WASTE HEAT RECOVERY

1. INTRODUCTION

This section briefly describes the main features of waste heat recovery.

Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is then "dumped" into the environment and not reused for useful and economic purposes. The essential fact is not the amount of heat, but rather its "value". The mechanism to recover the unused heat depends on the temperature of the waste heat gases and the economics involved.

Large quantities of hot flue gases are generated from boilers, kilns, ovens and furnaces. If some of the waste heat could be recovered then 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 adopting the following measures as outlined in this chapter can minimize losses.

2. TYPES OF WASTE HEAT RECOVERY EQUIPMENT

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This section describes the various commercial equipment that can be used to recover waste heat and for other applications and uses.

2.1 Recuperators

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Ducts 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.

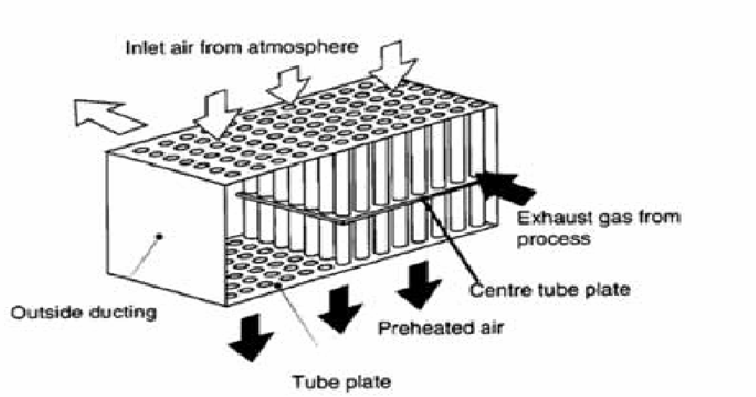

Figure 1. Waste Heat Recovery using Recuperator (SEAV, 2004)

2.1.1 Metallic radiation recuperator

The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing as shown in Figure 2.

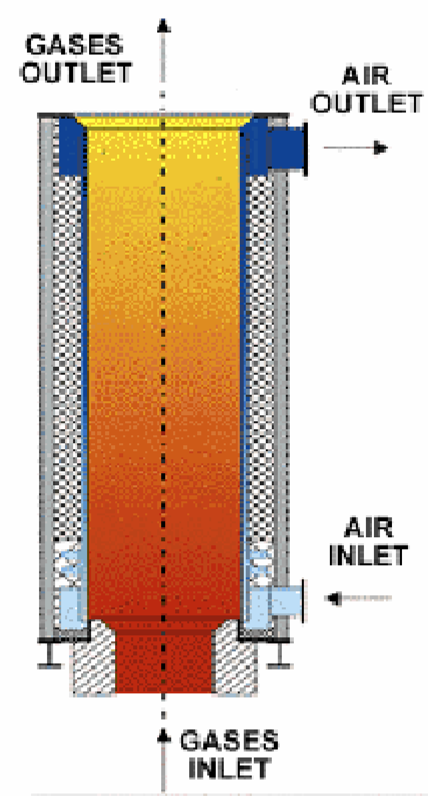

Figure 2. Metallic Radiation Recuperator (Hardtech Group)

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. This is the energy, which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore, stack losses are decreased not only by lowering the stack gas temperatures but also by discharging smaller quantities of exhaust gas. 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 shown in the diagram, the two gas flows are usually parallel, although the configuration would be simpler and the heat transfer would be more efficient if the flows were opposed in direction (or counterflow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases and consequently extending its service life.

2.1.2 Convective recuperator

A second common configuration for recuperators is called the tube type or convective recuperator. As seen in the figure below, 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 the direction normal to their axes.

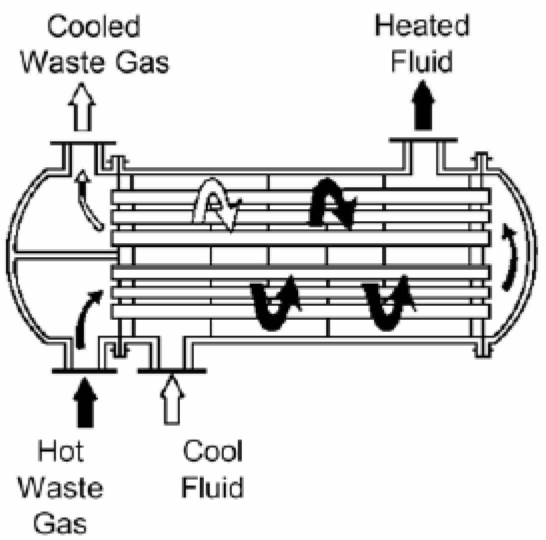

Figure 3. Convective Recuperator
(Reay, D.A., 1996)

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 made possible through the use of multiple tubes and multiple passes of the gases.

