REFRIGERATION AND AIR CONDITIONING

Unit 1

Introduction: Refrigeration and second law of Thermodynamics, Refrigeration effect and unit of Refrigeration, Heat pump, reversed Carnot cycle. Vapour Compression Refrigeration System: Analysis of simple vapour compression Refrigeration cycle by p-h and T-S diagram, Effect of operating conditions, liquid vapour heat exchangers, actual refrigeration cycle, Multiple Evaporator and Compressor System: Application, air compressor system, Individual compressor, compound compression, cascade system, application, air compressor systems, individual compressor, compound compression, cascade system.

Unit 2

Gas Cycle Refrigeration: Limitation of Carnot cycle with gas, reversed Brayton cycle, Brayton cycle with regenerative heat exchanger, Air cycle for air craft, Necessity of cooling of air craft, Basic cycle, boot strap, regenerative type air craft refrigeration cycle.

Unit 3

Vapour Absorption System: Simple Vapour absorption system, Electrolux Refrigerator, Analysis of Ammonia absorption refrigeration system, Lithium Bromide Absorption Refrigeration System. Refrigerants: Classification, Nomenclature, selection of refrigerants, global warming potential of CFC Refrigerants, Refrigeration Equipments - Compressor, condenser, evaporator, expansion devices – types and working.

Unit 4

Psychometric: Psychrometric properties, psychometric relations, pyschrormetric charts, psychrometric processes, cooling coils, By-pass factor and air washers.

Human Comfort: Mechanism of body heat losses, factors affecting human comfort, effective temperature, comfort chart.

Unit 5

Cooling Load Calculations: Internal heat gain, system heat gain, RSHF, ERSHF,GSHF, cooling load estimation, heating load estimation, psychrometric calculation for cooling, selection of air conditioning, apparatus for cooling and dehumidification, air conditioning system

UNIT-1

4.7 Factors Affecting Human Comfort:
4.8 Comfort Chart:
Unit-5

5.1cooling Load And Coil Load Calculations
5.2internal Heat Gain,
5.3selection Of Air Conditioning
5.4cooling Load Estimation
5.5 Air Conditioning System

Lecture Plan

Subject name: **Refrigeration and air conditioning** **Subject Code: 7ME2A** **Year:4th** **Semester: 7th**	**POs** **PO1; PO2; PO3;PO6;PO7; PO12**	**COs** 1. To apply the fundamentals of sciences and engineering for understanding the working of different types of refrigeration systems. 2. To analyze the effect of different refrigeration conditions on the performance of refrigerator and environment. 3. To identify best refrigeration system and component of refrigeration system according to need of customers. 4. To design air condition unit according to the specific need of customers.

S. No.	**Lecture No.**	**Topic to be discussed**	**COs**	**Objective of Unit**	**Outcome of Lecture and CO** **Students are able to:-**	**Methods**	**From page to**
UNIT -1	1	Introduction of refrigeration and second law of Thermodynamics, Refrigeration unit, Heat pump, reversed Carnot cycle.	CO1	Understand vapour compression system; analyze the vapour refrigeration cycles and methods for improving the performance of cycle.	understand about basics of refrigeration	Chalk and Talk	T3(64-84); T2(25-25)
	2	Vapour Compression Refrigeration System:, Analysis of simple vapour compression Refrigeration cycle by PH, TS diagram	CO2		understand about vapour compression refrigeration cycle	Chalk and Talk	T3(87-89);
	3	Effect of operating conditions, actual refrigeration cycle	CO1		understand about the effect of operating condition on C.O.P	Chalk and Talk	T3(87-89); T3(91)
	4	Problems	CO1 CO2		calculate the refrigeration load and C.O.P of cycle	Chalk and Talk	T3(94-95)
	5	Problems	CO1 CO2		calculate the refrigeration load and C.O.P of cycle	Chalk and Talk	T3(96-99)
	6	Application of Multiple Evaporator and Compressor System, air compressor system, Individual compressor,	CO2		the effect of multiple evaporator and compressor on refrigerating capacity	Chalk and Talk	T3(214-216) T3(222-225)

	7	compound compression, cascade system	CO2		the effect of multiple evaporator and compressor on refrigerating capacity	Chalk and Talk	T3(218); T3(226-228);T2 (113)
	8	Problems	CO1 CO2		calculate the refrigeration load with multiple component and C.O.P of cycle	Chalk and Talk	T3(219-221)
UNIT -2	9	Introduction of Gas Cycle Refrigeration, Limitation of Carnot cycle with gas, reversed Brayton cycle	CO1 CO2	Understand air refrigeration system operations and analyse the air refrigeration cycles and methods for improving the performance of cycle.	understand about gas refrigeration cycle and limitations of cycle	Chalk and Talk	T3(367-383)
	10	Problems	CO1 CO2		calculate the refrigerant effect and C.O.P of simple system	Chalk and Talk	T3(374-376)
	11	Brayton cycle with regenerative heat exchanger, Air cycle for air craft	CO1 CO2		understand the methods for improving the performance of cycle	Chalk and Talk	T3(377-381)
	12	Problems	CO1 CO2		calculate the refrigerant effect and C.O.P of improved system	Chalk and Talk	T3(381-383)
	13	Necessity of cooling of air craft, Basic cycle, boot strap regenerative type air craft refrigeration cycle	CO1 CO2		understand about refrigeration cycles use in air crafts	Chalk and Talk	T3(378)
	14	Problems	CO1 CO2		calculate the refrigerant effect and C.O.P of air craft refrigeration system	Chalk and Talk	T3(400-401)
	15	Problems	CO1 CO2		calculate the refrigerant effect and C.O.P of iair craft refrigeration system	Chalk and Talk	
UNIT -3	16	Introduction of Vapour Absorption	CO1, CO2 CO3	Understand vapour absorption	understand about vapour absorption	Chalk and Talk Projector	T3(402-405);

		System, Simple Vapour absorption system, Analysis of Ammonia absorption refrigeration system		system operation, selection of refrigerants , Familiarize the components of refrigeration systems	refrigeration systems		
	17	Electrolux Refrigerator, Lithium Bromide Absorption Refrigeration System.	CO1, CO2 CO3		understand about vapour absorption refrigeration systems	Chalk and Talk Projector	T3(423-425); T3(431-432)
	18	Classification and Nomenclature of refrigerants,	CO1,		understand about the nomenclature and desire properties of refrigerant	Chalk and Talk	T3(128-129);
	19	Selection of refrigerants, global warming potential of CFC Refrigerants	CO1, CO2		understand the effect of refrigerant on environment	Chalk and Talk	T3(136; 153); T2(335-337)
	20	Type and working of refrigeration compressors	CO3		understand different types of refrigeration compressors	Projector	T2 (146-147;170-172)
	21	Type and working of refrigeration condensers	CO3		understand different types of refrigeration compressors	Projector	T3(286-300)
	22	Type and working of refrigeration evaporators	CO3		understand different types of refrigeration evaporators	Projector	T3(319-333)
	23	Type and working of refrigeration ,expansion devices	CO3		understand different types of refrigeration expansion devices	Projector	T3(303-310)
UNIT -4	24	Introduction of air conditioning,	CO4	Understand air conditioning systems and process. Calculations of psychometric process for cooling, heating load	understand about basics of air conditioning systems and psychometric properties	Chalk and Talk	T1 (40-43) ;T3(446-447)
	25	Psychometric properties, psychometric relations, Problems	CO4		calculate simple problems of cooling load estimation	Chalk and Talk	T1 (40-42) : T3 (452-458)
	26	psychometric charts,	CO4		understand about different	Chalk and Talk	T3 (465-471; 478-484; 486-

		Psychometric processes, cooling coils, By-pass factor and air washers		estimation.	psychometric process and calculation	Projector	491);T1 (43-46)
	27	Problems	CO4		calculate cooling/heating load for air conditioning unit	Chalk and Talk	T3 (464,485)
	28	Problems	CO4		calculate cooling/heating load for air conditioning unit	Chalk and Talk	T3 (475-476;492-493;)
	29	Problems	CO4		calculate cooling/heating load for air conditioning unit	Chalk and Talk	T3 (495-496)
	30	Mechanism of body heat losses, factors affecting human comfort, effective temperature,	CO4		understand different factors affecting human comfort	Chalk and Talk Projector	T3 (516-521)
	31	comfort chart	CO4		use of comfort chart	Chalk and Talk Projector	
UNIT -5	32	Cooling Load Calculations: Internal heat gain, system heat gain, RSHF	CO4	Design air conditioning systems using cooling load estimation	calculate total sensible heat load and total latent heat load for a room	Chalk and Talk Projector	T3 (497-500; 502-503;508-509)
	33	ERSHF, GSHF, cooling load estimation, heating load estimation	CO4		estimate total cooling load of the room for human comfort	Chalk and Talk Projector	T3 (622-630);T1(63-69)
	34	Problems	CO4		design air conditioning system according to human comfort	Chalk and Talk	T3 (501-504)
	35	Problems	CO4		design air conditioning system according to human comfort	Chalk and Talk	T3 (505-508)
	36	Problems	CO4		design air conditioning system according to human comfort	Chalk and Talk	T3 (509-511)
	37	selection of air conditioning, apparatus for cooling	CO4		Understand about the selection of apparatus for	Chalk and Talk	T3(662-667)

					cooling, heating		
	38	Dehumidification, air conditioning system.	CO4		Understand about the selection of apparatus for humidification and dehumidification	Chalk and Talk	T2(842-845;869-870)
	39	Problems	CO1-CO4		estimate human comfort condition for a desire space	Chalk and Talk	T3 (630-638;643-6465;647-648)
	40	problems	CO1-CO4		estimate human comfort condition for a desire space	Chalk and Talk	

Recommended books:	**T1:** Refrigeration and Air Conditioning, Stoecker W.F., McGraw Hill Publication. **T2:** Modern Refrigeration and Air Conditioning, Andrew D. Althouse, Good Heart-Willcox Co. **T3**: Refrigeration and Air Conditioning, Arora C.P., Tata McGraw Hill New Delhi

UNIT-1

1.1 REFRIGERATION

Refrigeration is a process in which work is done to move heat from one location to another. The work of heat transport is traditionally driven by mechanical work, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including, but not limited to: household refrigerators, industrial freezers, cryogenics, and air conditioning. Heat pumps may use the heat output of the refrigeration process, and also may be designed to be reversible, but are otherwise similar to refrigeration units.

Refrigeration has had a large impact on industry, lifestyle, agriculture and settlement patterns. The idea of preserving food dates back to the ancient Roman and Chinese empires. However, refrigeration technology has rapidly evolved in the last century, from ice harvesting to temperature-controlled rail cars. The introduction of refrigerated rail cars contributed to the westward expansion of the United States, allowing settlement in areas that were not on main transport channels such as rivers, harbors, or valley trails. Settlements were also popping up in infertile parts of the country, filled with new natural resources. These new settlement patterns sparked the building of large cities which are able to thrive in areas that were otherwise thought to be unsustainable, such as Houston, Texas and Las Vegas, Nevada. In most developed countries, cities are heavily dependent upon refrigeration in supermarkets, in order to obtain their food for daily consumption. The increase in food sources has led to a larger concentration of agricultural sales coming from a smaller percentage of existing farms. Farms today have a much larger output per person in comparison to the late 1800s. This has resulted in new food sources available to entire populations, which has had a large impact on the nutrition of society.

1.2 SECOND LAW OF THERMODYNAMICS

The second law of thermodynamics states that the entropy of an isolated system never decreases, because isolated systems always evolve toward thermodynamic equilibrium, a state with maximum entropy. The second law is an empirically validated postulate of thermodynamics. In classical thermodynamics, the second law is a basic postulate defining the concept of thermodynamic entropy, applicable to any system involving measurable heat transfer. In statistical thermodynamics, the second law is a consequence of unitarily in quantum mechanics. In statistical mechanics information entropy is defined from information theory, known as the Shannon entropy. In the language of statistical mechanics, entropy is a measure of the number of alternative microscopic configurations corresponding to a single macroscopic state. The second law refers to increases in entropy that can be analyzed into two varieties, due to dissipation of energy and due to dispersion of matter. One may consider a compound thermodynamic system that initially has interior walls that restrict transfers within it. The second law refers to events over time after a thermodynamic operation on the system, that allows internal heat transfers, removes or weakens the constraints imposed by its interior walls, and isolates it from the surroundings. As for dissipation of energy, the temperature becomes spatially homogeneous, regardless of the presence or absence of an externally imposed unchanging external force field. As for dispersion of matter, in the absence of an externally imposed force field, the chemical concentrations also become as spatially homogeneous as is allowed by the permeability's of the interior walls. Such homogeneity is one of the characteristics of the state of internal thermodynamic equilibrium of a thermodynamic system

1.3 UNIT OF REFRIGERATION AND COP

The standard unit of refrigeration is *ton refrigeration* or simply *ton* denoted by TR. It is equivalent to the rate of heat transfer needed to produce 1 ton (2000 lbs) of ice at 32 0F from water at 32 0F in one day, i.e., 24 hours. The enthalpy of solidification of water from and at 32 0F in British thermal unit is 144 Btu/lb. Thus

$$1\ \mathrm{TR} = \frac{2000\,\mathrm{lb} \times 144\,\mathrm{Btu/lb}}{24\,\mathrm{hr}}$$
$$= 12000\ \mathrm{Btu/hr} = 200\ \mathrm{Btu/min}$$

In general, 1 TR means 200 Btu of heat removal per minute. Thus if a refrigeration system is capable of cooling at the rate of 400 Btu/min, it is a 2 ton machine. A machine of 20 ton rating is capable of cooling at a rate of 20 □ 200 = 4000 Btu/min. This unit of refrigeration is currently in use in the USA, the UK and India. In many countries, the standard MKS unit of kcal/hr is used. In the MKS it can be seen that

$$1\ \mathrm{TR} = 12000\ \mathrm{Btu/hr} = \frac{12000}{3.968} = 3024.2\ \mathrm{kcal/hr}$$
$$= 50.4\ \mathrm{kcal/min} \approx 50\ \mathrm{kcal/min}$$

If Btu ton unit is expressed into SI system, it is found to be 210 kJ/min or 3.5 kW.

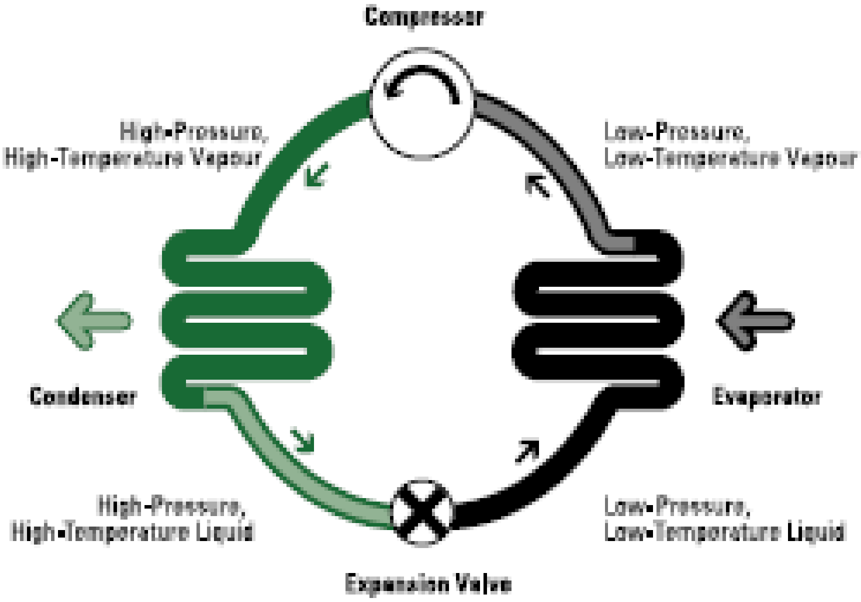
Refrigeration effect is an important term in refrigeration that defines the amount of cooling produced by a system. This cooling is obtained at the expense of some form of energy. Therefore, it is customary to define a term called coefficient of performance (COP) as the ratio of the refrigeration effect to energy input.

$$\mathrm{COP} = \frac{\text{Refrigerat ion effect}}{\text{Energy input}}$$

While calculating COP, both refrigeration effect and energy input should be in the same unit.

1.4 HEAT PUMP

A heat pump is an electrical device that extracts heat from one place and transfers it to another. The heat pump is not a new technology; it has been used in Canada and around the world for decades. Refrigerators and air conditioners are both common examples of this technology.



