Module 4

INTRODUCTION TO HVAC SYSTEM

HVAC stands for Heating, Ventilation, and Air Conditioning. HVAC systems control the indoor environment (temperature, humidity, air flow, and air filtering) Mechanical intervention to condition the air to a preferred temperature and relative humidity. HVAC is a basic requirement for our indoor air quality, what you breathe, temperature, humidity --in our house. So when you hear the term "HVAC" it means the entire air system of your home.

The goal of the heating, ventilating, and air conditioning (HVAC) system is to create and maintain a comfortable environment within a building. A comfortable environment, however, is broader than just temperature and humidity. Comfort requirements that are typically impacted by the HVAC system include:

Dry-bulb temperature (Temperature of air measured by a thermometer freely hanged)
Humidity
Air movement
Fresh air
Cleanliness of the air
Noise levels

In addition, there are other factors that affect comfort but are not directly related to the HVAC system. Examples include adequate lighting, and proper furniture and work surfaces.

For generalizing the HVAC system, it can be dissected into five system loops

1. Airside loop
2. Chilled water loop
3. Refrigeration loop
4. Heat rejection loop
5. Control loop

Airside loop

The first component of this loop is the conditioned space. The first two comfort requirements mentioned were drybulb temperature and humidity. In order to maintain the dry-bulb temperature in the conditioned space, heat (referred to as sensible heat) must be added or removed at the same rate as it leaves or enters the space. In order to maintain the humidity level in the space, moisture (sometimes referred to as latent heat) must be added or removed at the same rate as it leaves or enters the space.

Most HVAC systems used today deliver conditioned (heated, cooled, humidified, or dehumidified) air to the conditioned space to add or remove sensible heat and moisture. This conditioned air is called supply air. The air that carries the heat and moisture out of the space is called return air. Imagine the conditioned supply air as a sponge. In the cooling mode, as it enters a space, this “sponge” (supply air) absorbs sensible heat and moisture. The amount of sensible heat and moisture absorbed depends on the temperature and humidity, as well as the quantity, of the supply air. Assuming a fixed quantity of air, if the supply air is colder, it can remove more sensible heat from the space. If the supply air is drier, it can remove more moisture from the space. 2

In order to determine how much supply air is needed for a given space, and how cold and dry it must be, it is necessary to determine the rate at which sensible heat and moisture (latent heat) enter, or are generated within, the conditioned space.

Chilled water loop

Chilled water systems in residential HVAC systems are extremely rare. A typical chiller uses the process of refrigeration to chill water in a chiller barrel. This water is pumped through chilled water piping throughout the building where it will pass through a coil. Air is passed over this coil and the heat exchange process takes place. The heat in the air is absorbed into the coils and then into the water. The water is pumped back to the chiller to have the heat removed. It then makes the trip back through the building and the coils all over again.

Refrigeration loop

The refrigeration system removes heat from an area that is low-pressure, low temperature (evaporator) into an area of high-pressure, high temperature (condenser). It mainly has the following components

1. Evaporator
2. Compressor
3. Condenser
4. Metering Device

Evaporator – This is the coil that is inside of the house. Warm air will pass over the coil which contains the refrigerant, then the refrigerant absorbs the heat, then the you are left with cold air which is distributed to the rooms that you are trying to cool.

Compressor – This is the life force of the refrigeration cycle, what it does is it will circulate refrigerant throughout the whole system. It will compress cold vapor into hot vapor, it also increases the low vapor pressure into high vapor pressure.

Condenser – This is the coil that is located outside on a central air conditioning system. It removes the heat that is carried through the refrigerant, forcing the hot air out.

Metering Device – Controls the flow of the refrigerant to the evaporator. There are different kinds of metering devices, some of them will have pressure limiting devices to protect the compressor from overloading, while some will control the evaporators pressure or superheat. Some common metering devices are thermostatic expansion valves, automatic expansion valves, capillary tubes, and fixed-bore.

