West Heat Recovery

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Waste Heat Recovery

- **Introduction**

  A **waste heat recovery unit (WHRU)** isan energy recovery heat exchanger that transfers heat from process outputs at high temperature to another part of the process for some purpose, usually increased efficiency. The WHRU is a tool involved in cogeneration. Waste heat may be extracted from sources such as hot flue gases from a diesel generator, steam from cooling towers, or even waste water from cooling processes such as in steel cooling.

  Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.
  Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces.
  If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting following measures as outlined in this chapter.

Introduction

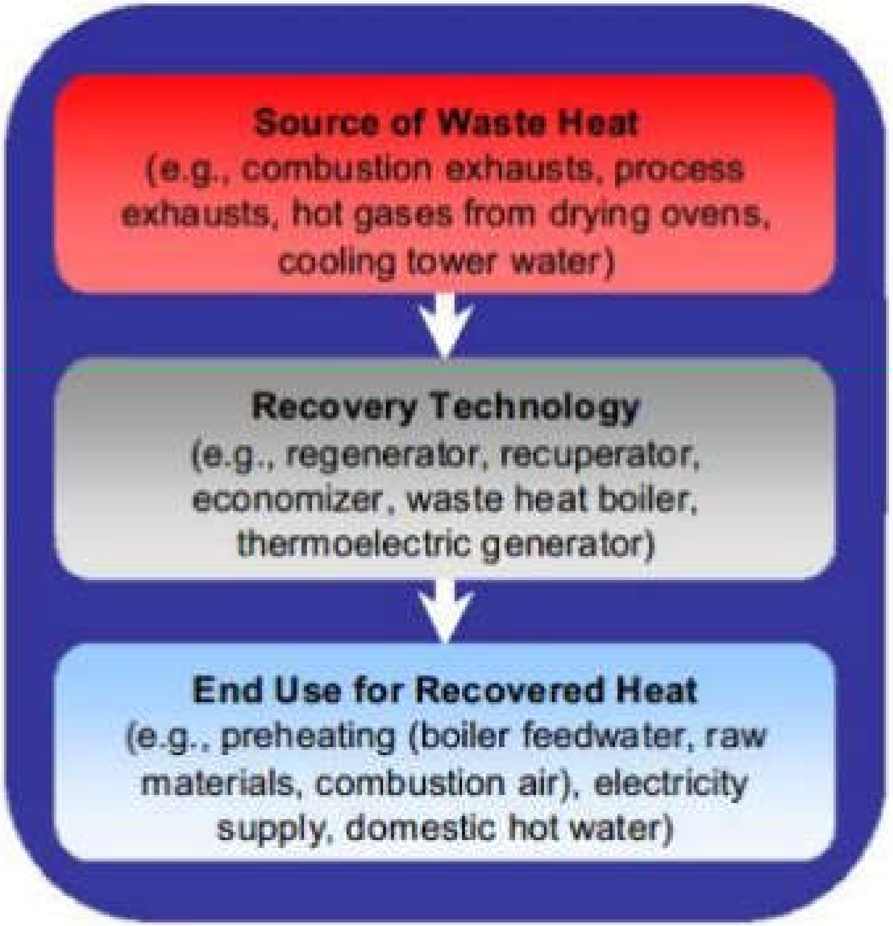
- A valuable alternative approach to improving overall energy efficiency is to capture and reuse the lost or "waste heat" that is intrinsic to all industrial manufacturing

- Captured and reused waste heat is an emission free substitute for costly purchased fuels or electricity

- In some cases, such as industrial furnaces, efficiency improvements resulting from waste heat recovery can improve energy efficiency by 10% to as much as 50%

- RD&D opportunities include optimizing existing recovery technologies as well as developing new heat recovery technologies.

Existing technologies can be further improved to maximize recovery, expand application constraints, and improve economic feasibility



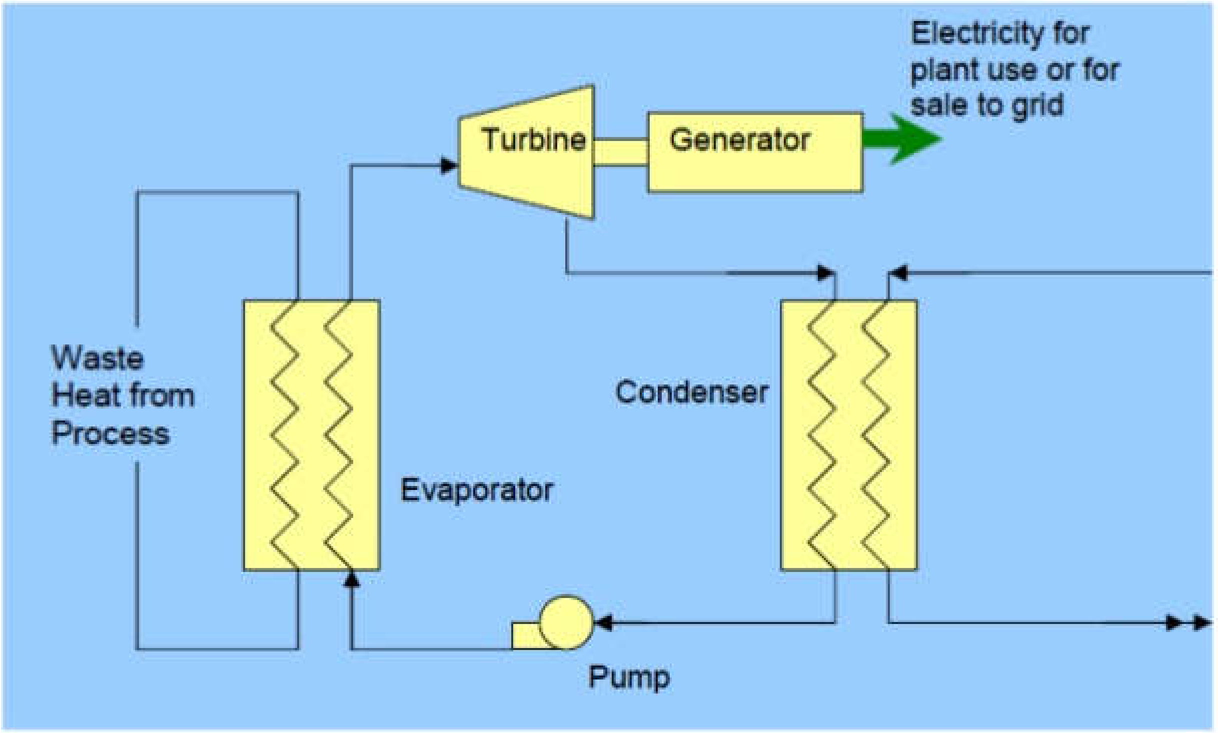
Waste Heat Sources	Uses for Waste Heat
• Combustion Exhausts: Glass melting furnace Cement kiln Fume incinerator Aluminum reverberatory furnace Boiler • Process off-gases: Steel electric arc furnace Aluminum reverberatory furnace • Cooling water from: Furnaces Air compressors Internal combustion engines • Conductive, convective, and radiative losses from equipment: Hall-Hèroult cells [a] • Conductive, convective, and radiative losses from heated products: Hot cokes Blast furnace slags [a]	• Combustion air preheating • Boiler feedwater preheating • Load preheating • Power generation • Steam generation for use in: power generation mechanical power process steam • Space heating • Water preheating • Transfer to liquid or gaseous process streams

