator, on the net power production.

According to the studies conducted in 2015 by Simone Amicabile, Jeong-Ik Lee, Dongsuk Kum on

- A comprehensive design methodology of organic Rankine cycles for the waste heat recovery of automotive heavy-duty diesel engines.
- One of the most promising approaches to recover the waste heat from internal combustion engines is the Organic Rankine Cycle owing to its efficiency and reliability. The design optimization of ORC, however, is nontrivial because there exist many design variables and practical considerations. The present paper proposes a comprehensive design methodology to optimize the Organic Rankine Cycles (ORC) considering a wide range of design variables as well as practical aspects such as component limitations and costs.
- The design process is comprised of three steps: heat source selection, candidate fluid selection, and thermodynamic cycle optimization. In order to select the best waste heat source, the available energy and other practical considerations of various heat sources have been compared. Among others, the Exhaust Gas Recirculation (EGR) cooler is found to be the best heat source, and thus used for the rest of this study. Based on a systematic working fluid analysis, Ethanol, Pentane, and R245fa are selected as three candidate fluids.
- For the comprehensive ORC optimization, four types of cycle layouts are considered;
 1. Subcritical cycle without a recuperator
 2. Subcritical cycle with a recuperator
 3. Super critical cycle without a recuperator
 4. Super critical cycle with a recuperator
- Four cycle layouts coupled with three candidate fluids give a total of twelve cycle analysis.

- Results show that the best performance is provided by the regenerative subcritical cycle with Ethanol, while the solution with minimum capital cost is the subcritical cycles with Ethanol but without a recuperator.

Wentao Li, Jingquan Zhao, Lin Fu, Weixing Yuan, Zhonghai Zheng, Yan Li in 2014 performed a Energy efficiency analysis of condensed waste heat recovery ways in cogeneration plant.

- Making full use of condensed waste heat is an effective approach to increase heating capacity and reduce air pollutant emissions of the cogeneration plant. In this article, the heating equivalent electricity method is adopted to evaluate energy efficiencies and applicability of different condensed waste heat recovery ways, such as the condenser, the single-effect lithium bromide absorption heat pump and the bleeding-steam-driven compression heat pump. The following discussion is based on a 300 MW water-cooling steam turbine heating system and a 300 MW air-cooling steam turbine heating system. Combining with the characteristics of the water-cooling steam turbine and the air-cooling steam turbine, main factors affecting energy efficiencies are analyzed.
- Applicability evaluations of these condensed waste heat recovery ways are made by comparing energy efficiencies with each other under design conditions. Analysis shows that direct heat exchange by the condenser should be given the first priority. The condenser is most suitable to provide basic heating load. For the heat source composed of several steam turbines, the corresponding condensers should be connected in series.
- The proportion of steam turbines with high backpressures should be controlled due to high energy consumptions and inflexibility of adjustment. When supply water temperature is low, a surplus of bleeding steam pressure causes large irreversible loss in the generator of the single-effect absorption heat pump.
- A waste of energy grade of the bleeding steam makes the energy efficiency of the single-effect absorption heat pump lower than that of the bleeding-steam-driven compression heat pump. However, when bleeding steam pressure matches with the single-effect absorption heat pump, the energy

efficiencies of them are basically the same. Therefore, the bleeding-steam-driven compression heat pump is more suitable when bleeding steam pressure is high. Due to large irreversible loss, energy efficiency of the heating network heater is the lowest.

Research Gap

On the basis of comprehensive Literature review I found that there are various studies, analysis and research have been done on waste heat recovery system and its application in different areas. But there is still wide scope of study and research in this area. Some of the important observations where there is still need of research and development are:

- Development of new technologies and devices having better efficiency for the waste heat recovery so that maximum amount heat rejected to the environment as a waste heat can be recovered.
- To check the feasibility of waste heat recovery system with different processes so that the heat recovered can be utilized economically and efficiently.
- To study and detect new sources of waste heat recovery in the existing systems and process followed in different industries and plants. And check the feasibility of heat recovery by performing Thermal analysis.

Objective:

The main objective of this study is to perform energy analysis of an Integrated Steel Plant to search the scope of waste heat recovery from the different heat sources in the steel plant. And to utilize this waste heat recovered in Vapour Absorption refrigeration system efficiently to provide air conditioning to the different areas in the steel plant wherever required.

Probable advantages of the system:

- Energy efficiency of the plant will improve.
- No need of
- Reduction in Electricity consumption.
- Availability of central air conditioning unit to the Steel Plant.
- Availability of comfort to the manpower.

Chapter: 4 Lithium Bromide Vapour Absorption system

Vapour absorption refrigeration systems in which pair of Lithium Bromide salt and Water is used are extensively utilized in air conditioning units of large capacity. In these types of units it is not possible to produce the refrigeration effect below 273K because a salt solution of Lithium Bromide is used as absorbent and water is used as refrigerant. As in Lithium Bromide V-A-system water is used as refrigerant so it is not possible to produce the refrigeration effect below 273K using these systems. Therefore this system is used only in those applications in which refrigeration effect above 273K is required. Hence this system is only used for air conditioning purposes. As the vapour produced in the generator is almost a pure refrigerant therefore relatively it is easier to analyse this system, unlike Ammonia and Water V-A-systems in which vapours of both ammonia and water are produced in the generator.