Heat pumps transfer heat by circulating a substance called a refrigerant through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en route to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle. Refrigerators and air conditioners are both examples of heat pumps operating only in the cooling mode. A refrigerator is essentially an insulated box with a heat pump system connected to it. The evaporator coil is located inside the box, usually in the freezer compartment. Heat is absorbed from this location and transferred outside, usually behind or underneath the unit where the condenser coil is located. Similarly, an air conditioner transfers heat from inside a house to the outdoors. The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control for your home heating in winter and cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat to a house even on cold winter days. In fact, air at –18°C contains about 85 percent of the heat it contained at 21°C. An air-source heat pump absorbs heat from the outdoor air in winter and rejects heat into outdoor air in summer. It is the most common type of heat pump found in Canadian homes at this time. However, ground-source (also called earth-energy, geothermal, geoexchange) heat pumps, which draw heat from the ground or ground water, are becoming more widely used, particularly in British Columbia, the Prairies and Central Canada.

1.5 REVERSED CARNOT CYCLE

The Carnot cycle is a theoretical thermodynamic cycle proposed by Nicolas Léonard Sadi Carnot in 1824 and expanded by others in the 1830s and 1840s. It can be shown that it is the most efficient cycle for converting a given amount of thermal energy into work, or conversely, creating a temperature difference (e.g. refrigeration) by doing a given amount of work.

Every single thermodynamic system exists in a particular state. When a system is taken through a series of different states and finally returned to its initial state, a thermodynamic cycle is said to have occurred. In the process of going through this cycle, the system may perform work on its surroundings, thereby acting as a heat engine. A system undergoing a Carnot cycle is called a Carnot heat engine, although such a "perfect" engine is only a theoretical limit and cannot be built in practicThe Carnot cycle when acting as a heat engine consists of the following steps:

Reversible isothermal expansion of the gas at the "hot" temperature, T_1 (isothermal heat addition or absorption). (1 to 2 on Figure 1, A to B in Figure 2)

During this step the gas is allowed to expand and it does work on the surroundings. The temperature of the gas does not change during the process, and thus the expansion is isothermal. The gas expansion is propelled by absorption of heat energy Q_1 and of entropy $\Delta S = Q_1/T_1$ from the high temperature reservoir.

Isentropic (reversible adiabatic) expansion of the gas (isentropic work output).(2 to 3 on Figure 1, B to C in Figure 2)

the mechanisms of the engine are assumed to be thermally insulated, thus they neither gain nor lose heat. The gas continues to expand, doing work on the surroundings, and losing an equivalent amount of internal energy. The gas expansion causes it to cool to the "cold" temperature, T_2. The entropy remains unchanged.

Reversible isothermal compression of the gas at the "cold" temperature, T_2. (Isothermal heat rejection).(3 to 4 on Figure 1, C to D on Figure 2)

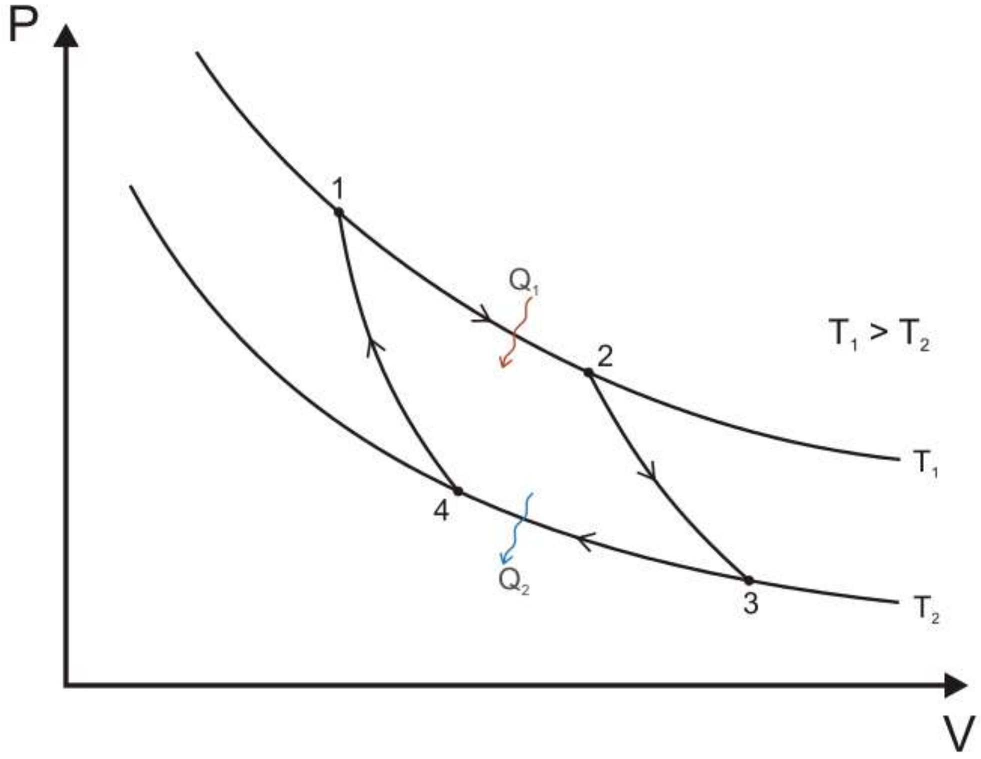
Now the surroundings do work on the gas, causing an amount of heat energy Q_2 and of entropy $\Delta S = Q_2/T_2$ to flow out of the gas to the low temperature reservoir. (This is the same amount of entropy absorbed in step 1, as can be seen from the Clausius inequality.)

Isentropic compression of the gas (isentropic work input). (4 to 1 on Figure 1, D to A on Figure 2)

Once again the mechanisms of the engine are assumed to be thermally insulated. During this step, the surroundings do work on the gas, increasing its internal energy and compressing it, causing the temperature to rise to T_1. The entropy remains unchanged. At this point the gas is in the same state as at the start of step 1.

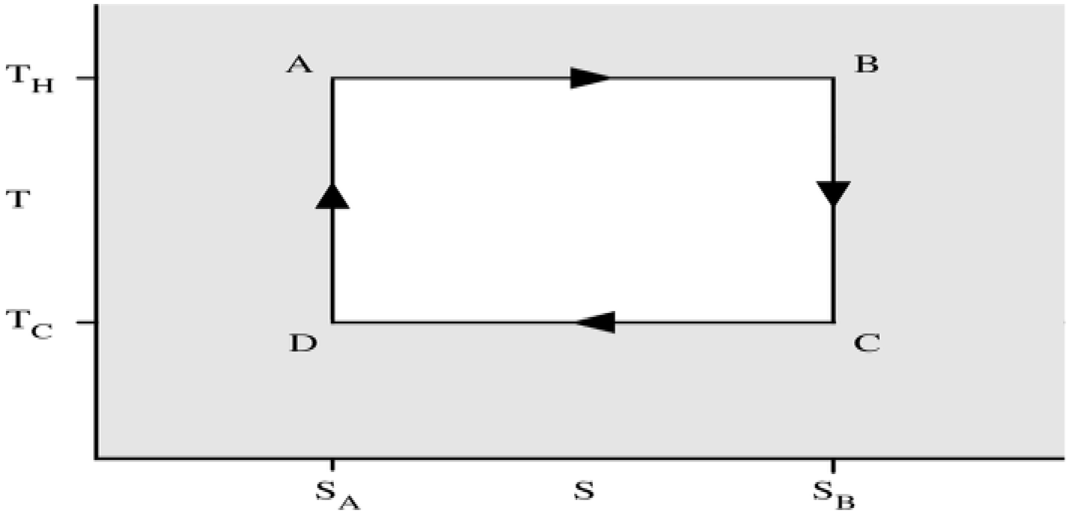
The pressure-volume graph

When the Carnot cycle is plotted on a pressure volume diagram, the isothermal stages follow the isotherm lines for the working fluid, adiabatic stages move between isotherms and the area bounded by the complete cycle path represents the total work that can be done during one cycle.



The temperature-entropy diagram

The behavior of a Carnot engine or refrigerator is best understood by using a temperature-entropy diagram(TS diagram), in which the thermodynamic state is specified by a point on a graph with entropy (S) as the horizontal axis and temperature (T) as the vertical axis. For a simple system with a fixed number of particles, any point on the graph will represent a particular state of the system.



A thermodynamic process will consist of a curve connecting an initial state (A) and a final state (B). The area under the curve will be:

$$Q = \int_A^B T\,dS \qquad (1)$$

which is the amount of thermal energy transferred in the process. If the process moves to greater entropy, the area under the curve will be the amount of heat absorbed by the system in that process. If the process moves towards lesser entropy, it will be the amount of heat removed. For any cyclic process, there will be an upper portion of the cycle and a lower portion. For a clockwise cycle, the area under the upper portion will be the thermal energy absorbed during the cycle, while the area under the lower portion will be the thermal energy removed during the cycle. The area inside the cycle will then be the difference between the two, but since the internal energy of the system must have returned to its initial value, this difference must be the amount of work done by the system over the cycle. Referring to figure 1, mathematically, for a reversible process we may write the amount of work done over a cyclic process as:

$$W = \oint PdV = \oint (dQ - dU) = \oint (TdS - dU) \qquad (2)$$

Since *dU* is an exact differential, its integral over any closed loop is zero and it follows that the area inside the loop on a T-S diagram is equal to the total work performed if the loop is traversed in a clockwise direction, and is equal to the total work done on the system as the loop is traversed in a counterclockwise direction

1.6 Vapour Compression Refrigeration System:

Vapor-compression refrigeration is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

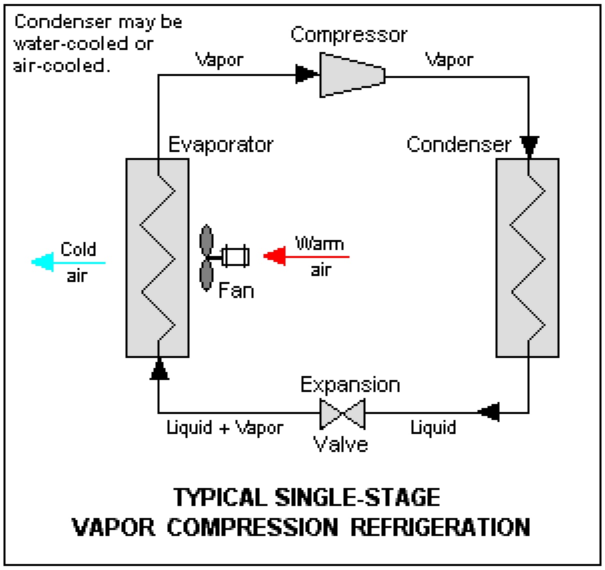
Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, water source heat pump, geo thermal heat pump or chiller (heat pump).

The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Figure 1 depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor[2] and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air. That hot vapor is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool water or cool air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case).

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser.

To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor.



1.7 Analysis of simple vapour compression Refrigeration cycle by ph and T-S diagram with Effect of operating conditions:

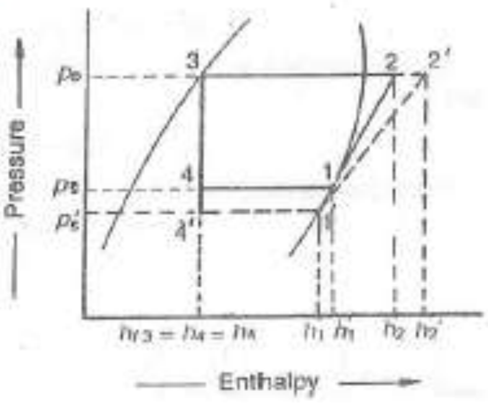
1.7.1 Effect of Suction Pressure

The suction pressure (or evaporator pressure) decreases due to the frictional resistance of flow of the refrigerant. Let us consider a theoretical vapour compression cycle 1-2-3-4 when the suction pressure decreases from *ps* to *ps*□ as shown on p-h diagram in Figure 2.3.

It may be noted that the decrease in suction pressure :

(a) decreases the refrigerating effect from $(h_1 - h_4)$ to $(h_1^1 - h_4^1)$, and

(b) Increases the work required for compression from $(h_2 - h_1)$ to $(h_2^1 - h_1^1)$.



Since the C.O.P, of the system is the ratio of refrigerating effect to the work done, therefore with the decrease in suction pressure, the net effect is to decrease the C.O.P. of the refrigerating system for the same refrigerant flow. Hence with the decrease in suction pressure the refrigerating capacity of the system decreases and the refrigeration cost increases.

1.8.2 Effect of Discharge Pressure

In actual practice, the discharge pressure (or condenser pressure) increases due to frictional resistance of flow of the refrigerant. Let us consider a theoretical vapour compression cycle l-2-3-4 when the discharge pressure increases from pD to pD‟ as shown on p-h diagram in Figure 2.4 resulting in increased compressor work and reduced refrigeration effect. 21

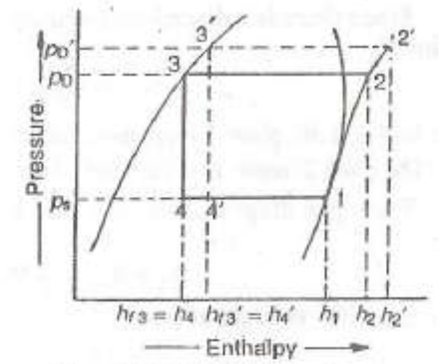


Figure 2.4 : Effect of Discharge Pressure

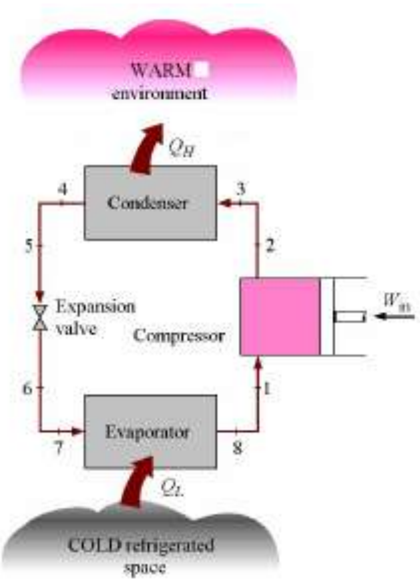
Heat exchangers are off-the-shelf equipment targeted to the efficient transfer of heat from a hot fluid flow to a cold fluid flow, in most cases through an intermediate metallic wall and without moving parts. We here focus on the thermal analysis of heat exchangers, but proper design and use requires additional fluid dynamic analysis (for each fluid flow), mechanical analysis (for closure and resistance), materials compatibility, and so on. Heat losses or gains of a whole heat exchanger with the environment can be neglected in comparison with the heat flow between both fluid flows; i.e. a heat exchanger can be assumed globally adiabatic. Thermal inertia of a heat exchanger is often negligible too (except in special cases when a massive porous solid is used as intermediate medium), and steady state can be assumed, reducing the generic energy balance to openings

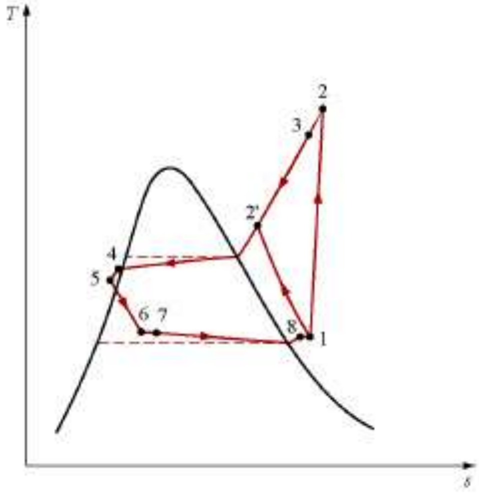
Although heat flows from hot fluid to cold fluid by thermal conduction through the separating wall (except in direct-contact types), heat exchangers are basically heat convection equipment, since it is the convective transfer what governs its performance. Convection within a heat exchanger is always forced, and may be with or without phase change of one or both fluids. When one just relies in natural convection to the environment, like in the space-heating hot-water home radiator, or the domestic fridge back radiator, they are termed 'radiators' (in spite of convection being dominant), and not heat exchangers. When a fan is used to force the flow of ambient air (or when natural or artificial wind applies, like for car radiator) the name heat exchanger is often reserved for the case where the ambient fluid is ducted. Other names are used for special cases, like ‘condenser’ for the case when one fluid flow changes from vapour to liquid, ‘vaporiser’ (or evaporator, or boiler) when a fluid changes from liquid to vapour, or the ‘cooling tower’ dealt with below. Devices with just one fluid flow (like a solar collector, a spacecraft radiator, a submerged electrical heater, or a simple pipe with heat exchange with the environment) are never named heat exchangers.