a. Not currently recoverable with existing technology

Factors Affecting Waste Heat Recovery Feasibility

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

Waste Heat Recovery with Rankine Cycle



High Temperature Heat Recovery

Table: Typical waste heat temperature at high temperature range from various sources

Types of Devices	*Temperature (^{0}C)*
Nickel refining furnace	1370 – 1650
Aluminium refining furnace	650 –760
Zinc refining furnace	760 – 1100
Copper refining furnace	760 – 815
Steel heating furnace	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

Medium Temperature Heat Recovery

Table: Typical waste heat temperature at medium temperature range from various sources

Types of Devices	*Temperature (^0C)*
Steam boiler exhaust	230 – 480
Gas turbine exhaust	370 – 540
Reciprocating engine exhaust	315 – 600
Reciprocating engine exhaust (turbo charged)	230 – 370
Heat treatment furnace	425 – 650
Drying & baking ovens	230 – 600
Catalytic crackers	425 – 650
Annealing furnace cooling systems	425 – 650

Low Temperature Heat Recovery

Source	*Temperature ^0C*
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

Classification of WHRS on basis of Type of Equipment's

- There are many different commercial recovery units for the transferring of energy from hot medium space to lower one:
- **Recuperators**: This name is given to different types of heat exchanger that the exhaust gases are passed through, consisting of metal tubes that carry the inlet gas and thus preheating the gas before entering the process. The heat wheel is an example which operates on the same principle as a solar air conditioning unit.
- **Regenerators:** This is an industrial unit that reuses the same stream after processing. In this type of heat recovery, the heat is regenerated and reused in the process.
- **Heat pipe exchanger**: Heat pipes are one of the best thermal conductors. They have the ability to transfer heat hundred times more than copper. Heat pipes are mainly known in renewable energy technology as being used in evacuated tube collectors. The heat pipe is mainly used in space, process or air heating, in waste heat from a process is being transferred to the surrounding due to its transfer mechanism.
- **Thermal Wheel or rotary heat exchanger**: consists of a circular honeycomb matrix of heat absorbing material, which is slowly rotated within the supply and exhaust air streams of an air handling system.
- **Economizer**: In case of process boilers, waste heat in the exhaust gas is passed along a recuperators that carries the inlet fluid for the boiler and thus decreases thermal energy intake of the inlet fluid.

Classification of WHRS on basis of Type of Equipment's

- **Heat pumps:** Using an organic fluid that boils at a low temperature means that energy could be regenerated from waste fluids.
- **Run around coil:** comprises two or more multi-row finned tube coils connected to each other by a pumped pipework circuit.

Commercial Waste Heat Recovery Devices

1. Waste Heat Recovery Boilers
2. Recuperators
   a) Radiation/Convective Hybrid Recuperator:
   b) Ceramic Recuperator
3. Regenerators
4. Heat pipe exchanger
5. Thermal Wheel
6. Economizer
   a) Shell and Tube Heat Exchanger
   b) Plate heat exchanger
7. Heat pumps
8. Heat Wheels
9. Heat Pipe
10. Run Around Coil Exchanger
11. Thermo-compressor
12. Direct Contact Heat Exchanger
    a) Hot-Hot mixing
    b) Different Phase mixing
    c) Hot-Cold Mixing

Waste Heat Recovery Technologies

1. Recuperators:

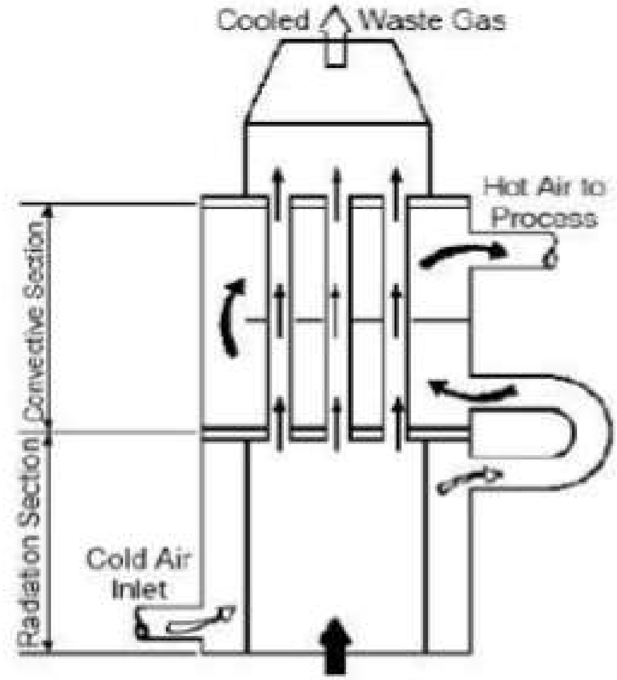
- Recover exhaust gas waste heat in medium to high temperature applications such as soaking or annealing ovens, melting furnaces, afterburners, gas incinerators, radiant tube burners, and reheat furnaces.