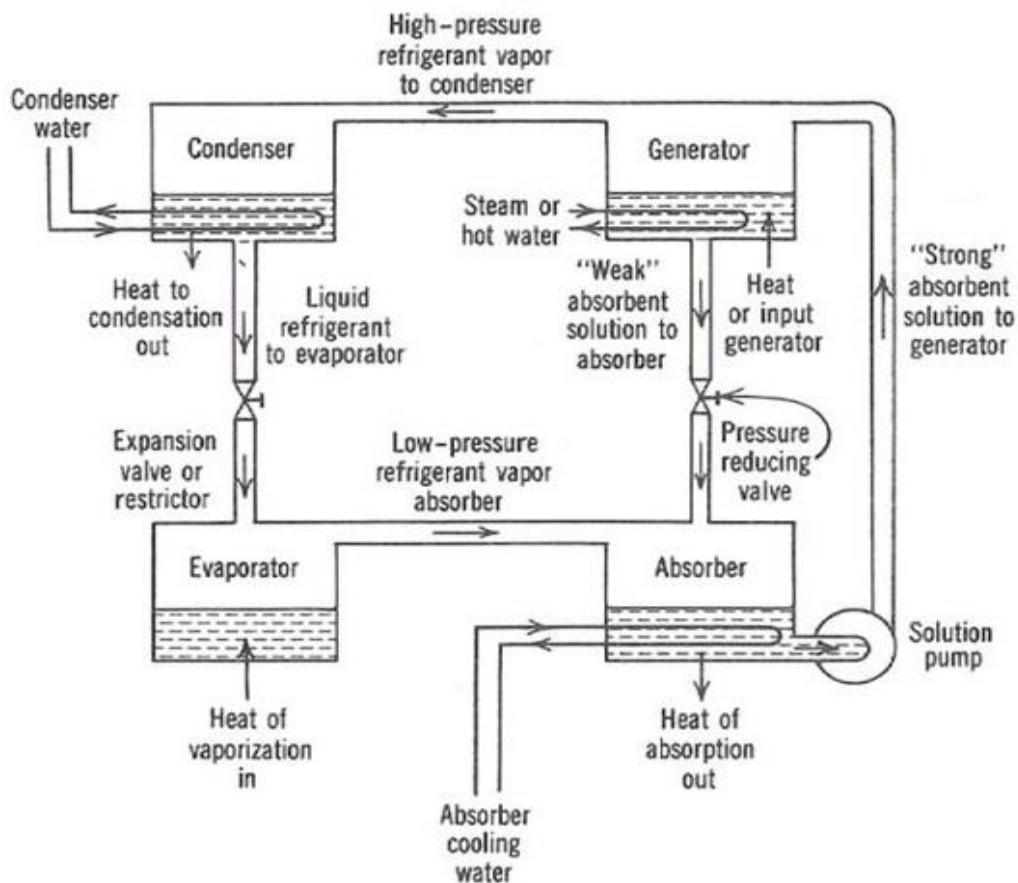


Fig-9 Basic Absorption Refrigeration Cycle

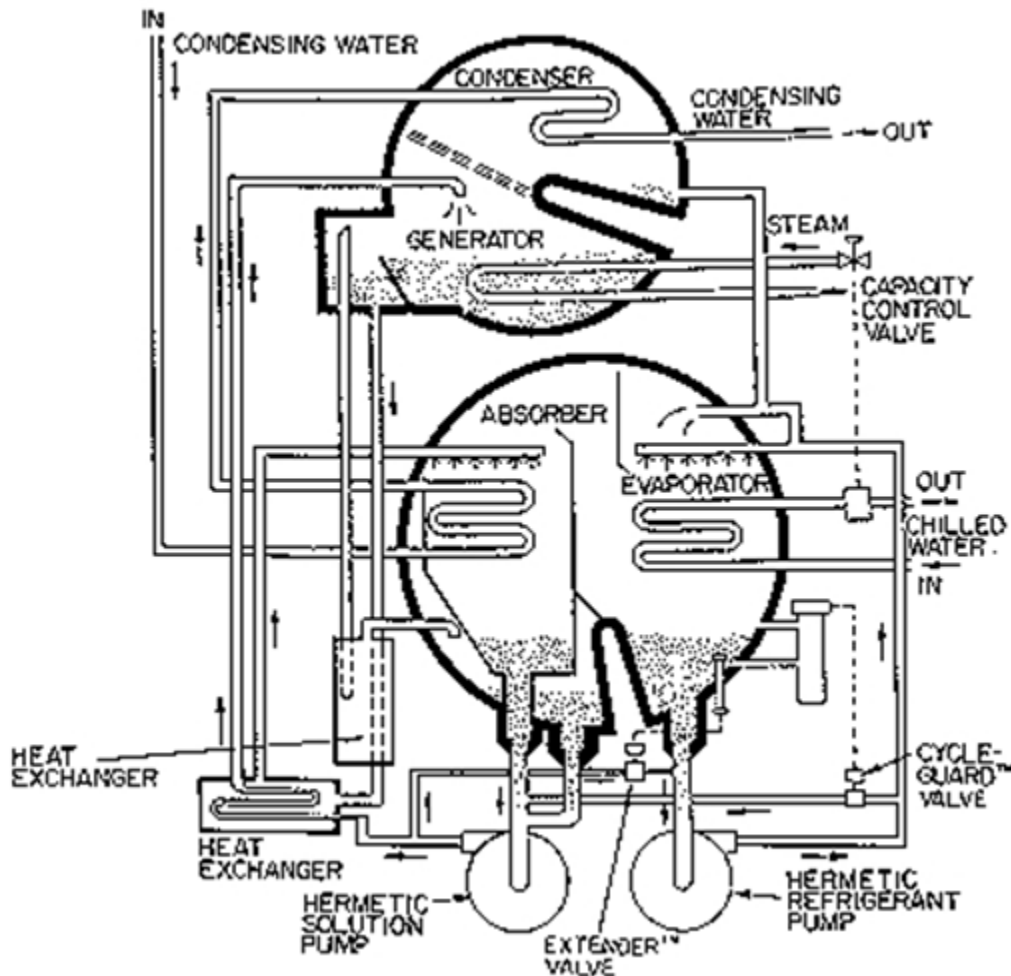


Fig-10 Flow circuitry of Lithium Bromide absorption refrigeration system

Some important points with respect to the vapour absorption cycle:

1. V-A cycle operates on low grade energy.
2. This cycle is used where cost of electricity is very high.
3. V-A cycle is used where large amount of waste heat is available.
4. Pump work in V-A cycle is negligible.
5. In V-A cycle heat is rejected in the condenser and absorber
6. Vapour absorption refrigeration system is a combination of ideal Heat Engine Refrigerator.

$$\begin{aligned}
 7. \text{ COP of V-A cycle} &= \frac{\text{Desired effect}}{\text{Energy input}} \\
 &= \frac{R_E}{Q_G + W_P} \quad (1)
 \end{aligned}$$

Where, R_E is the Refrigeration effect, Q_G is the heat provided to the generator

And W_P is the pump work.

In Vapour absorption cycle work input is very less so we can neglect it, therefore

$$\text{COP} = \frac{RE}{QG} \quad (2)$$

According to first law of thermodynamics:

$$Q_G + R_E = Q_C + Q_A \quad (3)$$

According to second law of thermodynamics:

$$(\Delta S)_{\text{sys}} + (\Delta S)_{\text{surr}} \geq 0 \quad (4)$$

$$(\Delta S)_{\text{sys}} = 0$$

$$(\Delta S)_{\text{surr}} \geq 0 \quad (5)$$

$$-\frac{QG}{TG} - \frac{RE}{TR} + \frac{QC}{T_o} + \frac{QA}{T_o} \geq 0 \quad (6)$$

$$-\frac{QG}{TG} - \frac{RE}{TR} + \frac{QG}{T_o} + \frac{RE}{T_o} \geq 0 \quad (7)$$

$$\frac{TG - T_o}{TG} \times \frac{TR}{T_o - TR} \geq \frac{RE}{QG} \quad (8)$$

$$\text{COP}_{\text{Max.}} = \frac{TG - T_o}{TG} \times \frac{TR}{T_o - TR} \quad (9)$$

4.8.1 Lithium Bromide Water solutions properties

4.8.1.1 Concentration

The concentration of Lithium Bromide Water solutions can be represented either in mole fraction (x) or mass fraction (ξ). For Lithium Bromide Water solutions, the mass fraction ξ is defined as the ratio of mass of anhydrous Lithium Bromide to the total mass of the solution i.e.

$$\xi = \frac{m_L}{m_L + m_W} \quad (10)$$

Where, m_L is the mass of anhydrous Lithium Bromide in the solution

m_W is the mass of water in the solution

The concentration of the Lithium Bromide Water solution can also be expressed in the term of mole fraction as:

$$X = \frac{n_L}{n_L + n_W} \quad (11)$$

Where, n_L is the number of moles of anhydrous Lithium Bromide in the solution

n_W is the number of water in the solution

The number moles of Water and Lithium Bromide can be easily obtained from their molecular masses and respective masses in the solution

$$n_L = \frac{m_L}{M_L} \text{ and } n_W = \frac{m_W}{M_W} \quad (12)$$

Where, M_L is the molecular mass of anhydrous Lithium Bromide (86.8 g/mol) and M_W is the molecular mass of water (18.0 g/mol).

4.8.1.2 Vapour Pressure of Lithium Bromide Water solutions

On the implementation of Raoult's law of partial pressure we can observed that the vapour pressure of solution of Lithium Bromide and Water is negligibly small as compared to the vapour pressure of the Lithium Bromide which is given by:

$$P = P_W(1-x) \quad (13)$$

Where,

x is the mole fraction of Lithium Bromide in solution

P_W is the saturation pressure of water at the temperature of the solution.

It is observed that for very dilute solutions of Lithium Bromide and Water the Raoult's law is approximately correct (i.e. $x \rightarrow 0$). The concentrated solutions of Lithium Bromide and water do not follow the Raoult's law of partial pressure.

For example, when the mass fraction of Lithium Bromide is 0.50 and temperature of

the solution is 25°C, in these conditions Raoult's law gives 0.0262 bar vapour pressure of Lithium Bromide, whereas the practical measurements shows that it is only 0.0085 bar. The ratio of actual vapour pressure to the vapour pressure given by Raoult's law is known as coefficient of activity. For the example given above, the coefficient of activity is 0.324.

4.8.1.3 Enthalpy of Lithium Bromide Water Solution

As the strong solution of Lithium Bromide and Water deviates from the behaviour of the ideal solution, it is observed that the enthalpy of the solution increases. This shows that the adiabatic mixing of anhydrous Lithium Bromide and water at same temperature is an endothermic process, so process has negative heat of mixing. Hence the specific enthalpy of the solution is given by:

$$h = \xi \cdot h_L + (1 - \xi)h_w + h_w$$

Where, h_L is the specific enthalpy of anhydrous Lithium Bromide and h_w is the specific enthalpy of water. Figure-13 showing a chart which gives the specific enthalpy temperature mass fraction data for Lithium Bromide water solutions.

