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Review on Principle and Applications of Waste Heat Recovery Unit

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ABSTRACT

The following paper gives a brief idea about the principle of waste heat recovery. It defines the waste heat recovery system using heat wheels, heat pipes, heat exchangers and explains the classification, advantages and limitations of the system. The paper explains a commercial example of the waste heat recovery unit.

Keywords: Acrylonitrile, Recuperator, Heat wheel

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I. INTRODUCTION

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.

Qualitative Heat losses

Depending upon the type of process, waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery.

In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

Quantitative Heat losses

In any heat recovery situation it is essential to know the amount of heat recoverable and also how it can be used. An example of the availability of waste heat is given below:

• Heat recovery from heat treatment furnace In a heat treatment furnace, the exhaust gases are leaving the furnace at 900°C at the rate of 2100 m^3/hour. The total heat recoverable at 180°C final exhaust can be calculated as

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

Q is the heat content in kCal
V is the flow rate of the substance in m^3/hr
ρ is density of the flue gas in kg/ m^3
Cp is the specific heat of the substance in kCal/kg °C
ΔT is the temperature difference in °C
Cp (Specific heat of flue gas) = 0.24 kCal/kg/°C

Heat available (Q) = 2100 x 1.19 x 0.24 x (900-180) = 4,31,827 kCal/hr By installing a recuperator, this heat can be recovered to pre-heat the combustion air. The fuel savings would be 33% (@ 1% fuel reduction for every 22°C reduction in temperature of flue gas.

II. WASTE HEAT RECOVERY-PRINCIPLE

A waste heat recovery (WHRU) is an energy recovery heat exchanger that recovers heat from hot streams with potential high energy content. Waste heat found in the exhaust gas of various processes or even from the exhaust stream of a conditioning unit can be used to preheat the incoming gas. This is one of the basic methods for recovery of waste heat. Example of such a system is Recuperator. 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.

III. CLASSIFICATION OF WASTE HEAT RECOVERY SYSTEMS

The waste heat recovery systems are mainly classified into three categories, namely;

- Low temperature waste heat recovery system
- Moderate temperature waste heat recovery system
- High temperature waste heat recovery system

Typical waste heat temperature at low temperature range from various sources,

Source	Temperature, °C
Process steam condensate	55-88
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

Typical waste heat temperature at medium temperature range from various sources

Type of Device	Temperature, °C
Steam boiler exhausts	230 – 480
Gas turbine exhausts	370-540
Reciprocatingengine exhausts	315-600
Reciprocatingengine 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

Typical waste heat temperature at high temperature range from various sources

Source	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

IV. 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:

- 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. **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 equipments such as fans, stacks, ducts, burners, etc.

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.

V. DISADVANTAGES OF WASTE HEAT RECOVERY SYSTEM

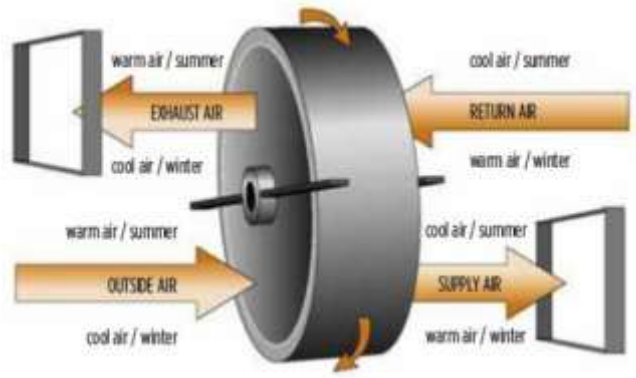
- Capital cost: The capital cost to implement a waste heat recovery system may outweigh the benefit gained in heat recovered. It is necessary to put a cost to the heat being offset.

- Maintenance of Equipment: Additional equipment requires additional maintenance cost.

VI. COMMERCIAL WASTE HEAT RECOVERY DEVICES

- Heat wheels

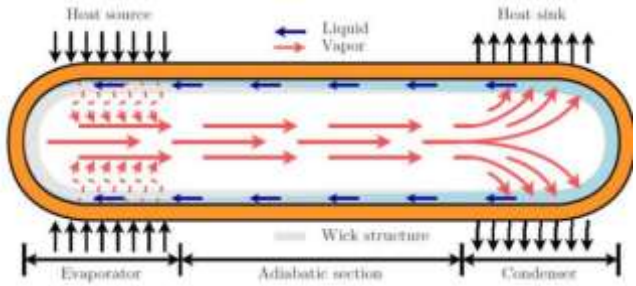
A heat wheel is finding increasing applications in low to medium temperature waste heat recovery systems.



It is a sizable porous disk, fabricated with material having a fairly high heat capacity, which rotates between two side by-side ducts: one a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel to, and on the partition between, the two ducts. As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air. The overall efficiency of sensible heat transfer for this kind of regenerator can be as high as 85 percent. Heat wheels have been built as large as 21 metres in diameter with air capacities up to 1130 m^3/ min. A variation of the Heat Wheel is the rotary regenerator where the matrix is in a cylinder rotating across the waste gas and air streams. The heat or energy recovery wheel is a rotary gas heat regenerator, which can transfer heat from exhaust to incoming gases. Its main area of application is where heat exchange between large masses of air having small temperature differences is required. Heating and ventilation systems and recovery of heat from dryer exhaust air are typical applications.

Heat Pipe

A heat pipe can transfer up to 100 times more thermal energy than copper, the best known conductor. In other words, heat pipe is a thermal energy absorbing and transferring system and have no moving parts and hence require minimum maintenance.



The Heat Pipe comprises of three elements – a sealed container, a capillary wick structure and a working fluid. The capillary wick structure is integrally fabricated into the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external surface of the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. Thermal energy applied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vapourisation and this part of the heat pipe becomes an evaporator region. The vapour then travels to the other end the pipe where the thermal energy is removed causing the vapour to condense into liquid again, thereby giving up the latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporated region.

Performance and Advantage :

The heat pipe exchanger (HPHE) is a lightweight compact heat recovery system. It virtually does not need mechanical maintenance, as there are no moving parts to wear out. It does not need input power for its operation and is free from cooling water and lubrication systems. It also lowers the fan horsepower requirement and increases the overall thermal efficiency of the system. The heat pipe heat recovery systems are capable of operating at 315°C with 60% to 80% heat recovery capability.

Typical Application :

The heat pipes are used in following industrial applications:

- Process to Space Heating: The heat pipe heat exchanger transfers the thermal 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.
- Process to Process: The heat pipe heat exchangers recover waste thermal energy from the process exhaust and transfer this energy to the incoming process air. The incoming air thus become warm and can be used for the same process/other processes and reduces process energy consumption.
- HVAC Applications: Cooling: Heat pipe heat exchangers precools the building make up air in summer and thus reduces the total tons of refrigeration, apart from the operational saving of

the cooling system. Thermal energy is supply recovered from the cool exhaust and transferred to the hot supply make up air. Heating: The above process is reversed during winter to preheat the make up air.

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