- Recuperators can be based on radiation, convection, or combinations

- Recuperators are constructed out of either metallic or ceramic materials. Metallic recuperators are used in applications with temperatures below 2,000ºF [1,093ºC], while heat recovery at higher temperatures is better suited to ceramic tube recuperators.

- These can operate with hot side temperatures as high as 2,800ºF [1,538ºC] and cold side temperatures of about 1,800°F [982ºC].

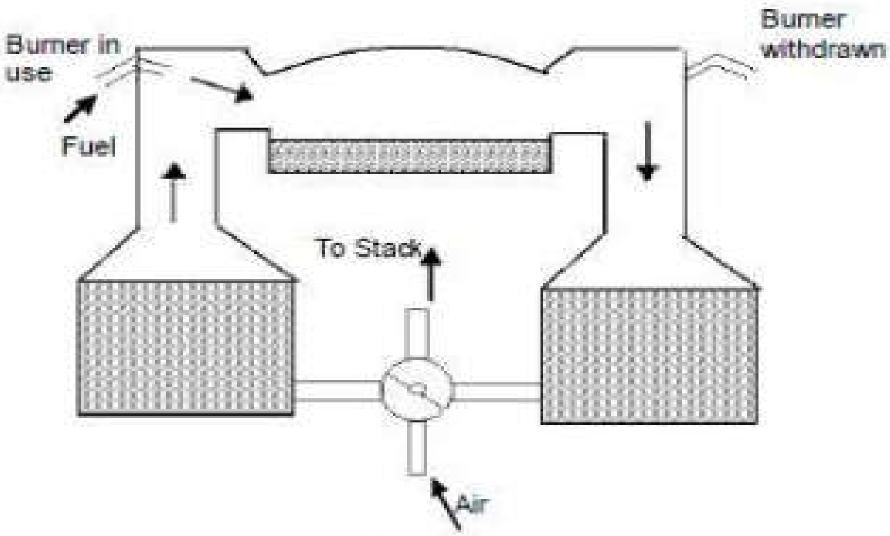
(a)



(b) -

Figure 5 - (a) Convection Recuperator (Source: Allstom, 2007)**. -**
(b) Combined Radiation/Convection Recuperator (Source: PG&E)

2. Regenerators:



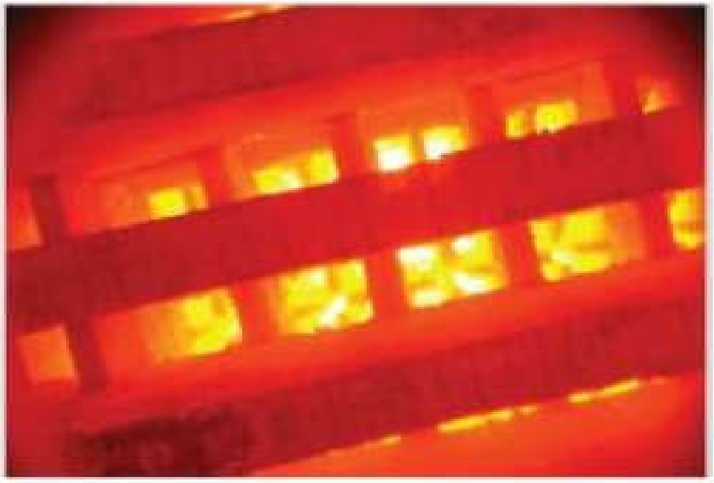


Figure 6 - (a) Regenerative Furnace Diagram,
(b) Checkerwork in Glass Regenerative Furnace (Source: GS Energy & Environment, 2007)

- Regenerators are most frequently used with glass furnaces and coke ovens, and were historically used with steel open hearth furnaces, before these furnaces were replaced by more efficient designs.

- They are also used to preheat the hot blast provided to blast stoves used in iron making; however, regenerators in blast stoves are not a heat recovery application, but simply the means by which heat released from gas combustion is transferred to the hot blast air.

- Regenerator systems are specially suited for high temperature applications with dirty exhausts.

- One major disadvantage is the large size and capital costs, which are significantly greater than costs of recuperators

4. Passive Air Preheater:

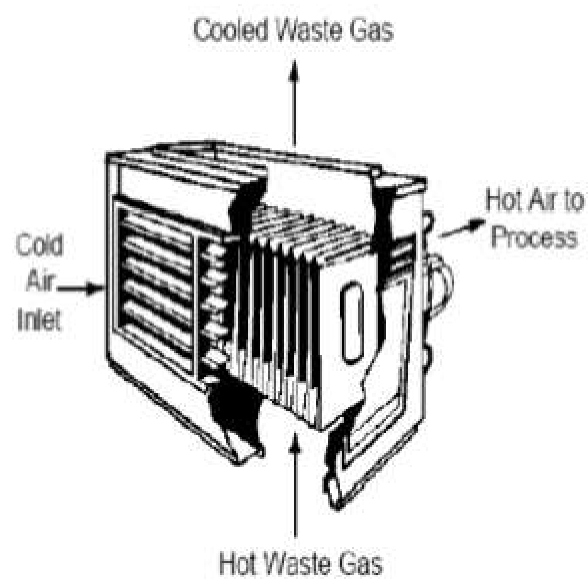
- Passive air preheaters are gas to gas heat recovery devices for low to medium temperature applications where cross contamination between gas streams must be prevented.
- Applications include ovens, steam boilers, gas turbine exhaust, secondary recovery from furnaces, and recovery from conditioned air.