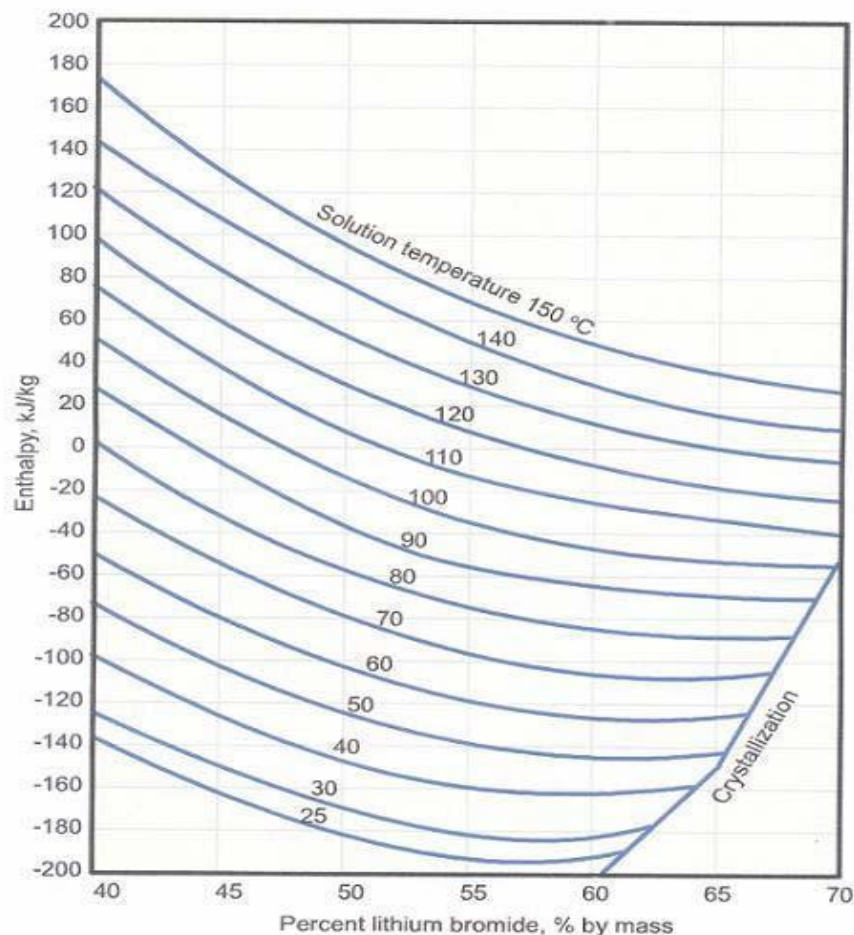


Fig-11 Enthalpy Temperature Concentration diagram for H₂O-LiBr solution

4.8.1.4 Enthalpy values for Water for both liquid state and superheated vapour

The enthalpy of water vapour and liquid water at different pressures and temperatures can be obtained from the data of pure water property. For all practical purposes, liquid water enthalpy, $h_{w,liquid}$ at any temperature T can be obtained from the equation:

$$h_{w,liquid} = 4.19(T - T_{ref}) \text{ KJ/Kg} \quad (14)$$

Where, T_{ref} is the temperature at 0°C

The vapours of water produced in the generator of Lithium Bromide Water system is in super heated condition as the generator temperature is much higher than the saturation water temperature at that pressure. The enthalpy of super heated water vapours i.e. $h_{w,sup}$ at low temperature T and low pressures can be obtained approx. by the equation:

$$h_{w,sup} = 2501 + 1.88(T - T_{ref}) \quad (15)$$

4.8.1.5 Crystallization

The mass fraction temperature pressure and temperature enthalpy mass fraction charts (Figs. 3 and 4) showing the lines marked as crystallization in the right lower section. The region below and to the right of these lines indicates the solidification of Lithium Bromide salt. In the region of crystallization region a two phase mixture of Lithium Bromide and Water solution and the crystals of pure Lithium Bromide salt exist in equilibrium state. The system of Lithium Bromide and Water should operate away from the region of crystallization as the blockage of the valve and pipes may takes place due to the formation of solid crystals. Crystallization of Li-Br may occur when the hot concentrated solution of Lithium Bromide is cooled in the heat exchanger to low temperatures. To prevent the above problem, the reduction in condenser pressure below a certain value, low temperature of cooling water in the condenser should be prevented. Therefore in the commercial systems, the pressure of condenser maintained high artificially even though the available temperature of the heat sink is low. This actually causes the reduction in the performance of the system, but it is necessary for the proper functioning of the system.

4.8.2 Problems related to the Lithium Bromide Water systems

Problems to water Lithium Bromide systems are:

1. Crystallization of Lithium Bromide
2. Air leakage due to vacuum
3. Pressure drop due to frictional losses

To prevent the problem of crystallization the pressure of the condenser has to be maintained at certain level, irrespective of temperature of cooling water, which can be achieved by regulating the flow rate of cooling water to the condenser. Some additives are also added in practical Lithium Bromide Water systems to prevent crystallization. As the whole system operates under vacuum, outside air may leak into the system. Therefore an air purging unit is used in practical systems. Usually a double stage ejector type purging system is used to eliminate air from the practical system. Since the working pressures are very small and specific volume of water vapour is high, so pressure drops due to friction should be minimized. This can be achieved by using single and double drum arrangements in commercial systems.

4.8.3 Commercial systems

Commercial Lithium Bromide Water systems are as follows:

1. Single effect or single stage system
2. Multi effect or multi stage system

Single stage systems are those which operate under two pressures, one corresponding to the condenser and generator which is a high pressure side and the other one is corresponding to absorber and evaporator. Single stage systems can be either:

1. Double drum type
2. Single drum type

As the absorber and evaporator function at the same pressure they can be housed in the same container, similarly condenser and generator can be placed in another vessel together as these two components also operate under same pressure. Thus a Double drum system consists of two containers functioning at low pressures and high pressures. Figure 15 shows a single stage and double drum system.

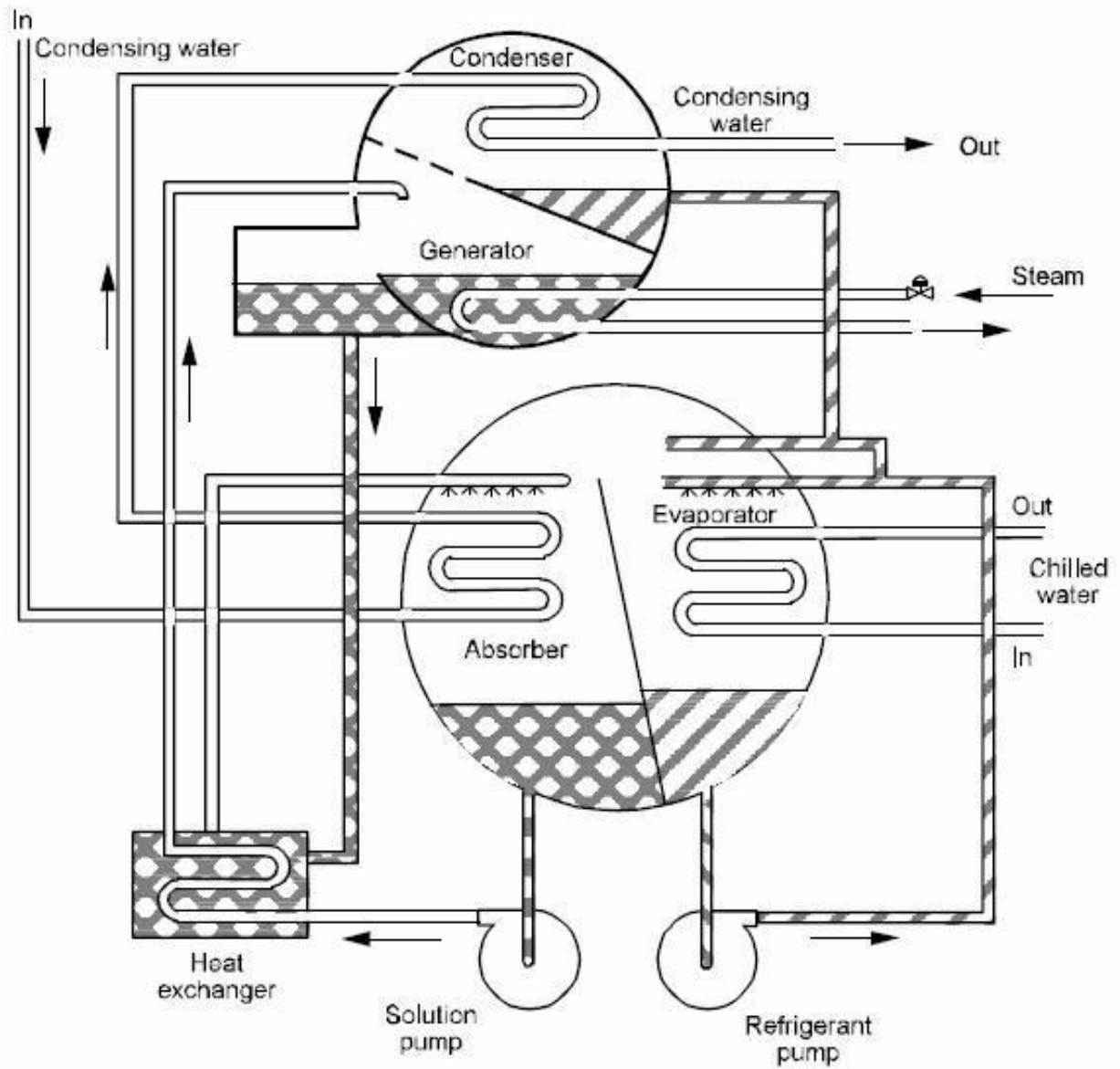


Fig-12 Double Drum type Lithium Bromide Water system

It can be seen in the figure that the cooling water flows first to the absorber which extracts heat from the absorber and then flows towards the condenser to extract the heat from the condenser heat. This is known as series arrangement. This kind of arrangement is beneficial as the required flow rate of cooling water will be small and also by carrying the cooling water first to the absorber, the condenser can be operated at a higher pressure to prevent crystallization. It is also possible that the cooling water will flow parallel to the condenser and the absorber. However, the requirement of cooling water will be high in this case. A pump for refrigerant circulates the liquid water in evaporator and the water is sprayed on the evaporator tubes for better mass and heat transfer. The tubes of heater are immersed in the pool of strong solution of generator for the generation of vapour. The reduction in pressure between absorber and evaporator and between condenser and are minimized, large sized lines of vapour are eliminated and the leakage of air can also be minimized due to less number of joints. The figure given below shows a single effect system of single drum type. In this type of system all the four components are placed in the single container. This container is divided into two sides one is high pressure and the other is low pressure sides by using a diaphragm.