2.1.3 Hybrid recuperator

For maximum effectiveness of heat transfer, hybrid recuperators are used. These are combinations of radiation and convective designs, with a high-temperature radiation section followed a by convective section (see Figure 4).

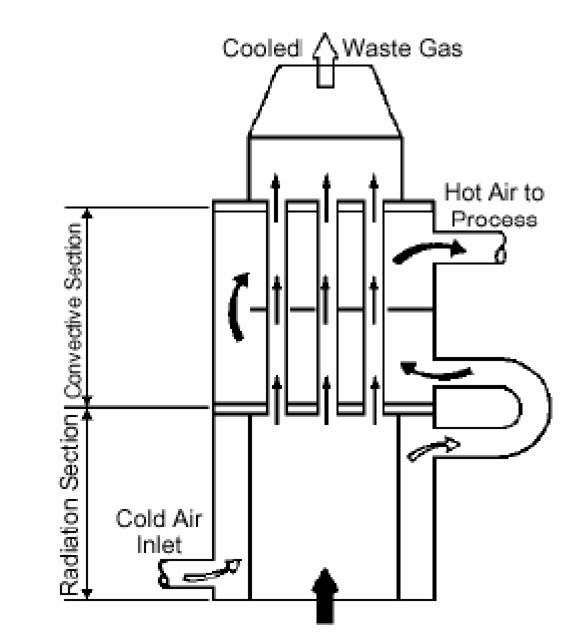

Figure 4. Hybrid Recuperator
(Reay, D.A., 1996)

These are more expensive than simple metallic radiation recuperators, but are less bulky.

2.1.4 Ceramic recuperator

The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 1100 ^{0}C. In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed whose materials allow operation on the gas side to be at 1550 ^{0}C and on the preheated air side to be 815 ^{0}C on a more or less practical basis. Early ceramic recuperators were built of tile and joined with furnace cement, and thermal cycling caused cracking of joints and rapid deterioration of the tubes. Later developments introduced various kinds of short silicon carbide tubes, which can be joined by flexible seals located in the air headers.

Earlier designs had experienced leakage rates from 8 to 60 per cent. The new designs are reported to last two years with air preheat temperatures as high as 700 ^{0}C, with much lower leakage rates.

2.2 Regenerators

Regenerators are suitable for large capacities and have been widely used in glass and steel melting furnaces. Important relations exist

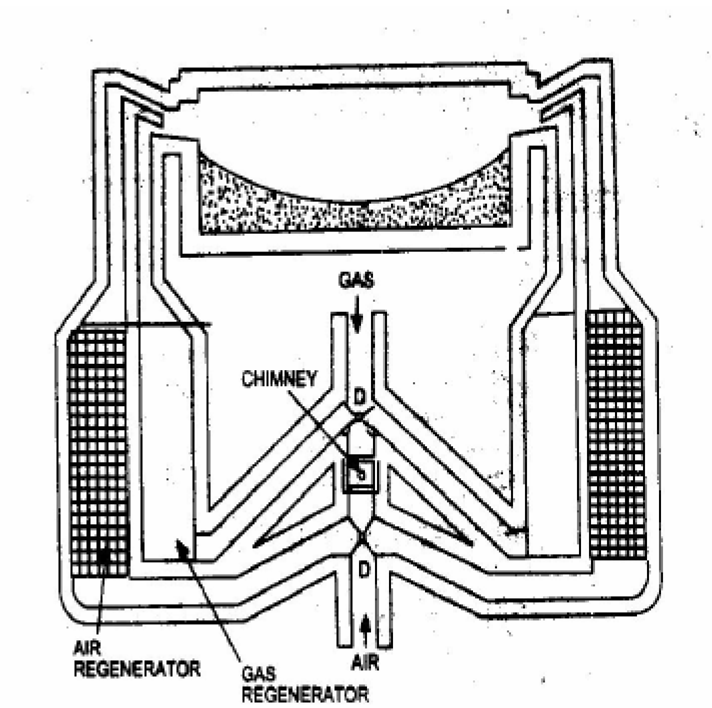

Figure 5. Regenerator
(Department of Coal, India, 1985)

between the sizes 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 result in lower average temperature of preheat and consequently reduction in the fuel economy. Accumulation of dust and slagging on the surfaces reduce efficiency of the heat transfer as the furnace becomes old. Heat losses from the walls of the regenerator and air in-leaks during the gas period and out-leaks during the air period also reduces the heat transfer.