Passive preheaters can be of two types –

1. **the plate type**
2. **Heat pipe.**

1. Plate Type Exchanger

- Consists of multiple parallel plates that create separate channels for hot and cold gas streams.
- Hot and cold flows alternate between the plates and allow significant areas for heat transfer.
- They are often bulkier, more costly, and more susceptible to fouling problems.



2. Heat Pipe Heat Exchanger

- The heat pipe heat exchanger consists of several pipes with sealed ends.

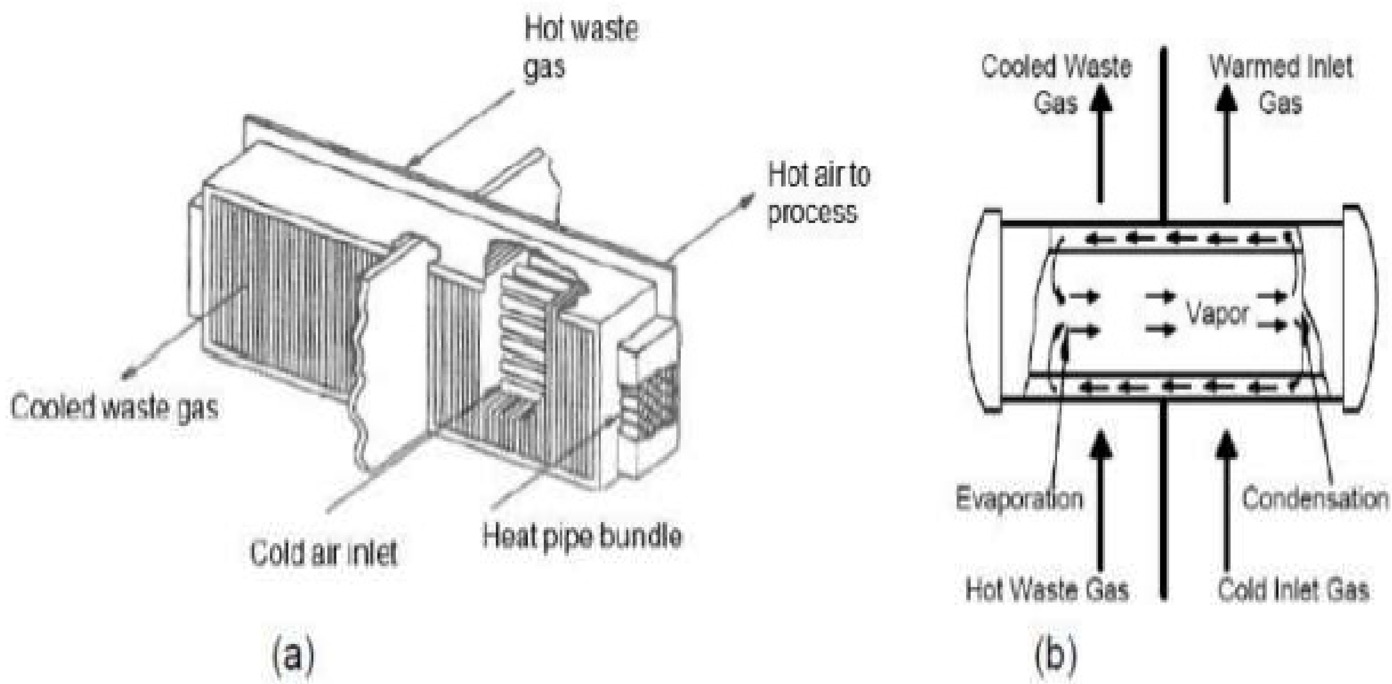


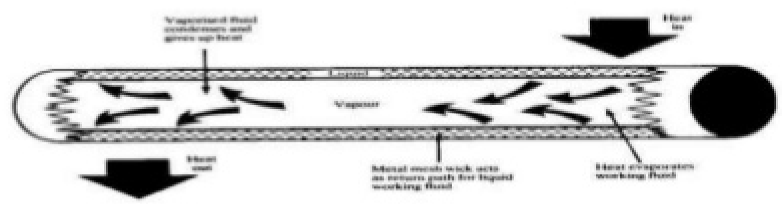
Figure 9 - (a) Heat Pipe Heat Exchanger (Source: Turner, 2006),
(b) Heat Pipe (Source: PG&E, 1997)

- Each pipe contains a capillary wick structure that facilitates movement of the working fluid between the hot and cold ends of the pipe.

- Hot gases pass over one end of the heat pipe, causing the working fluid inside the pipe to evaporate.

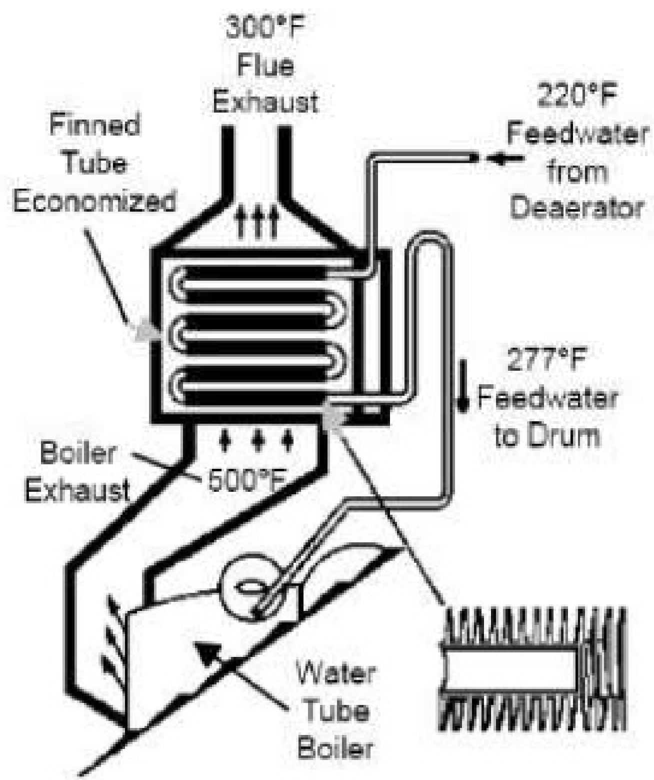
- Pressure gradients along the pipe cause the hot vapor to move to the other end of the pipe, where the vapor condenses and transfers heat to the cold gas.

