

Chapter 2.8: Waste Heat Recovery

Part-I: Objective type questions and answers

1.	Major advantage of waste heat recovery in industry is: a) reduction in pollution b) increase in efficiency c) <u>both a & b</u> d) none of the above
2.	Heat recovery equipment will be most effective when the temperature of flue gas is: a) 250°C b) 200 °C c) <u>400 °C</u> d) 280 °C
3.	The waste gases coming out from gas turbine exhausts are of the order of: a) <u>370-540</u> b) 450 – 700 c) 700-800 d) 250-440
4.	Recuperator is used mainly as a waste heat recovery system in a _____. a) boiler b) <u>billet Reheating Furnace</u> c) compressor d) none of the above
5.	Recuperator will be more efficient if the flow path of hot and cold fluids is in: a) co-current mode b) <u>counter current mode</u> c) cross current mode d) none of the above
6.	The major limitation of metallic recuperator is ----- a) limitation of handling CO _x , NO _x etc. b) <u>limitation of reduced life for handling temperature more than 1000.°C</u> c) manufacturing difficulty of the required design d) none of the above
7.	Ceramic recuperators can withstand temperatures up to: a) 600 °C b) <u>1300.°C</u> c) 1700°C d) 950°C
8.	Air preheater is not used as a waste heat recovery system in a _____. a) boiler b) billet Reheating Furnace c) heat treatment furnace d) <u>compressor</u>
9.	Typical waste gases temperature from glass melting furnace a) <u>1000-1550.°C</u> b) 800-950 °C c) 650–750 °C d) 760-815 °C

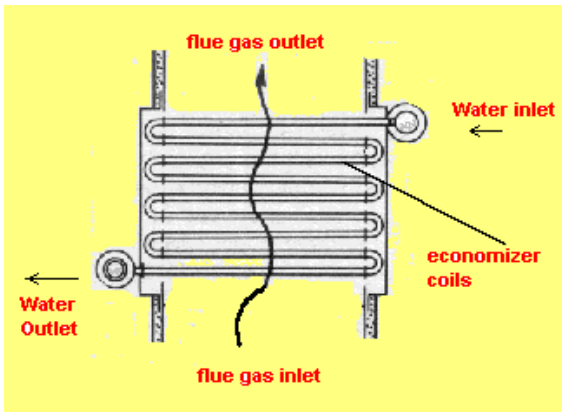
10.	Regenerator is widely used in: a) reheating Furnaces b) heat treatment furnaces c) baking Ovens d) <u>glass melting furnaces</u>
11.	In a low to medium temperature waste heat recovery system which of the device is most suitable a) economiser b) <u>heat wheels</u> c) air preheater d) recuperator
12.	Recovery of heat from dryer exhaust air is a typical application of: a) waste heat recovery boiler b) heat pump c) <u>heat wheels</u> d) economizer
13.	From a reciprocating engine exhausts (turbo charged), the temperature of waste gases lies in the range of a) <u>230-450 °C</u> b) 600 °C c) 800-900 °C d) none of the above
14.	Capillary wick is a part of a) heat pump b) heat wheel c) <u>heat pipe</u> d) regenerator
15.	Economizer is provided to utilize the flue gas heat for ____ a) <u>preheating the boiler feed water</u> b) preheating the stock c) preheating the combustion air d) preheating fuel
16.	A recuperator counter flow type for preheating air receives flue gases at 816 °C and exits at 371 °C. The air enters at 37.8 °C and is preheated to 260 °C. The LMTD is : a) 604 b) 404 c) <u>435</u> d) 224
17.	For every 6°C rise in feed water temperature through an economiser the fuel savings in the boiler is of the order of a) <u>1%</u> b) 1.5% c) 3% d) 2%
18.	Recovery of waste heat from hot fluid to fluid is called: a) thermo compressor b) waste heat recovery boiler c) <u>heat Pump</u> d) economizer
19.	Thermo-compressor is commonly used for a) compressing hot air b) <u>flash steam recovery</u> c) distillation d) reverse compression of CO ₂
20.	Pick up the odd one out:

a) regenerator	b) recuperator	c) metallic recuperator	d) <u>economiser</u>
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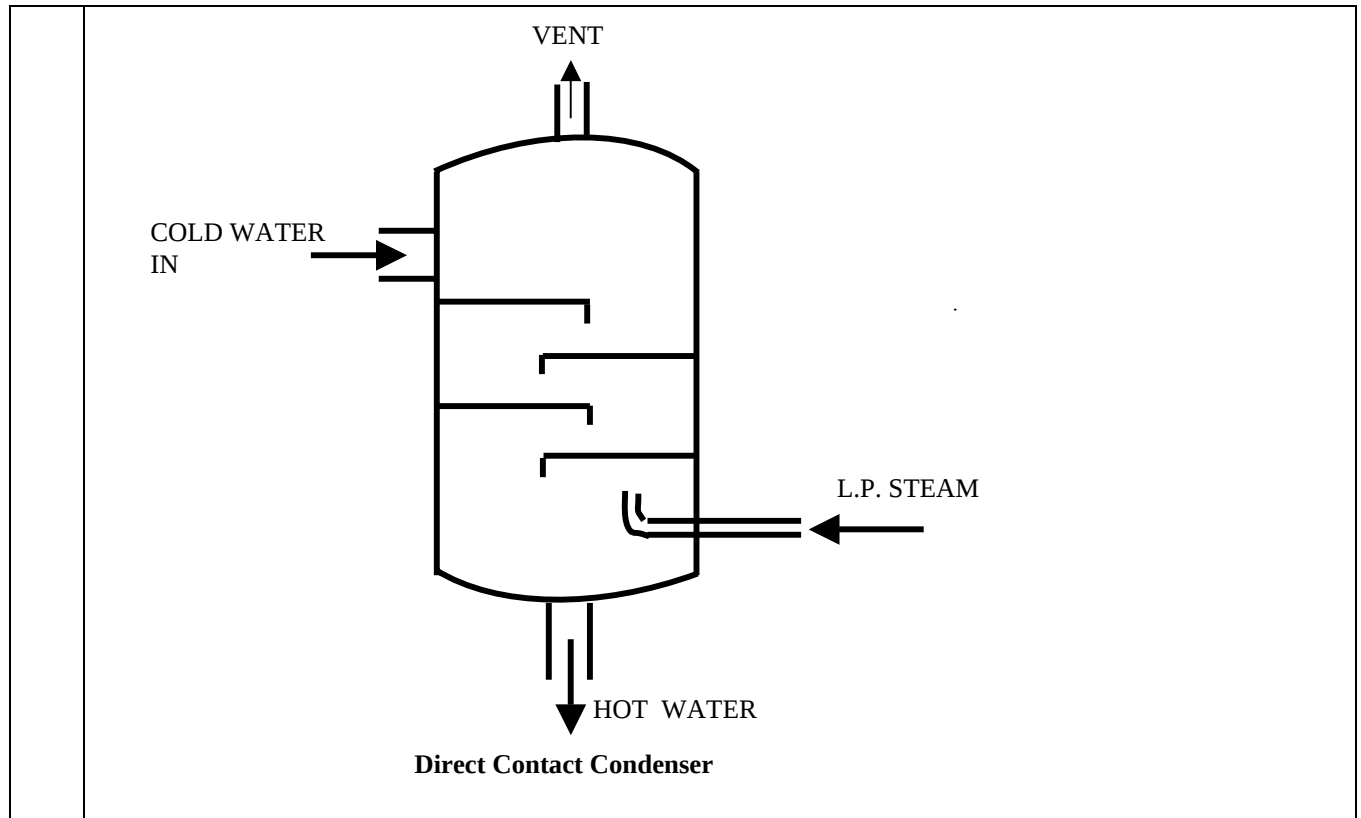
Part-II: Short questions and answers

1.	List some of the direct and indirect benefits of waste heat recovery systems. Direct Benefits 1. Efficiency of process is increased 2. Reduction in process cost. Indirect Benefits: a. Reduction in pollution b. Reduction in equipment sizes c. Reduction in auxiliary energy consumption
2.	What are the major points to be considered for developments of WHRS? Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail review of the following documents will help in identifying: a) Sources and uses of waste heat b) Upset conditions occurring in the plant due to heat recovery c) Availability of space d) Any other constraint, such as dew point occurring in an equipments etc. After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipments to recover and utilize the same.
3.	Mention any three commercial waste heat recovery devices. 1. Recuperator 2. Economizers 3. WHRSG 4. Heat pumps
4.	What is the principle of 'recuperators'? The recuperator is a waste heat recovery device or a heat exchanger between waste gases and the air to be pre-heated. Heat exchange takes place between the flue gases and the air through metallic or ceramic walls.