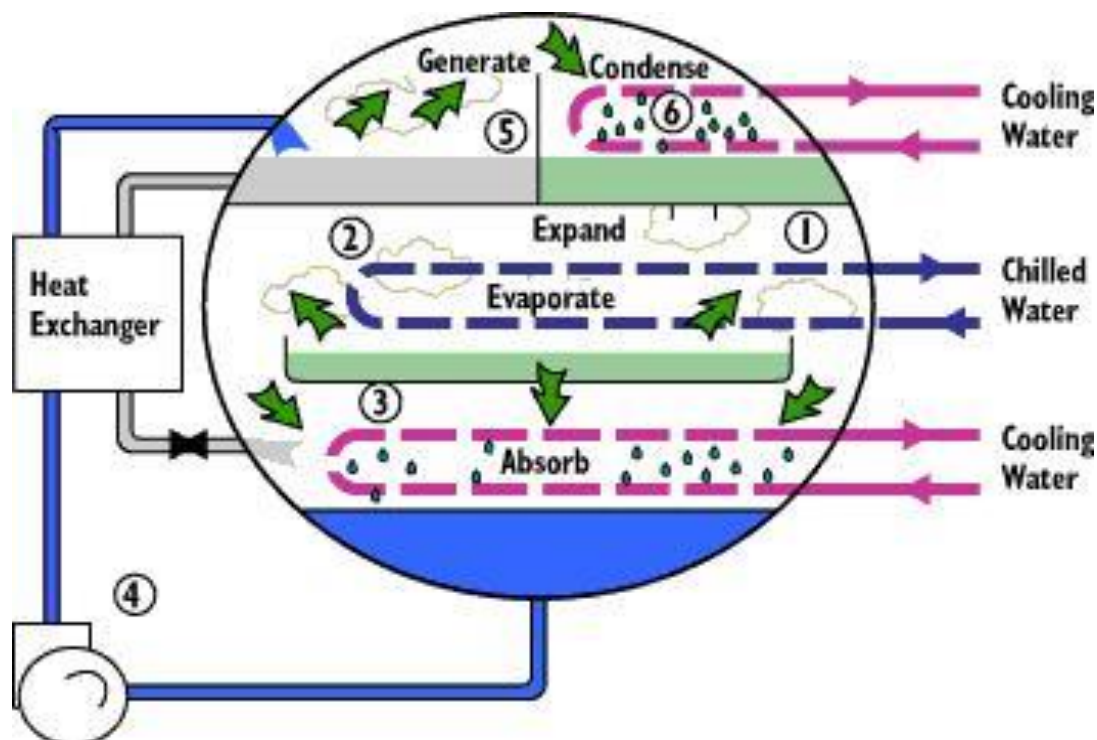


Fig-13 Single Drum type Lithium Bromide Water system

In the multi stage systems a number of generators are used which are working at

successively reducing pressures. The thermal energy is provided to the highest stage generator working at the highest pressure. The enthalpy of the steam produced from this generator is utilized to produce more refrigerant vapour in the lower stage generator and so on. This is the way in which heat input to the system is utilized efficiently by producing more vapour of refrigerant and leads to the higher COP's. The systems working on multi effect are more complex in construction as compared to the single stage system and have need of a much higher temperatures of the heat source in the highest stage generator. In Figure-17 and 18 double effect systems are shown.