- The condensate then cycles back to the hot side of the pipe via capillary action.



5. Economizers /Finned Tube Heat Exchangers

- Used to recover heat from low to medium temperature exhaust gases for heating liquids.
- Applications include boiler feed water preheating, hot process liquids, hot water for space heating, or domestic hot water
- Consists of a round tube with attached fins that maximize surface area and heat transfer rates.
- Liquid flows through the tubes and receive heat from hot gases flowing across the tubes.



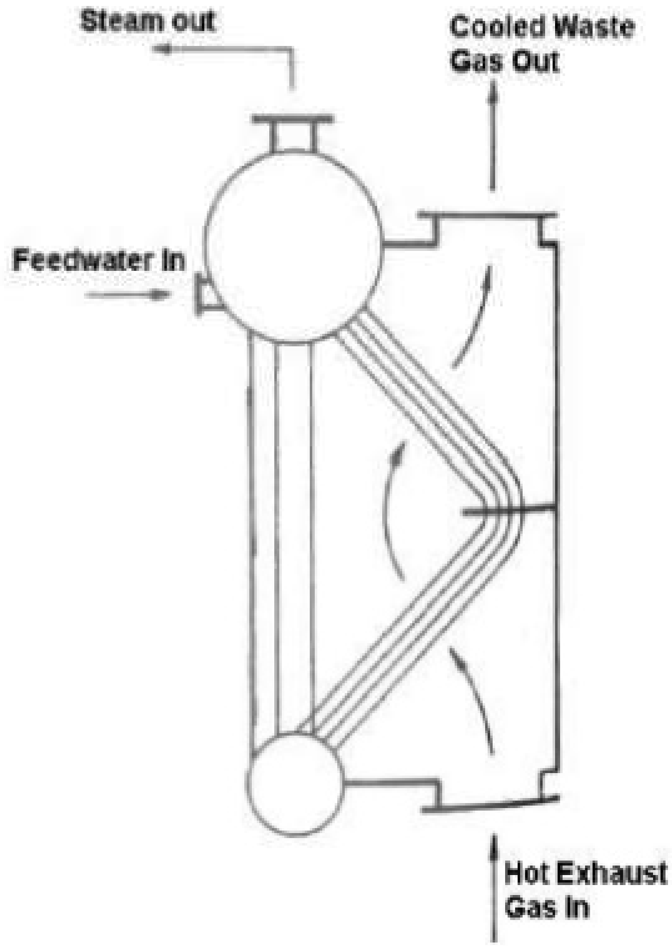
6. Waste Heat Boilers

- Example: the **two pass boiler** shown in Figure are water tube boilers that use medium to high temperature exhaust gases to generate steam.

- Waste heat boilers are available in a variety of capacities, allowing for gas intakes from 1000 to 1 million ft^3/min.

- In cases where the waste heat is not sufficient for producing desired levels of steam, auxiliary burners or an afterburner can be added to attain higher steam output.

- The steam can be used for process heating or for power generation.



West Heat Recovery Boiler (WHRB)