Heat rejection loop

In the refrigeration loop, the condenser transfers heat from the hot refrigerant to air, water, or some other fluid. In a water-cooled condenser, water flows through the tubes while the hot refrigerant vapor enters the shell space surrounding the tubes. Heat is transferred from the refrigerant to the water, warming the water. The water flowing through the condenser must be colder than the hot refrigerant vapor. A heat exchanger is required to cool the water that returns from the condenser at particular temperature and back to the desired temperature of before it is pumped back to the condenser. Which is done by heat rejection loop. When a water-cooled condenser is used, this heat exchanger is typically either a cooling tower or a fluid cooler (also known as a dry cooler). 3

A fluid cooler is similar to an air-cooled condenser. Water flows through the tubes of a finned-tube heat exchanger and fans draw outdoor air over the surfaces of the tubes and fins. Heat is transferred from the warmer water to the cooler air. The third component of the heat-rejection loop moves the condensing media around the loop. In the case of a water cooled condenser, a pump is needed to move the water through the tubes of the condenser, the piping, the cooling tower, and any other accessories installed in the heat-rejection loop.

One method of varying the quantity of water flowing through the water-cooled condenser is to use a modulating control valve. As the heat-rejection requirement decreases, the modulating control valve directs less water through the condenser. If a three-way valve is used, the excess water bypasses the condenser and mixes downstream with the water that flows through the condenser.

Controls Loop

The fifth, and final, loop of the HVAC system is the controls loop. Each of the previous four loops contains several components. Each component must be controlled in a particular way to ensure proper operation. Typically, each piece of equipment (which may be comprised of one or more components of a loop) is equipped with a unit-level, automatic controller. In order to provide intelligent, coordinated control so that the individual pieces of equipment operate together as an efficient system, these individual unit-level controllers are often connected to a central, system-level controller. Finally, many building operators want to monitor the system, receive alarms and diagnostics at a central location, and integrate the HVAC system with other systems in the building. These are some of the functions provided by a building automation system (BAS).

The interconnection of first 4 loop in HVAC system is shown in the figure below 4

LECTURE 2: Coefficient of Performance

Ratio of work or useful output to the amount of work or energy input is called as coefficient of performance. It is used generally as a measure of the energy-efficiency of air conditioners, space heaters and other cooling and heating devices. COP equals heat delivered (output) in British thermal units (Btu) per hour divided by the heat equivalent of the electric energy input (one watt = 3.413 Btu/hour) or, alternatively, energy efficiency ratio divided by 3.413. Higher the COP, higher the efficiency of the equipment. Higher COPs equate to lower operating costs. The COP usually exceeds 1, especially in heat pumps, because, instead of just converting work to heat (which, if 100% efficient, would be a COP_hp of 1), it pumps additional heat from a heat source to where the heat is required. When calculating the COP for a heat pump, the heat output from the condenser (Q) is compared to the power supplied to the compressor (W).

The COP for heating and cooling are different, because the heat reservoir of interest is different. When one is interested in how well a machine cools, the COP is the ratio of the heat removed from the cold reservoir to input work. However, for heating, the COP is the ratio of the heat removed from the cold reservoir plus the input work to the input work

where

Qc is the heat removed from the cold reservoir.

QH is the heat supplied to the hot reservoir.

For a better assessment of performance of refrigeration plant calculation of COP is an important factor.

The theoretical Coefficient of Performance (Carnot cycle), COP Carnot is a standard measure of refrigeration efficiency of an ideal refrigeration system- depends on two key system temperatures, namely, evaporator temperature Te and condenser temperature Tc with COP being given as:

COPCarnot = Te / (Tc - Te)

This expression also indicates that higher COPCarnot is achieved with higher evaporator temperature and lower condenser temperature. But COPCarnot is only a ratio of temperatures, and hence does not take into account the type of compressor. Hence the COP normally used in the industry is given by

where the cooling effect is the difference in enthalpy across the evaporator and expressed as kW.

Difference between COP and efficiency

Both efficiency and COP are trying to give you the performance value of the system, whether it is refrigerator or engine, where it involves input and output energies. But the difference is, What types of energies are involved in. There are two types of energies namely, High Grade Energy and Low grade Energy. For efficiency, the ratios are between (1-(heat out/ heat supplied)) same form of energies. That is heat, low grade energy. So it never be grater 5 than 1. Whereas the COP deals with the ratio between (heat removed / electricity supplied) both are different types. Electricity is a high grade energy. And hence the COP is greater than 1.