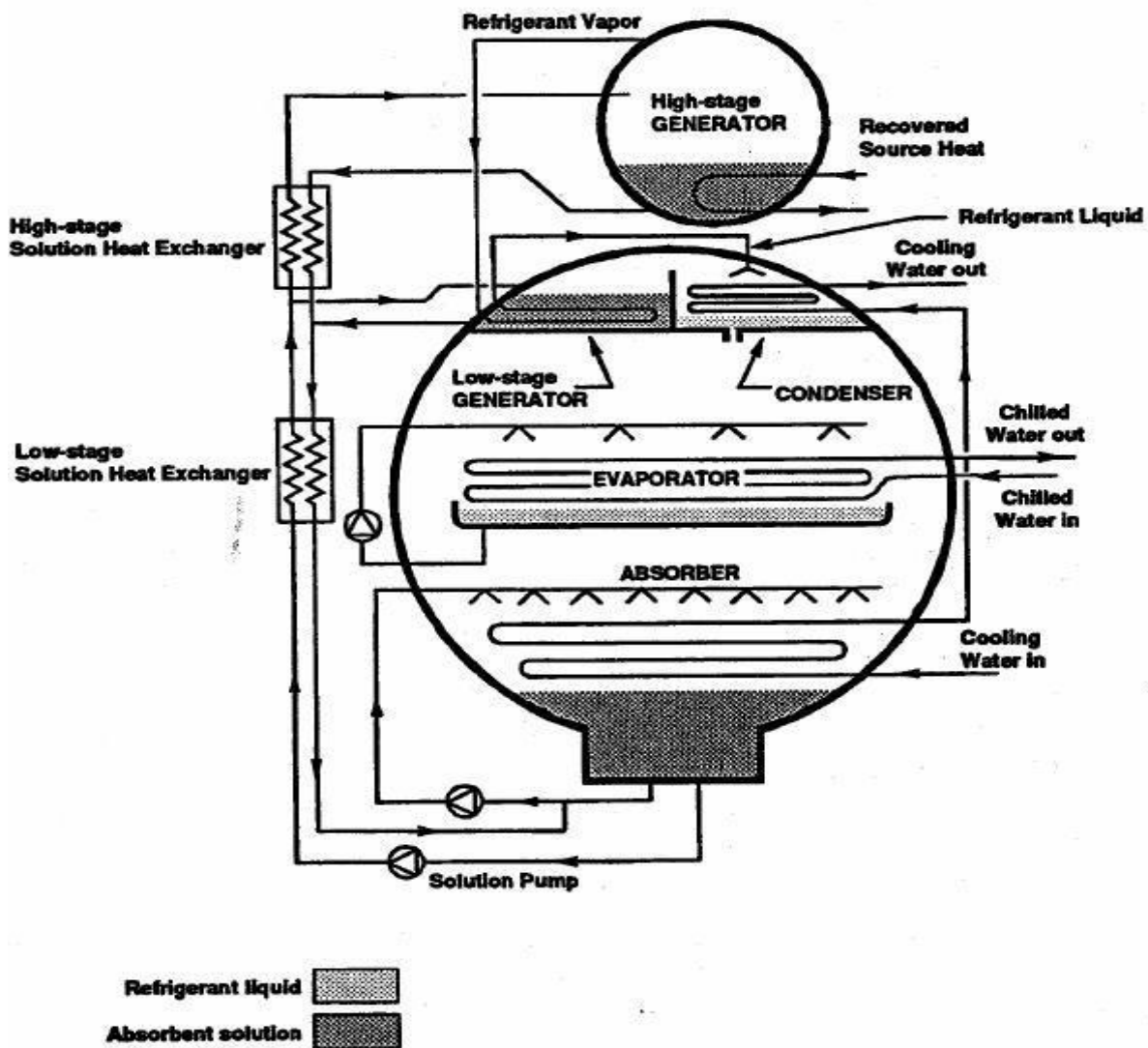


Fig-14 Double effect Lithium Bromide Water system

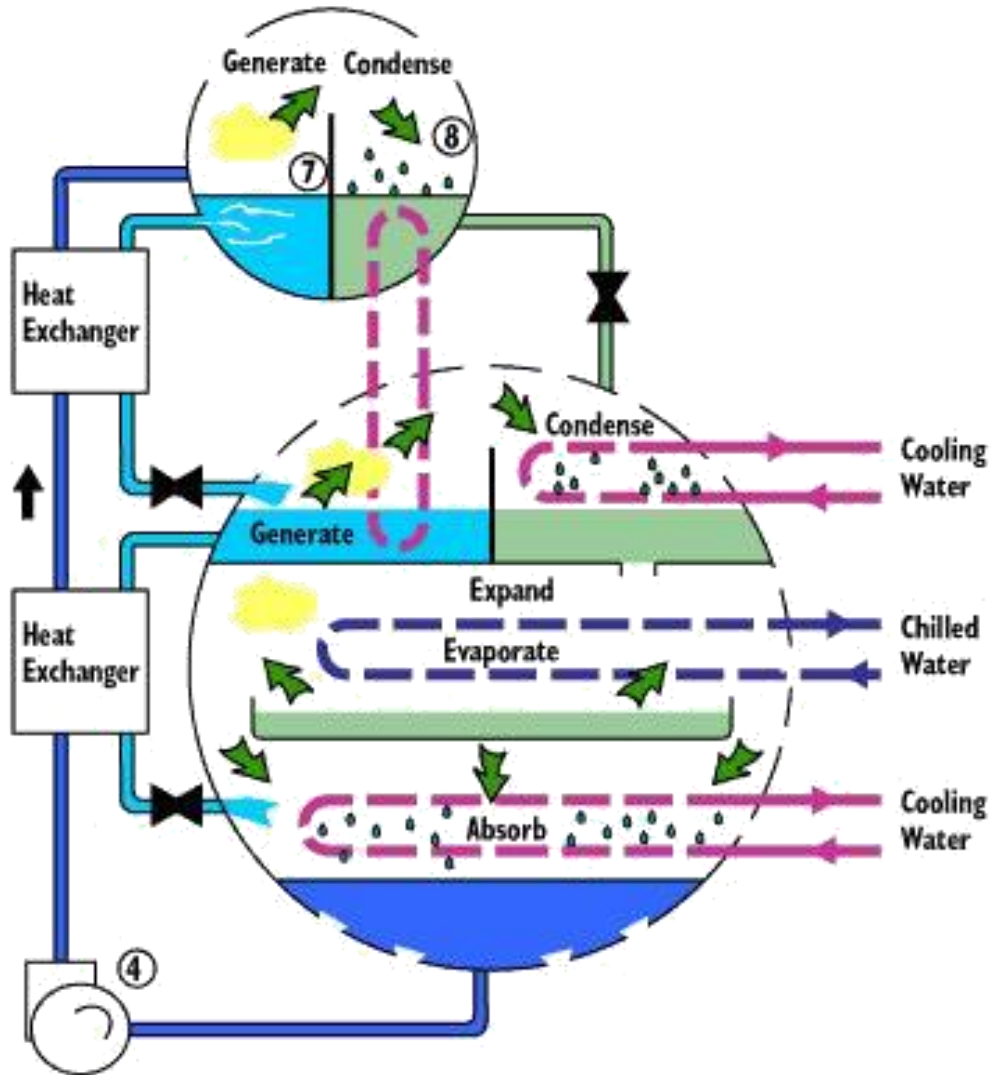


Fig-15 Double effect Lithium Bromide Water system

4.8.4 Heat Sources for Lithium Bromide Water system

A Lithium Bromide Water vapour absorption system can be run using a wide range of heat sources. Systems having large capacity are generally run on hot water or steam. On the other hand the systems having small capacity are generally run directly on gas or oil. A system working on single effect needs a heat source at a temperature of near about 393K to produce the chilled water of 280K when the absorber of the system operates at near about 40°C and the condenser operates at near about 319K. The Coefficient of Performance of the system having single effect is obtained in the range of 0.6 to 0.8 while the Coefficient of Performance for the multi effect system can be obtained as high as 1.2 to 1.4.

4.8.4.1 Minimum Temperatures of heat source for Li-Br-H₂O systems

The statistics for Lithium Bromide Water vapour absorption system having single stage with an output chilled water temperature of 279.7K is given in Table-5.

Temperature of cooling water (Inlet to the Condenser and Absorber)	Minimum Temperature of Heat source (Inlet to the Generator)	COP
296.9K	338K	0.75
299.7K	348K	0.74
302.4K	358K	0.72
305.2K	368K	0.71

Table-5 Statistics for a single effect Lithium Bromide Water system

The values given in the above table are simulated values. These values are verified from the actually working commercial systems having efficient designs of mass transfer and heat transfer. The actual requirement of the temperatures from the heat source will be greater than the reported values if the mass transfer and heat transfer are not efficient. If the temperature of the heat source falls below the minimum temperature for a given temperature of the heat source, as given in the table-5 then the Coefficient of Performance of the system drops significantly. And if the temperature of the heat falls below a certain limit of the temperature i.e. minimum temperature for generation, for a given temperature of the cooling water then the system will not work. Usually 10°C to 15°C is the range of minimum temperature of generation which is lower than the minimum temperature of the heat source. The requirement of minimum temperature of heat source will be higher if the air cooled absorbers and condensers are used, which is approximately 150°C. The Coefficient of Performance of the system can be increased significantly by implementing multi effect systems. The addition of each stage in the system increases the requirement of the temperature of heat source approximately by 323K.

4.8.5 Capacity control

The reduction on load is known as the capacity control because without any control the capacity will reach its maximum value. Usually under the full load as well as under the partial load conditions the temperature of the outlet chilled water is maintained at a close constant value. The regulation of refrigeration capacity can be done either by:

1. The regulation of flow rate of weak solution pumped to the generator with the help of solution pump.
2. Reducing the temperature of the generator by reduction in the flow rate of hot water or by throttling the steam supply.
3. Increasing the temperature of the condenser through bypassing the supply of cooling water to the condenser.

The method given in the first point does not affect the Coefficient of Performance of the process significantly as the input heat required decreases with the reduction in flow rate of weak solution. But, this method possibly will cause the problem of crystallization therefore at times a blend of the above three methods is used in commercial systems for the better capacity control.

Chapter: 5

Sources of Waste heat in an Integrated Steel Plant

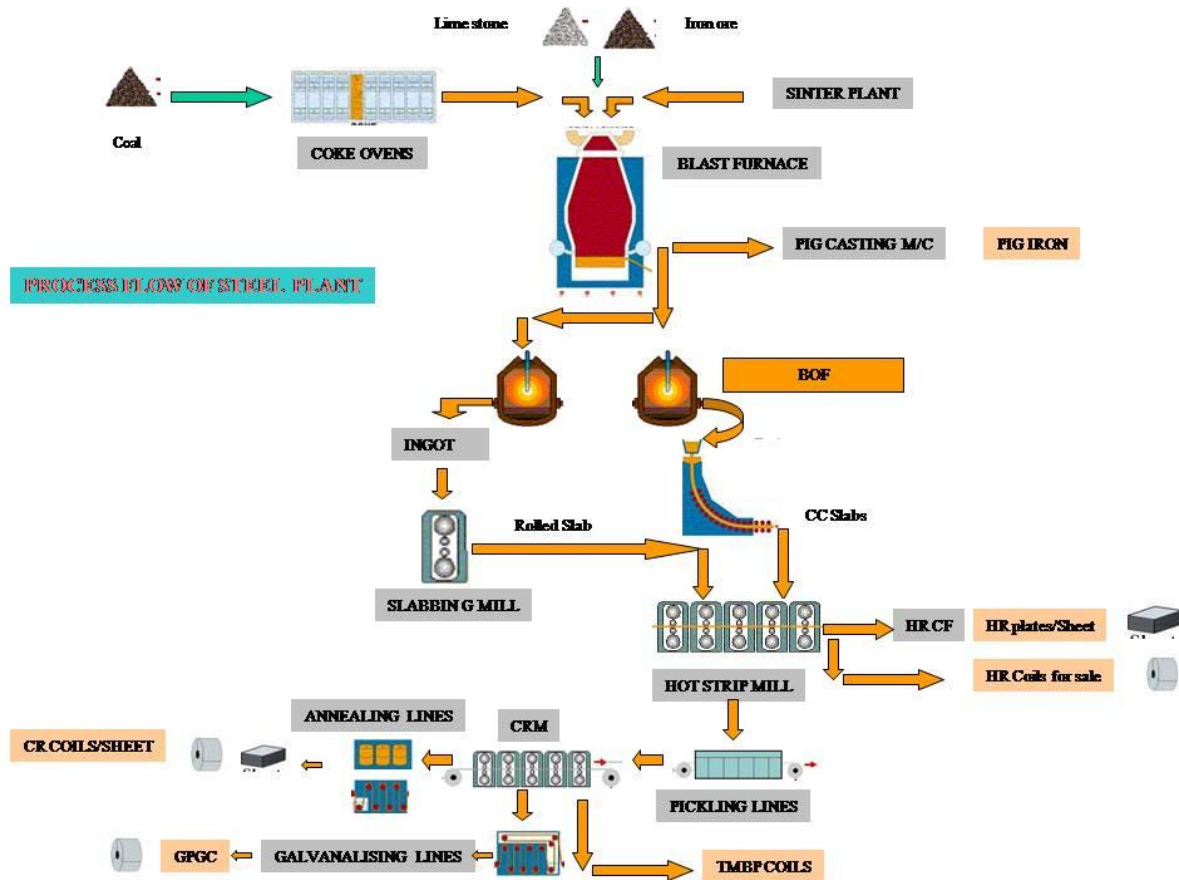


Fig-16 Flow diagram of Bokaro steel Limited

Sources and Areas for the Waste heat recovery in an Integrated Steel Plant are as follows:

1. Coke Oven
2. Blast Furnace
3. Oxygen Lance in Steel melting shop
4. Slabbing mill
5. Hot strip mill
6. Continuous casting Shop
7. Cold Rolling mill
8. Sinter plant

Chapter: 6 Calculations for the Waste heat losses in an ISP

Assumptions based calculations are done in this chapter for the waste heat losses in an Integrated Steel plant. As the chemical composition of the exhaust gases from the Coke Oven, Blast Furnace and Basic Oxygen Furnace could not be calculated by assuming the complete combustion of fuel therefore some estimation are done for the composition of exhaust gases, flow rate and Waste heat losses, which are given below in the following tables:

	Production (tons steel/year)	Net energy Cons. (10^6 Btu/ton)	Net energy Cons. (TBtu/year)	Assumed average exhaust temperature	
				°F	°C
Steel	104579800				
Integrated Steel plant	56473092				
Coke Ovens	56473092	1.16	66		
Coke Oven Gas	56473092			1800	980
Waste Gas	56473092			392	200
Blast Furnace	56473092	11.31	642		
Blast Furnace Gas				200	430
Blast stove	56473092	1.24	70		
Without Recovery	28236546			482	250
With Recovery	28236546			266	130
Basic Oxygen Furnace	56473092	0.82	50	3100	1700

Table-6 Assumptions done for the calculation energy consumption and waste heat in a steel plant

	Waste heat (TBtu/yr) 77°F Ref.	Waste heat (10^{12} Btu/yr) 300°F Ref.	Carnot Efficiency	Work potential (10^{12} Btu/yr)
Integrated Steel plant				
Coke Ovens				
Coke Oven Gas	15.8	13.9	76%	12.1
Waste Gas	11.2	10.0	37%	4.1
Blast Furnace				
Blast Furnace Gas	5.3		19%	1.0
Blast stove				
Without Recovery	10.6	1.9	43%	4.6

With Recovery	3.2		26%	0.8
Basic Oxygen Furnace	27.1	26.0	85%	23.0

Table-7 Estimation of waste heat lost in exhaust gases

	H ₂ Gas	CO Gas	CO ₂ Gas	N ₂ Gas	CH ₄ Gas
Coke Oven Gas	52%	4%	2%	-	37%
Coke Oven Waste Gas	-	-	8%	70%	-
Blast Furnace Gas	3%	26%	21%	50%	-
Blast Furnace Off Gas	-	-	8%	-	-
Hot Blast Stove Gas	-	-	26%	68%	-
Basic Oxygen Furnace Gas	-	73%	16%	8%	-

Table-8 Exhaust gases composition

Source	Assumed average exhaust temperature	
	°F	°C
Coke Oven Gas	1800	980
Coke Oven Waste Gas	392	200
Blast Furnace Gas	200	430
Hot Blast Stove off Gas Without Heat Recovery	482	250
Hot Blast Stove off Gas With Heat Recovery	266	130
Basic Oxygen Furnace	3100	1700

Table-9 Average exhausts temperature of exhaust gases

Coke Oven Gas Enthalpy	
77°F Reference	1501 Btu/lb COG
300°F Reference	1319 Btu/lb COG
Production Rates	
Pig Iron Production	2.43 ton pig iron/ton Coke
Steel Production	1.06 ton steel/ton pig iron
Coke Oven Gas Production(per ton of steel)	0.09ton COG/ton steel
Coke Oven Gas Production(per ton of Coke)	0.24 ton COG/ton Coke

Waste heat loss	
77°F Reference	0.28×10 ⁶ Btu/ton steel
300°F Reference	0.25×10 ⁶ Btu/ton steel

Table-10 Estimation of Waste heat in Coke Oven gas

Flue Gas Enthalpy	
77°F Reference	23 Btu/lb COG
300°F Reference	-
Production Rates	
Liquid Steel Production	1.06 ton steel/ton pig iron
Blast Furnace Gas Production(per ton of pig iron)	4369 lb gas/ton pig iron
Blast Furnace Gas Production(per ton of steel)	4107 lb gas/ton of steel
Waste heat loss	
77°F Reference	0.09×10 ⁶ Btu/ton steel
300°F Reference	-

Table-11 Estimation of Waste heat in Blast Furnace gas

Flue Gas Enthalpy	
77°F Reference	2409 Btu/lb gas
300°F Reference	93 Btu/lb gas
Production Rates	
BOF Gas Production	199.15lb gas/ton liquid steel
Waste heat loss	
77°F Reference	0.48×10 ⁶ Btu/ton liquid steel
300°F Reference	0.46×10 ⁶ Btu/ton liquid steel

Table-12 Estimation Waste heat in Basic Oxygen Furnace Off gas

Chapter: 7 Energy analysis & Production Data of an ISP

7.1 Introduction

An Integrated Steel plant is that in consumable goods of steel are produced from the Iron ore. In the process of steel production hot molten metal is produced in the Blast Furnace by the reduction of iron ore with help of Coke, Sinter, Dolomite and Lime stone. The Coke is produced in the Coke Oven from the coking coal. The coking coal is imported from the outside and it is the primary fuel for an ISP. Coke Oven gas, Blast Furnace gas, mixed gas, Convertor gas and steam are the secondary energy or fuel source. Sinter is produced by the combination of Iron ore fines, Lime dust, Dolomite and Coke breeze in the sinter plant.

The hot molten metal produced in the Blast Furnace is converted in to steel of desired composition in the SMS. In SMS, Oxidation of hot metal is done in the LD convertor with the help of Oxygen lance and other additives are added to produce required grade of Steel. This Steel is casted in to steel Ingots, Blooms or Slabs and then rolled into desired product in rolling mills.

All the above processes require a lot of energy to be carried out. This energy comes from the coking coal which is the primary source. Blast Furnace, HSM, Sinter plant, Coke Oven, SM, SMS, & CCS, Power plant and CRM are the major consumers of energy in a steel plant.

Characteristic	B.F Gas	COG	Convertor Gas
C.V (kCal/Nm ³)	800-810	4100-4250	1600-1800
Density (kg/Nm ³)	1.3-1.35	0.44-0.46	1.33-1.36
Ignition temperature (°C)	680	560	610
Flame temperature (°C)	1400	2000	1900
Yield (Nm ³ /T)	1700-2000	300-325	35-60
Air/Gas ratio	0.8	4.2	1.6-1.8
Explosive limit	37-71	5-32	20-70

Table-13 Characteristics of fuel gases used in an Bokaro steel plant

Mixed Gas	C.V (kCal/Nm³)
Coke oven mixed gas	1000-1050
Blast furnace mixed gas	900-950
Sinter plant mixed gas	1550-1750
HSM mixed gas	1900-2200
SM mixed gas	1459-1550
CRM mixed gas	1750-1850

Table-14 C.V of Mixed gas used in Bokaro Steel plant

Parameters	Unit	2010-11	2011-12	2012-13	2013-14
Coke Rate	kg/thm	519.1	515.7	509.4	518.1
Fuel Rate	kg/thm	552.9	570.4	584.9	593.2
Sp. Power Cons.	kwh/tcs	448.8	426.4	427.3	429.3
Sp. Power Cons.	kwh/tss	471.5	467.6	482.7	462.4
Sp. Energy Cons.	GCal/tcs	6.780	6.779	6.741	6.747
Sp. Steam Cons.	kg/tcs	1366	1299	1423	1340
Energy Cost	Rs/GCal	1866.0	2037.7	2123.2	2218.5