1.8 actual refrigeration cycle:

Irreversibility’s in various components

- Pressure drop due to fluid friction
- Heat transfer from or to surroundings





1.9 Multiple Evaporator and Compressor System

A multiple-effect evaporator, as defined in chemical engineering, is an apparatus for efficiently using the heat from steam to evaporate water.[1] In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the last. Because the boiling temperature of water decreases as pressure decreases, the vapor boiled off in one vessel can be used to heat the next, and only the first vessel (at the highest pressure) requires an external source of heat. While in theory, evaporators may be built with an arbitrarily large number of stages, evaporators with more than four stages are rarely practical except in systems where the liquor is the desired product such as in chemical recovery systems where up to seven effects are used.

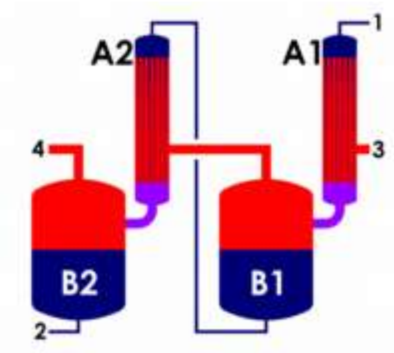


Diagram of a double-effect falling film evaporator. Condensing vapors from flash tank B1 heat evaporator A2. 1=feed, 2=product, 3=steam, 4=vapors

The multiple-effect evaporator was invented by American inventor and engineer Norbert Rillieux. Although he may have designed the apparatus during the 1820s and constructed a prototype in 1834, he did not build the first industrially practical evaporator until 1845 . Originally designed for concentrating sugar in sugar cane juice, it has since become widely used in all industrial applications where large volumes of water must be evaporated, such as salt production and water desalination.

Multiple effect evaporation commonly uses sensible heat in the condensate to preheat liquor to be flashed. In practice the design liquid flow paths can be somewhat complicated in order to extract the most recoverable heat and to obtain the highest evaporation rates from the equipment.

Multiple-effect evaporation plants in sugar beet factories have up to eight effects. Six effect evaporators are common in the recovery of black liquor in the craft process process for making wood pulp.

ASSIGNMENT-1

Q.1 Define refrigeration, tone of refrigeration, COP and refrigerant fluid.
(R.T.U 2013)

Q.2 Calculate the COP of a simple saturated vapour compression refrigeration system working on R-12, when evaporator temperature is 15°c, condenser temp. is +30°c and Cp for superheated refrigerant is 0.628 KJ/KgK. Also calculate the mass of refrigerant per tone of refrigeration effect produced and power input. Assume isentropic process. **(R.T.U. 2013, 2011)**

Q.3 Explain the effect of superheating in compressor and under cooling in vapour compressor system. Show these on T-s and p-h diagram. **(R.T.U 2012)**

Q.4 Describe the multistage vapour compression cycle. Show in diagram the condition, pressure and temp of refrigerant. What should be the pressure in the intercooler for ideal condition? **(R.T.U 2011)**

CLASS TEST-1

Q.1 Explain compound compression with flash inter cooling with single expansion valve along the flow line to evaporator. (R.T.U 2009)

Q.2 what is the difference between direct and indirect refrigeration system? Explain the advantage of one over the other.

Q.3 Describe with a neat sketch the working of actual vapour compression refrigeration cycle. How the actual cycle differs from the theoretical one?

Q. 4 what will happen if Carnot cycle for a heat engine is carried out in a reversed mode? Explain and find the parameters used to measure its efficiency?

PREVIOUS YEAR QUESTIONS

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UNIT-2

2.1 Limitation of Carnot cycle with gas

Carnot's theorem, developed in 1824 by Nicolas Léonard Sadi Carnot, also called Carnot's rule, is a principle that specifies limits on the maximum efficiency any heat engine can obtain, which thus solely depends on the difference between the hot and cold temperature reservoirs.

Carnot's theorem states:

All heat engines between two heat reservoirs are less efficient than a Carnot engine operating between the same reservoirs.

Every Carnot engine between a pair of heat reservoirs is equally efficient, regardless of the working substance employed or the operation details.

The formula for this maximum efficiency is

Where TC is the absolute temperature of the cold reservoir, TH is the absolute temperature of the hot reservoir, and the efficiency is the ratio of the work done by the engine to the heat drawn out of the hot reservoir.

Based on modern thermodynamics, Carnot's theorem is a result of the second law of thermodynamics. Historically, however, it was based on contemporary caloric theory and preceded the establishment of the second law.

2.2 REVERSE BRAYTON CYCLE:

The Brayton cycle is a thermodynamic cycle that describes the workings of a constant pressure heat engine. Gas turbine engines and air breathing jet engines use the Brayton Cycle. Although the Brayton cycle is usually run as an open system (and indeed must be run as such if internal combustion is used), it is conventionally assumed for the purposes of thermodynamic analysis that the exhaust gases are reused in the intake, enabling analysis as a closed system.

The engine cycle is named after George Brayton (1830–1892), the American engineer who developed it, although it was originally proposed and patented by Englishman John Barber in 1791.[1] It is also sometimes known as the Joule cycle. The Ericsson cycle is similar to the Brayton cycle but uses external heat and incorporates the use of a regenerator. There are two types of Brayton cycles, open to the atmosphere and using internal combustion chamber or closed and using a heat exchanger. A Brayton-type engine consists of three components:

A compressor
A mixing chamber
An expander

In the original 19th-century Brayton engine, ambient air is drawn into a piston compressor, where it is compressed; ideally an isentropic process. The compressed air then runs through a mixing chamber where fuel is added, an isobaric process. The heated (by compression), pressurized air and fuel mixture is then ignited in an expansion cylinder and energy is released, causing the heated air and combustion products to expand through a piston/cylinder; another ideally isentropic process. Some of the work extracted by the piston/cylinder is used to drive the compressor through a crankshaft arrangement.

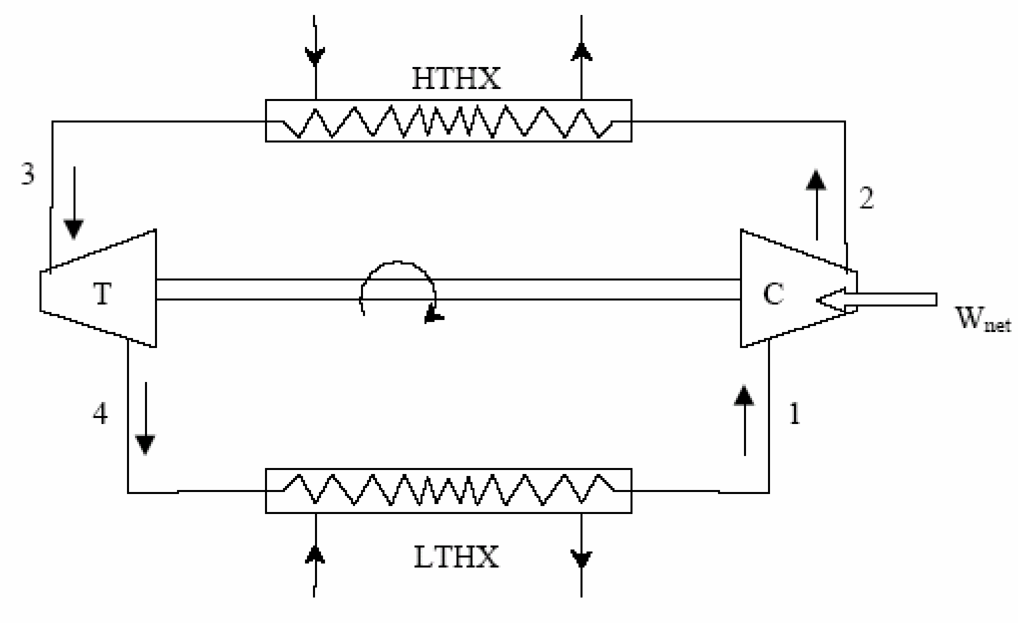
The term Brayton cycle has more recently been given to the gas turbine engine. This also has three components:

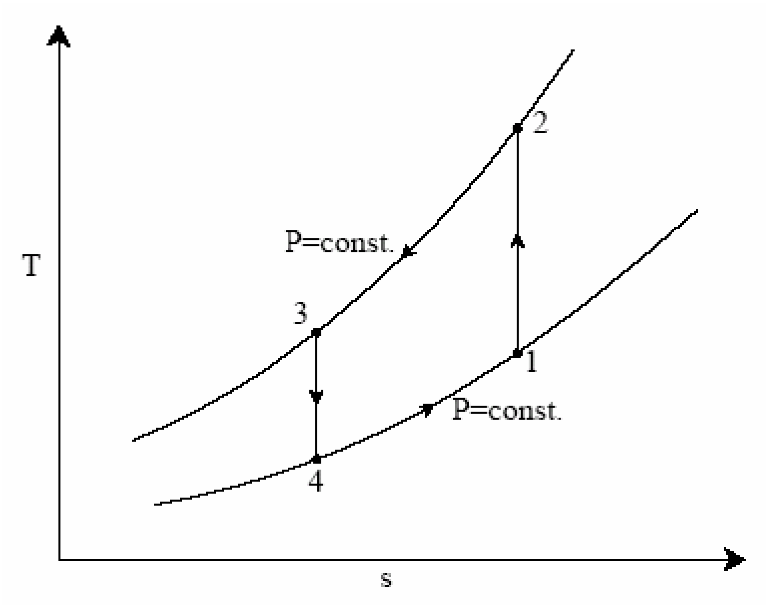
A gas compressor

A burner (or combustion chamber)

An expansion turbine

Ideal Brayton cycle:





Isentropic process - ambient air is drawn into the compressor, where it is pressurized.

$$W_{1-2} = \dot{m}(h_2 - h_1) = \dot{m}\, c_p (T_2 - T_1)$$

$$s_2 = s_1$$

$$\text{and } T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = T_1\, r_p^{\frac{\gamma-1}{\gamma}}$$

isobaric process - the compressed air then runs through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.

$$Q_{2-3} = \dot{m}(h_2 - h_3) = \dot{m}\, c_p (T_2 - T_3)$$

$$s_2 - s_3 = c_p \ln \frac{T_2}{T_3}$$

$$P_2 = P_3$$

Isentropic process - the heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

$$W_{3-4} = \dot{m}(h_3 - h_4) = \dot{m}\, c_p (T_3 - T_4)$$

$$s_3 = s_4$$

$$\text{and } T_3 = T_4 \left(\frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} = T_4\, r_p^{\frac{\gamma-1}{\gamma}}$$

Isobaric process - heat rejection (in the atmosphere).

From the above equations, it can be easily shown that:

$$\left(\frac{T_2}{T_1} \right) = \left(\frac{T_3}{T_4} \right)$$

Applying 1st law of thermodynamics to the entire cycle:

$$\oint \delta q = (q_{4-1} - q_{2-3}) = \oint \delta w = (w_{3-4} - w_{1-2}) = -w_{net}$$

The COP of the reverse Brayton cycle is given by:

$$COP = \left| \frac{q_{4-1}}{w_{net}} \right| = \left(\frac{(T_1 - T_4)}{(T_2 - T_1) - (T_3 - T_4)} \right)$$

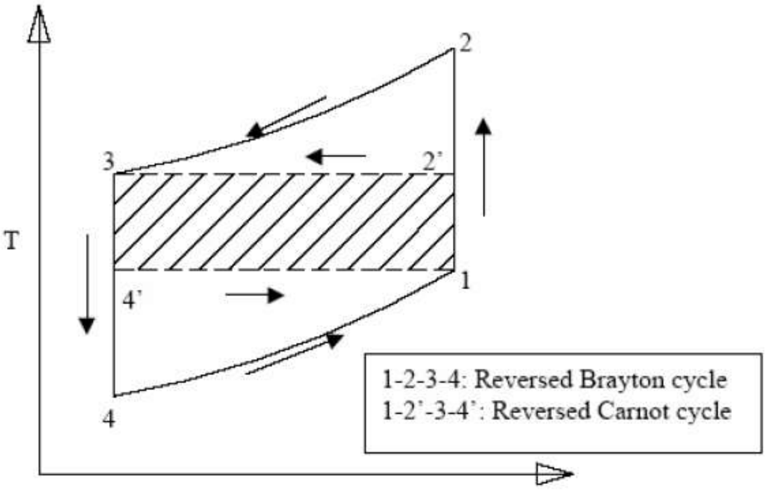
using the relation between temperatures and pressures, the COP can also be written as:

$$COP = \left(\frac{(T_1 - T_4)}{(T_2 - T_1) - (T_3 - T_4)} \right) = \left(\frac{T_4}{T_3 - T_4} \right) = \left(\frac{(T_1 - T_4)}{(T_1 - T_4)(r_p^{\frac{\gamma-1}{\gamma}} - 1)} \right) = (r_p^{\frac{\gamma-1}{\gamma}} - 1)^{-1} \quad (9.16)$$

From the above expression for COP, the following observations can be made:

a) For fixed heat rejection temperature (T_3) and fixed refrigeration temperature (T_1), the COP of reverse Brayton cycle is always lower than the COP of reverse Carnot cycle (Fig. 9.3), that is

$$COP_{Brayton} = \left(\frac{T_4}{T_3 - T_4}\right) < COP_{Carnot} = \left(\frac{T_1}{T_3 - T_1}\right)$$



b) COP of Brayton cycle approaches COP of Carnot cycle as T_1 approaches T_4 (thin cycle), however, the specific refrigeration effect [$c_p(T_1-T_4)$] also reduces simultaneously.

c) COP of reverse Brayton cycle decreases as the pressure ratio r_p increases

Actual Brayton cycle:
Adiabatic process - compression.
Isobaric process - heat addition.
Adiabatic process - expansion.
Isobaric process - heat rejection.

A Brayton cycle that is driven in reverse, via net work input, and when air is the working fluid, is the air refrigeration cycle or Bell Coleman cycle. Its purpose is to move heat, rather than produce work. This air cooling technique is used widely in jet aircraft for air conditioning systems utilizing air tapped from the engine compressors.

2.3 AIR CYCLE FOR THE AIRCRAFT:

An air cycle is the refrigeration unit of the environmental control system (ECS) used in pressurized gas turbine-powered aircraft. Normally an aircraft has two or three of these ACM. Each ACM and its components are often referred as an air conditioning pack. The air cycle cooling process uses air instead of a phase changing material such as Freon in the gas cycle. No condensation or evaporation of a refrigerant is involved, and the cooled air output from the process is used directly for cabin ventilation or for cooling electronic equipment.

2.4 Necessity of cooling of air craft:

The environmental control system (ECS) of an aircraft provides air supply, thermal control and cabin pressurization for the crew and passengers. Avionics cooling, smoke detection and fire suppression are also commonly considered part of an aircraft's environmental control system.

Air is supplied to the ECS by being "bled" from a compressor stage of each gas turbine engine, upstream of the combustor. The temperature and pressure of this "bleed air" varies widely depending upon which compressor stage and the RPM of the engine.

A "manifold pressure regulating shut-off valve" (MPRSOV) restricts the flow as necessary to maintain the desired pressure for downstream systems. This flow restriction results in efficiency losses. To reduce the amount of restriction required, and thereby increase efficiency, air is commonly drawn from two bleed ports (three on the Boeing 777).

When the engine is at low thrust, the air is drawn from the "high pressure bleed port." As thrust is increased, the pressure from this port rises until "crossover," where the "high pressure shut-off valve" (HPSOV) closes and air is thereafter drawn from the "low pressure bleed port."

To achieve the desired temperature, the bleed-air is passed through a heat exchanger called a "pre-cooler." Air from the jet engine fan is blown across the pre-cooler, which is located in the engine strut. A "fan air modulating valve" (FAMV) varies the cooling airflow, and thereby controls the final air temperature of the bleed air.

At the heart of the "cold air unit"(CAU) is the "Air Cycle Machine" (ACM) cooling device. Some aircraft, including early 707 jetliners, used vapor-compression refrigeration like that used in home air conditioners. An ACM uses no Freon: the air itself is the refrigerant. The ACM is preferred over vapor cycle devices because of reduced weight and maintenance requirements.