5.	What is the advantage of 'ceramic recuperators' over 'metallic recuperators'? The ceramic recuperators can allow operation on gas side up to 1300 °C , whereas metallic recuperators can with stand up to 1000 °C only.
6.	What is the principle of 'regenerators'? The regenerator is a waste heat recovery device used to recover heat from waste gases to preheat the combustion air. Regenerator consists of multiples of slightly separated metal plates supported in a frame attached to a slowly moving rotor shaft, which is arranged edge on to the gas and air flow. As these plates pass progressively through the gas stream, they give up heat to the air before re-entering the hot stream, thus maintaining the regenerative cycle.
7.	Describe briefly about 'heat wheels'? A heat wheel 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.
8.	List some of the major applications of a 'heat wheel'? The main area of application of heat wheel 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.
9.	What is a '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 require minimum maintenance.
10.	List at least five applications of 'heat pipe'? • Process to Space Heating • Process to Process • HVAC Applications make up air. • Preheating of boiler combustion air • Recovery of Waste heat from furnaces • Reheating of fresh air for hot air driers • Recovery of waste heat from catalytic deodorizing equipment • Reuse of Furnace waste heat as heat source for other oven

	• Cooling of closed rooms with outside air • Preheating of boiler feed water with waste heat recovery from flue gases in the heat pipe economizers. • Drying, curing and baking ovens • Waste steam reclamation • Brick kilns (secondary recovery) • Reverboratory furnaces (secondary recovery) • Heating, ventilating and air-conditioning systems
11.	Explain with a neat sketch the function of an economizer? Economizer is provided to utilize the flue gas heat for pre-heating the boiler feed water. A schematic diagram of the economizer is shown in Figure. For every 22^o C reduction in flue gas temperature by passing through an economizer or a pre-heater, there is 1% saving of fuel in the boiler. 
12.	What is the advantage of 'plate heat exchanger' over 'shell and tube heat exchanger'? The heat recovery efficiency is higher for plate heat exchanger when compared with shell and tube heat exchanger.
13.	What is the principle of run around coil exchanger? The heat from hot fluid is transferred to the colder fluid via an intermediate fluid known as the Heat Transfer Fluid. One coil of this closed loop is installed in the hot stream while the other is in the cold stream. Circulation of this fluid is maintained by means of land circulating pump.
14.	When run around coil exchangers are preferred? Run around coils is preferred when the hot and cold fluids are located far away from each other and are not easily accessible.

15.	What is the principle of heat pump? By nature heat must flow spontaneously from a system at high temperature to one at a lower temperature. Heat pump reverses the direction of spontaneous energy flow by the use of a thermodynamic system.
16.	Give three examples of low temperature air to air heat recovery devices? a) Heat wheel b) Heat pipe c) Heat pump
17.	Why 'thermo compressors' are required? Thermo compressors are required to reuse very low pressure steam, by compressing it with very high pressure steam and reuse as a medium pressure steam.
18.	Give two examples of usage of 'heat pipe'? i) 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. ii) 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.
19.	Briefly explain the principle of 'thermo compression'. In many cases, very low pressure steam is reused as water after condensation for lack of any better option of reuse. In many cases it becomes feasible to compress this low pressure steam by very high pressure steam and reuse it as a medium pressure steam. The major energy in steam is in its latent heat value and thus thermo compressing would give a large improvement in waste heat recovery. The thermo compressor is simple equipment with a nozzle where HP steam is accelerated into a high velocity fluid. This entrains the LP steam by momentum transfer and then recompresses in a divergent venturi. It is typically used in evaporators where the boiling steam is recompressed and used as heating steam.
20.	Write short notes on Direct Contact Heat Exchanger. Low pressure steam may also be used to preheat the feed water or some other fluid where miscibility is acceptable. This principle is used in Direct Contact Heat Exchanger (DCHE) and finds wide use in a steam generating station. They essentially consist of a number of trays mounted one over the other or packed beds. Steam is supplied below the packing while the cold water is sprayed at the top. The steam is completely condensed in the incoming water thereby heating it. Typical application is in the deaerator of a steam generation station. A figure of DCHE is shown below.