Table-15 Important Energy Parameters at Bokaro Steel Plant

7.2 Production data of Bokaro Steel Plant for month Feb. 2015

7.2.1 Material Input

S.NO.	Material	Quantity (ton)
1.	Coking Coal (dry)	265569
2.	Coke Breeze in Sinter Plant	22268
3.	Sinter in B.F	345130
4.	B.F Coke(dry) in B.F	170342
5.	Nut Coke (dry) in B.F	10294
6.	C.D.I in B.F (dry)	18407
7.	Tar in B.F	0
8.	Hot metal to SMS-1	72270
9.	Hot metal to SMS-2	257136
10.	Hot metal to Foundry	5562
11.	Pig iron to SMS	50
12.	Ingot Rolled	60039
13.	Slab Rolled	291491
14.	HR coil to HRCF	54308
15.	HR coil to CRM	50170

7.2.2 Material Output

S.NO.	Material	Quantity (ton)
1.	Gross coke production	196521
2.	B.F Coke production	181915
3.	Nut Coke production	10294
4.	Gross Sinter production	426689
5.	Skip Sinter production	352206
6.	Hot metal production	340057
7.	Pig iron production	4733
8.	SMS-1 production	65325
9.	SMS-2 production	245505
10.	CCS Slab production	245505
11.	Crude steel production	310830
12.	SM slab production	52414
13.	HR coil production	280029
14.	HR Plate production	280302
15.	CR Plate production	45289

7.3 Coke Oven

A Coke Oven is a chamber of refractory bricks having a dome like structure. It is normally 4m in width and 2.5m in height. The top of the Coke Oven has a hole for charging the coal which is known as charging lid. A hole is provided in the periphery of the lower part of the Coke Oven wall for the discharge of the coke produced. A Coke Oven battery has several numbers of Ovens. These ovens are constructed with common walls between neighbouring Ovens in a single row. There are generally 69 Ovens in a Coke oven battery.

The Coal is charged from the top of the coke oven to produce a uniform layer of around 65cm to 100cm depth. The air is provided in the starting to ignite the coal. After the ignition as the supply of Oxygen is cut down Carbonization of coal starts and produces a volatile matter inside the closed chamber of the coke oven. Coal Carbonization initiates from the top to the bottom and is completed approximately in twenty hours. Heat is supplied by the burners using Coke Oven gas or mixed gas which is a Combination of Coke Oven gas and Blast furnace gas as a fuel. The coke oven gas is recovered from volatile matter produced in coke oven with help of By-product plant. Some other by products like Fertilizer, Benzene, and Naphthalene etc. are recovered from the volatile matter of the Coke Oven and sold commercially in the market and remaining flue gases are endorsed to escape to the environment after proper filtration. The hot coke produced is pushed out of the coke oven with the help of the pusher car through the side door and then it is quenched with phenolic water. During quenching of coal with Phenolic water large amount of steam is produced, which is rejected directly in to the air. The top and the walls of the coke oven battery retain sufficient amount of heat to start the carbonization of the next charging.

When the partial combustion of coal takes place in a coke oven, the impurities present in the coal which are not driven out in the form of gases and get accumulated in the form of slag that is effectively an accumulation of the removed impurities. Since this is not a desired coke product therefore earlier it was nothing more than an unwanted by-product and was thrown away as a waste. But this waste slag is found to have several valuable uses and now it has been used as a constituent in making of bricks, granule covered shingles, cement, and sometimes it is also used as a fertilizer.

The coke coming out of the coke oven has lot of heat energy which is wasted during the quenching of coke in the form of steam. This waste can be recovered and can be used for providing heat to the generator of vapour absorption air conditioning unit and can also be used for power generation using Heat Recovery Steam Generator.

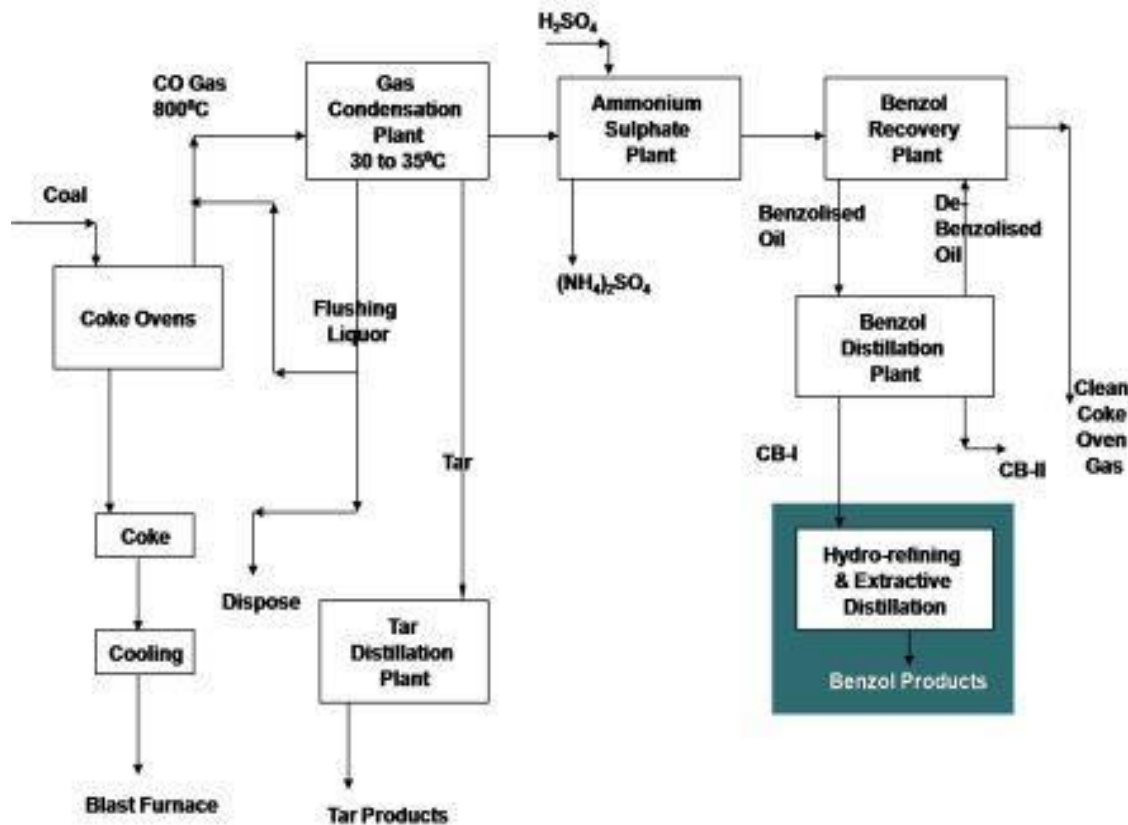


Fig-16 Flow diagram of coke oven and by product plant

Energy Calculation for Coke Oven for Feb. 2015 of BSL

Gross coke Production = 196521 T

Actual Production Ratio = 0.632

Balanced Production Ratio = 0.597

Input Item	Unit	Total Quantity	Unit Cons.	G.Cal/T of Product	G.Cal/TCS Actual	G.Cal/TCS Balanced
Coking coal	T	265569.4	1.351	8.727	5.518	5.211
B.F gas	1000Nm ³	91575.0	0.466	0.407	0.257	0.243
COG	1000Nm ³	24394.0	0.124	0.495	0.313	0.295
Electricity	MWh	4845.0	0.025	0.059	0.037	0.035
M.P steam	T	28072.0	0.143	0.101	0.064	0.060

L.P steam	T	10073.0	0.051	0.034	0.021	0.020
Output Item						
Gross Coke	T	196521.0	1.000	6.285	3.974	3.753
COG	1000Nm ³	82008.0	0.417	1.663	1.051	0.993
Tar	T	8106.0	0.041	0.351	0.222	0.209
Benzol	KL	121.0	0.001	0.005	0.003	0.003
W.H steam	T	0.0	0.000	0.000	0.000	0.000

7.4 Continuous Casting shop

Continuous casting is the process in which a semi-finished billet, bloom or slab is produced by the solidification of molten steel for rolling in the finishing mills like Hot strip mill and Cold rolling mill. This process is also known as Strand Casting. Earlier steel was poured into stationary trapezoidal shaped moulds to produce ingots before the introduction of the Continuous Casting. After the evolution of the Continuous Casting better productivity, quality, yield and improved cost efficiency is attained. This process permits lesser production cost of steel slabs with better quality & finish. As the process of continuous casting provides lesser costs of continuous, standardized production and as well as this process offers better control over the process because of automation involved, this process is primarily used for the casting steel into slabs.