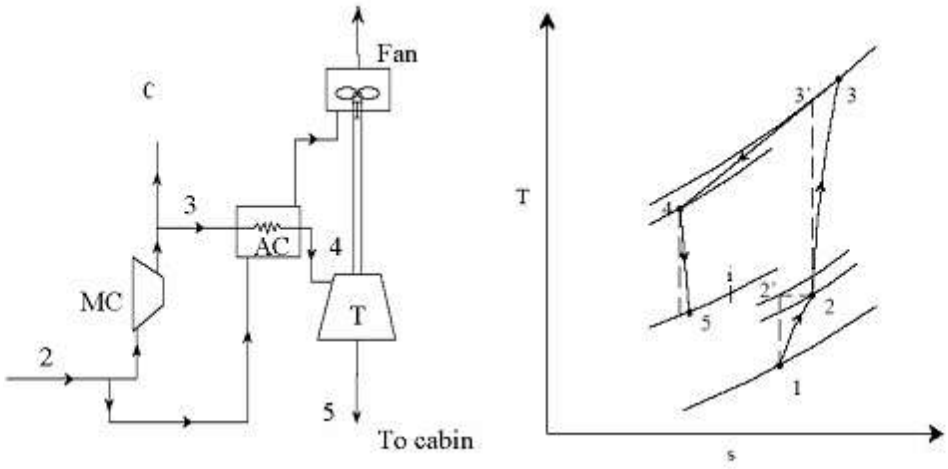
On most jetliners, the A/C packs are located in the "wing to body fairing" between the two wings beneath the fuselage. On some jetliners (Douglas Aircraft DC-9 Series) the A/C packs are located in the tail. The A/C packs on the McDonnell Douglas DC-10/MD-11 and Lockheed L-1011 are located in the front of the aircraft beneath the flight deck. Nearly all jetliners have two packs, although larger aircraft such as the Boeing 747, Lockheed L-1011, and McDonnell-Douglas DC-10/MD-11 have three. The quantity of bleed air flowing to the A/C pack is regulated by the "flow control valve" (FCV). One FCV is installed for each pack. A normally closed "isolation valve" prevents air from the left bleed system from reaching the right pack (and vice versa), although this valve may be opened in the event of loss of one bleed system.

Downstream of the FCV is the cold air unit (CAU), also referred to as the refrigeration unit. There are many various types of CAUs; however, they all use typical fundamentals. The bleed air enters the primary "ram air heat exchanger", where it is cooled by either ram air, expansion or a combination of both. The cold air then enters the compressor, where it is re-pressurized, which reheats the air. A pass through the secondary "ram air heat exchanger" cools the air while maintaining the high pressure. The air then passes through a turbine which expands the air to further reduce heat. Similar in operation to a turbo-charger unit, the compressor and turbine are on a single shaft. The energy extracted from the air passing through the turbine is used to power the compressor. The air flow then is directed to the Re-heater before it passes to the condenser to be ready for water extraction by water extractor

The air is then sent through a water separator, where the air is forced to spiral along its length and centrifugal forces cause the moisture to be flung through a sieve and toward the outer walls where it is channeled toward a drain and sent overboard. Then, the air usually will pass through a water separator coalesce or the sock. The sock retains the dirt and oil from the engine bleed air to keep the cabin air cleaner. This water removal process prevents ice from forming and clogging the system, and keeps the cockpit and cabin from fogging on ground operation and low altitudes.For a sub-zero bootstrap CAU, the moisture is extracted before it reaches the turbine so that sub-zero temperatures may be reached.

The temperature of the pack outlet air is controlled by the adjusting flow through the "ram air system" (below), and modulating a "temperature control valve" (TCV) which bypasses a portion of the hot bleed air around the ACM and mixes it with the cold air downstream of the ACM turbine.

2.5 Aircraft cooling systems



In an aircraft, cooling systems are required to keep the cabin temperatures at a comfortable level. Even though the outside temperatures are very low at high altitudes, still cooling of cabin is required due to:

i. Large internal heat generation due to occupants, equipment etc.

ii. Heat generation due to skin friction caused by the fast moving aircraft

iii. At high altitudes, the outside pressure will be sub-atmospheric. When air at this low pressure is compressed and supplied to the cabin at pressures close to atmospheric, the temperature increases significantly. For example,

When outside air at a pressure of 0.2 bar and temperature of 223 K (at 10000 m altitude) is compressed to 1 bar, its temperature increases to about 353 K. If the cabin is maintained at 0.8 bar, the temperature will be about 332 K. This effect is called as ram effect. This effect adds heat to the cabin, which needs to be taken out by the cooling system.

iv. Solar radiation for low speed aircraft flying at low altitudes, cooling system may not be required, however, for high speed aircraft flying at high altitudes, a cooling system is a must.

Even though the COP of air cycle refrigeration is very low compared to vapour compression refrigeration systems, it is still found to be most suitable for aircraft refrigeration systems as:

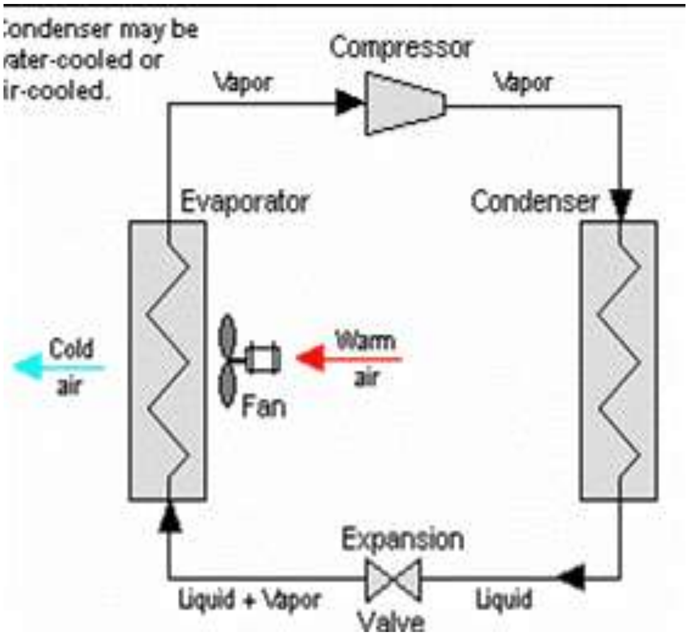
i. Air is cheap, safe, non-toxic and non-flammable. Leakage of air is not a problem

ii. Cold air can directly be used for cooling thus eliminating the low temperature heat exchanger (open systems) leading to lower weight

iii. The aircraft engine already consists of a high speed turbo-compressor; hence separate compressor for cooling system is not required. This reduces the weight per kW cooling considerably. Typically, less than 50% of an equivalent vapours compression system

iv. Design of the complete system is much simpler due to low pressures. Maintenance required is also less.

2.5.1 Simple aircraft refrigeration cycle



The schematic of a simple aircraft refrigeration system and the operating cycle on T-s diagram. This is an open system. As shown in the T-s diagram, the outside low pressure and low temperature air (state 1) is compressed due to ram effect to ram pressure (state 2). During this process its temperature increases from 1 to 2. This air is compressed in the main compressor to state 3, and is cooled to state 4 in the air cooler. Its pressure is reduced to cabin pressure in the turbine (state 5), as a result its temperature drops from 4 to 5. The cold air at state 5 is supplied to the cabin. It picks up heat as it flows through the cabin providing useful cooling effect. The power output of the turbine is used to drive the fan, which maintains the required air flow over the air cooler. This simple system is good for ground cooling (when the aircraft is not moving) as fan can continue to maintain airflow over the air cooler

By applying steady flow energy equation to the ramming process, the temperature rise at the end of the ram effect can be shown to be: 2

$$\frac{T_{2'}}{T_1} = 1 + \frac{\gamma - 1}{2} M^2$$

where M is the Mach number, which is the ratio of velocity of the aircraft (C) to the sonic velocity a

$(a = \sqrt{\gamma R T_1}\ )$, i.e.,

$$M = \frac{C}{a} = \frac{C}{\sqrt{\gamma R T_1}}$$

Due to irreversibilities, the actual pressure at the end of ramming will be less than the pressure resulting from isentropic compression. The ratio of actual pressure rise to the isentropic pressure rise is called as ram efficiency, ηRam, i.e.,

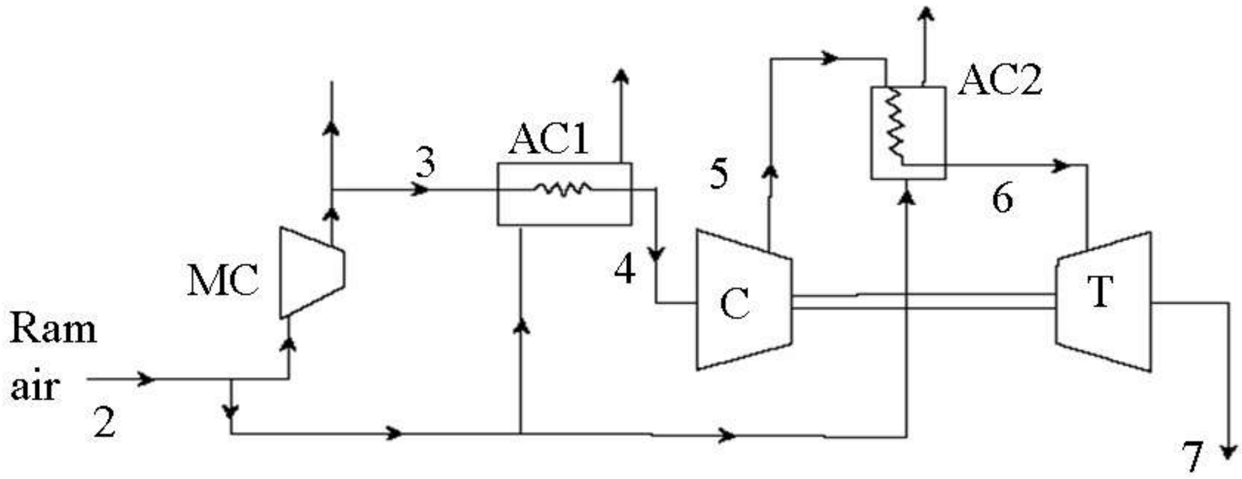
$$\eta_{Ram} = \frac{(P_2 - P_1)}{(P_{2'} - P_1)}$$

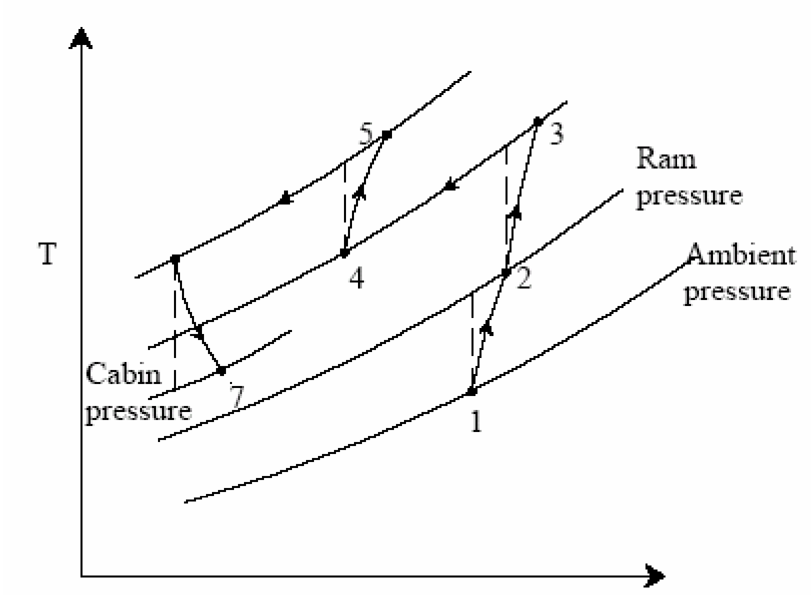
The refrigeration capacity of the simple aircraft cycle discussed, $\dot{Q}$ is given by:

$$\dot{Q} = \dot{m}\, c_p (T_i - T_5)$$

where $\dot{m}$ is the mass flow rate of air through the turbine.

2.5.2 Bootstrap system:





The schematic of a bootstrap system, which is a modification of the simple system. As shown in the figure, this system consists of two heat exchangers (air cooler and after cooler), in stead of one air cooler of the simple system. It also incorporates a secondary compressor, which is driven by the turbine of the cooling system. This system is suitable for high speed aircraft, where in the velocity of the aircraft provides the necessary airflow for the heat exchangers, as a result a separate fan is not required. As shown in the cycle diagram, ambient air state 1 is pressurized to state 2 due to the ram effect. This air is further compressed to state 3 in the main compressor. The air is then cooled to state 4 in the air cooler. The heat rejected in the air cooler is absorbed by the ram air at state 2. The air from the air cooler is further compressed from state 4 to state 5 in the secondary compressor. It is then cooled to state 6 in the after cooler, expanded to cabin pressure in the cooling turbine and is supplied to the cabin at a low temperature T7. Since the system does not consist of a separate fan for driving the air through the heat exchangers, it is not suitable for ground cooling. However, in general ground cooling is normally done by an external air conditioning system as it is not efficient to run the aircraft engine just to provide cooling when it is grounded.

ASSIGNMENT-2

Q.1 Describe with neat sketch working of reversed Brayton cycle and compare it with reversed Carnot cycle. (RTU 2013)

Q.2 A refrigerator working on refrigerant R-12 has a load of 25 ton. The pressure limits are 10 bar and 2 bar, whereas the vapour leaves the evaporator dry and saturated condition. Calculate the COP of the system and power required. (R.T.U. 2012)

Q.3 Write short note on Cascade refrigeration Cycles. (R.T.U. 2008, 2006)

Q.4 Derive expression for COP for an air refrigeration system working on reversed Brayton cycle. (R.T.U. 2007)

CLASS TEST-2

Q.1 Write short notes on:

1) Dry air rated temp.
2) Bootstrap system.

Q.2 Describe with neat sketch working of reversed Brayton cycle and compare it with reversed Carnot cycle?

Q.3 why the air cycle refrigeration is preferred in air craft’s. List its advantages.

Q.4 Describe with neat sketch the working of cascade cycle. What are its uses?

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UNIT-3

3.1 Absorption refrigerator

An absorption refrigerator is a refrigerator that uses a heat source (e.g., solar energy, a fossil-fueled flame, waste heat from factories, or district heating systems) which provides the energy needed to drive the cooling process.

Absorption refrigerators are often used for food storage in recreational vehicles. The principle can also be used to air-condition buildings using the waste heat from a gas turbine or water heater. This use is very efficient, since the gas turbine then produces electricity, hot water, and air-conditioning (called cogeneration/regeneration).

Both absorption and compressor refrigerators use a refrigerant with a very low boiling point (less than 0 °F (−18 °C)). In both types, when this refrigerant evaporates (boils), it takes some heat away with it, providing the cooling effect. The main difference between the two systems is the way the refrigerant is changed from a gas back into a liquid so that the cycle can repeat. An absorption refrigerator changes the gas back into a liquid using a method that needs only heat, and has no moving parts other than the refrigerant itself.

The absorption cooling cycle can be described in three phases:

1. Evaporation: A liquid refrigerant evaporates in a low partial pressure environment, thus extracting heat from its surroundings (e.g. the refrigerator's compartment). Due to the low pressure, the temperature needed for evaporation is also lower.
2. Absorption: The now gaseous refrigerant is absorbed by another liquid (e.g. a salt solution), reducing its partial pressure in the evaporator and allowing more refrigerant to evaporate.
3. Regeneration: The refrigerant-saturated liquid is heated, causing the refrigerant to evaporate out. This happens at a significantly higher pressure. The refrigerant is then condensed through a heat exchanger to replenish the supply of liquid refrigerant in the evaporator.

In comparison, a compressor refrigerator uses an electrically powered compressor to increase the pressure on the gas, and then condenses the hot high pressure gas back to a liquid by heat exchange with a coolant (usually air). Once the high pressure gas has cooled and condensed into a liquid, it passes through an orifice which creates a pressure drop, which causes the liquid to evaporate. The evaporation process absorbs heat, and the temperature of the refrigerant drops to its boiling point at the now low pressure.