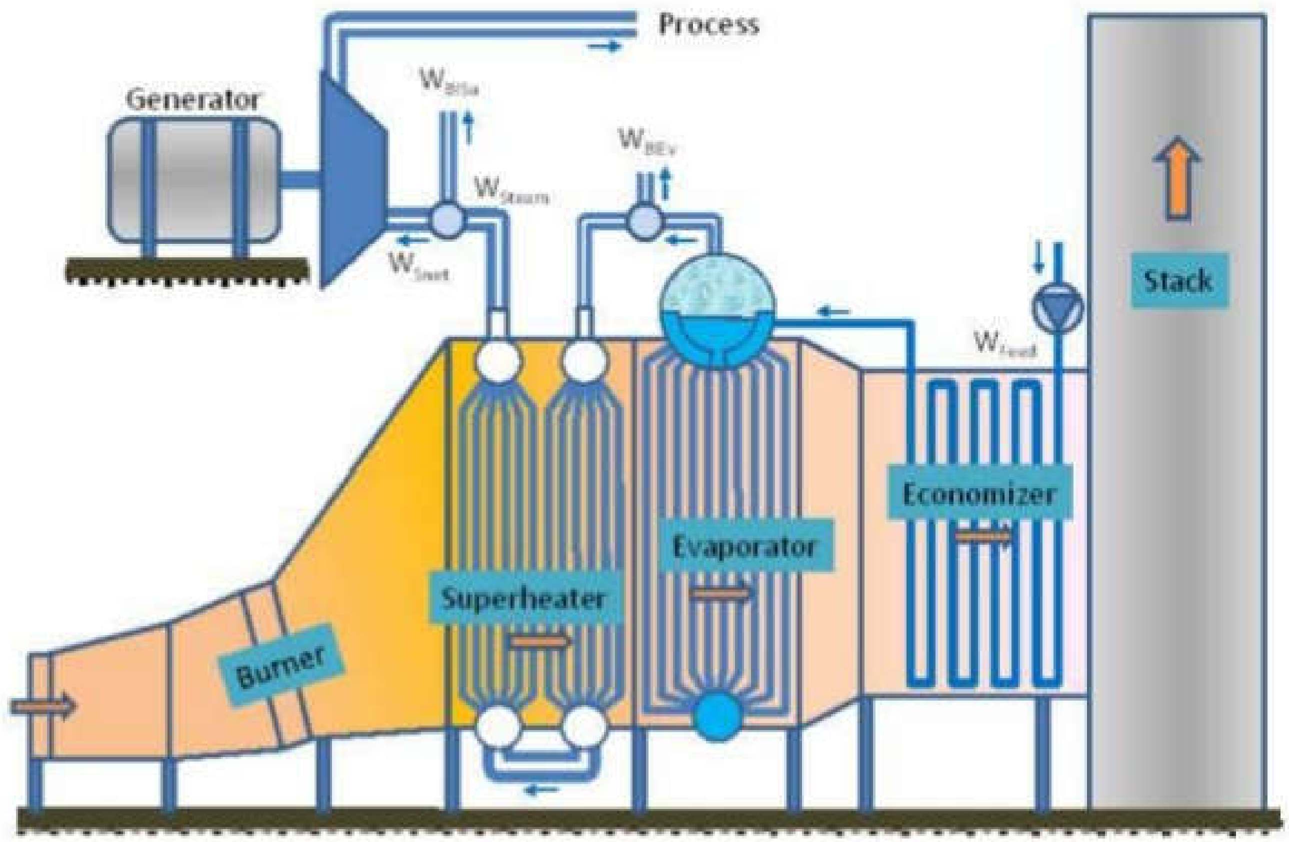


Fig: Schematic Diagram of WHRB system in Combine Cycle Power Plant

Feed Water Heater

- A feed water heater is a power plant component used to pre-heat water delivered to a steam generating boiler Preheating the feed water reduces the irreversibilities involved in steam generation and therefore improves the thermodynamic efficiency of the system. This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feed water is introduced back into the steam cycle.
- In a steam power plant (usually modelled as a modified Rankine cycle), feed water heaters allow the feed water to be brought up to the saturation temperature very gradually. This minimizes the inevitable irreversibilities associated with heat transfer to the working fluid (water). See the article on the second law of thermodynamics for a further discussion of such irreversibilities.

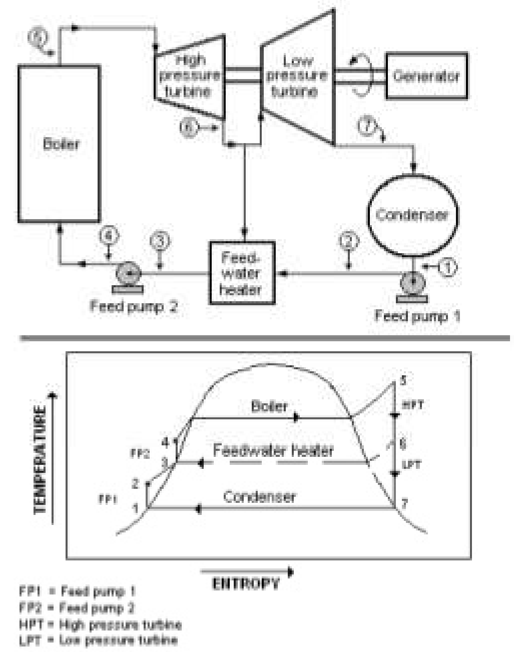


Fig: A Rankine cycle with two steam turbines and a single open feed water heater.

Low Temperature Energy Recovery Options and Technologies

- There are various applications where low grade waste heat has been cost effectively recovered for use in industrial facilities.

- The large quantities of waste heat available in the range of 100-400°F [38-200°C].

- Much industrial waste heat is in the low temperature range. For example, combustion systems such as boilers frequently use recovery technologies that exhaust gases at around 300350°F [150°-180°C], accounting for at least 460 TBtu of waste heat per year.

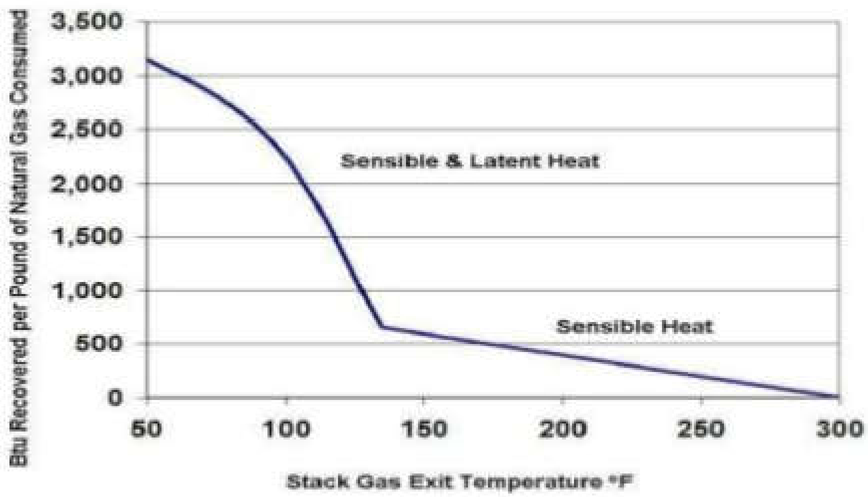
- Large quantities of waste heat can be found in industrial cooling water and cooling air; for example cooling of air compressors alone accounts for about 18 TBtu of waste heat per year.

- One integrated steel mill in Japan successfully installed a power generation plant with a **3.5 MW** capacity using cooling water at only 208°F [98°C]

- In the case of combustion exhaust gases, substantial heat can be recovered if water vapor contained in the gases is cooled to lower temperatures.
- Minimum temperature limits around 250-300°F [120-150°C] are frequently employed in order to prevent water in the exhaust gases from condensing and depositing corrosive substances on the heat exchanger surface.