2.3 Heat Wheels

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

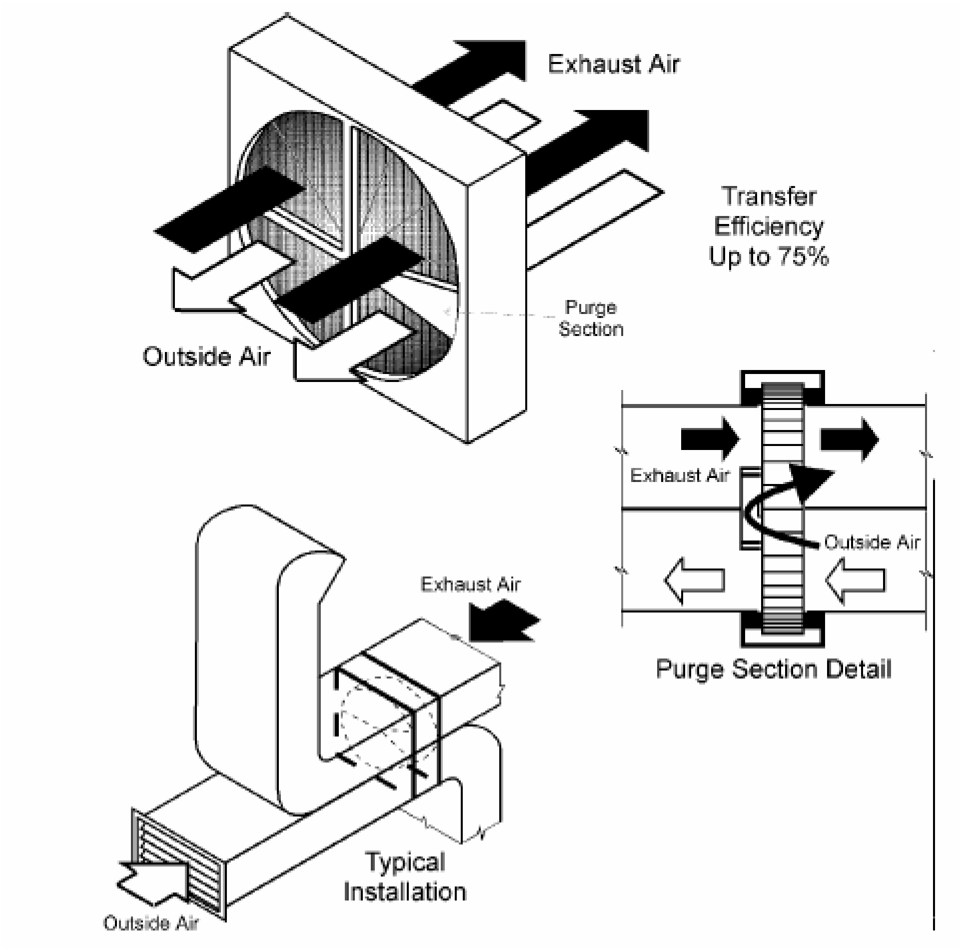

Figure 6. Heat Wheel
(SADC, 1999)

It is a sizable porous disk, fabricated with material having a fairly high heat capacity, which rotates between two side-by-side ducts: one is a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel 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 per cent. Heat wheels have been built as large as 21 meters in diameter with air capacities up to 1130 m3 / 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 is exchanged between large masses of air having small temperature differences. Heating and ventilation systems and recovery of heat from dryer exhaust air are typical applications.

2.4 Heat Pipe

2.4.1 Description

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 having no moving parts and hence requires minimal 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 vaporization 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. Figure 7 shows the heat pipe.

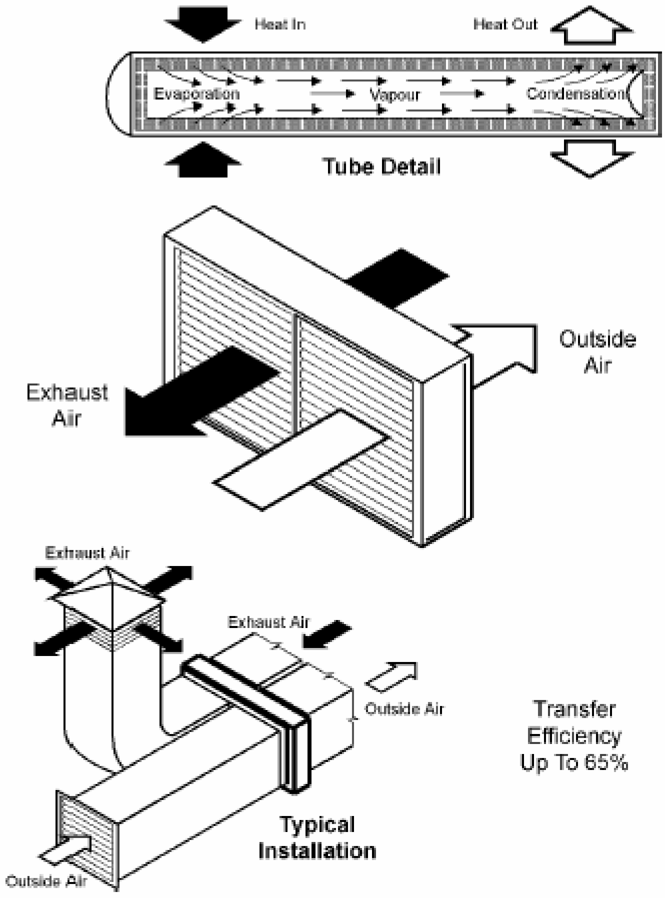

Figure 7. Heat Pipe
(SADC, 1999)

2.4.2 Performance and advantages

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 that 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^{o}C with 60% to 80% heat recovery capability.