Another difference between the two types is the refrigerant used. Compressor refrigerators typically use an HCFC or HFC, while absorption refrigerators typically use ammonia or water

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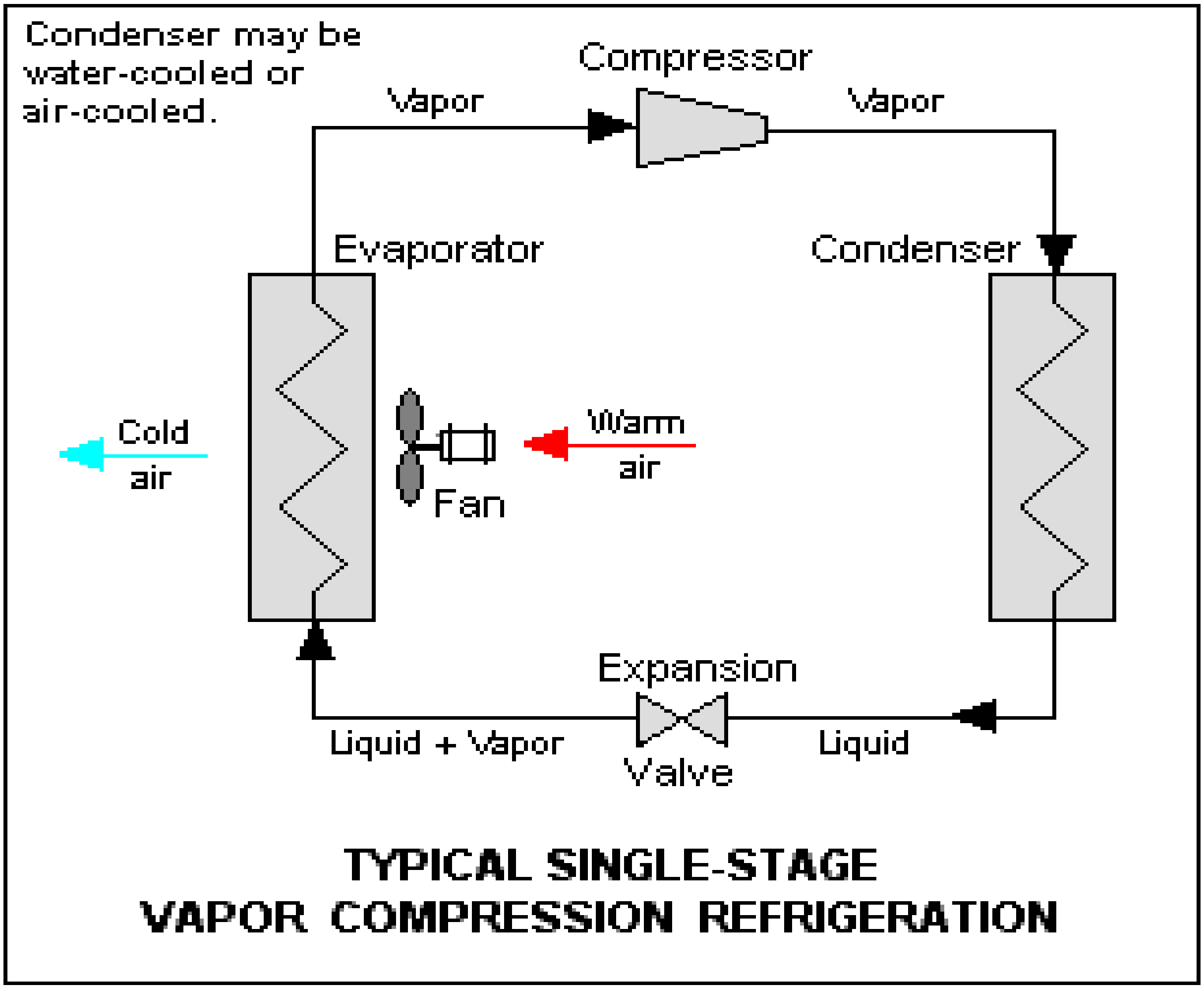

TYPICAL SINGLE-STAGE VAPOR COMPRESSION REFRIGERATION

3.2 ELECTROLUX REFRIGERATOR

- The domestic absorption type refrigerator was developed from an invention by Carl Munters and Baltzer Von Platen. This system is often called “Munters Platen System”.
- This type of refrigerator is also called “Three-fluids absorption system”. The three fluids used in this system are ammonia, hydrogen and water.

The “ammonia” is used as a refrigerant because it possesses most of the desirable properties. Though it is toxic, and not otherwise preferred in domestic appliances, it is very safe in this system due to absence of any moving parts in the system and, therefore, there is the least chance of any leakage.

The “hydrogen” being the lightest gas, is used to increase the rate of evaporation (the lighter the gas, faster is the evaporation) of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. This is used in the low-pressure side of the system. - The “water” is used as a solvent because it has the ability to absorb ammonia readily.

3.2.1Principle and Working of Electrolux Refrigerators.

‟. It is a domestic refrigerator and is the best known absorption type of refrigerator. Here pump is dispensed with. The small energy supply is by means of a heater which may be electric or gas.

Principle. The principle involved makes use of the properties of gas-vapor mixtures. If a liquid is exposed to an inert atmosphere, it will evaporate until the atmosphere is saturated with the vapor of the liquid. This evaporation requires heat which is taken from the surroundings in which the evaporation takes place. A cooling effect is thus produced. The partial pressures of the refrigerant vapor (in this case ammonia) must be low in the evaporator, and higher in the condenser. The total pressure throughout the circuit must be constant so that the only movement of the working fluid is by convection currents. The partial pressure of ammonia is kept low in requisite parts of the circuit by concentrating hydrogen in those parts.

Working. The ammonia liquid leaving the condenser enters the evaporator and evaporates into the hydrogen at the low temperature corresponding to its low partial pressure. The mixture of ammonia and hydrogen passes to the absorber into which is also admitted water from the separator. The water absorbs the ammonia and the hydrogen returns to the evaporator. In the absorber the ammonia therefore passes from the ammonia circuit into water circuit as ammonia in water solution. This strong solution passes to the generator where it is heated and the vapor given off rises to the separator. The water with the vapor is separated out and a weak solution of ammonia is passed back to the absorber, thus completing the water circuit. The ammonia vapor rises from the separator to the condenser where it is condensed and then returned to the evaporator. The actual plant includes refinements and practical modifications (which are not included here). The following points are worth noting:

- The complete cycle is carried out entirely by gravity flow of the refrigerant.
- The hydrogen gas circulates only from the absorber to the evaporator and back.
- with this type of machine efficiency is not important since the energy input is small.
- It has not been used for industrial applications as the C.O.P. of the system is very low.

3.3 Analysis of Ammonia absorption refrigeration system

Shortage of energy production and fast increasing energy consumption, there is a need to minimize the use of energy and conserve it in all possible ways. Energy conservation (i.e., energy saved is more desirable than energy produced) is becoming a slogan of the present decade and new methods to save energy, otherwise being wasted, are being explored. Recovering energy from waste heat and/or utilizing it for system efficiency improvement is fast becoming a common scientific temper and industrial practice now days. The present energy crisis has forced the scientists and engineers all over the world to adopt energy conservation measures in various industries. Reduction of the electric power and thermal energy consumption are not only desirable but unavoidable in view of fast and competitive industrial growth throughout the world. Refrigeration systems form a vital component for the industrial growth and affect the energy problems of the countryat large. Therefore, it is desirable to provide a base for energy conservation and energy recovery from Vapour Absorption System. Although, the investigations undertaken in this work are of applied research nature but certainly can create a base for further R & D activities in the direction of energy conservation and heat recovery options for refrigeration systems and the analysis can be extended further to other Refrigeration and Air Conditioning Systems. In recent years, research has been devoted to improvement of Absorption Refrigeration Systems (ARSs). Mechanical Vapour Compression Refrigeration requires high grade energy for their operation. Apart from this, recent studies have shown that the conventional working fluids of vapour compression system are causing ozone layer depletion and green house effects. However, ARS’s harmless inexpensive waste heat, solar, biomass or geothermal energy sources for which the cost of supply is negligible in many cases. Moreover, the working fluids of these systems are envoi mentally friendly [1-3]. The overall performance of the absorption cycle in terms of refrigerating effect per unit of energy input generally poor, however, waste heat such as that rejected from a power can be used to achieve better overall energy utilization. Ammonia/water (NH3/H20) systems are widely used where lower temperature is required. However, water/lithium bromide (H20/LiBr) system are also widely used where moderate temperatures are required (e.g. air conditioning), and the latter system is more efficient than the former [4-6]. The objective of this paper is to evaluate thermodynamic properties and tabulated also energy transfer rate in each components are calculated and tabulated with the help of empirical relation. Mass flow rate and heat rate in each components of the system are evaluated and tabulated. The coefficient of performance of the system is determining for various temperatures ranges. The result of this study can be used either for sizing a new refrigeration cycle or rating an existing system.

3.4 Lithium Bromide Absorption Refrigeration System:

In a water-lithium bromide vapor absorption refrigeration system, water is used as the refrigerant while lithium bromide (Li Br) is used as the absorbent. In the absorber, the lithium bromide absorbs the water refrigerant, creating a solution of water and lithium bromide. This solution is pumped by the pump to the generator where the solution is heated. The water refrigerant gets vaporized and moves to the condenser where it is cooled while the lithium bromide flows back to the absorber where it further absorbs water coming from the evaporator.

The water-lithium bromide vapor absorption system is used in a number of air conditioning applications. This system is useful for applications where the temperature required is more than 32 degree F.

Special Features of Water-Lithium Bromide Solution

Here are some special features of the water and lithium bromide in an absorption refrigeration system:

1) Lithium bromide has great affinity for water vapor, however, when the water-lithium bromide solution is formed, they are not completely soluble with each other under all the operating conditions of the absorption refrigeration system. Because of this, the designer must take care that such conditions would not be created where crystallization and precipitation of the lithium bromide would occur.

2) The water used as the refrigerant in the absorption refrigeration system means the operating pressures in the condenser and the evaporator must be very low. Even the difference of pressure between the condenser and the evaporator must be very low. This can be achieved even without installing the expansion valve in the system, since the drop in pressure occurs due to friction in the refrigeration piping and in the spray nozzles.

3) The capacity of any absorption refrigeration system depends on the ability of the absorbent to absorb the refrigerant, which in turn depends on the concentration of the absorbent. To increase the capacity of the system, the concentration of absorbent should be increased, which would enable absorption of more refrigerant. Some of the most common methods used to change the concentration of the absorbent are: controlling the flow of the steam or hot water to the generator, controlling the flow of water used for condensing in the condenser, and re-concentrating the absorbent leaving the generator and entering the absorber.

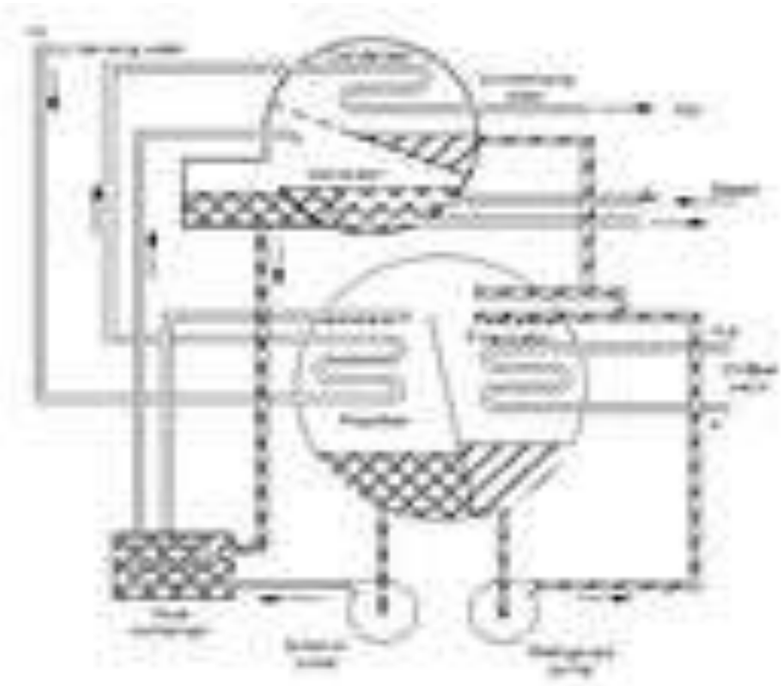

Figure 13.1 Diagram of two-shell lithium bromide cycle water chiller (ASHRAE, 1983).

3.5 CLASSIFICATION OF REFRIGERANTS

Refrigerants can be broadly classified based on the following:

Working Principle

Under this heading, we have the primary or common refrigerants and the Secondary refrigerants.

The primary refrigerants are those that pass through the processes of Compression, cooling or condensation, expansion and evaporation or Warming up during cyclic processes. Ammonia, R12, R22, carbon dioxide Come under this class of refrigerants.

On the other hand, the medium which does not go through the cyclic Processes in a refrigeration system and is only used as a medium for heat transfer are referred to as secondary refrigerants. Water, brine solutions of Sodium chloride and calcium chloride come under this category.

Safety Considerations

Under this heading, we have the following three sub-divisions.

Safe refrigerants

These are the non-toxic, non-flammable refrigerants such as R11, R12, R13, R14, R21, R22, R113, R114, methyl chloride, carbon dioxide, water etc.

Toxic and moderately flammable

Dichloroethylene methyl format, ethyl chloride, sulphur dioxide, Ammonia etc. come under this category.

Highly flammable refrigerants

Chemical Compositions

They are further sub-divided as55

Halocarbon compounds Refrigerants

These are obtained by replacing one or more hydrogen atoms in ethane or methane with halogens.

Azeotropes

These are the mixtures of two or more refrigerants and behave as a compound.

Oxygen and Nitrogen Compounds

Refrigerants having either oxygen or nitrogen molecules in their Structure, such as ammonia, are grouped separately and have a Separate nomenclature from the halogenated refrigerants.

Cyclic organic Compounds

The compounds coming under this class are R316, R317 and R318.

Inorganic Compounds

These are further divided into two categories: Cryogenic and Noncryogenic.

The refrigerants under this category are butane, isobutene, propane, ethane, methane, ethylene etc**.**

Chemical Compositions

They are further sub-divided as55

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These are obtained by replacing one or more hydrogen atoms in Ethane or methane with halogens.

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These are further divided into two categories: Cryogenic and Noncryogenic.

ASSIGNMENT-3

Q.1 Derive the expression for ideal COP in the case of vapour absorption system. (RTU 2013)

Q.2 A) What are the limitations of Carnot cycle used in cooling when it is operating on gas.

B) Describe the performance of the closed air refrigeration system. (RTU 2012)

Q.3 what must be the ideal properties of a refrigerant? Compare NH_3, R-12 and R-22 for these properties. (RTU 2011)

Q.4 Explain criterion for selection of a compressor in vapour compression cycle of refrigeration. (RTU 2011, 2010)

Q.5 Explain with help of a sketch the working of rotary compressor. (RTU 2009)

CLASS TEST-3

Q.1 Derive the expression for an ideal COP in the case of vapour absorption system.

Q.2 Describe with neat sketch any three types of expansion devices used in refrigeration.

Q.3 what is the important function of an intercooler used in multi stage compression. Derive the expression for an ideal pressure in multi stage compression intercooler.

Q.4 (a) Describe with neat sketch the working of a simple vapour absorption system.

(b) How refrigerants are classified? What is the system used in naming them

PRVIOUS YEAR QUESTIONS

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UNIT-4

4.1 Psychrometric

Psychrometric or **psychrometry** or **hygrometry** are terms used to describe the field of engineering concerned with the determination of physical and thermodynamic properties of gas-vapor mixtures. The term derives from the Greek *psuchron*meaning "cold “and *metron* meaning "means of measurement"

4.2 Psychrometric properties

Dry-bulb temperature (DBT)

The dry-bulb temperature is the temperature indicated by a thermometer exposed to the air in a place sheltered from direct solar radiation. The term dry-bulb is customarily added to temperature to distinguish it from wet-bulb and dew point temperature. In meteorology and psychometrics the word temperature by itself without a prefix usually means dry-bulb temperature. Technically, the temperature registered by the dry-bulb thermometer of a psychrometer. The name implies that the sensing bulb or element is in fact dry. WMO provides a 23 page chapter on the measurement of temperature.

Wet-bulb temperature

The thermodynamic wet-bulb temperature is a thermodynamic property of a mixture of air and water vapor. The value indicated by a wet-bulb thermometer often provides an adequate approximation of the thermodynamic wet-bulb temperature.

The accuracy of a simple wet-bulb thermometer depends on how fast air passes over the bulb and how well the thermometer is shielded from the radiant temperature of its surroundings. Speeds up to 5,000 ft/min (~60 mph) are best but it may be dangerous to move a thermometer at that speed. Errors up to 15% can occur if the air movement is too slow or if there is too much radiant heat present (from sunlight, for example).

A wet bulb temperature taken with air moving at about 1–2 m/s is referred to as a screen temperature, whereas a temperature taken with air moving about 3.5 m/s or more is referred to as sling temperature.

A psychrometer is a device that includes both a dry-bulb and a wet-bulb thermometer. A sling psychrometer requires manual operation to create the airflow over the bulbs, but a powered psychrometer includes a fan for this function. Knowing both the dry-bulb temperature (DBT) and wet-bulb temperature (WBT), one can determine the relative humidity (RH) from the psychrometric chart appropriate to the air pressure.

Relative humidity

The ratio of the vapor pressure of moisture in the sample to the saturation pressure at the dry bulb temperature of the sample.