- However, cooling the flue gas further could significantly increase heat recovery by allowing the latent heat of vaporization to be recovered. A pound of water requires 1,000 Btu of energy to evaporate. Conversely, if a pound of water vapor condenses, it transfers 1,000 Btu to its environment.

- This latent heat comprises a significant portion of the energy contained in exhaust gases. Technologies that can minimize chemical attack while cooling exhaust gases below the condensation point can achieve significant increases in energy efficiency via recovering the latent heat of evaporation.



Heat Recovery Curve for Gas Boiler (Source: Schneider, 2015)

Challenges to Recovering Low Temperature Waste Heat

Corrosion of the heat exchanger surface: As water vapor contained in the exhaust gas cools, some of it will condense and deposit corrosive solids and liquids on the heat exchange surface. The heat exchanger must be designed to withstand exposure to these corrosive deposits. This generally requires using advanced materials

Large heat exchange surfaces required for heat transfer: Heat transfer rates are a function of the thermal conductivity of the heat exchange material, the temperature difference between the two fluid streams, and the surface area of the heat exchanger. Since low temperature waste heat will involve a smaller temperature gradient between two fluid streams, larger surface areas are required for heat transfer.

Finding a use for low temperature heat: Recovering heat in the low temperature range will only make sense if the plant has a use for low temperature heat. Potential end uses include domestic hot water, space heating, and low temperature process heating.

Low Temperature HE Devices (CONCEPTS)

1. Deep Economizers:

Designed to cool exhaust gas to 150-160ºF [65ºC-71ºC] and to withstand the acidic condensate depositing on its surface. Designs include the following options:

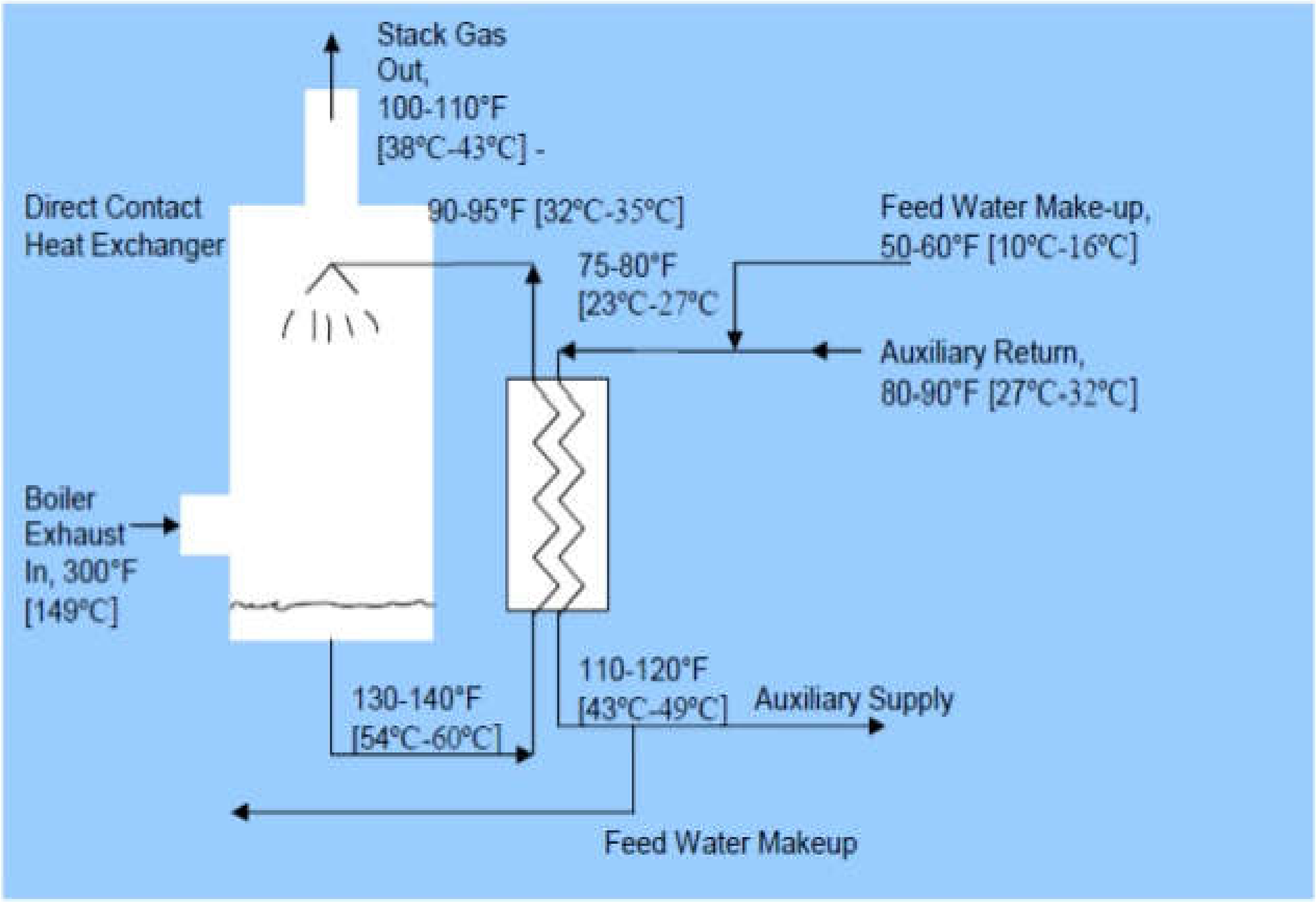
- Installing a “throwaway” section on the cold end of the economizer.
- The tubing in the cold end will degrade over time and will need to be repeatedly replaced. The frequency of replacements will depend on the flue gas composition and the material of construction.
- Designing the economizer with stainless steel tubes. Stainless steel can withstand acidic gases better than the mild steel typically used in construction.