In other words the efficiency is calculated for the devices which are power producing, while in case of power absorbing devices COP is calculated because we want to check performance of device for a given power input.

LECTURE 3: Factors Affecting Performance & Energy Efficiency of Refrigeration Plants

The main factors affecting the performance and energy efficiency of refrigeration plants are the following

- Design of Process Heat Exchangers
- Maintenance of Heat Exchanger Surfaces
- Multi-Staging For Efficiency
- Matching Capacity to System Load
- Capacity Control and Energy Efficiency
- Multi-level Refrigeration for Plant Needs
- Chilled Water Storage
- System Design Features

Design of Process Heat Exchangers

There is a tendency of the process group to operate with high safety margins which influences the compressor suction pressure / evaporator set point. For instance, a process cooling requirement of 15°C would need chilled water at a lower temperature, but the range can vary from 6°C to say 10°C. At 10°C chilled water temperature, the refrigerant side temperature has to be lower, say –5°C to +5°C. The refrigerant temperature, again sets the corresponding suction pressure of refrigerant which decides the inlet duty conditions for work of compression of the refrigerant compressor. Having the optimum / minimum driving force (temperature difference) can, thus, help to achieve highest possible suction pressure at the compressor, thereby leading to less energy requirement. This requires proper sizing of heat transfer areas of process heat exchangers and evaporators as well as rationalizing the temperature requirement to highest possible value.

A 1°C raise in evaporator temperature can help to save almost 3 % on power consumption. From the table 4.4 it can be identified that the power consumption of compressor can be reduced by providing proper temperature at the evaporator. As the evaporator temperature reduces the power 6

consumption in compressor increases. The effect of condenser temperature on refrigeration plant energy requirements is given in Table 4.5. As condenser temperature increases the power consumption of the compressor increases. From both the table we can conclude that designing of the heat exchanger plays a good role in power consumption. Thus, with proper design of the heat exchangers used in refrigerators the power consumption of various components can be reduced.

Maintenance of Heat Exchanger Surfaces

An effective maintenance holds the key to optimizing power consumption. Heat transfer can also be improved by ensuring proper separation of the lubricating oil and the refrigerant, timely defrosting of coils, and increasing the velocity of the secondary coolant (air, water, etc.). However, increased velocity results in larger pressure drops in the distribution system and

higher power consumption in pumps / fans. Therefore, careful analysis is required to determine the most effective and efficient option.
Fouled condenser tubes force the compressor to work harder to attain the desired capacity. For example, a 0.8 mm scale build-up on condenser tubes can increase energy consumption by as much as 35 %. Similarly, fouled evaporators (due to residual lubricating oil or infiltration of air) result in increased power consumption. Equally important is proper selection, sizing, and maintenance of cooling towers. A reduction of 0.55°C temperature in water returning from the cooling tower reduces compressor power consumption by 3.0 % (see Table 4.6).

 Multi-Staging for Efficiency

Efficient compressor operation requires that the compression ratio be kept low, to reduce discharge pressure and temperature. For low temperature applications involving high compression ratios, and for wide temperature requirements, it is preferable (due to equipment design limitations) and often economical to employ multi-stage reciprocating machines or centrifugal / screw compressors. Multi-staging systems are of two-types: compound and cascade – and are applicable to all types of compressors. With reciprocating or rotary compressors, two-stage compressors are preferable for load temperatures from –20 to –58°C, and with centrifugal machines for temperatures around –43°C.
In multi-stage operation, a first-stage compressor, sized to meet the cooling load, feeds into the suction of a second-stage compressor after inter-cooling of the gas. A part of the high-pressure liquid from the condenser is flashed and used for liquid sub-cooling. The second compressor, therefore, has to meet the load of the evaporator and the flash gas. A single refrigerant is used in the system, and the work of compression is shared equally by the two compressors. Therefore, two compressors with low compression ratios can in combination provide a high compression ratio. For temperatures in the range of –46°C to –101°C, cascaded systems are preferable. In this system, two separate systems using different refrigerants are connected such that one provides the means of heat rejection to the other. The chief advantage of this system is that a low temperature refrigerant which has a high 7

suction temperature and low specific volume can be selected for the low-stage to meet very low temperature requirements.