Dew point temperature

The saturation temperature of the moisture present in the sample of air, it can also be defined as the temperature at which the vapour changes into liquid (condensation). Usually the level at which water vapor changes into liquid marks the base of the cloud in the atmosphere hence called condensation level. So the temperature value that allows this process (condensation) to take place is called the 'dew point temperature'. A simplified definition is the temperature at which the water vapour turns into "dew" (Chamunoda Zambuko 2012).

Humidity

Specific Humidity

Specific humidity is defined as the proportion of the mass of water vapor per unit mass of the moist air sample (dry air plus the water vapor); it is closely related to humidity ratio and always lowers in value.

Absolute

The mass of water vapor per unit volume of air containing the water vapor. This quantity is also known as the water vapor density.[5]

Specific enthalpy

Analogous to the specific enthalpy of a pure substance. In psychometrics, the term quantifies the total energy of both the dry air and water vapour per kilogram of dry air.

Specific volume

Analogous to the specific volume of a pure substance. In psychometrics, the term quantifies the total volume of both the dry air and water vapour per kilogram of dry air.

Psychrometric ratio

The psychrometric ratio is the ratio of the heat transfer coefficient to the product of mass transfer coefficient and humid heat at a wetted surface. It may be evaluated with the following equation:

Where:

= Psychrometric ratio, dimensionless

= convective heat transfer coefficient, W m-2 K-1

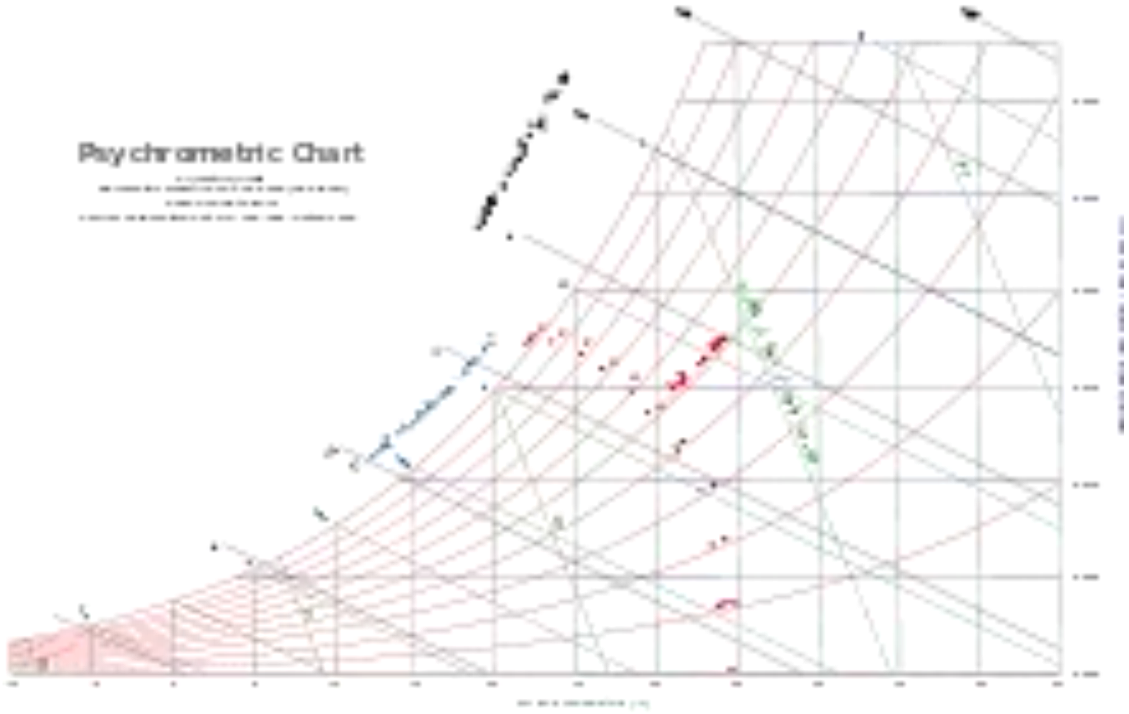
= convective mass transfer coefficient, kg m-2 s-1

= humid heat, J kg-1 K-1

The psychrometric ratio is an important property in the area of psychometrics, as it relates the absolute humidity and saturation humidity to the difference between the dry bulb temperature and the adiabatic saturation temperature.

Mixtures of air and water vapor are the most common systems encountered in psychrometry. The psychrometric ratio of air-water vapor mixtures is approximately unity, which implies that the difference between the adiabatic saturation temperature and wet bulb temperature of air-water vapor mixtures is small. This property of air-water vapor systems simplifies drying and cooling calculations often performed using psychrometic relationships.

4.3 Psychrometric charts:



A psychrometric chart for sea-level elevation Terminology

A psychrometric chart is a graph of the thermodynamic parameters of moist air at a constant pressure, often equated to an elevation relative to sea level. The ASHRAE-style psychrometric chart, shown here, was pioneered by Willis Carrier in 1904.[9] It depicts these parameters and is thus a graphical equation of state. The parameters are:

Dry-bulb temperature (DBT) is that of an air sample, as determined by an ordinary thermometer. It is typically plotted as the abscissa (horizontal axis) of the graph. The SI units for temperature are Kelvin’s or degrees Celsius; other units are degrees Fahrenheit and degrees Rankine.

Wet-bulb temperature (WBT) is that of an air sample after it has passed through a constant-pressure, ideal, adiabatic saturation process, that is, after the air has passed over a large surface of liquid water in an insulated channel. In practice this is the reading of a thermometer whose sensing bulb is covered with a wet sock evaporating into a rapid stream of the sample air (see Hygrometer). When the air sample is saturated with water, the WBT will read the same as the DBT. The slope of the line of constant WBT reflects the heat of vaporization of the water required to saturate the air of a given relative humidity.

Dew point temperature (DPT) is the temperature at which a moist air sample at the same pressure would reach water vapor “saturation.” At this point further removal of heat would result in water vapor condensing into liquid water fog or, if below freezing point, solid hoarfrost. The dew point temperature is measured easily and provides useful information, but is normally not considered an independent property of the air sample as it duplicates information available via other humidity properties and the saturation curve.

Relative humidity (RH) is the ratio of the mole fraction of water vapor to the mole fraction of saturated moist air at the same temperature and pressure. RH is dimensionless, and is usually expressed as a percentage. Lines of constant RH reflect the physics of air and water: they are determined via experimental measurement. The concept that air "holds" moisture, or that moisture “dissolves” in dry air and saturates the solution at some proportion, is erroneous (albeit widespread); see relative humidity for further details.

Humidity ratio is the proportion of mass of water vapor per unit mass of dry air at the given conditions (DBT, WBT, DPT, RH, etc.). It is also known as the moisture content or mixing ratio. It is typically plotted as the ordinate (vertical axis) of the graph. For a given DBT there will be a particular humidity ratio for which the air sample is at 100% relative humidity: the relationship reflects the physics of water and air and must be determined by measurement. The dimensionless humidity ratio is typically expressed as grams of water per kilogram of dry air, or grains of water per pound of air (7000 grains equal 1 pound).

Specific enthalpy, symbolized by h, is the sum of the internal (heat) energy of the moist air in question, including the heat of the air and water vapor within. Also called heat content per unit mass. In the approximation of ideal gases, lines of constant enthalpy are parallel to lines of constant WBT. Enthalpy is given in (SI) joules per kilogram of air, or BTU per pound of dry air.

Specific volume is the volume of the mixture (dry air plus the water vapor) containing one unit of mass of “dry air”. The SI units are cubic meters per kilogram of dry air; other units are cubic feet per pound of dry air. The inverse of specific volume is usually confused as the density of the mixture (see "Applying the Psychrometric Relationships" CIBSE, August 2009). However, to obtain the actual mixture density one must multiply the inverse of the specific volume by unity plus the humidity ratio value at the point of interest (see ASHRAE Fundamentals 1989 6.6, equation 9).

The psychrometric chart allows all the parameters of some moist air to be determined from any three independent parameters, one of which must be the pressure. Changes in *state*, such as when two air streams mix, can be modeled easily and somewhat graphically using the correct psychrometric chart for the location's air pressure or elevation relative to sea level. For locations at not more than 2000 ft (600 m) of altitude it is common practice to use the sea-level psychrometric chart.

In the ω-t chart, the dry bulb temperature (t) appears as the abscissa (horizontal axis) and the humidity ratio (ω) appear as the ordinate (vertical axis). A chart is valid for a given air pressure (or elevation above sea level). From any two independent ones of the six parameters dry bulb temperature, wet bulb temperature, relative humidity, humidity ratio, specific enthalpy, and specific volume, all the others can be determined. There are possible combinations of independent and derived parameters.

*** Dry bulb temperature:**

These lines are drawn straight, not always parallel to each other, and slightly inclined from the vertical position. This is the *t*–axis, the abscissa (horizontal) axis. Each line represents a constant temperature.

*** Dew point temperature:**

From the state point follow the horizontal line of constant humidity ratio to the intercept of 100% RH, also known as the *saturation curve*. The dew point temperature is equal to the fully saturated dry bulb or wet bulb temperatures.

*** Wet bulb temperature:**

These lines are oblique lines that differ slightly from the enthalpy lines. They are identically straight but are not exactly parallel to each other. These intersect the saturation curve at DBT point.

*** Relative humidity:**

These hyperbolic lines are shown in intervals of 10%. The saturation curve is at 100% RH, while dry air is at 0% RH.

*** Humidity ratio:**

These are the horizontal lines on the chart. Humidity ratio is usually expressed as mass of moisture per mass of dry air (pounds or kilograms of moisture per pound or kilogram of dry air, respectively). The range is from 0 for dry air up to 0.03 (lbmw/lbma) on the right hand ω-axis, the ordinate or vertical axis of the chart.

*** Specific enthalpy:**

These are oblique lines drawn diagonally downward from left to right across the chart that are parallel to each other. These are not parallel to wet bulb temperature lines.

Specific volume:

These are a family of equally spaced straight lines that are nearly parallel.

The region above the saturation curve is a two-phase region that represents a mixture of saturated moist air and liquid water, in thermal equilibrium.

The protractor on the upper left of the chart has two scales. The inner scale represents sensible-total heat ratio (SHF). The outer scale gives the ratio of enthalpy difference to humidity difference. This is used to establish the slope of a condition line between two processes. The horizontal component of the condition line is the change in sensible heat while the vertical component is the change in latent heat

4.4 air washer

A device for cooling and cleaning air in which the entering warm, moist air is cooled below dew point by refrigerated water so that although the air leaves close to saturation with water, it has less moisture per unit volume than when it entered.

Apparatus to wash particulates and soluble impurities from air by passing the air stream through a liquid bath or spray.

4.5 Mechanism of body heat losses

Most of the heat produced in the body is generated in the deep organs (especially in the liver, brain, and heart) and in the skeletal muscles during exercise. Then this heat is transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings.

Insulator S Therefore, the rate at which heat is lost is determined almost entirely by two factors:

(1) How rapidly heat can be conducted from where it is produced in the body core to the skin and

(2) Rapidly heat can then be transferred from the skin to the surroundings. Y stem of the Body

The skin, the subcutaneous tissues, and especially the fat of the subcutaneous tissues act together as a heat insulator for the body. The fat is important because it conducts heat only one third as readily as other tissues.

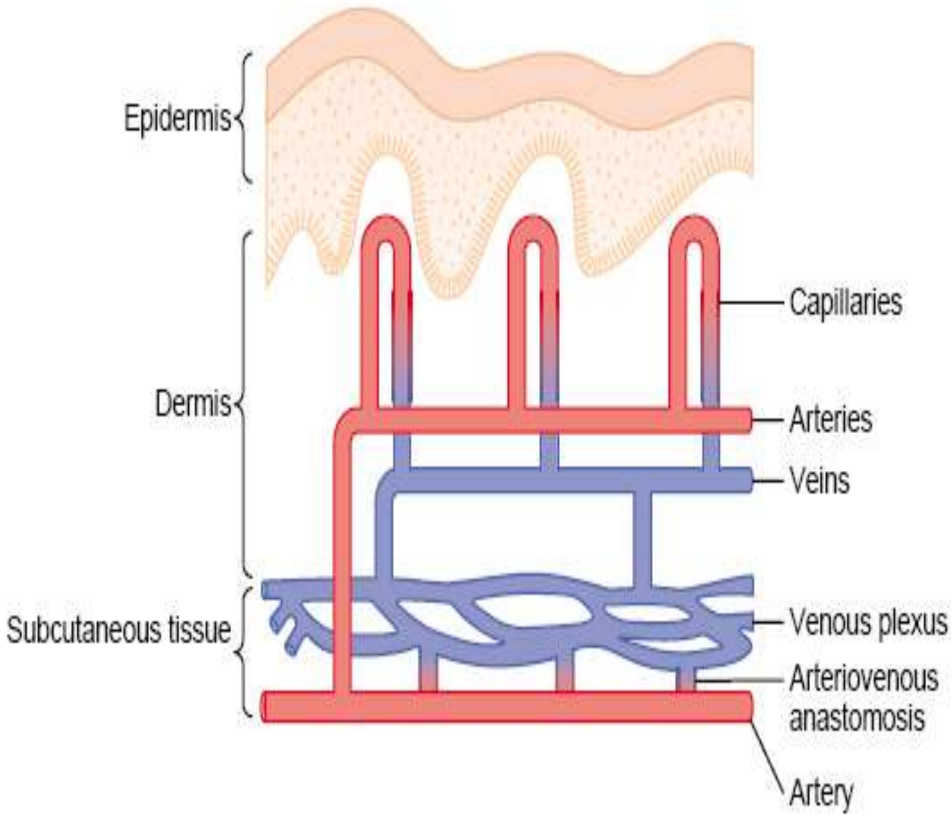
When no blood is flowing from the heated internal organs to the skin, the insulating properties of the normal male body are about equal to three quarters the insulating properties of a usual suit of clothes. In women, this insulation is even better.

The insulation beneath the skin is an effective means of maintaining normal internal core temperature, even though it allows the temperature of the skin to approach the temperature of the surroundings.

Blood Flow to the Skin from the Body Core

Provides Heat Transfer

Blood vessels are distributed profusely beneath the skin. Especially important is a continuous venous plexus that is supplied by inflow of blood from the skin capillaries, shown in Figure 73–2.



In the most exposed areas of the body—the hands, feet, and ears—blood is also supplied to the plexus directly from the small arteries through highly muscular arteriovenous anastomoses.

The rate of blood flow into the skin venous plexus can vary tremendously—from barely above zero to as great as 30 per cent of the total cardiac output.

A high rate of skin flow causes heat to be conducted from the core of the body to the skin with great efficiency, whereas reduction in the rate of skin flow can decrease the heat conduction from the core to very little.

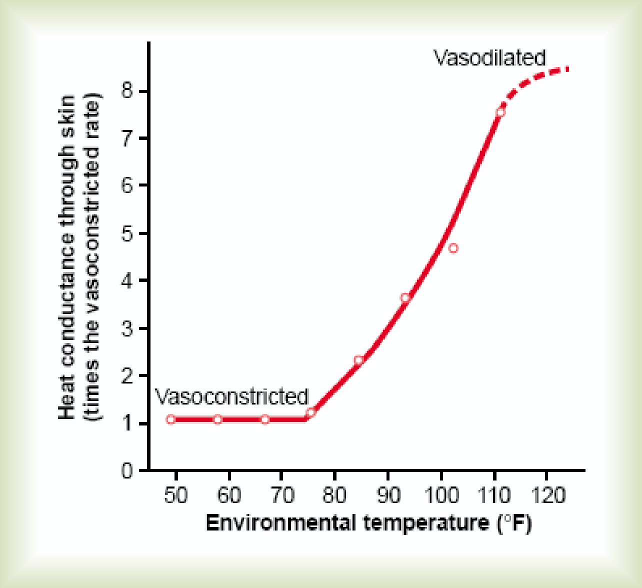


Figure 73–3

Effect of changes in the environmental temperature on heat conductance from the body core to the skin surface. (Modified from Benzinger TH: Heat and Temperature Fundamentals of Medical Physiology. New York: Dowden, Hutchinson & Ross, 1980.)

Figure 73–3 shows quantitatively the effect of environmental air temperature on conductance of heat from the core to the skin surface and then conductance into the air, demonstrating an approximate eightfold increase in heat conductance between the fully vasoconstrictor state and the fully vasodilator state.

Therefore, the skin is an effective controlled “heat radiator” system, and the flow of blood to the skin is a most effective mechanism for heat transfer from the body core to the skin.

4.6 Effective temperature

As long as skin temperature is greater than the temperature of the surroundings, heat can be lost by radiation and conduction. But when the temperature of the surroundings becomes greater than that of the skin, instead of losing heat, the body gains heat by both radiation and conduction. Under these conditions, the only means by which the body can rid itself of heat is by evaporation.