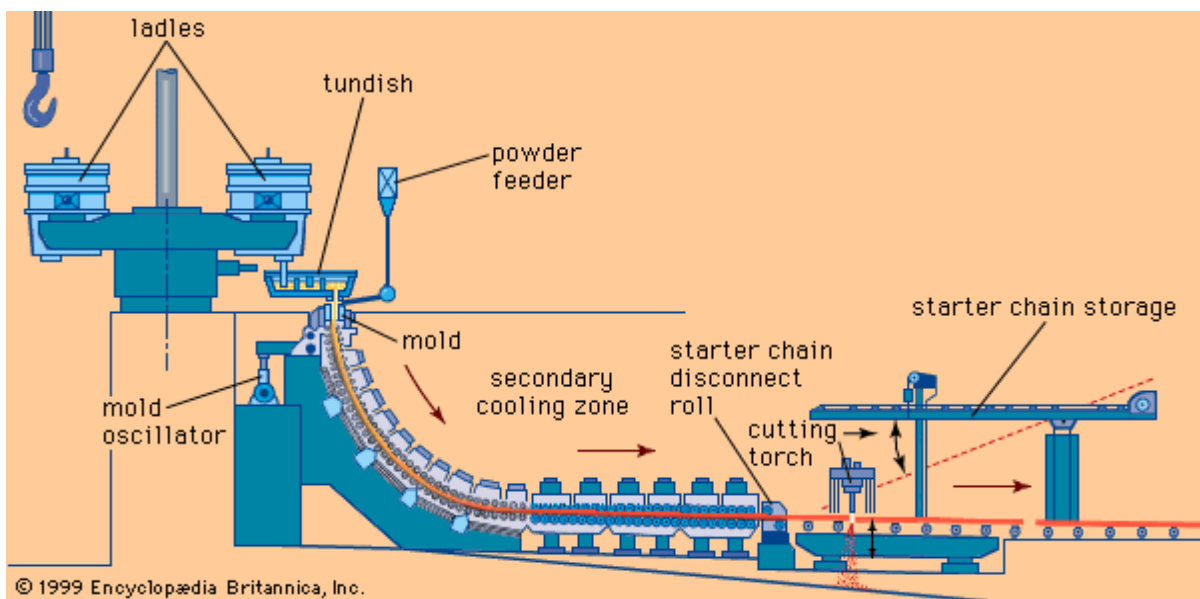


Fig-17 Flow diagram of CCS

As shown in Figure-22 the waste heat of secondary cooling zone and the heat energy stored in casted slabs coming out of Continuous casting line can be recovered and can be used for providing heat to the generator of vapour absorption air conditioning unit.

Energy Calculation for CCS for Feb. 2015 of BSL

CCS Slab Production = 245505 T

Actual production ratio = 0.790

Balanced production ratio = 0.790

Input Item	Unit	Total Quantity	Unit Cons.	G.Cal/T of Product	G.Cal/TCS Actual	G.Cal/TCS Balanced
COG	1000Nm ³	941	0.004	0.015	0.012	0.012
Electricity	MWh	8282	0.034	0.081	0.064	0.064
Oxygen	1000Nm ³	0	0.000	0.000	0.000	0.000
Propane	T	30	0.0001	0.001	0.001	0.001

7.5 Cold Rolling Mill

Cold rolling mill is a type of rolling mill in which HR sheets are rolled to reduce the thickness and to improve the surface finish and physical properties. In cold rolling mill fuel gas is consumed for annealing of the coil and in hot dip galvanizing line to preheat the CR sheets before galvanising it and to melt the Zinc. Desulphurised coke oven gas and CBM is used in CRM for these purpose.

Energy Calculation for CRM for Feb. 2015 of BSL

Production of H.R products = 45289 T

Actual production ratio = 0.146

Balanced production ratio = 0.192

Input Item	Unit	Total Quantity	Unit Cons.	G.Cal/T of Product	G.Cal/TCS Actual	G.Cal/TCS Balanced
B.F Gas	1000Nm ³	7144	0.158	0.138	0.020	0.026
COG	1000Nm ³	4035	0.089	0.355	0.052	0.068
Conv. Gas	1000Nm ³	0	0.000	0.000	0.000	0.000
Naphtha	KL	0	0.000	0.000	0.000	0.000

Electricity	MWh	8172	0.180	0.433	0.063	0.083
L.P steam	T	17787	0.393	0.260	0.038	0.004
CBM	T	107	0.002	0.019	0.003	0.050

7.6 Hot Strip Mill

Hot strip mill is a kind of rolling mill in which hot slabs of steel are rolled to produce HR coils, HR plates and HR sheets. The HR products produced in the HSM are hot and have the temperature of near about 350°C. As the weight of each HR product is in tons so at this temperature range they possessed large amount of energy in the form of heat.

After the rolling, these products are cooled in an open atmosphere due to which all the heat energy is rejected in to the environment as waste heat. This waste heat can be recovered by cooling the HR products in a closed area in a controlled manner with the help of cooling fluid. The waste heat carried by cooling fluid can be used in various purposes like preheating of combustion air, generating low pressure steam and it can also be used to provide heat to generator of vapour absorption air conditioning system to produce cooling effect.

Energy Calculation for HSM for Feb. 2015 of BSL

Production of H.R products = 280302 T

Actual production ratio = 0.902

Balanced production ratio = 0.926

Input Item	Unit	Total Quantity	Unit Cons.	G.Cal/T of Product	G.Cal/TCS Actual	G.Cal/TCS Balanced
B.F Gas	1000Nm ³	37420	0.133	0.117	0.105	0.108
COG	1000Nm ³	26107	0.093	0.371	0.335	0.344
Conv. Gas	1000Nm ³	0	0.000	0.000	0.000	0.000
Naphtha	KL	0	0.000	0.000	0.000	0.000
Electricity	MWh	20743	0.074	0.178	0.160	0.164
M.P steam	T	0	0.000	0.000	0.000	0.000
L.P steam	T	11653	0.042	0.027	0.025	0.025
CBM	1000Nm ³	0	0.000	0.000	0.000	0.000
Propane Gas	T	19	0.0001	0.001	0.001	0.001

Output Item						
E.C.S steam	T	44000	0.157	0.104	0.094	0.096

$$\text{Average production rate of HR products} = \frac{280302}{28 \times 24} = 1459.9 \text{ T/hr} = 1459900 \text{ kg/hr}$$

$$\text{Average temperature of HR products} = 423 \text{ K}$$

Results:

$$\text{Average production rate of HR products} = \frac{280302}{28 \times 24} = 1459.9 \text{ T/hr} = 1459900 \text{ kg/hr}$$

$$\text{Average temperature of HR products} = 423 \text{ K}$$

$$\text{Specific heat capacity of Steel at } 423 \text{ K} = 375 \text{ J kg}^{-1} \text{ K}^{-1}$$

$$\text{We assume that the average ambient temperature} = 313 \text{ K}$$

$$\Delta T = 423 - 313 = 110 \text{ K}$$

$$\text{Theoretical average heat rate available} = m \times C_p \times \Delta T \quad (16)$$

$$= 1459900 \times 375 \times 110$$

$$= 6.0220875 \times 10^{10} \text{ J/hr}$$

$$= 1.6728021 \times 10^7 \text{ J/sec}$$

Calculation of maximum Theoretical COP of the system

$$\text{COP}_{\text{Max.}} = \frac{T_G - T_o}{T_G} \times \frac{T_R}{T_o - T_R}$$

$$T_o = 313 \text{ K}$$

$$T_G = 423 \text{ K}$$

$$T_R = 280 \text{ K}$$

$$\text{COP}_{\text{max}} = 2.2$$

$$\text{Efficiency of Heat recovery system} = 35\%$$

$$\text{Energy Available for air conditioning} = 0.35 \times 1.6728021 \times 10^7$$

$$= 5854807 \text{ J/sec}$$

$$\text{COP of Air conditioning unit} = 0.75$$

$$\text{Cooling effect} = \text{Energy input} \times \text{COP}$$

$$\begin{aligned}\text{Cooling effect can be produced} &= 5854807 \times .75 \\ &= 4391105\text{J/sec} \\ &= 4391105 \text{ Watt} \\ &= 1254 \text{ Ton}\end{aligned}$$

Conclusion:

With all the studies and information I have concluded that:

The Coke coming out of the Coke oven, casted slabs of steel produced in continuous casting shop, hot Slag produced in Blast Furnace, Sinter produced in Sinter plant and HR products of HSM have sufficient amount of waste heat that can be used to provide to the generator of the vapour absorption Air conditioning system.

The HR products produced in HSM have sufficient amount of heat that is $5.23942 \times 10^7\text{J/sec}$ and also have suitable temperature of near about 623K which is a feasible heat source to run the Li-Br vapour absorption Air conditioning system.

The heat pipe has better efficiency as compared to the other type waste heat recovery systems and it has 100 times faster heat transfer capacity so heat pipes are used to recover waste heat from the HR products of the HSM.

The overall efficiency of the plant will improve after the implementation of Waste heat recovery in the HSM.

Vapour absorption Air conditioning system unit using waste heat recovery can be installed successfully.

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