Part-III: Long type questions and answers

1.	Explain any three types of 'recuperators'? a) Metallic radiation recuperator: The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. 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. b) Convective recuperator: These are all shell and tube type recuperator and are generally more compact and have a higher effectiveness than radiation recuperator, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases. 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. c) Ceramic Recuperator: The principal limitation on the heat recovery of metal recuperator is the reduced life of the liner at inlet
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	temperatures exceeding 1100°C. In order to overcome the temperature limitations of metal recuperator, ceramic tube recuperator have been developed whose materials allow operation on the gas side to 1550°C and on the preheated air side to 815°C on a more or less practical basis. This recuperator has short silicon carbide tubes which can be joined by flexible seals located in the air headers.
2.	What are waste heat recovery boilers? Explain the need and benefits? Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gas turbines, incinerators, etc., pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or processing steam. Because the exhaust gases are usually in the medium temperature range and in order to conserve space, a more compact boiler can be produced if the water tubes are finned in order to increase the effective heat transfer area on the gas side. The pressure at which the steam is generated and the rate of steam production depends on the temperature of waste heat. The pressure of a pure vapor in the presence of its liquid is a function of the temperature of the liquid from which it is evaporated. If the waste heat in the exhaust gases is insufficient for generating the required amount of process steam, auxiliary burners which burn fuel in the waste heat boiler or an after-burner in the exhaust gases flue are added. Waste heat boilers are built in capacities from 25 m³ almost 30,000 m³ / min. of exhaust gas. Typical applications of waste heat boilers are to recover energy from the exhausts of gas turbines, reciprocating engines, incinerators, and furnaces.
3.	Explain the principles of 'Heat pump'. Heat must flow spontaneously "downhill", that is from a system at high temperature to one at a lower temperature. It is possible to reverse the direction of spontaneous energy flow by the use of a thermodynamic system known as a heat pump. This device consists of two heat exchangers, a compressor and an expansion device. A liquid or a mixture of liquid and vapor of a pure chemical species flows through an evaporator, where it absorbs heat at low temperature and, in doing so, is completely vaporized. The low temperature vapor is compressed by a compressor, which requires external work. The work done on the vapor raises its pressure and temperature to a level where its energy becomes available for use. The vapor flows through a condenser where it gives up its energy as it condenses to a liquid. The liquid is then expanded through an expansion valve back to the evaporator where the cycle repeats. The heat pump was developed as a space heating system where low temperature energy from the ambient air, water, or earth is raised to heating system temperatures by doing compression work with an electric motor-driven compressor. The heat pumps have the ability to upgrade heat to a value more than twice that of the energy consumed by the device. The potential for application of heat pump is growing and number of industries have been benefited by recovering low grade waste heat by upgrading it and using it in the main process stream. Heat pump applications are most promising when both the heating and cooling capabilities can be used in combination. One such example of this is a plastics factory where chilled water from a heat is used to cool injection-moulding machines whilst the heat output from the heat pump is used to provide factory or office heating. Other examples of heat pump installation include product drying, maintaining dry atmosphere for storage and drying compressed air.
4.	Explain the principle of operation of heat pipe. Discuss three examples of its industrial application. The heat pipe is a thermal energy absorbing and transferring system and has no moving parts and hence requires 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. The heat pipe heat recovery systems are capable of operating at 315°C. with 60% to 80% heat recovery capability. <u>Industrial applications of heat pipe:</u> 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 exchanger precool 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.
5.	In a process, low pressure and high pressure steam is available. Describe how can this steam be reused in industry? Which equipment is used for recovery of this? Explain with a neat sketch the principle of operation of such system? In many cases, very low pressure steam is reused as water after condensation for lack of any better option of reuse. In many cases it becomes feasible to compress this low pressure steam by very high pressure steam and reuse it as a medium pressure steam. The major energy in steam is its latent heat value and thus thermo compressing would give a large improvement in waste heat recovery. The thermo compressor is a simple equipment with a nozzle where HP steam is accelerated into a high velocity fluid. This entrains the LP steam by momentum transfer and then recompresses in a divergent venture. A figure of thermo compressor is shown below. 