Therefore, anything that prevents adequate evaporation when the surrounding temperature is higher than the skin temperature will cause the internal body temperature to rise. This occurs occasionally in human beings who are born with congenital absence of sweat glands. These people can stand cold temperatures as well as normal people can, but they are likely to die of heatstroke in tropical zones because without the evaporative refrigeration system, they cannot prevent a rise in body temperature when the air temperature is above that of the body.

Effect of Clothing on Conductive Heat Loss.

Clothing entraps air next to the skin in the weave of the cloth, thereby increasing the thickness of the so-called private zone of air adjacent to the skin and also decreasing the flow of convection air currents. Consequently, the rate of heat loss from the body by conduction and convection is greatly depressed. A usual suit of clothes decreases the rate of heat loss to about half that from the nude body, but arctic-type clothing can decrease this heat loss to as little as one sixth.

About half the heat transmitted from the skin to the clothing is radiated to the clothing instead of being conducted across the small intervening space. Therefore, coating the inside of clothing with a thin layer of gold, which reflects radiant heat back to the body, makes the insulating properties of clothing far more effective than otherwise. Using this technique, clothing for use in the arctic can be decreased in weight by about half. The effectiveness of clothing in maintaining body temperature is almost completely lost when the clothing becomes wet, because the high conductivity of water increases the rate of heat transmission through cloth 20-fold or more. Therefore, one of the most important factors for protecting the body against cold in arctic regions is extreme caution against allowing the clothing to become wet. Indeed, one must be careful not to become overheated even temporarily, because sweating in one's clothes makes them much less effective thereafter as an insulator.

Sweating and Its Regulation by the Autonomic Nervous System

Stimulation of the anterior hypothalamus-preoptic area in the brain either electrically or by excess heat causes sweating. The nerve impulses from this area that cause sweating are transmitted in the autonomic pathways to the spinal cord and then through sympathetic outflow to the skin everywhere in the body. It should be recalled from the discussion of the autonomic nervous system in Chapter 60 that the sweat glands are innervated by *cholinergic* nerve fibers (fibers that secrete acetylcholine but that run in the sympathetic nerves along with the adrenergic fibers).

The sweat glands secrete large quantities of sweat when the sympathetic nerves are stimulated, but no effect is caused by stimulating the parasympathetic nerves. However, the sympathetic fibers to most sweat glands are cholinergic (except for a few adrenergic fibers to the palms and soles), in contrast to almost all other sympathetic fibers, which are adrenergic. Furthermore, the sweat glands are stimulated primarily by centers in the hypothalamus that are usually considered to be parasympathetic centers. Therefore, sweating could be called a parasympathetic function, even though it is controlled by nerve fibers that anatomically are distributed through the sympathetic nervous system. These glands can also be stimulated to some extent by epinephrine or nor epinephrine circulating in the blood, even though the glands themselves do not have adrenergic innervations. This is important during exercise, when these hormones are secreted by the adrenal medullae and the body needs to lose excessive amounts of heat produced by the active muscles.

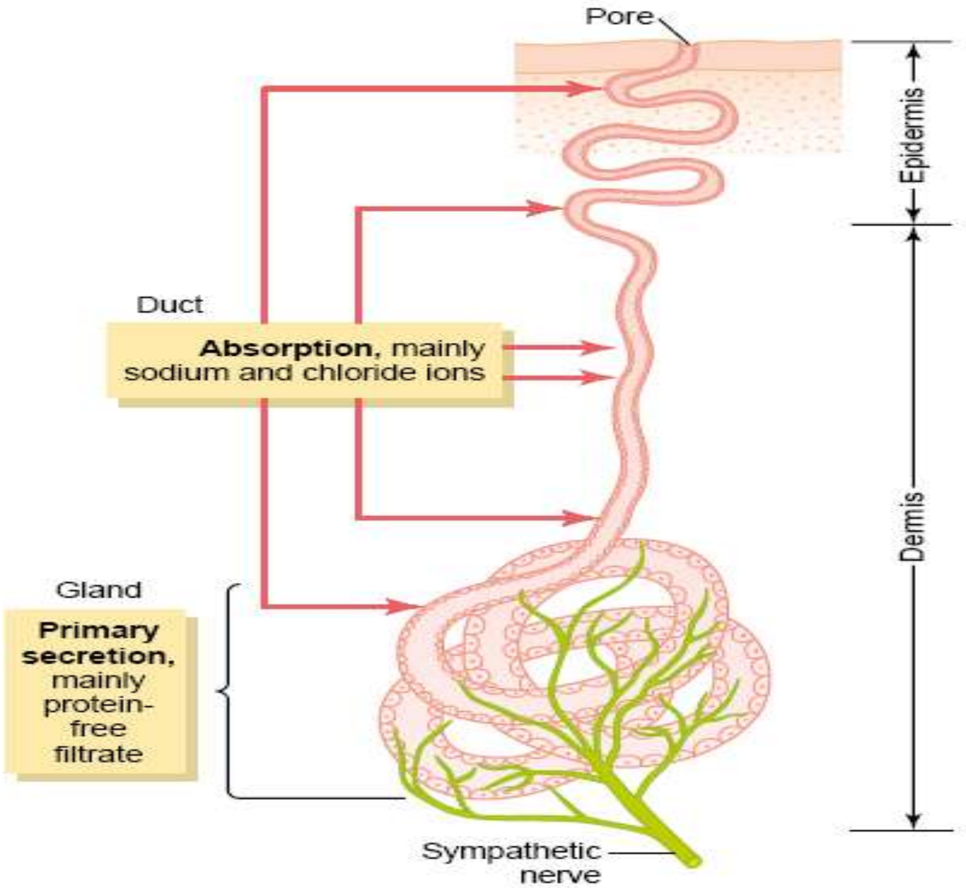


Figure 73–5

Sweat gland innervated by an acetylcholine-secreting sympathetic nerve. A *primary protein-free secretion* is formed by the glandular portion, but most of the electrolytes are reabsorbed in the duct, leaving a dilute, watery secretion.

Mechanism of Sweat Secretion.

In Figure 73–5, the sweat gland is shown to be a tubular structure consisting of two parts:

(1) a deep sub dermal *coiled portion* that secretes the sweat, and

(2) a *duct portion* that passes outward through the dermis and epidermis of the skin.

As is true of so many other glands, the secretary portion of the sweat gland secretes a fluid called the *primary secretion* or *precursor secretion;* the concentrations of constituents in the fluid are then modified as the fluid flows through the duct. The precursor secretion is an active secretary product of the epithelial cells lining the coiled portion of the sweat gland. Cholinergic sympathetic nerve fibers ending on or near the glandular cells elicit the secretion. The composition of the precursor secretion is similar to that of plasma, except that it does not contain plasma proteins. The concentration of sodium is about 142 mEq/L and that of chloride is about 104 mEq/L, with much smaller concentrations of the other solutes of plasma. As this precursor solution flows through the duct portion of the gland, it is modified by reabsorption of most of the sodium and chloride ions. The degree of this reabsorption depends on the rate of sweating, as follows.

When the sweat glands are stimulated only slightly, the precursor fluid passes through the duct slowly. In this instance, essentially all the sodium and chloride ions are reabsorbed, and the concentration of each falls to as low as 5 mEq/L. This reduces the osmotic pressure of the sweat fluid to such a low level that most of the water is also reabsorbed, which concentrates most of the other constituents. Therefore, at low rates of sweating, such constituents as urea, lactic acid, and potassium ions are usually very concentrated.

Conversely, when the sweat glands are strongly stimulated by the sympathetic nervous system, large amounts of precursor secretion are formed, and the duct may reabsorb only slightly more than half the sodium chloride; the concentrations of sodium and chloride ions are then (in an unacclimatized person) a maximum of about 50 to 60 mEq/L, slightly less than half the concentrations in plasma. Furthermore, the sweat flows through the glandular tubules so rapidly that little of the water is reabsorbed. Therefore, the other dissolved constituents of sweat are only moderately increased in concentration—urea is about twice that in the plasma, lactic acid about 4 times, and potassium about 1.2 times.

There is a significant loss of sodium chloride in the sweat when a person is unacclimatized to heat, but, there is much less electrolyte loss, despite increased sweating capacity, once a person has become acclimatized.

4.7 factors affecting human comfort:

Human factors and ergonomics (HF&E), also known as comfort design, functional design, and user-friendly systems,[1] is the practice of designing products, systems or processes to take proper account of the interaction between them and the people that use them.

It is a multidisciplinary field incorporating contributions from psychology, engineering, biomechanics, industrial design, physiology and anthropometry. In essence it is the study of designing equipment and devices that fit the human body and itscognitive abilities. The two terms "human factors" and "ergonomics" are essentially synonymous.[2][3][4]

The International Ergonomics Association defines ergonomics or human factors as follows:[5]

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

—International Ergonomics Association

HF&E is employed to fulfill the goals of occupational health and safety and productivity. It is relevant in the design of such things as safe furniture and easy-to-use interfaces to machines and equipment. Proper ergonomic design is necessary to prevent repetitive strain injuries and other musculoskeletal disorders, which can develop over time and can lead to long-term disability.

Human factors and ergonomics is concerned with the "fit" between the user, equipment and their environments. It takes account of the user's capabilities and limitations in seeking to ensure that tasks, functions, information and the environment suit each user.

To assess the fit between a person and the used technology, human factors specialists or ergonomists consider the job (activity) being done and the demands on the user; the equipment used (its size, shape, and how appropriate it is for the task), and the information used (how it is presented, accessed, and changed). Ergonomics draws on many disciplines in its study of humans and their environments, including anthropometry, biomechanics, mechanical engineering, industrial engineering, industrial design, information design, kinesiology, physiology, cognitive psychology and industrial and organizational psychology.

4.8 comfort chart:

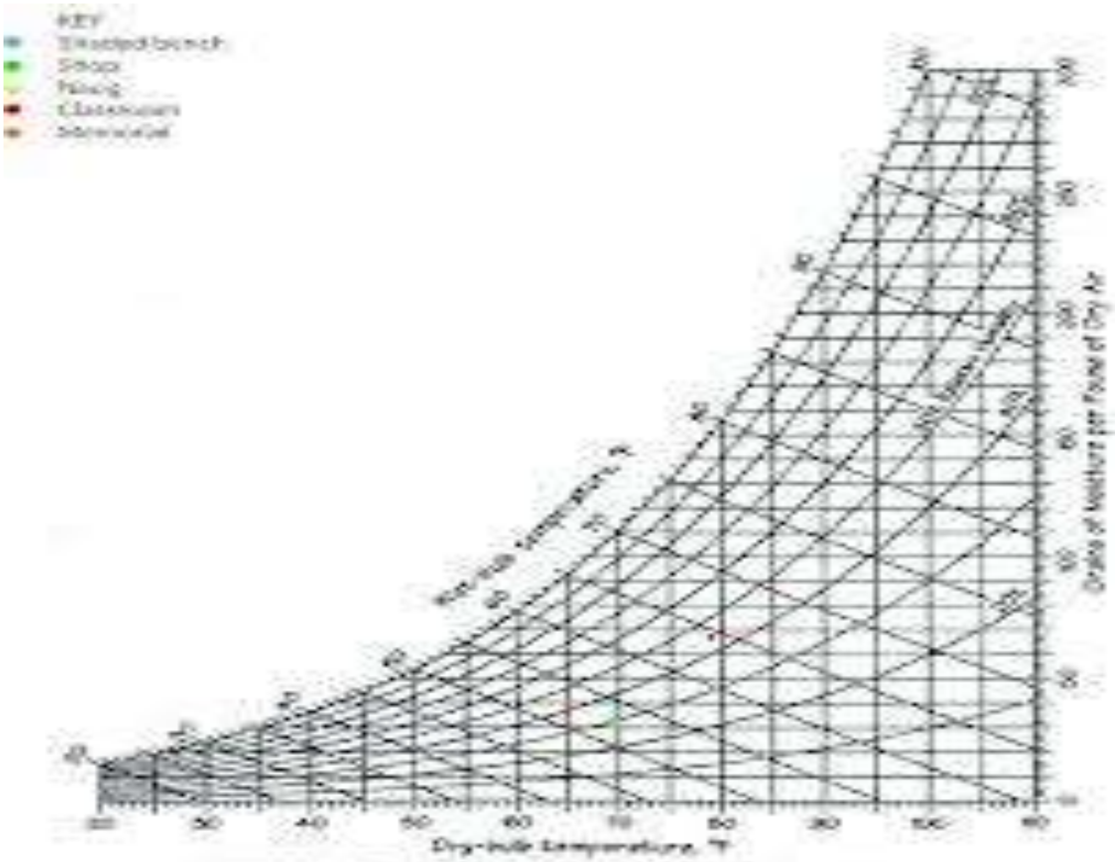


FIGURE 9.5. The psychrometric chart, which plots air-moisture mixtures

ASSIGNMENT-4

Q.1 what are sensible heating and cooling process? Where they are used ? Explain with neat sketch and show on psychrometric chart. Define bypass factor also. (RTU 2013)

Q.2 Define the specific humidity, relative humidity, humidity ratio and dew point temp. (RTU 2011)

Q.3 20 m3 of air per minute at 30°c and 60% RH is cooled to 22°c DBT maintaining specific humidity constant. Find the Heat removed from air, R.H. of cooled air and WBT of the cooled air. Take air pressure 1 bar. (RTU 2008)

Q.4 Explain cooling and humidification process and show it on psychometric chart. (RTU 2010)

CLASS TEST-4

\Q.1 Explain the following: (RTU 2010, 2011)

1) WBT and DBT 2) Degree of saturation and relative humidity

Q.2 What are the sensible heating and cooling processes? Where there are used?

Q.3 What is the mechanism of maintaining a constant temperature of a human body? How it controls and adjusts to various weather conditions.

Q.4 Define specific humidity and relative humidity. Derive the formula in terms of pressure to calculate these.

PREVIOUS YEAR QUESTIONS

Q.1 what are sensible heating and cooling process? Where they are used ? Explain with neat sketch and show on psychrometric chart. Define bypass factor also. (RTU 2013)

Q.2 Define the specific humidity, relative humidity, humidity ratio and dew point temp. (RTU 2011)

Q.3 20 m3 of air per minute at 30°c and 60% RH is cooled to 22°c DBT maintaining specific humidity constant. Find the Heat removed from air, R.H. of cooled air and WBT of the cooled air. Take air pressure 1 bar. (RTU 2008)

Q.4 Explain cooling and humidification process and show it on psychometric chart. (RTU 2010)

Q.5 Explain the following: (RTU 2010,2011)

1) WBT and DBT 2) Degree of saturation and relative humidity

Q.6 What are the sensible heating and cooling processes? Where there are used?

Q.7 What is the mechanism of maintaining a constant temperature of a human body? How it controls and adjusts to various weather conditions.

Q.8 Define specific humidity and relative humidity. Derive the formula in terms of pressure to calculate these.

UNIT-5

COOLING LOAD AND COIL LOAD CALCULATIONS

Components of Cooling Load

Cooling load calculations for air conditioning system design are mainly used to determine the volume flow rate of the air system as well as the coil and refrigeration load of the equipment—to size

The HVAC&R equipment and to provide the inputs to the system for energy use calculations in Order to select optimal design alternatives. Cooling load usually can be classified into two categories:

External and internal.

External Cooling Loads. These loads are formed because of heat gains in the conditioned space From external sources through the building envelope or building shell and the partition walls. Sources of external loads include the following cooling loads:

1. Heat gain entering from the exterior walls and roofs
2. Solar heat gain transmitted through the fenestrations
3. Conductive heat gain coming through the fenestrations
4. Heat gain entering from the partition walls and interior doors
5. Infiltration of outdoor air into the conditioned space

Internal Cooling Loads. These loads are formed by the release of sensible and latent heat from the heat sources inside the conditioned space. These sources contribute internal cooling loads:

1. People
2. Electric lights
3. Equipment and appliances

If moisture transfers from the building structures and the furnishings are excluded, only infiltrated air, occupants, equipment, and appliances have both sensible and latent cooling loads. The remaining components have only sensible cooling loads.

All sensible heat gains entering the conditioned space represent radiative heat and convective heat except the infiltrated air. As in Sec. 6.1, radiative heat causes heat storage in the building structures, converts part of the heat gain into cooling load, and makes the cooling load calculations More complicated. Latent heat gains are heat gains from moisture transfer from the occupants, equipment, appliances, or infiltrated air. If the storage effect of the moisture is ignored, all release heat to the space air instantaneously and, therefore, they are instantaneous cooling loads.