2.4.3 Typical applications

Heat pipes are used in the following industrial applications:

- Process of 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 thermal energy waste from the exhaust process and transfer this energy to the incoming process air. The incoming air thus becomes warm and can be used either for the same process/other processes and hence, reduce process energy consumption.
- HVAC Applications:
  - Cooling: Heat pipe heat exchangers pre-cools the building make up air in summer and thus reduces the total tones 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.
- Other applications in industries are:
  - 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)
  - Reverberatory furnaces (secondary recovery)
  - Heating, ventilating and air-conditioning systems

2.5 Economizers

In the case of boiler systems, an economizer can be provided to utilize the flue gas heat for pre-heating the boiler feed water. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler.

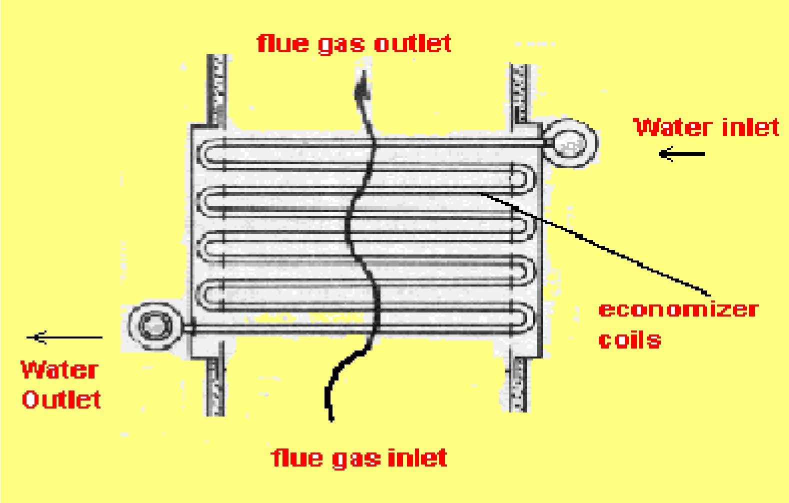

Figure 8. Economizer
(Bureau of Energy Efficiency, 2004)

For every 220 ^{0}C reduction in flue gas temperature by passing through an economizer or a pre-heater, there is 1% saving of fuel in the boiler. In other words, for every 60 ^{0}C rise in feed water temperature through an economizer, or 200 ^{0}C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel in the boiler.

2.6 Shell and Tube Heat Exchangers

When the medium containing waste heat is a liquid or a vapor which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tube, so that the higher-pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. When a vapor contains the waste heat, it usually condenses, giving up its latent heat to the liquid being heated. In this application, the vapor is almost invariably contained within the shell. If the reverse is attempted, the condensation of vapors within small diameter parallel tubes causes flow instabilities. Tube and shell heat exchangers are available in a wide range of standard sizes with many combinations of materials for the tubes and shells. A shell and tube heat exchanger is illustrated in Figure 9 below.

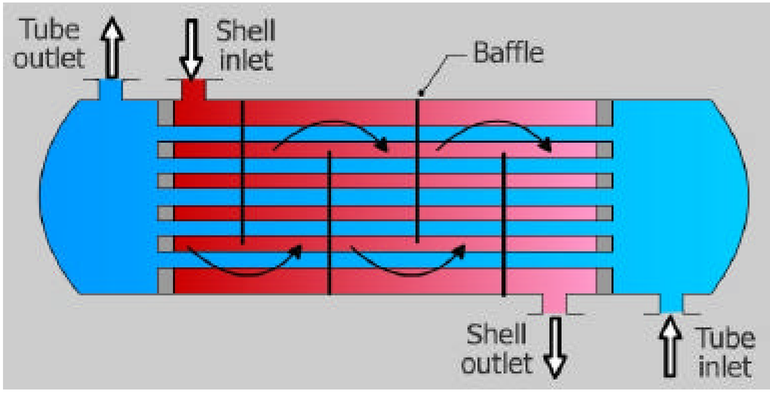

Figure 9. Shell & Tube Heat Exchanger
(King Fahad University of Petroleum & Minerals, 2003)

Typical applications of shell and tube heat exchangers include heating liquids with the heat contained by condensates from refrigeration and air-conditioning systems; condensate from process steam; coolants from furnace doors, grates, and pipe supports; coolants from engines, air compressors, bearings, and lubricants; and the condensates from distillation processes.

2.7 Plate Heat Exchanger

The cost of a heat exchange surface is a major cost factor when the temperature differences are not large. One way of meeting this problem is the plate type heat exchanger, which consists of a series of separate parallel plates forming a thin flow pass. Each plate is separated from the next by gaskets and the hot stream passes in parallel through alternative plates whilst the liquid to be heated passes in parallel between the hot plates. To improve heat transfer the plates are corrugated.

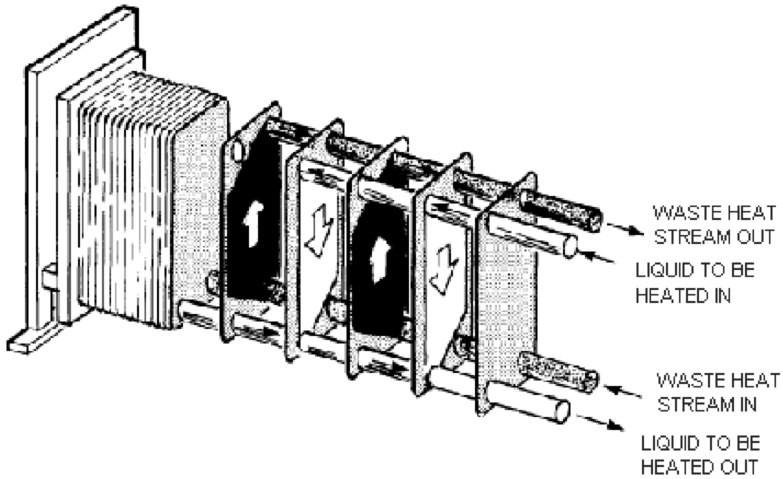

Figure 10. Plate Heat Exchanger
(Canada Agriculture and Agri-Food)

Hot liquid passing through a bottom port in the head is permitted to pass upwards between every second plate while cold liquid at the top of the head is permitted to pass downwards between the odd plates. When the directions of hot & cold fluids are opposite, the arrangement is described as counter current. A plate heat exchanger is shown in Figure 10.
Typical industrial applications are:

- Pasteurization section in a milk packaging plant.
- Evaporation plants in the food industry.

2.8 Run Around Coil Exchangers

Run Around Coil Exchangers are quite similar in principle to the heat pipe 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 a circulating pump.

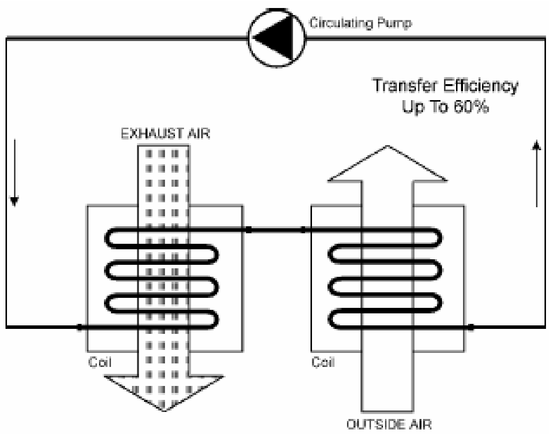

Figure 11. Run Around Coil Exchanger
SADC , 1999

It is more useful when the hot land cold fluids are located far away from each other and are not easily accessible.

Typical industrial applications are heat recovery from ventilation, air conditioning and low temperature heat recovery.

2.9 Waste Heat Recovery Boilers

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 out for use as heating or processing steam.

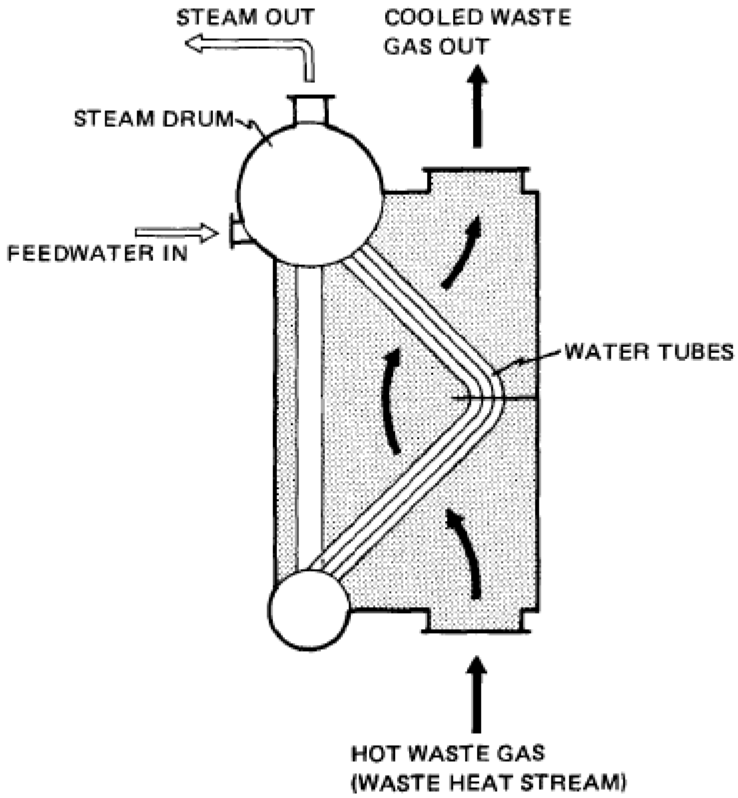

Figure 12. Two-Pass Water Tube Waste Heat Recovery Boiler

(Canada Agriculture and Agri-Food)

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. Figure 12 shows a mud drum, a set of tubes over which the hot gases make a double pass, and a steam drum which collects the steam generated above the water surface. The pressure at which the steam is generated and the rate at which steam is produced depend 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. The steam tables tabulate this relationship between saturation pressure and temperature. 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 which the exhaust gases flue are added. Waste heat boilers are built in capacities from 25 m3 almost 30,000 m3 /min. of exhaust gas.

2.10 Heat Pumps

In the various commercial options previously discussed, we find waste heat being transferred from a hot fluid to a fluid at a lower temperature. Heat must flow spontaneously "downhill", that is from a system at high temperature to one at a lower temperature. When energy is repeatedly transferred or transformed, it becomes less and less available for use. Eventually, energy has such low intensity (resides in a medium at such low temperature) that it is no longer available to function.

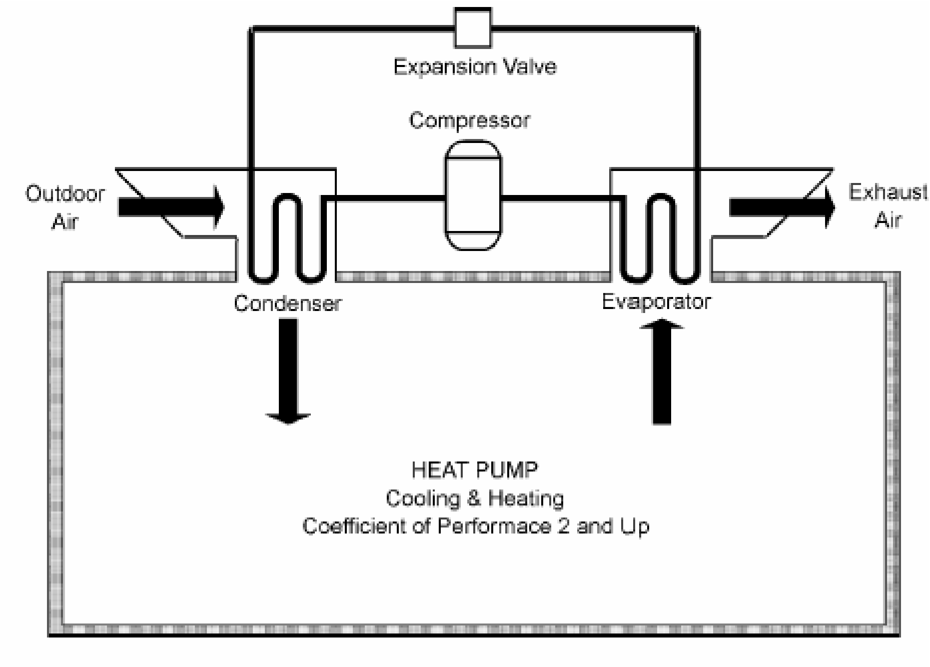

Figure 13. Heat Pump Arrangement
(SADC, 1999)

It has been a general rule of thumb in industrial operations that fluids with temperatures less than 120°C **(**or, better, 150°C to provide a safe margin), are set as the limit for waste heat recovery because of the risk of condensation of corrosive liquids. However, as fuel costs continue to rise, even such waste heat can be used economically for space heating and other low temperature applications. It is possible to reverse the direction of spontaneous energy flow by the use of a thermodynamic system known as heat pump.

The majority of heat pumps work on the principle of the vapour compression cycle. In this cycle, the circulating substance is physically separated from the source (waste heat, with a temperature of Tin) and user (heat to be used in the process, Tout) streams, and is re-used in a cyclical fashion, therefore being called 'closed cycle'. In the heat pump, the following processes take place:

- In the evaporator, the heat is extracted from the heat source to boil the circulating substance;
- The compressor compresses the circulating substance, thereby raising its pressure and temperature. 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 heat is delivered to the condenser;
- The pressure of the circulating substance (working fluid) is reduced back to the evaporator condition in the throttling valve, 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 arrangement of a heat pump is shown in figure 13.

The heat pumps have the ability to upgrade heat to a value more than twice the energy consumed by the device. The potential for application of heat pumps is growing and a growing 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.

2.11 Thermo-compressor

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 big improvement in waste heat recovery.

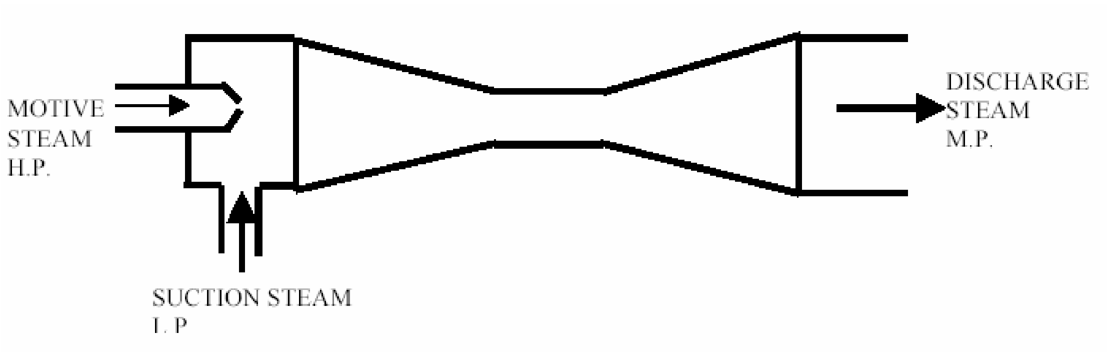

Figure 14. Thermo-compressor

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 venturi. A figure of thermo compressor is shown in Figure 14.

It is typically used in evaporators where the boiling steam is recompressed and used as heating steam.

3. ASSESSMENT OF WASTE HEAT RECOVERY

This section explains how to assess the potential for waste heat recovery and gives examples.

3.1 Determining the Waste Heat Quality

When recovering waste heat, the quality of waste heat must be considered first.

Depending upon the type of process, waste heat can be discarded at virtually any temperature from that of chilled cooling water to high temperature waste gases in an industrial furnace or kiln. Usually, higher temperatures equate to higher quality of heat recovery and greater cost effectiveness. In any study of waste heat recovery, it is absolutely necessary that there is 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 with the highest potential. An example of this technique of waste heat recovery is where the high temperature stage is used for air pre-heating and the low temperature stage is used for process feed water heating or steam generation.

3.1.1 Quality and potential uses

In considering the potential to recover heat, it is useful to note all the possible sources of waste and their quality and possible uses (see Table 1)

Table 1. Waste Heat Source and Quality

No	Source of waste heat	Quality of waste heat and possible use
1	Heat in flue gases	The higher the temperature, the greater the potential value for heat recovery
2	Heat in vapor streams	As for heat in flue gases, but when condensed, latent heat is also recoverable
3	Convective & 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	1. High grade if it can be utilized to reduce demand for refrigeration 2. 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 & liquid effluents leaving process	Poor, if heavily contaminated & thus require alloy heat exchanger

3.1.2 Recovery potential for different industrial processes

Waste heat can be recovered from various industrial processes. A distinction is made between high, medium and low temperatures of waste heat.

Table 2 gives the temperatures of waste gases from industrial process equipment in the high temperature range. All of these results are from direct fuel fired processes.

Table 2. 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

Table 3 gives the temperatures of waste gases from process equipment in the medium temperature range. Most of the waste heat in this temperature range comes from the exhaust of directly fired process units.

Table 3. Typical Waste Heat Temperature at Medium Temperature Range from Various Sources

Types of Devices	Temperature (^{0}C)
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

Table 4 lists some heat sources in the low temperature range. In this range, it is usually not practical to extract work from the source, though steam production may not be completely excluded if there is a need for low-pressure steam. Low temperature waste heat may be useful in a supplementary way for preheating purposes.

Table 4. Typical Waste Heat Temperature at Low Temperature Range from Various Sources

Source	Temperature ^{0}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

Source	Temperature ^{0}C
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

3.2 Determining the Waste Heat Quantity

In any heat recovery situation it is essential to know the amount of heat recoverable and also its usage.

The total heat that could potentially be recovered can be calculated using this formula:

Q = V x r x Cp x DT

Where,

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
Cp is the specific heat of the substance in kCal/kg oC
ΔT is the temperature difference in oC

Example

A large paper manufacturing company identifies an opportunity to save money by recovering heat from hot wastewater. The discharge of the wastewater from the operation range is 10000 kg/hr at 75^{0}C. Rather than discharging this water to drain, it was decided to preheat the 10000 kg/hr of cold inlet water having a yearly average temperature of 20^{0}C, by passing it through a counterflow heat exchanger with automatic back flushing to reduce fouling. Based on a heat recovery factor of 58% and an operation of 5000 hours per year, the annual heat saving (Q) is:

$$Q = m \times \eta \times Cp \times \Delta T$$

Where,

Q is the heat content in kcal
m is the mass flow rate
Cp is the specific heat of the substance in kcal/kg oC, in the case water
ΔT is the temperature difference in oC
η is the recovery factor

Therefore, for this example

m = 1000 kg/hr = 10000 x 5000 kg/yr = 50000000 kg/year
Cp = 1 kCal/kg^{0}C

ΔT = $(75 – 20)\ ^0C$ = $55\ ^0C$
η = Heat Recovery Factor = 58% or 0.58

The calculation of Q is as follows:
Q = 50000000 x 1 x 55 x 0.58
= 1595000000 kCal/year

Gross calorific value (GCV of oil) = 10,200 kCal/kg
Equivalent oil savings = 159500000 / 10200 = 156372 liters
Cost of oil = 0.35 US$/liter
Financial savings = 54730 US$/year

4. ENERGY EFFICIENCY OPPORTUNITIES

Areas for potential waste recovery are dependent on the type of industrial process, and are therefore covered in other energy equipment modules.

5. OPTION CHECKLIST

The most important options to maximize energy efficiency when applying waste heat recovery are

- Recover heat from flue gas, engine cooling water, engine exhaust, low pressure waste steam, drying oven exhaust, boiler blowdown, etc.
- Recover heat from incinerator off-gas.
- Use waste heat for fuel oil heating, boiler feedwater heating, outside air heating, etc.
- Use chiller waste heat to preheat hot water.
- Use heat pumps.
- Use absorption refrigeration.
- Use thermal wheels, run-around systems, heat pipe systems, and air-to-air exchangers.

Options to recover waste heat are covered in other energy equipment modules.

6. WORKSHEETS

This section includes the following worksheets:
- Heat Recovery Questionnaire
- Matrix of Waste Heat Recovery Devices & Applications

Worksheet 1. Heat Recovery Questionnaire

1. From which equipment do you want to recover heat? Oven, furnace, etc.

   - Oven
   - Flue Gas
   - Dryer
   - Bake Oven
   - Furnace
   - Paint Dryer
   - Kiln
   - Melting Furnace
   - Boiler
   - Die Cast Machine
   - Cupola
   - Exhaust Air
   - Other (Please specify)

2. Hot Side Flows:
   a. At what temperature does hot exhaust leave this equipment?
   b. What is the quantity of this hot exhaust?

3. Is this hot exhaust gas clean (natural gas, propane, #2 fuel oil) or does it contain contaminates or corrodents such as sulphur, chlorides, etc?

Clean:	Dirty:	
Exhaust is from:	Exhaust is from and/or contains:	
__________ Air	__________ Fuel Oil	
__________ Natural Gas	________________ Coal	
__________ Propane	________________ Sulphur	_______%
__________ Fuel Oil	________________ Chloride	_______%
__________ Electricity	__________ Paint Vapours	_______%
__________ Other	__________ Other	_______%

4. Cold Side Flows:

Entering Fluid Temperature	^0C	
Entering Fluid Volume	^0C	
Leaving Fluid Temperature Desired	^0C	
Energy to be recovered	kJ/hr	
Available Flow	L/s	

5. Fuel Cost: (USD/kg)
6. Operating Hours

Worksheet 2. Matrix of Waste Heat Recovery Devices And Applications

Heat Recovery Device	**Temp. Range**	**Typical Sources**	**Typical Uses**
Radiation Recuperator	H	Incinerator or boiler exhaust	Combustion air preheat
Convective Recuperator	M-H	Soaking or annealing ovens, melting furnaces, afterburners, gas incinerators, radiant tube burners, reheat furnaces	Combustion air preheat
Furnace Regenerator	H	Glass and Steel melting furnaces	Combustion air preheat
Metallic Heat Wheel	L-M	Curing and drying ovens, boiler exhaust	Combustion air preheat, Space preheat
Ceramic Heat Wheel	M-H	Large boiler or Incinerator exhaust	Combustion air preheat
Finned tube Regenerator	L-M	Boiler Exhaust	Boiler makeup water preheat
Shell & tube Regenerator	L	Refrigeration condensates, waste steam, distillation condensates, coolants from engines, air compressors, bearings and lubricants	Liquid flows requiring heating
Heat Pipes	L-M	Drying, curing and baking ovens, Waste steam, air dryers, Kilns and Reverberatory furnaces	Combustion air preheat, boiler makeup water preheat, Steam generation, domestic hot water, space heat
Waste heat boiler	M-H	Exhaust from gas turbines, reciprocating engines, incinerators and furnaces	Hot water or steam generation

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