Multi stage compressors

Reciprocating/piston compressors use a cylinder to force air into a chamber, where it is compressed. The simplest compressor designs feature a single cylinder/chamber arrangement. While straightforward, this setup is limited in its efficiency and capacity for delivering high volumes of pressurized air. That’s where multi-stage compressors come in. By increasing the number of cylinder stages, these machines work more effectively and can handle more tools at once.
Multi-stage compressors feature a series of cylinders, each of a different diameter. Between each compression stage, the air passes through a heat exchanger, where it is cooled. Cooling the air reduces the amount of work necessary to compress it further.
In a two-stage compressor, air is then forced into an additional chamber where it is pressurized to the required extent. In a three-stage compressor, an additional cycle of compression and cooling occurs before this.

 Matching Capacity to System Load

During part-load operation, the evaporator temperature rises and the condenser temperature falls, effectively increasing the COP. But at the same time, deviation from the design operation point and the fact that mechanical losses form a greater proportion of the total power negate the effect of improved COP, resulting in lower part-load efficiency. Therefore, consideration of part-load operation is important, because most refrigeration applications have varying loads. The load may vary due to variations in temperature and process cooling needs. Matching refrigeration capacity to the load is a difficult exercise, requiring knowledge of compressor performance, and variations in ambient conditions, and detailed knowledge of the cooling load.

 Capacity Control and Energy Efficiency

The capacity of compressors is controlled in a number of ways like on/off control, bypass or spill-back method, constant-speed step control, clearance volume control, valve control etc . Capacity control of a refrigeration plant can be defined as a system which monitors and controls the output of the plant as per the load on demand.

Capacity regulation through speed control is the most efficient option. However, when employing speed control for reciprocating compressors, it should be ensured that the lubrication system is not affected. In the case of centrifugal compressors, it is usually desirable to restrict speed control to about 50 % of the capacity to prevent surging. Below 50 %, vane control or hot gas bypass can be used for capacity modulation.

The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situations where part-load operation is common. Screw compressor performance can be optimized by changing the volume ratio. In some cases, this may result in higher full-load efficiencies as compared to reciprocating and centrifugal compressors. Also, the ability of screw compressors to tolerate oil and liquid refrigerant slugs makes them preferred in some situations.

 Multi-level Refrigeration for Plant Needs

The selection of refrigeration systems also depends on the range of temperatures required in the plant. For diverse applications requiring a wide range of temperatures, it is generally more economical to provide several packaged units (several units distributed throughout the plant) instead of one large central plant. Another advantage would be

the flexibility and reliability accorded. The selection of packaged units could also be made depending on the distance at which cooling loads need to be met. Packaged units at load centers reduce distribution losses in the system. Despite the advantages of packaged units, central plants generally have lower power consumption since at reduced loads power consumption can reduce significantly due to the large condenser and evaporator surfaces. Many industries use a bank of compressors at a central location to meet the load. Usually the chillers feed into a common header from which branch lines are taken to different locations in the plant. In such situations, operation at part-load requires extreme care. For efficient operation, the cooling load, and the load on each chiller must be monitored closely. It is more efficient to operate a single chiller at full load than to operate two chillers at part-load. The distribution system should be designed such that individual chillers can feed all branch lines. Isolation valves must be provided to ensure that chilled water (or other coolant) does not flow through chillers not in operation. Valves should also be provided on branch lines to isolate sections where cooling is not required. This reduces pressure drops in the system and reduces power consumption in the pumping system. Individual compressors should be loaded to their full capacity before operating the second compressor. In some cases it is economical to provide a separate smaller capacity chiller, which can be operated on an on-off control to meet peak demands, with larger chillers meeting the base load.

Flow control is also commonly used to meet varying demands. In such cases the savings in pumping at reduced flow should be weighed against the reduced heat transfer in coils due to reduced velocity. In some cases, operation at normal flow rates, with subsequent longer periods of no-load (or shut-off) operation of the compressor, may result in larger savings.

 Chilled Water Storage

Depending on the nature of the load, it is economical to provide a chilled water storage facility with very good cold insulation. Also, the storage facility can be fully filled to meet the process requirements so that chillers need not be operated continuously. This system is usually economical if small variations in temperature are acceptable. This system has the added advantage of allowing the chillers to be operated at periods of low electricity demand to reduce peak demand charges - Low tariffs offered by some electric utilities for operation at night time can also be taken advantage of by using a storage facility. An added benefit is that lower ambient temperature at night lowers condenser temperature and thereby increases the COP. If temperature variations cannot be tolerated, it may not be economical to provide a storage facility since the secondary coolant would have to be stored at a temperature much lower than required to provide for heat gain. The additional cost of cooling to a lower temperature may offset the benefits. The solutions are case specific. For example, in some cases it may be possible to employ large heat exchangers, at a lower cost burden than low temperature chiller operation, to take advantage of the storage facility even when temperature variations are not acceptable. Ice bank system which store ice rather than water are often economical.

 System Design Features

In overall plant design, adoption of good practices improves the energy efficiency significantly. Some areas for consideration are:

_ Design of cooling towers with FRP impellers and film fills, PVC drift eliminators, etc.

_ Use of softened water for condensers in place of raw water.

_ Use of economic insulation thickness on cold lines, heat exchangers, considering cost of heat gains and adopting practices like infrared thermography for monitoring - applicable especially in large chemical / fertilizer / process industry.

_ Adoption of roof coatings / cooling systems, false ceilings / as applicable, to minimize refrigeration load.

_ Adoption of energy efficient heat recovery devices like air to air heat exchangers to pre-cool the fresh air by indirect heat exchange; control of relative humidity through indirect heat exchange rather than use of duct heaters after chilling.

_ Adopting of variable air volume systems; adopting of sun film application for heat eflection; optimizing lighting loads in the air conditioned areas; optimizing number of air changes in the air conditioned areas are few other examples.

LECTURE 4: Energy Saving Opportunities of Refrigeration Plants

a) Cold Insulation

When a cold fluid is being transported through a system exposed to the ambient air, heat is being transferred from the air into the fluid in the system and the following occurs:

 A temperature drop across the surface air film on the jacketing material

 A further temperature drop across the insulation system

 Yet a further temperature drop across the containing material

 And finally another temperature drop across the fluid film into the fluid itself.

For avoiding all the above causes cold insulation should be done. Thus Insulate all cold lines / vessels using economic insulation thickness to minimize heat gains; and choose appropriate (correct) insulation. Two common materials used in cold insulation are:

 Polyurethane Foam: Perfect for handling low thermal conductivity and substances with below freezing temperatures. Polyurethane foam also allows for low smoke emission and low water vapor permeability.
 Rubber Foam: Rubber foam is also often recommended for condensation control as the closed cell technology is highly resistant to moisture vapor.

b) Building Envelope

A building envelope is the physical separator between the conditioned and unconditioned environment of building including the resistance to air, water, heat, light, and noise transfer. Optimize air conditioning volumes by measures such as use of false ceiling and segregation of critical areas for air conditioning by air curtains.
An air curtain is a fan-powered device that creates an invisible air barrier over the doorway to separate efficiently two different environments, without limiting the access of the people or vehicles. The energy saving air screen reduces heating and cooling costs by up to 80% while protecting the internal climate and increasing people comfort. .

c) Building Heat Loads Minimization

Minimize the air conditioning loads by measures such as roof cooling, roof painting, efficient lighting, pre-cooling of fresh air by air- to-air heat exchangers, variable volume air system, optimal thermo-static setting of temperature of air conditioned spaces, sun film applications, etc.

d) Process Heat Loads Minimisation

Minimize process heat loads in terms of TR capacity as well as refrigeration level, i.e., temperature required, by way of:
i) Flow optimization
ii) Heat transfer area increase to accept higher temperature coolant
iii) Avoiding wastages like heat gains, loss of chilled water, idle flows.
iv) Frequent cleaning / de-scaling of all heat exchangers

e) At the Refrigeration A/C Plant Area

i. Ensure regular maintenance of all A/C plant components as per manufacturer guidelines.
ii. Ensure adequate quantity of chilled water and cooling water flows, avoid bypass flows by closing valves of idle equipment.
iii. Minimize part load operations by matching loads and plant capacity on line; adopt variable speed drives for varying process load.
iv. Make efforts to continuously optimize condenser and evaporator parameters for minimizing specific energy consumption and maximizing capacity.
v. Adopt VAR system where economics permit as a non-CFC solution.

LECTURE 5: Introduction to Waste Heat Recovery system

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 minimize the overall losses.

Classification of Waste heat recovery system

In considering the potential for heat recovery, it is useful to note all the possibilities, and grade the waste heat in terms of potential value are present

The waste heat recovery system can be classified as:

1. High temperature heat recovery system
2. Medium temperature heat recovery system
3. Low temperature heat recovery system

High temperature heat recovery system

The following Table 8.2 gives temperatures of waste gases from industrial process equipment in the high temperature range. All of these results from direct fuel fired processes.

Medium Temperature heat recovery system

The following Table 8.3 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.

Low Temperature Heat Recovery

The following Table 8.4 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.

LECTURE 6: 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 equipments 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..

LECTURE 7: Analysis of waste heat recovery for Energy saving opportunities

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:

In a heat treatment furnace, the exhaust gases are leaving the furnace at 900 °C at the rate of 2100 m3/hour. The total heat recoverable at 1800C final exhaust can be calculated as

Q = V ×□□□× Cp × □T

Q is the heat content in kCal

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

□□is density of the flue gas in kg/m3

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

□T is the temperature difference in °C .3

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

Heat available (Q) = 2100 × 1.19 × 0.24 × ((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.

LECTURE 8: Commercial Waste Heat Recovery Devices

Some of the common commercial waste heat recovery devices are following:

a) Recuperator
b) Radiation/Convective Hybrid Recuperator
c) Ceramic Recuperator
d) Regenerator
e) Heat Wheels
f) Heat Pipe
g) Economiser
h) Thermocompressor
i) Direct Contact Heat Exchanger

Recuperators

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases .

The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing as shown in Figure 8.2. 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 energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading.

A second common configuration for recuperators is called the tube type or convective recuperator. As seen in the figure 8.3, 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 made possible through the use of multiple tubes and multiple passes of the gases.

Figure 8.4 Convective Radiative Recuperator

Radiation/Convective Hybrid Recuperator:

For maximum effectiveness of heat transfer, combinations of radiation and convective designs are used, with the high-temperature radiation recuperator being first followed by convection type. These are more expensive than simple metallic radiation recuperators, but are less bulky. A Convective/radiative Hybrid recuperator is shown in Figure 8.4

Ceramic Recuperator

The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 1100°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 1550°C and on the preheated air side to 815°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 percent. The new designs are reported to last two years with air preheat temperatures as high as 700°C, with much lower leakage rates.

Regenerator

The Regeneration which is preferable for large capacities has been very 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 result in lower average temperature of preheat and consequently reduce fuel economy. (Refer Figure 8.5).

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 air period also reduces the heat transfer. .5

Heat Wheels

A heat wheel is finding increasing applications in low to medium temperature waste heat recovery systems. Figure 8.6 is a sketch illustrating the application of a heat wheel. 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 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 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 .6

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. A figure of Heat pipe is shown in Figure 8.7

Economiser

In case of boiler system, economizer can be provided to utilize the flue gas heat for preheating 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. An economizer is shown in Figure 8.8. For every 22°C reduction in flue gas temperature by passing through an economiser or a pre-heater, there is 1% saving of fuel in the boiler. In other words, for every 6°C rise in feed water temperature through an economiser, or 20°C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel in the boiler.

Shell and Tube Heat Exchanger

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 tubes 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 8.9.

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.

Plate heat exchanger

The cost of heat exchange surfaces 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 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.

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 8.10.

Typical industrial applications are:

– Pasteurisation section in milk packaging plant.

– Evaporation plants in food industry.

Run Around Coil Exchanger

It is 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 circulating pump.

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.

Waste Heat 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 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 Figure 8.11 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 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. 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 the exhaust gases flue are added. Waste heat boilers are built in capacities from 25 m3 almost 30,000 m3 / min. of exhaust gas. .8

Thermocompressor
In many cases, very low pressure steam are 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 thermocompressing would give a large improvement in waste heat recovery. The thermocompressor 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. Afigure of thermocompressor is shown in Figure 8.13. It is typically used in evaporators where the boiling steam is recompressed and used as heatingsteam.