The **internal sensible heat gain** consists of the sensible heat gain from people, from electric lights, and from equipment and appliances.

People. Human beings release both sensible heat and latent heat to the conditioned space. The radiative portion of the sensible heat gain is about 70 percent when the indoor environment of the conditioned space is maintained within the comfort zone. The space sensible heat gain for Occupants staying in a conditioned space at time t, denoted by qsp,t, Btu/h (W), can be calculated as

qsp,t = Np,t (SHGp) (6.14)

where Np,t number of occupants in conditioned space at time t

SHGp sensible heat gain of each person, Btu/h (W)

Space latent heat gain for occupants staying in a conditioned space at time t, denoted by qlp,t, Btu/h (W), is given as

qlp,t =Np,t(LHGp) (6.15)

where LHGp latent heat gain of each person, Btu/h (W). Table 6.1 lists the heat gain from occupants in conditioned space, as abridged from ASHRAE Handbook 1989, Fundamentals. In Table 6.1, total heat is the sum of sensible and latent heat. The adjusted heat is based on a normally distributed percentage of men, women, and children among the occupants.

Space Cooling Load Calculation

The types of conversion of space heat gains to space cooling loads can be grouped into the following two categories:

1. Space sensible cooling loads Qrs,t that are only a fraction of the space sensible heat gain qrs,t. These kinds of sensible heat gains have both radiative and convective components, and it is difficult to separate the convective component from the radiative component, such as sensible heat gains from exterior walls and roofs, and solar heat gains through windows. Equation (6.28) will be used to convert these types of sensible heat gains qrs,t to cooling loads Qrs,t.
2. Space heat gains qin,t are instantaneous space cooling loads Qin,t, both in Btu/h (W), or

Qin, t qin,t (6.30)

This category includes all latent heat gains qrl, convective sensible heat gains, infiltration sensible heat gain qinf,s, and sensible heat gains whose convective component can be separated from the radiative component, such as air-to-air heat gain from windows, lights, and people.

The space cooling load Qrc, t

, Btu/h (W), is their sum, or

Qrc,t = Qrs,t + Qin, t + Ql,t + Qs,t =Ql,t (6.31)

where Qs,t, Ql,t space sensible cooling load and latent load, respectively, Btu/h (W).

As mandated in ASHRAE/IESNA Standard 90.1-1999, Optimum Start Controls, pickup loads either for cooling or heating depend on the difference between space temperature and occupied set point and the amount of time prior to scheduled occupancy, and is often determined by computer Software.

Calculation of Internal **Cooling** Loads and Infiltration

The calculation of the internal heat gains of people, lights, equipment, and appliances qint,s and heat gains of infiltration qinf, all in Btu/h (W), using the CLTD/SCL/CLF method is the same as that Which uses TFM. The sensible internal heat gain that contains the radiative component is then multiplied by a cooling load factor CLFint to convert to space sensible cooling load Qint,s, Btu/h (W), and can be calculated as

Qint,s qint,s (CLFint) (6.39)

In conditioned spaces in which an air system is operated at nighttime shutdown mode, CLFint is equal to 1 during the occupied period when the air system is operating. Refer to ASHRAE Handbook 1993, Fundamentals, for CLFint when the air system is operated 24 h continuously.

Since internal latent heat gains qint, l are instantaneous internal latent cooling loads Qint, l both in Btu/h (W),

Qint,l qint,l (Internal load density (ILD), W/ft2 (W/m2), indicates the total internal heat gains of people, lights, and equipment, and it can be calculated as

(6.41)

Where SHGp, LHGp sensible and latent heat gains for occupants, respectively, Btu/h (W)

Afl floor area, ft2 (m2)

WA,l, WA,e lighting and equipment power density, respectively, W/ft2 (W/m2)

Both infiltration sensible heat gain qinf,s and infiltration latent heat gain qinf, l, in Btu/h (W), are instantaneous space cooling loads; they also can be expressed as

Qinf,s = qinf,s+ Qinf, l = qinf, l (6.42) where Qinf,s, Qinf, l infiltration sensible and latent cooling loads, respectively, Btu/h (W).

Cooling Moist Air - Sensible Cooling

If the temperature on a cooling surface - tC - is above or equal to the dew point temperature - tDP - of the surrounding air, the air will be cooled without any change in specific humidity. It is Sensible Heat - the "temperature heat" - in the air that is removed.

The air cools along a constant specific humidity - x - line as indicated in the Mollier diagram below

With a cold surface of unlimited size and a very small amount of air, it would be possible to reach point C. In the real world a limited surface is never 100% effective and the final state of the cooled and dehumidified air will be somewhere on the straight line between point A and C - point B.

The amount of condensated vapor will be the difference in specific humidity xA - xB.

Note! This process decreases the specific humidity and increases the relative humidity.

ASSIGNMENT-5

Q.1 What is internal heat gain? Write short notes on loads due to occupancy, lighting and appliances. (RTU 2013)

Q.2 What is evaporating cooling ? what are its limitations? Show the cooling process on psychrometric chart. (RTU 2013)

Q.3 What are the factors affecting air conditioning ? Explain (RTU 2011. 2009)

CLASS TEST-5

Q.1 Write short notes on distribution of air in conditioned space. (RTU 2006)

Q.2 Describe the central air conditioning system for year round air-conditioning. Show the processes on skeleton psychrometric chart for summer and winter operations. (2005

PREVIOUS YEAR QUESTIONS

Q.1 What is internal heat gain ? Write short notes on loads due to occupancy, lighting and appliances. (RTU 2013)

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Q.4 Write short notes on distribution of air in conditioned space. (RTU 2006)

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JAIPUR ENGINEERING COLLEGE
AND RESEARCH CENTRE

QUESTION BANK

6ME5-11: REFRIGERATION AND AIR CONDITIONING

UNIT 1

Q1. What do you understand by refrigeration? what is the unit of refrigeration.

Q2. Explain the difference between heat pump and refrigerator and also prove

$COP_{HP}=1+COP_{REF}$.

Q3. Explain reversed Carnot cycle with neat diagram.

Q4. Explain reversed Brayton cycle with neat diagram.

Q5. Explain Bell- Coleman cycle with neat diagram

Q6. Explain vapour compression refrigeration cycle with neat diagram. Draw P-H and T-S diagram also.

Q7. Explain the actual vapour compression refrigeration cycle with neat diagram.

Q8. In a refrigerator working on Bell-Coleman cycle, the air is drawn into the cylinder of the compressor from the cold chamber at a pressure of 1.03 bar and temperature 12^{0}C . After isentropic compression to 5.5 bar, the air is cooled at constant pressure to a temperature of 22^{0}C. The polytropic expansion $pv^{1.25}$=C, then follows and the air expanded to 1.03 bar is passed to cold chamber. (Y= 1.4, Cp= 1.003kj/kgk)Determine:

(i) work done

(ii) C.O.P.

Q9. In a refrigerator working on Bell-Coleman cycle, the air is drawn into the cylinder of the compressor from the cold chamber at a pressure of 1 bar and temperature 05^{0}C. After isentropic compression to 5 bar, the air is cooled at constant pressure to a temperature of 25^{0}C. The polytropic expansion $pv^{1.2}$=C, then follows and the air expanded to 1bar is passed to cold chamber. (γ= 1.4, Cp= 1kJ/kgK)Determine: work done.

Q10 A Vapour compression refrigerator works between the pressure limits of 60 bar and 25 bar. The working fluid is just dry at the end of compression and there is no under cooling of he fluid before the expansion. Determine the C.O.P of the cycle and capacity of refrigerator if the fluid flow rate of 5 kg/min.

Pressure(bar)	Temperature(K)	Enthalpy(kj/kg)		Entropy(kj/kgk)	
		Liquid	Vapour	Liquid	Vapour
60	295	151.96	293.29	0.554	1.0332
25	261	56.32	322.58	0.226	1.2464

UNIT 2

Q11.A refrigeration machine requires to produce ice at 0 C from water at 20 C. The machine has a condenser temperature of 298 K while the evaporator temperature is 268 K. The relative efficiency of the machine is 50% and 6 kg of Freon-12 refrigerant is circulated through the system per minute. The refrigerant enters the compressor with the dryness fraction of 0.6 specific heat of water is 4.187 KJ/Kg K and the latent heat of ice is 335 KJ/Kg. Calculate the amount of ice produced in 24 hours. The table of properties of Freon-12 is given below

Temperature (K)	Liquid Heat (KJ/Kg)	Latent Heat (KJ/Kg)	Entropy Of Liquid (KJ/Kg K)
298	59.7	138.0	0.2232
268	31.4	154.0	0.1251

Q12.A simple air cooled system is used for an aeroplane having a load of 10 tonnes. The atmospheric pressure and temperature are 0.9 bar and 10^0C respectively. The pressure increase to 1.013 bar due to ramming. The temperature of the air is reduced by 50^0C in the heat exchanger. The pressure in the cabin is 1.01 bar and the temperature of air leavingthe cabin is 25^0C. Determine power required and C.O.P of system. Assume expansion and compression are isentropic. The pressure of compressed air is 3.5 bar.

Q13. In an aircraft a bootstrap refrigeration system is used to take 18 tonnes of refrigeration load. The ambient conditions are -50^0C and .225 bars. The pressure ratio of the main compressor is 3.5 and required air for refrigeration is bled-off from the main compressor. The air taken from the main compressor is further compressed in secondary compressor which is run by cooling air turbine. The output of the cooling air turbine is just sufficient to run the secondary turbine. The refrigerating air coming out from secondary compressor is cooled by ram air to 50^0C. The air pressure coming out of cooling turbine and supplied to the cabin is 1 bar. The temperature maintained in the cabin is 25^0C.

$\eta ram=\eta c1=\eta c2=90\%$, $\eta t=80\%$,

When aircraft is moving with a speed of 1000km/h, determine:

(i) Delivery pressure of secondary compressure, (ii) COP

Q14. Explain the bootstrap regenerative cycle with neat diagram.

Q15. Q. Find the C.O.P for a refrigerator working between the temperature range of 25^0 C and -5^0C. The dryness fraction during the suction stroke is 0.6. Following properties are given:

Temperature(K)	Enthalpy(kj/kg)		Entropy(kj/kg)		Latent heat(kj/kg)
	Liquid	Vapour	Liquid	Vapour	
298	164.77	282.23	0.5978	0.9918	117.46
268	72.57	321.33	0.2862	1.2146	248.76

Q16. Explain the working of simple air cycle cooling system used for aircrafts.

Q17. A refrigeration machine requires to produce ice at 0 C from water at 20 C. The machine has a condenser temperature of 298 K while the evaporator temperature is 268 K. The relative efficiency of the machine is 50% and 6 kg of Freon-12 refrigerant is circulated through the system per minute. The refrigerant enters the compressor with the dryness fraction of 0.6 specific heat of water is 4.187 KJ/Kg K and the latent heat of ice is 335 KJ/Kg. Calculate the amount of ice produced in 24 hours. The table of properties of Freon-12 is given below

Temperature (K)	Liquid Heat (KJ/Kg)	Latent Heat (KJ/Kg)	Entropy Of Liquid (KJ/Kg K)

298	59.7	138.0	0.2232
268	31.4	154.0	0.1251

Q18. Explain the cascade system with neat diagram.

Q 19. State merits and demerits of an air refrigeration system.

Q 20. Explain the different types of compressor

UNIT 3

Q21. State the advantages of vapour absorption refrigeration system over vapour compression system.

Q22. Explain the Electrolux refrigeration absorption system with neat diagram.

Q23. Enumerate the desirable properties of an ideal refrigerant.

Q24. Explain the Lithium Bromide absorption system with neat diagram.

Q25. How are refrigerants designated?

Q26. Name three refrigerants that are commonly used in commercial refrigerators. Discuss their relative merits and demerits.

Q27. What is a secondary refrigerant? Where is it used?

Q28. Give the main types of condensers in use with specific application of each type.

Q29. Explain the different types of evaporators.

Q30. Explain briefly about the thermostatic valve and capillary tube.

UNIT 4

Q.31 What is an effective temperature? Explain briefly Effective temperature chart and comfort chart.

Q32. Air at 12^{0}C DBT and 70%RH is to be heated and humidified to 36.5^{0}C DBT and 21^{0}C WBT. The air is preheated sensibly before passing to the washer in which water is circulated. The relative humidity of the air coming out of the air washer is 70%.This air is again reheated sensibly to obtain the final desired condition. Determine:

(i) Total heating required
(ii) Make up water required in the air washer.

Q33. 120m^3 of air per minute at 35^{0}C DBT and 50% RH is cooled to 20^{0}C DBT by passing through a cooling coil. Determine the following

(i) WBT and RH of out coming air

(ii) Capacity of cooling coil in tones.

Q34. Describe briefly the following processes:

(i) Cooling and dehumidification (ii) Heating and humidification
(ii) Heating and dehumidification

Q35. Write a short note on by pass factor.

Q36. State and explain factors which govern optimum effective temperature.

Q37. How are air conditioning systems classified?

Q38. What is effective room sensible heat factor?

Q39. Explain briefly air washers and radiators.

UNIT 5

Q40. Write a short note on thermodynamics of a human body.

Q41. State the advantages of central system over unitary system of air conditioning.

Q42. Explain the difference between summer air conditioning and winter air conditioning.

Q43. Enumerate and explain the components of cooling load estimate.

Q44. What is the function of a filter? How are filters classified?

Q45. It is required to design a cold storage for storing 450 tonnes of vegetables with the following available data:

Inside design conditions……………………………………….19^{o}C DBT,60% RH

Outdoor conditions ……………………………………36^o C DBT, 28^O C WBT

Infiltrated air ……………………………………………………180 m^3 /h

Fresh air supplied from outside………………………………..4500 m^3 /h

No. of persons working in the cold storage … ………….20

Sensible heat gain through glass………………………………….5.5 k w

Sensible heat gain through walls and ceilings……………………10.8 k w

Water contents of vegetables…………………………………….74%

Loss Water contents……………………………………..0.01 per cent per hour

Heat from equipment and reaction heat of vegetables …………3.1 kw

If the air –conditioning is achieved by first cooling and dehumidifying and then heating . and the temperature of air entering the room is not to exceed 16^{o} C, determine.

(i) Amount of re circulated air, if the re circulated air is mixed with fresh air before entering the cooling coil ;
(ii) Capacity of the cooling coil in tonnes of refrigeration and its by-pass factor if dew point temperature of the heating coil in kw
(iii) Capacity of the heating coil in kw

Q46. The following data is available for designing an air –conditioning system for a restaurant:

Inside design conditions…………………………………….26^{o}C dDBT,60% RH

Outdoor conditions ……………………………….….36^{o} C DBT, 27^{O} C WBT

Minimum temperature of air supplied…………………………..1550 m^3 /h

Total infiltrationair……………………………………………..390 m^3 /h

Seating chairs for dining…………………………………………………45

Employees serving the meals…………………………………………..5

Sensible heat gain per person---60kw

Latent heat gain per sitting person---45kw

Latent heat gain per employee---75kw

Sensible heat added from meal--0.16kw

Sensible heat added from meal--0.16kw

Latent heat added from meal---0.28kw

Total heat flow through walls, roof and floor----------------------------5.9kw

Solar heat gain through glass--1.9kw

Equipment sensible heat gain---2.75kw

Equipment latent heat gain---0.65kw

Motor power connected to fan--7.5kw

If the fan is installed before the conditioner, determine:

(i) Amount of air delivered
(ii) Percentage of recirculated air
(iii) Load on coil in tonnes
(iv) DPT and by-pass factor

Q47. Air flowing at the rate of 100m^3/min at 40^{0}C DBT and 50% RH is mixed with another stream at the rate of 20m^3/min at 26o C DBT and 50% RH . The mixture flows over a cooling coil whose ADP temperature is 10^0 C and bypass factor is 0.2. Find DBT and RH of air coil.

Q48. Air flowing at the rate of 100m^3/min at 30^{0}C DBT and 60% RH is mixed with another stream at the rate of 20m^3/min at 20^o C DBT and 60% RH. The mixture flows over a cooling coil whose ADP temperature is 10^0 C and bypass factor is 0.2. Find DBT and RH of air coil. If this air is supplied to an air conditioned room where DBT of 26^0 and RH of 60% are maintained, estimate room sensible heat factor and cooling load capacity of the coil in tones.

Q49. The A.C. plant supplies a total of 4500 m^3/ min of dry air which comprises by weight 20% fresh air at 40^{0}C DBT and 27^0 C WBT and 80% re circulated air at 25^0 C DBT and 50% RH. The air leaves the cooling coil at 13^0 C saturated states. Calculate cooling and room heat gain.

Q50. Describe briefly with neat sketch a window type air conditioner.