- Using carbon steel for the majority of the heat exchanger, but using stainless steel tubes in the cold end where acidic deposits will occur.
- Using glass tubed heat exchangers (mainly for gas-gas applications such as air preheaters). Using advanced materials such as Teflon.

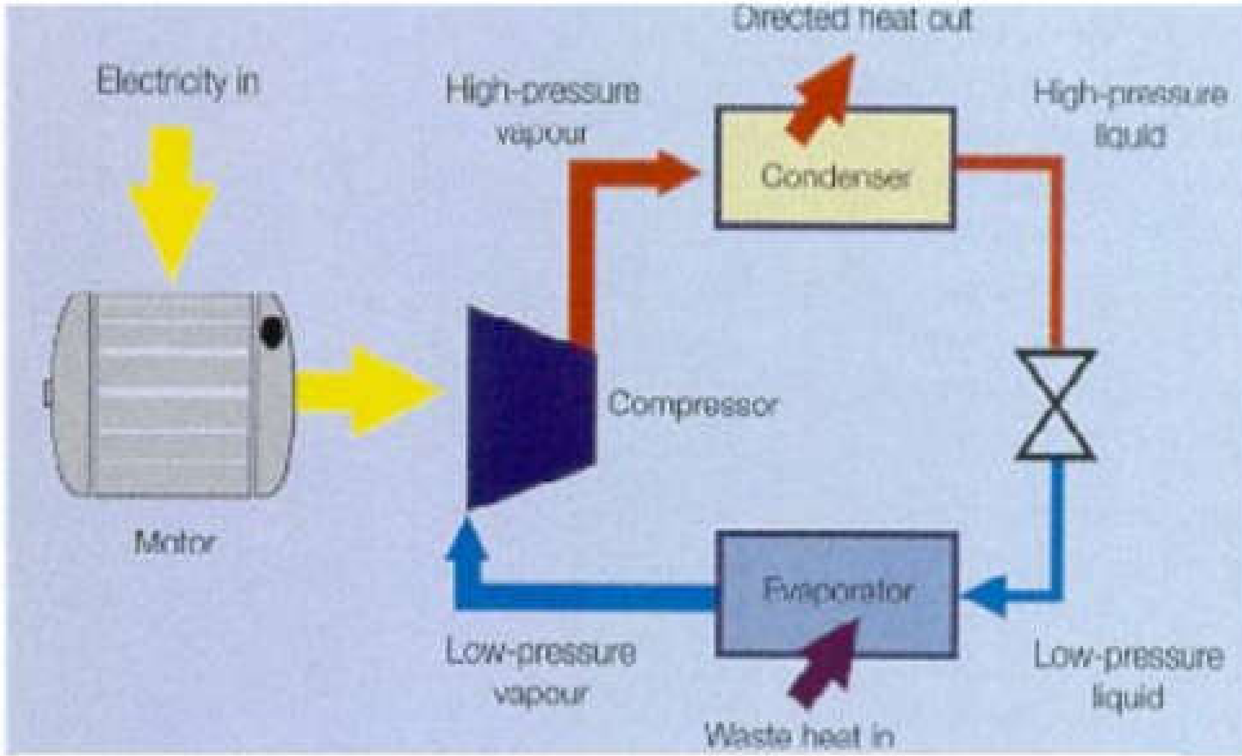
2. Indirect Contact Condensation Recovery:

- Indirect contact condensation recovery units cool gases to 100 to 110ºF [38-43ºC].
- In this range, the water vapor in gases will condense almost completely.
- Indirect contact exchangers consist of a shell & tube heat exchangers.
- They can be designed with stainless steel, glass, Teflon, or other advanced materials.

3. Direct Contact Condensation Recovery:



4. Heat Pumps:

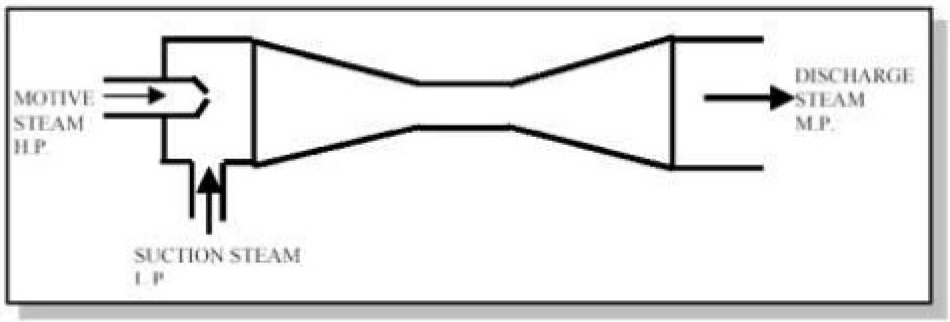


1. In the evaporator the heat is extracted from the heat source to boil the circulating substance
2. The circulating substance is compressed by the compressor, raising its pressure and temperature
3. The heat is delivered to the condenser

4. The pressure of the circulating substance (working fluid) is reduced back to the evaporator condition in the throttling valve, where the cycle repeats.

4.1. Thermo-compressors:

- Compress low-pressure steam by very high-pressure steam and reuse as medium pressure steam
- Nozzle for acceleration of HP steam to a high velocity fluid.



Direct Benefits

- Recovery of waste heat has a direct effect on the efficiency of the process.
- This is reflected by reduction in the utility consumption & costs, and process cost.

Indirect Benefits

- **Reduction in pollution**: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, etc, releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.
- **Reduction in equipment sizes**: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipment
- **Reduction in auxiliary energy consumption:** Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.

Benefits of Waste Heat Recovery

Benefits of 'waste heat recovery' can be broadly classified in two categories:

- **Direct Benefits:**
  Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost.

- **Indirect Benefits:**

a) **Reduction in pollution:**

A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc., releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

b) **Reduction in equipment sizes:**

Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipment's such as fans, stacks, ducts, burners, etc.

c) **Reduction in auxiliary energy consumption:**

Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc..