# ME8595 THERMAL ENGINEERING – II L T P C 3 0 0 3

**OBJECTIVES:**

To apply the thermodynamic concepts for Nozzles, Boilers, Turbines, and Ref. & Air conditioning systems.

To understand the concept of utilizing residual heat in thermal systems.

[UNIT I STEAM NOZZLE 9](#_TOC_250000)

Types and Shapes of nozzles, Flow of steam through nozzles, Critical pressure ratio, Variation of mass flow rate with pressure ratio. Effect of friction. Metastable flow.

UNIT II BOILERS 9

Types and comparison. Mountings and Accessories. Fuels - Solid, Liquid and Gas. Performance calculations, Boiler trial.

UNIT III STEAM TURBINES 9

Types, Impulse and reaction principles, Velocity diagrams, Work done and efficiency – optimal operating conditions. Multi-staging, compounding and governing.

UNIT IV COGENERATION AND RESIDUAL HEAT RECOVERY 9

Cogeneration Principles, Cycle Analysis, Applications, Source and utilization of residual heat. Heat pipes, Heat pumps, Recuperative and Regenerative heat exchangers. Economic Aspects.

UNIT V REFRIGERATION AND AIR – CONDITIONING 9

Vapour compression refrigeration cycle, Effect of Superheat and Sub-cooling, Performance calculations, Working principle of air cycle, vapour absorption system, and Thermoelectric refrigeration. Air conditioning systems, concept of RSHF, GSHF and ESHF, Cooling load calculations. Cooling towers – concept and types.

# TOTAL: 45 PERIODS

**TEXT BOOKS:**

1. Kothandaraman, C.P., Domkundwar .S and Domkundwar A.V.,”A course in

Thermal Engineering”, Dhanpat Rai & Sons, 2016.

1. Mahesh. M. Rathore, “Thermal Engineering”, 1st Edition, Tata Mc Graw Hill

Publications, 2010.

# REFERENCES:

1.Arora .C.P., “Refrigeration and Air Conditioning”, Tata Mc Graw Hill, 2008 2.Ballaney. P.L ." Thermal Engineering”, Khanna publishers, 24th Edition 2012 3.Charles H Butler : Cogeneration” McGraw Hill, 1984.

1. Donald Q. Kern, “ Process Heat Transfer”, Tata Mc Graw Hill, 2001.
2. Sydney Reiter “Industrial and Commercial Heat Recovery Systems” Van Nostrand

Reinhols, 1985.

# COURSE OUTCOMES (COs)

|  |  |
| --- | --- |
| **C301.1** | Ability to solve problems in steam nozzles |
| **C301.2** | Ability to explain the functioning and features of different types of boilers and  auxiliaries and to calculate performance parameters |
| **C301.3** | Ability to explain the flow in steam turbines, draw velocity diagrams for steam  turbines and solve problems. |
| **C301.4** | Ability to summarize the concept of cogeneration, working features of heat  pumps and heat exchangers |
| **C301.5** | Ability to solve problems using refrigerant table/charts and psychrometric  charts |

**MAPPING BETWEEN COs, POs AND PSOs**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **COs** | **PROGRAMME OUTCOMES (POs)** | | | | | | | | | | | | **PSOs** | | |
| **PO1** | **PO2** | **PO3** | **PO4** | **PO5** | **PO6** | **PO7** | **PO8** | **PO9** | **PO10** | **PO11** | **PO12** | **PSO1** | **PSO2** | **PSO3** |
| **C301.1** | 3 | 2 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 3 | 0 | 1 |
| **C301.2** | 2 | 2 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 2 | 0 | 1 |
| **C301.3** | 2 | 2 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 2 | 0 | 1 |
| **C301.4** | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 1 | 1 | 1 | 0 | 2 | 2 | 0 | 2 |
| **C301.5** | 2 | 2 | 2 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 0 | 2 | 2 | 0 | 2 |

# RELATION BETWEEN COURSE CONTENTS WITH COs UNIT I STEAM NOZZLE

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl.**  **No.** | **Knowledge level** | **Contents** | **COs** |
| 1 | R/U | Types and shapes of nozzles | **C301.1** |
| 2 | Ap/E/R/U | Flow of steam through nozzles | **C301.1** |
| 3 | Ap/An/E/R/U | Variation of mass flow rate with pressure  ratio, Critical pressure ratio | **C301.1** |
| 4 | Ap/An/E/R/U | Effect of friction | **C301.1** |
| 5 | Ap/An/E/R/U | Metastable flow | **C301.1** |

**UNIT II BOILERS**

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| --- | --- | --- | --- |
| **Sl.**  **No.** | **Knowledge level** | **Contents** | **COs** |
| 1 | R/U | Types and comparison of boilers | **C301.2** |
| 2 | R/U | Mountings and accessories | **C301.2** |
| 3 | Ap/An/E/R/U | Fuels - Solid, liquid and gas. | **C301.2** |
| 4 | Ap/An/E/R/U | Performance calculations of boilers | **C301.2** |
| 5 | Ap/R/U | Boiler trial | **C301.2** |

# UNIT III STEAM TURBINES

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| --- | --- | --- | --- |
| **Sl.**  **No.** | **Knowledge level** | **Contents** | **COs** |
| 1 | Ap/An/E/R/U | Types of steam turbines, impulse and reaction  principles, velocity diagrams | **C301.3** |
| 2 | Ap/An/E/R/U | Work done and efficiency – Optimal operating  conditions | **C301.3** |
| 3 | Ap/An/E/R/U | Multi-staging of steam turbines | **C301.3** |
| 4 | Ap/R/U | Compounding of steam turbines | **C301.3** |
| 5 | Ap/R/U | Governing of steam turbines | **C301.3** |

**UNIT IV COGENERATION AND RESIDUAL HEAT REVOVERY**

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| --- | --- | --- | --- |
| **Sl.**  **No.** | **Knowledge level** | **Contents** | **COs** |
| 1 | Ap/An/E/R/U | Cogeneration principles, cycle analysis,  applications | **C301.4** |
| 2 | Ap/An/E/R/U | Source and utilisation of residual heat | **C301.4** |
| 3 | Ap/R/U | Heat pipes and heat pumps | **C301.4** |
| 4 | Ap/R/U | Recuperative and regenerative heat exchangers | **C301.4** |
| 5 | Ap/R/U | Economic Aspects | **C301.4** |

# UNIT V REFRIGERATION AND AIR-CONDITIONING

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl.**  **No.** | **Knowledge level** | **Contents** | **COs** |
| 1 | Ap/An/E/R/U | Vapour compression refrigeration cycle, effect  of superheat and sub-cooling, performance calculations, working principle of air cycle | **C301.5** |
| 2 | Ap/R/U | Vapour absorption system | **C301.5** |
| 3 | Ap/C/R/U | Thermoelectric refrigeration | **C301.5** |
| 4 | Ap/An/E/R/U | Air conditioning systems, concept of RSHF,  GSHF and ESHF, cooling load calculations. | **C301.5** |
| 5 | Ap/An/E/R/U | Cooling towers – concept and types | **C301.5** |

**Ap – Apply An – Analyze C – Create**

# E – Evaluate R – Remember U – Understand

# UNIT-I STEAM NOZZLE

# PART-A (C301.1)

1. **What is steam nozzle?**

A steam nozzle is defined as a passage of varying cross section, through which heat energy of steam is converted to kinetic energy. Its major function is to produce steam jet with high velocity to drive steam turbines.

# Write about the function of nozzle

The major function of nozzle is to produce jet of steam or gas of high velocity to produce thrust for the propulsion of rocket motors and jet engines and drive steam or gas turbines.

# List the types of nozzle.

* 1. Convergent Nozzle, 2. Divergent Nozzle, 3. Convergent-Divergent Nozzle

# Define Convergent nozzle.

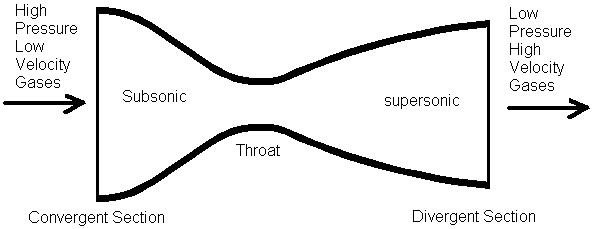
|  |  |
| --- | --- |
| In a convergent nozzle, the cross sectional area decreases continuously from its entrance to exit. It is used in a case where the back pressure is equal to or greater than the  critical pressure ratio |  |

1. **Define divergent nozzle.**

|  |  |
| --- | --- |
| The cross sectional area of divergent nozzle increases continuously from its entrance to exit. It is used in a case, where the back pressure is less than the critical pressure  ratio |  |

# Define Convergent-Divergent nozzle.

|  |  |
| --- | --- |
| In this case, the cross sectional area first decreases from its entrance to throat, and then increases from throat to exit.it is widely used in many type of steam turbines |  |

1. **Draw the shape of supersonic nozzle. [May 2016]**
2. **Define critical pressure ratio. Give its expression. [Nov 2017,Nov 2018,Jul 2021]** The critical pressure ratio is the pressure ratio which will accelerate the flow to a velocity equal to the local velocity of sound in the fluid. The maximum gas flow through a nozzle is determined by the critical pressure. The pressure at which the area is minimum and discharge per unit area is maximum is called critical pressure ratio.

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# Define nozzle efficiency or coefficient of nozzle [Dec 2013, Nov 2018]

The nozzle efficiency is therefore defined as the ratio of the actual enthalpy drop to the isentropic enthalpy drop between the same pressures. Nozzle efficiency = (actual enthalpy drop) / (isentropic enthalpy drop)

# List the effects of friction in nozzle. [May 2014, Dec 2015, May 2018]

In practice, there is friction produced between the steam and the sides of the nozzle; this friction causes a resistance to the flow which is converted into heat. The heat formed tends drying the steam. i) The expansion is no more isentropic and enthalpy drop is reduced ii) The final dryness fraction of steam is increased as the kinetic energy gets converted in to heat due to friction and is absorbed by steam. iii) The specific volume of steam is increased as the steam becomes more dry due to this frictional reheating.

# List the factors which influence nozzle efficiency.

When the steam flows through a nozzle the final velocity of steam for given pressure drop is reduced due to the following reasons

1. The friction between the nozzle surface and steam
2. The internal friction of steam itself
3. The shock losses.
4. **Define degree of undercooling and degree of super saturation. [Jul 2021]** The difference of supersaturated temperature and saturation temperature at that pressure is known as degree of under cooling.

The ratio of super saturation pressures corresponding to the temperature between super saturated region is known as the degree of super saturation.

# Define coefficient of velocity in nozzle. [Dec 2014]

The ratio of the actual velocity of gas emerging from a nozzle to the velocity calculated under ideal conditions; it is less than 1 because of friction losses.

# Define coefficient of Discharge.

The ratio of the actual discharge to maximum discharge is known as coefficient of discharge.

# What is meant by carry over loss?

The velocity of steam at exit is sufficiently high thereby resulting in a kinetic energy loss called Carry over loss or Leading velocity loss.

# If the enthalpy drop in a stem nozzle of efficiency 92% is 100 kJ/kg determine

**the exit velocity of steam. [May2017]**

C2 = √η(∆h) C2 = √0.92 × 10 0 𝑪𝟐 = 𝟗. 𝟓𝟗 𝒎/𝒔



# Write the equation of maximum discharge through a nozzle.

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p1 2n

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mmax = A

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# Mention the values of maximum discharge for various steam.

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| --- | --- | --- | --- |
| **Types of Steam** | **Index number** | **Maximum**  **Discharge** | **Critical**  **Pressure ratio** |
| Dry saturated | n=1.135 | p1  mmax = 0.637 A√v  1 | p2 = 0.577  p1 |
| Superheated | n=1.3 | p1  mmax = 0.666 A√v  1 | p2 = 0.546  p1 |
| Gas | n=1.4 | p1  mmax = 0.685 A√v  1 | p2 = 0.582  p1 |
| Wet steam | n= |  |  |

1. **What is meant by metastable flow?**

Equilibrium between the liquid and vapour phase is delayed and the steam Continues to expand in a dry state. The steam in such a set of conditions is said to be supersaturated or in metastable state as its temperature at any pressure is less than the saturation temperature corresponding to the pressure. The flow of supersaturated steam, through the nozzle is called supersaturated flow or metastable flow.

# What are the effects of super saturation or supersaturated flow? [Nov 2016]

* There is an increase in the entropy and specific volume of steam
* The heat drop is reduced below that for thermal equilibrium as an consequence the exit velocity is reduced.
* The density of supersaturated steam will be more than for the equilibrium conditions which gives the increase in the mass of steam discharged.
* The dryness fraction of steam is improved.

# Differentiate supersaturated flow and isentropic flow.

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| **S.No** | **Supersaturated flow** | **Isentropic flow** |
| **1** | Entropy is not constant | Entropy remains constant |
| **2** | Super saturation reduces the heat drop  therefore exit velocity is reduced | No reduction in enthalpy drop. |
| **3** | Mollier diagram cannot be used | Mollier diagram can be used. |

1. **What is meant by steam injector?**

A steam injector is a device employed to force water in to the boiler under pressure.

# List the applications of steam nozzle

1. To rotate steam turbine
2. Thermal power plant
3. To produce a very fine jet spray
4. It is also used for cleaning purpose.

# PART – B (C301.1)

1. Derive the condition for maximum flow rate in steam nozzle. **[May 2018]**
2. Define critical pressure ratio of a nozzle and discuss why attainment of sonic velocity. Also determines the maximum discharge through steam nozzle.
3. Derive the equation for critical pressure ratio. **[Nov 2017]**
4. Derive the following expression for nozzle flow: 𝑑𝐴 = 1 𝑑𝑝 [1−𝑀2] where the

𝐴 𝛾 𝑝

𝑀2

symbols are having usual meanings. **[Jul 2021]**

1. In a steam nozzle, the steam expands from 4 bar to 1 bar. The initial velocity is 60m/s and initial temperature is 200ºC. Determine the exit velocity if nozzle efficiency is 92%. **[Nov/Dec 2018]**
2. Steam expands isentropically in a nozzle from 1 MPa, 250º C to 10 KPa. The flow

rate of the steam is 1 kg/s. Find the following when the inlet velocity is neglected, (i) Quality of steam, (ii) Velocity of steam at the exit of the nozzle, (iii) Exit area of the nozzle. **[Dec 2013]**

1. The flow rate through steam nozzle with isentropic flow from pressure of 13 bar

was found 60 kg/min. steam is initially saturated. Determine the throat area. If the flow is super saturated, determine the increase in flow rate. **[May 2014]**

1. Dry saturated steam at a pressure of 11 bar enters a convergent-divergent nozzle and leaving at a pressure of 2 bar. If the flow is adiabatic and frictionless, determine i) the exit velocity of a steam, ii) Ratio of cross section of exit and that at throat. Assume the index of adiabatic expansion to be 1.135 **[May2015,Jul2021]**
2. Steam at a pressure of 10.5 bar and 0.95 dry is expanded through a CD nozzle.

The pressure of steam leaving the nozzle is 0.85 bar. Find the velocity of steam at throat for maximum discharge. Take n=1.35. Also find the area at the exit and steam discharge if the throat area is 1.2square cm. Assume the flow is isentropic and there are no friction losses**. [Dec 2014]**

1. (a) What are the effects of friction in a nozzle? Explain
2. (b) A convergent-divergent nozzle is required to discharge 2 kg/s of steam. The nozzle is supplied with steam at 7 bar and 180⁰C and discharge takes place against a back pressure of 1 bar. The expansion upto the throat is isentropic and the frictional resistance between the throat and the exit is equivalent to 63 kJ/kg of steam. Taking approach velocity of 75m/s and throat pressure of 4 bar estimate suitable areas for throat and exit and overall of the nozzle based on the enthalpy drop between the actual inlet pressure and temperature and the exit pressure. **[May 2013]**
3. In a test on a steam nozzle, the issuing steam jet impinges on a stationary flat

plate which is perpendicular to the direction of flow and the force on the plate is measured. With convergent-divergent nozzle supplied with steam at 10 bar dry saturated and discharging at 1 bar; the force is experimentally measured to be 600N. The area of the nozzle at throat measures 5 cm2 and that exit area is such that complete expansion is achieved under these conditions. Determine: (i) flow

rate of the steam, and (ii) the efficiency of the nozzle assuming that all losses occur after the throat. Assume n = 1.135 for isentropic expansion. **[May 2017]**

1. The dry and saturated steam at a pressure of 10.5 bar is expanded isentropically in a nozzle to a pressure of 0.7 bar. Determine the final velocity of the steam issuing from the nozzle, when (a) friction is neglected, and (h) 10% of the heat drop is lost in friction. The initial velocity of steam may be neglected.
2. Gases expand in a convergent divergent nozzle from 3.6 bar and 425° C to aback pressure of I bar, at the rate of 18kg/s. If the nozzle efficiency is 0.92, calculate the required throat and exit areas of the nozzle. Neglect inlet velocity and friction in the convergent part. For the gases, take Cp = 1.113 kJ/kg K and γ= 1.33
3. Dry saturated steam at 2.8bar is expanded through a convergent nozzle to 1.7 bar. The exit area is 3cm3. Calculate the exit velocity and mass flow rate for, (i) Isentropic expansion, (ii) Super saturated flow. **[Nov/Dec 2018]**
4. Explain the supersaturated or metastable flow of steam through nozzle and the

significance of Wilson’s line. **[May 2016]**

1. What are the effects of super saturation on discharge and heat drop?
2. The dry saturated steam is expanded in a nozzle from pressure of 10 bar to a pressure of 5 bar if she expansion is supersaturated, find: 1. the degree of undercooling and 2. the degree of supersaruration.

# PART – C (C301.1)

1. Dry saturated steam at a pressure of 8bar enters a convergent divergent nozzle and leaves it at a pressure of 1.5bar. If the flow is isentropic and if the corresponding expansion index is 1.133, find the ratio of cross-sectional area at exit and throat for maximum discharge. **[AU Nov/Dec 2015]**
2. Steam turbine develops 185 kW with a consumption of 16.5 kg/kW/h. The

pressure and temperature of the steam entering the nozzle are 12 bar and 220º C. The steam leaves the nozzle at 1.2 bar. The diameter of the nozzle at throat is 7mm, Find the number of nozzles. If 8% of the total enthalpy drop is lost in friction in the diverging part of the nozzle, determine the diameter at the exit of the nozzle and the exit velocity of the leaving steam. Sketch the skeleton Mollier diagram and show on it the values of pressure, temperature or dryness fraction, enthalpy and specific volume at inlet, throat and exit. **[Nov/Dec 2018]**

1. Calculate the throat and exit diameters of a convergent divergent nozzle which

will discharge 820kg of steam per hour from a pressure of 8bar superheated to 220⁰ C into a chamber having a pressure of 1.5bar. The friction loss in the divergent part of the nozzle maybe taken as 0.15 of the total enthalpy drop.

1. State the relation between the velocity of steam and heat during any part of a steam nozzle.
2. Find the percentage increase in discharge from a convergent-divergent nozzle expanding steam from 8.75 bar dry to 2 bar. when; 1. the expansion is taking place under thermal equilibrium, and 2. the steam is in metastable state during pan of its expansion. Take area of nozzle as 2500 mm2

# Define Boiler?

**UNIT – II BOILERS PART – A (C301.2)**

Boiler is defined as a closed vessel in which steam is produced from water by combustion of fuel.

# What are the primary requirements of steam generators or boilers?

* + The water must be contained safely
  + The steam must be safely delivered in desired condition (pressure, temperature, quality and required rate).

# List the purpose of boiler

* For generating power in steam engines or steam turbines.
* Industries like sugar mills, cement factory, chemical industries
* For heating the buildings and producing hot waters.

# Classify the boilers?

1. **According to flow medium inside the tubes:** Fire tube and Water tube.
2. **According to boiler pressure:** Low, Medium and High pressure
3. **According to draft used:** natural and artificial draft
4. **According to method of water circulation :** natural and force circulation
5. **According to furnace position:** Internally fired and externally fired
6. **According to number of tubes:** Single tube and multi tube boiler (vii)**According to mobility:** Stationary, portable, Marine boilers.

# Explain fire tube boiler.

Fire tube or “fire in tube” boilers; contain long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates. Fire tube boilers, typically have a lower initial cost, are more fuel efficient and easier to operate, but they are limited generally to capacities of 25 tons/hr and pressures of 17.5 kg/cm2.

# Explain water tube boiler.

Water tube or “water in tube” boilers in which the conditions are reversed with the water passing through the tubes and the hot gasses passing outside the tubes. These boilers can be of single- or multiple-drum type. These boilers can be built to any steam capacities and pressures, and have higher efficiencies than fire tube boilers.

# Explain Packaged Boiler.

The packaged boiler is so called because it comes as a complete package. Once delivered to site, it requires only the steam, water pipe work, fuel supply and electrical connections to be made for it to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection.

# What are the two main classification of a stoker fired boiler?

Chain grate or travelling grate stoker Spreader stoker

# What do you meant by tangential firing with respect to pulverized coal fired

**boiler?**

The method of firing used for coal firing in pulverized fuel fired boiler is the tangential firing. In this type of firing four burners are used at the corner to corner to create a fire ball at the center of the furnace.

# What are the main advantages of FBC over conventional firing?

Fluidised bed combustion has significant advantages over conventional firing systems and offers multiple benefits – namely fuel flexibility, reduced emission of noxious pollutants such as SOx and NOx, compact boiler design and higher combustion efficiency

# What are the parameters which affect the performance of the heat transfer in

**FBC?**

i) Bed temperature ,ii) Bed pressure ,iii) Superficial gas velocity ,iv) particle size

v) Heat exchanger design, and vi) Gas distributor plate design

# Define ‘fluidizing velocity’ for an FBC boiler?

The velocity required to make the particles in suspension in the air stream in a Fluidized Bed combustor is called fluidizing velocity.

# In a FBC boiler, when is the bed said to be fluidized state?

The bed of solid particles in a FBC exhibits the properties of a boiling liquid and assumes the appearance of a fluid. In this state the bed is said to be fluidized.

# List the three types of FBC boilers?

Atmospheric classic Fluidised Bed Combustion System (AFBC) Atmospheric circulating (fast) Fluidised Bed Combustion system(CFBC) Pressurised Fluidised Bed Combustion System (PFBC).

# What is the principle of CFBC (circulating fluidized bed combustion) boiler?

CFBC technology utilizes the fluidized bed principle in which crushed (6 –12 mm size) fuel and limestone are injected into the furnace or combustor. The particles are suspended in a stream of upwardly flowing air (60-70% of the total air), which enters the bottom of the furnace through air distribution nozzles. The balance of combustion air is admitted above the bottom of the furnace as

secondary air. While combustion takes place at 840-900oC, the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4-6 m/s. The particles are then collected by the solids separators and circulated back into the furnace. This combustion process is called circulating fluidized bed (CFB).

# List some of the features of bubbling bed boiler?

1. Distribution plate through which air is blown for fluidizing.
2. Immersed steam-raising or water heating tubes which extract heat directly from the bed.
3. Tubes above the bed which extract heat from hot combustion gas before it enters the flue duct.

# List the advantages of CFBC boilers over AFBC boilers.

* + Higher processing temperature because of high gas velocity through the system.
  + Lower combustion temperature of about 870 oC can be achieved constantly, which results in minimal NOx formation.
  + The combustion air is supplied at 1.5 to 2 psig rather than 3 to 5 psig as required by bubbling bed combustors.
  + Higher combustion efficiency.
  + Better turndown ratio.

# What is a high pressure boiler? Give two examples?

The boilers which produce steam at pressure of 80 bar and above are known as high pressure boiler. Examples: Lamont, Loeffler and Benson boilers.

# Name some high pressure boiler?

Lamont, Loeffler and Benson boilers

# What is supercritical boiler and list the advantages.

The steam generator or boiler designed between the working ranges of 125atm and 510oC to 300atm and 660oC is called super critical boiler.

Advantages: Large heat transfer rate, problems of corrosion and erosion are minimized, more adoptable to load fluctuations, high thermal efficiency.

# What are the advantages of high pressure boilers?

* + Less number of steam drums will be required
  + Less floor space is required
  + Use of high pressure and high temperature is economical
  + The tendency of scale formation is eliminated due to high velocity of water through tubes
  + The efficiency of the plant is increased

# Compare Fire tube boiler and water tube boiler. [Jul 2021]

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| **S.**  **No** | **Water Tube boiler** | **Fire Tube boiler** |
| 1 | Water is inside the tube and flue  gases surrounded to it. | Flue gases inside the tube and water  surrounded to it. |
| 2 | Operating pressure is up to 170-  180 bar (high pressure boilers). | Operating pressure is up to 25 bar  (low and medium pressure boilers). |
| 3 | Steam generation rate is very  high (more than 3000 kg/hr) | Less steam generation rate. |
| 4 | Suitable for power plants | Suitable for small industries |
| 5 | Example: Babcock and Wilcox  boiler | Example: Vertical boiler, locomotive  boiler, Lancashire boiler. |

1. **What do you mean by scale formation in boilers?**

A deposit of medium to extreme hardness occurring on water heating surfaces of a boiler because of an undesirable condition in the boiler water.

# Factors affecting selection of boiler

1. Size of drum (ii) Rate of heat generation (iii) Working pressure (iv) Type of boiler (v) Initial cost and (vi) Quality of steam

# Mention any four boiler mountings?

|  |  |
| --- | --- |
| * Water gauge * Pressure gauge * Safety valves * Fusible plug | * Feed check valve * Stop valve * Blow off cock |

1. **What is the purpose of a fusible plug in a boiler?**

Fusible plug is used to protect the fire tubes from getting burnt or melted when the water level in the boiler falls below the designated level.

# What is the use of blow off cock in Boilers?

**[May2017]**

The function of blow-off cock is to discharge mud and other sediments deposited in the bottom most part of the water space in the boiler, while boiler is in operation. It can also be used to drain-off boiler water

# What is the function of pressure relief valve?

The pressure is relieved by allowing the pressurized fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect [pressure vessels](http://en.wikipedia.org/wiki/Pressure_vessel) and other equipment from being subjected to pressures that exceed their design limits.

# What is the function of safety valve?

It is a mechanical device used to safe guard the boiler, in case the pressure inside the boiler rises above its normal working pressure.

# What is meant by Economiser? What are the types of Economiser?

An economizer is a device in which the waste heat of the flue gases is utilized for heating the feed water. Two types of economizer are (i) Independent type and

1. Integral type.

# State the function of Steam trap

The function of a steam trap is to drain away automatically the condensed steam from the steam pipe, steam jackets, and steam separators without permitting any steam to escape.

# Why boiler blow-down is required?

As the feed water evaporate into steam, dissolved solids concentrate in the boiler. Above certain level of concentration, these solids encourage carryover of water into steam. This leads to scale formation inside the boiler, resulting in localised overheating and ending finally in tube failure. Hence blow-down is very much required for boilers.

# What is the difference between boiler mountings and accessories? [Jul 2021]

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| --- | --- |
| **Boiler Mountings** | **Boiler Accessories** |
| The necessary devices installed or mounted for the safety of boiler and its control are called  boiler mountings. | The devices which are installed in the boiler for their efficient operation and smooth working are called boiler  accessories. |
| 1. Water level indicator. 2. Safety valves. 3. Fusible plug. 4.Pressure gauge | 1. Water heating devices. 2. Water feeding devices. 3. Super heater 4. Economizer |

1. **Difference between forced draught and induced draught?**

|  |  |  |
| --- | --- | --- |
| **S.**  **No** | **Forced draught** | **Induced draught** |
| 1 | A fan installed at the base of  boiler | A fan installed at the base of  chimney |
| 2 | It is positive pressure draught | It is negative pressure draught |
| 3 | Sealing is required at enclosure  of furnace | Sealing is not required at  enclosure of furnace. |

# What are the advantages of Mechanical Draught?

* Easy control of combustion and evaporation
* Reduced chimney height
* Prevention of smoke
* Improvement in the efficiency of the plant
* Capability of consuming low grade fuel.

# Define dryness fraction of steam

The dryness fraction of steam is the ratio of mass of actual dry saturated steam to the known quantities of of total mass of wet steam.

Dryness fraction (x) = Mass of dry saturated steam in given steam / Total mass of given wet steam.

# Give examples of Solid fuel, liquid fuel and gaseous fuel.

**Solid fuels:** Wood, coal, peat and coke.

**Liquid fuels:** Petrol, paraffin, Diesel oil and heavy fuel oil

**Gaseous fuels:** Natural gas, coal gas, coke oven gas and producer gas.

# What is calorific value of fuels?

It is defined as the amount of heat given out by the complete combustion of 1 kg of fuel. It is expressed in terms kJ/kg of fuel.

# What is the effect of Sulphur in coal when used in boiler?

Sulphur will get oxidised to SO2 and fraction of SO3 and will react with water to form sulphuric acid and this occurs at a temperature called the acid dew point which normally is about 120ºC. The sulphuric acid so formed corrodes the steel when it comes in contact with it.

# How the boiler efficiency is calculated?

For a steam generating unit, efficiency is defined as the ratio of heat absorbed by the boiler fluid to the fuel fired.

Heat absorbed by boiler fluid

𝜂𝐵𝑜𝑖𝑙𝑒𝑟 =

× 100

Fuel fired (or) fuel supplied

# What is the effect of boiler loading on boiler efficiency?

* + The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load. If the load on the boiler decreases further, efficiency also tends to decrease.
  + As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area, reduced the exit flue gas temperatures by a small extent, reducing the sensible heat loss.
  + Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss.

# Indicate the different methods of efficiency evaluation of Boiler.

The Direct Method, The Indirect Method

# Explain direct method of efficiency evaluation of Boiler.

This is also known as ‘input-output method’ due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula

𝐁𝐨𝐢𝐥𝐞𝐫 𝐄𝐟𝐟𝐢𝐜𝐢𝐞𝐧𝐜𝐲 = 𝐇𝐞𝐚𝐭 𝐎𝐮𝐭𝐩𝐮𝐭 × 𝟏𝟎𝟎 or 𝐁𝐨𝐢𝐥𝐞𝐫 𝐄𝐟𝐟𝐢𝐜𝐢𝐞𝐧𝐜𝐲 = 𝑸 (𝑯−𝒉) × 𝟏𝟎𝟎

𝐇𝐞𝐚𝐭 𝐈𝐧𝐩𝐮𝐭 𝒒×𝑮𝑪𝑽

# What are the Parameters to be monitored for the calculation of boiler efficiency by direct method.

Quantity of steam generated per hour (Q) in kg/hr. Quantity of fuel used per hour (q) in kg/hr.

The working pressure (in kg/cm2(g)) and superheat temperature (°C), if any The temperature of feed water (°C)

Type of fuel and gross calorific value of the fuel (GCV) in kCal/kg of fuel

# List the advantages and dis-advantages of direct method. Advantages of direct method:

Plant people can evaluate quickly the efficiency of boilers Requires few parameters for computation

Needs few instruments for monitoring

# Disadvantages of direct method:

Does not give clues to the operator as to why efficiency of system is lower Does not calculate various losses accountable for various efficiency level

# What are the parameters required to estimate the boiler efficiency by ‘direct

**method’?** Steam flow rate GCV of fuel Fuel flow rate

Steam conditions ( pressure and temperature) ,Feed water temperature

# Explain indirect method of efficiency evaluation of Boiler

Indirect method is also called as heat loss method. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The standards do not include blow down loss in the efficiency determination process.

# What are the principle heat losses that occur in a boiler?

* + The principle heat losses that occur in a boiler are:
  + Loss of heat due to dry flue gas
  + Loss of heat due to moisture in fuel and combustion air
  + Loss of heat due to combustion of hydrogen
  + Loss of heat due to radiation
  + Loss of heat due to unburnt fuel

# What are the main losses which are not accounted in an indirect method of boiler efficiency testing?

Standby losses Blow down loss Soot blower steam

Auxiliary equipment energy consumption

# What are the disadvantages of ‘direct method’ of boiler efficiency evaluation over ‘indirect method’?

1. Do not give clues to the operator as to why efficiency of system is lower
2. Do not calculate various losses accountable for various efficiency levels

# Define evaporation ratio.

Evaporation ratio is the ratio of quantity of steam generation to the quantity of fuel consumption.

Evaporation =

Quantity of steam generation

Quantity of fuel consumption

# State two causes for rise in exit flue gas temperature in a boiler

The rise in exist flue gas temperature in a boiler can be due to

1. Scale deposit inside the boiler tubes
2. Soot deposit on the outer surface of the boiler tube

# List out any four loss components in a heat balance of a boiler.

1. Dry flue gas loss
2. Surface heat loss
3. Loss due to incomplete combustion
4. Loss due to hydrogen in fuel

# Factors Affecting Boiler Performance

Excess air control Percentage loading of boiler

Steam generation pressure and temperature Boiler insulation

Quality of fuel

# What is the principle of mechanical deaeration (pressure type) of boiler feed

**water?**

The pressure-type de-aerators operates by allowing steam into the feed water through a pressure control valve to maintain the desired operating pressure, and hence temperature at a minimum of 105 °C. The steam raises the water temperature causing the release of O2 and CO2 gases that are then vented from the system. This type can reduce the oxygen content to 0.005 mg/litre.

# What is meant by boiler trial?

Boiler trial is the account of total heat coming to the boiler and leaving from the boiler. Actually the purpose of trail is to perform a test of all the equipment and to collect information of the flue gases coming out of the plant. This helps in further smooth running of the plant and to get an estimate of the power consumed by equipment.

# PART – B (C301.2)

1. how are boilers classified ? Explain the unique features of the high pressure boilers. **[Jul 2021]**
2. Explain the following boiler terms: Shell, grate, furnace, mountings, accessories, water level, scale, blowing off, lagging and refractory.
3. Enumerate the factors which should be considered while selecting a boiler and what are the essentials of good steam boiler?
4. Explain with neat sketch the construction and working of any two of the following high pressure boilers: (i) LaMont boiler (ii) Loffler boiler (iii) Benson boiler (iv) Velox boiler.
5. Explain with neat sketch the construction and working of FBC Boiler.
6. What is function of boiler mountings? How do accessories differ from mountings?
7. Explain with neat sketches any two of the boiler accessories
   1. Economiser (ii) Injector (iii) Air preheater (iv) Superheater
8. What is steam trap? Explain with neat sketch expansion type of steam trap.
9. What are the various types of draughts and write the advantages of artificial draught over natural draught.
10. Derive an expression for max discharge of gases through the chimney for a given height of the chimney
11. The following are the data collected for a boiler using coal as the fuel. Find out the boiler efficiency by indirect method.

|  |  |
| --- | --- |
| Fuel firing rate = 5599.17 kg/hr Steam generation rate = 21937.5 kg/hr Steam pressure = 43 kg/cm2(g)  Steam temperature = 377 °C Feed water temperature = 96 °C  %CO2 in Flue gas = 14 | Total surface area of boiler = 90 m2 GCV of Bottom ash = 800 kCal/kg GCV of fly ash = 452.5 kCal/kg Ratio of bottom ash to fly ash = 90:10 **Fuel Analysis (in %)**  Ash content in fuel = 8.63 |

|  |  |
| --- | --- |
| %CO in flue gas = 0.55  Average flue gas temperature = 190 °C Ambient temperature = 31 °C Humidity in ambient air = 0.0204 kg / kg dry air  Surface temperature of boiler = 70 °C  Wind velocity around the boiler = 3.5 m/s | Moisture in coal = 31.6  Carbon content = 41.65  Hydrogen content = 2.0413  Nitrogen content = 1.6  Oxygen content = 14.48 GCV of Coal = 3501 kCal/kg |

1. Estimate the mass of flue gases flowing through the chimney as per the data given below:

Draught produced = 20mm of water column, temp of the flue gases = 573K, Ambient temp =303K, mass of air used = 19kg per kg of fuel burnt, Dia of chimney = 2m and neglect the losses.

1. A steam generator evaporates 18000 kg/hr of steam at 12.5bar and a quality of

0.97 from feed water at 105oC when coal is fired at the rate of 2040 kg/hr. if the higher calorific value of the coal is 27400 kJ/kg find (i) The heat rate of boiler in kJ/hr. (ii) The equivalent evaporation (iii) The thermal efficiency

1. A fuel contains 90% C, 3.3% H2, 3% O2 0.8% N2 0.9% S2 and remaining incombustible mass. Find the HCV, LCV, chemically correct air-fuel ratio and composition of exhaust gas on percentage mass basis.
2. Discuss the pollution emission and the effect of lean burn on it.
3. Write the classification of fuels and explain briefly with the examples.
4. An oil fired package boiler was tested for 2 hours duration at steady state condition. The fuel and water consumption were 250 litres and 3500 litres respectively. The specific gravity of oil is 0.92. The saturated steam generation pressure is 7 kg/cm2 (g). The boil feed water temperature is 30ºC. Determine the boiler efficiency and evaporation ratio. **[Jul 2021]**

# PART – C (C301.2)

1. What are the basic requirements of combustion equipment? Explain briefly the following methods of burning of coal : (i) Stoker firing (ii) Pulverized fuel firing
2. What is the function of a steam separator? Discuss with a neat sketch any one type of steam separators.
3. The following observations were made during the trial of a boiler plant consisting of a battery of Lancashire boilers and an economizer: Calorific value of coal / kg = 29915 kJ, Mass of feed water per kg of dry coal = 9.1 kg ,Equivalent evaporation from and at 100oC per kg of dry coal = 9.6 kg ,Temperature of feed water to economizer = 12oC ,Temperature of feed water to boiler = 105oC, Air Temperature = 13oC, Temperature of flue gases entering economizer = 370 oC , Mass of flue gases entering the economizer = 18.2 kg /kg of coal , Mean specific heat of flue gases = 1.046 kJ/kgoC. Find (i) The efficiency of the boiler (ii) The efficiency of the economizer (iii) the efficiency of the whole boiler plant.
4. (i) What are the major performance features of the CFBC boiler (circulating fluidizing bed combustion boiler)?

(ii) Explain at least six advantages of fluidized bed boilers?

1. (i) What is the benefit of providing Economiser for a boiler?

(ii) Calculate the fuel oil savings by providing an Economiser for a boiler. The performance data of the boiler are given as below:

Average quantity of steam generated : 5 T/h

Average flue gas temperature : 315 oC (without economiser) Average steam generation / kg of fuel oil : 14 kg

Feed water inlet temperature : 110oC

Fuel oil supply rate : 314 kg/h

Flue gas quantity : 17.4 kg/kg of fuel

Gross calorific value of fuel : 10,000 kCal/kg Rise in feed water temperature by providing economizer: 26 °C Annual operating hours 8600

# UNIT-III STEAM TURBINES PART-A (C301.3)

1. **Define Steam turbine.**

A steam turbine is a prime mover in1iich rotary motion is obtained by the gradual change of momentum of the steam. The force exerted on the blades is due to the velocity of steam. This is due to the fact that the curved blades by changing the direction of steam receive a force or impulse.

# Advantage of steam turbine over reciprocating steam engines.

* + Steam turbine may develop higher speeds and a greater steam range is possible.
  + The efficiency of a steam turbine is higher.
  + The steam consumption is less.
  + Since all the moving pails are enclosed in a casing, the steam turbine is comparatively safe.
  + A steam turbine requires less space and lighter foundations, as there are little vibrations.
  + There is less frictional loss due to fewer sliding parts.
  + The applied torque is more uniform to the driven shaft.
  + A steam turbine requires less attention during running. Moreover, the repair Costs are generally less.

# Classify steam turbine according to the classification of flow.

i) Impulse turbine ii) Reaction turbine iii) combination of impulse and reaction

# Classification of steam Turbine

The steam turbines may be classified into the following types:

**According to the mode of steam action**: (i) Impulse turbine, and (ii) Reaction turbine.

**According to the direction of steam flow**: (i) Axial flow turbine, and (ii) Radial

flow turbine.

**According to the exhaust condition of steam**: (i) Condensing turbine, and (ii) Non-condensing turbine.

**According to the pressure of steam**: (i) High pressure turbine, (ii) Medium pressure turbine, and (iii) Low pressure turbine.

**According to the number of stages**: (i) Single stage turbine, and (ii) Multi-stage turbine.

# Define Impulse turbine.

An \*impulse turbine, as the name indicates, is a turbine which runs by the impulse of steam jet In this turbine, the steam is first made to flow through a nozzle. Then the steam jet impinges on the turbine blades (which are curved like buckets) and are mounted on the circumference of the wheel. The steam jet after impinging glides over the concave surface of the blades and finally leaves the turbine. This is also known as De-Level Impulse.

# Define two stages Impulse turbine.

The steam after leaving the moving blade is made to flow through a fixed blade ring (in order to make the steam to flow at a designed angle and again impinges on second moving blade. This type of turbine is called two-stage impulse turbine.

# Define Reaction turbine. [Jul 2021]

In a reaction turbine, the steam enters the wheel under pressure and flows over the blades. The steam while gliding propels the blades and makes them to move. As a matter of fact, the turbine runner is rotated by the reactive forces of steam jets. The backward motion of the blades is similar to the recoil of a gun. This is also known as Parson's Reaction Turbine

# Differentiate impulse turbine and reaction turbine. [MAY 2018]

|  |  |  |  |
| --- | --- | --- | --- |
| **S.No** | **Particulars** | **Impulse Turbine** | **Reaction Turbine** |
| 1 | Pressure drop | Only in nozzles and not  in moving blades. | In fixed blades (nozzles) as  well as in moving blades. |
| 2 | Area of blade  channels | Constant | Varying |
| 3 | Blades | Profile type | Aerofoil type. |
| 4 | Admission of  steam | Not all round | All round or complete |
| 5 | Nozzles | Diaphragm contains the nozzle | Fixed blades similar to moving blades attached to the casing serve as nozzles and  guide the steam. |
| 6 | Power | Not much power can be  developed. | Much power can be  developed. |
| 7 | Efficiency | Low | High |

1. **Define blade efficiency or diagram efficiency.**

It is the ratio of work done on the blade per second to the energy entering the blade per second.

# Define stage efficiency.

The stage efficiency covers all the losses in the nozzles, blades, diaphragms and discs that associated with that stage.

  *Networkdoneonshaftperkgofsteamflowing*

*stage*

*adiabaticheatdropperstage*

# Define blade velocity coefficient or coefficient of velocity or Friction factor.

**[Jul 2021]**

The blade velocity coefficient is defined as the ratio of relative velocity of steam as is passes over the blades without frictional resistance to relative velocity of steam with friction resistance.

*K*  *Cr*0 where K is blade velocity coefficient

*Cr*1

# Define blade speed ratio

Blade speed ratio is defined as the ratio of blade speed to steam speed

  *Cbl*

*C*1

1. **Define degree of reaction. [May/June 2014] [Nov/Dec 2014]** Degree of reaction or reaction ratio (R) is defined as the ratio of static pressure drop in the rotor to the static pressure drop in the stage or as the ratio of static enthalpy drop in the rotor to the static enthalpy drop in the stage.

# Define coefficient of velocity in nozzle? [Nov/Dec 2014]

The ratio of the actual velocity of gas emerging from a nozzle to the velocity calculated under ideal conditions; it is less than 1 because of friction losses.

# What is meant by carry over loss?

The velocity of steam at exit is sufficiently high thereby resulting in a kinetic energy loss called Carry over loss or Leading velocity loss.

# What are the methods adopted to prevent erosion in steam turbines?

1. By raising the temperature of steam at inlet, so that at exit of turbine the wetness does not exceed 10%
2. By adopting reheat cycle; so that wetness at exit remains in limit.
3. Drainage belts are provided on the turbine, so that the water droplets are on outer periphery, due to centrifugal force are drained. The drained amount is about 25 percent of total water particles present.

# What do you mean by bleeding in steam turbine?

Bleeding is the process of draining steam from the turbine at certain points during its expansion and using this steam for heating the feed water supplied to the boiler.

# What is meant by stage in turbine?

In an impulse turbine, stage means set of nozzles outside the turbine + moving blades on the rotor. In a reaction turbine, stage means one set of fixed blades + one set of moving blades.

# What are the losses in steam turbine?

Residual velocity losses, Loss due to friction, Radiation losses, Loss due to moisture.

# What are the possible causes of excessive vibration or noise in steam turbine?

Misalignment, worn bearings, unbalanced wheel, unbalanced coupling, bent shaft, piping strain.

# Define compounding of turbine and classify it. [NOV 2017]

The steam is expanded from the boiler pressure to condenser pressure in one stage the speed of the rotor becomes tremendously high which crops up practical complicacies. There are several methods of reducing this speed to lower value all these methods utilize a multiple system of rotor in series keyed on a common shaft and the steam pressure or jet velocity is absorbed in stages as the steam flows over the blades. This is known as compounding. The different methods of compounding are i) Velocity compounding ii) Pressure compounding iii) Pressure velocity compounding.

# What is the purpose of compounding?

Compounding is the method in which multiple system or rotors are keyed to common shaft in series and the steam pressure or jet velocity is absorbed in stages as it flows over the rotor blades.

Purpose of compounding: Reduction of pressure (from boiler pressure to condenser pressure) in single results in the very high velocity entering the turbine blades. Therefore, the turbine rotor will run at a high speed about 30,000 rpm which is not useful for practical purpose. In order to reduce the rotor speed up to about 400 m/sec, compounding of steam turbine is necessary.

# What is pressure compounding? [April/May 2015]

The Steam Pressure compounding is the method in which pressure in a steam turbine is made to drop in a number of stages rather than in a single nozzle. This method of compounding is used in Rateau and Zoelly turbines.

# What are the advantages of velocity compounded impulse turbine?

1. Owing to relatively large heat drop, a velocity compounded impulse turbine requires a comparatively small number of stages.
2. Due to number of stages being small, its cost is less
3. The steam temperature is sufficiently low in a two or three row wheel; therefore cast iron cylinder may be used. This will cause saving in material cost.

# What do you mean by governing of steam turbine? Classify it

Governing of steam is to control the rotational speed of turbine by controlling the flow of steam into turbine irrespective of varying load on turbine. Classification

i) Throttle governing ii) Nozzle governing iii) By-pass governing iv) combination of Throttle Nozzle By-pass governing.

# What is the remedy for a bent steam turbine shaft causing excessive vibration?

1. The run-out of the shaft near the centre as well as the shaft extension should be checked.
2. If the run-out is excessive, the shaft is to be replaced

# PART – B (C301.3)

1. Explain the pressure and velocity compounding diagram of multistage turbine with neat sketch. **[Nov/Dec 2014] [Jul 2021]**
2. Elucidate the working of velocity, pressure and velocity pressure compounding methods with neat sketch. **[May 2018]**
3. Explain the pressure band velocity compounding of a multi stage turbine.
4. In a single stage impulse turbine, nozzle angle is 20º and blade angles are equal. The velocity coefficient for blade is 0.85. Find maximum blade efficiency possible. If the actual blade efficiency is 92% of the maximum blade efficiency, find the possible ratio of blade speed to steam speed. **[Jul 2021]**
5. In a De-lavel turbine, the steam enters the wheel through a nozzle with a velocity

of 500 m/s and at an angle of 20º to the direction of motion of the blade. The blade speed is 200 m/s and the exit angle of the moving blade is 25°. Find the inlet angle of the moving blade, exit velocity of steam and its direction and work done per kg of steam.

1. In a De Laval Turbine steam issues from the nozzle with a velocity of 1200 m/s. The nozzle angle is 20˚C, the mean blade velocity is 400 m/s and the inlet and outlet angles are equal. The mass of steam flowing through the turbine per hour is 1000 kg. Calculate i) Blade angles ii) Relative velocity of steam entering the blades iii) Tangential force on the blades iv) Power developed v) Blade efficiency. Take blade velocity co-efficient as 0.8 **[April/May 2015]**
2. A steam jet enters the row of blades with a velocity of 375 m/s at an angle of 20º

with the direction of motion of the moving blades. If the blade speed is 165 m/s, find the suitable inlet and outlet blade angles assuming that there is no thrust on the blades. The velocity of steam passing over the blades is reduced by 15%. Also determine power developed by the turbine per kg of steam flowing aver the blades per second.

1. In a single stage impulse turbine the isentropic enthalpy drop of 200 kJ/kg occurs in the nozzle having efficiency of 96% and nozzle angle of 15°. The blade velocity coefficient is 0.96 and ratio of blade speed to steam velocity is 0.5. The steam mass flow rate is 20 kg/s and velocity of steam entering is 50 m/s. Determine (a) the blade angles at inlet and outlet if the steam enters blades smoothly and leaves axially, (b) the blade efficiency, (c) the power developed in kW and (d) the axial thrust.
2. Steam enters the blade row of an impulse turbine with the velocity of 600 m/s at an angle of 25°C to the plane of rotation of the blades the blade mean speed is 250 m/s. The blade angle at the exit side is 30°C. The blade friction loss is 10 %.

Determine blade angle inlet, blade efficiency and work done per kg of steam

# [May/ June 2014]

1. (a) The velocity of steam leaving the nozzle of an impulse turbine is 10000m/s and the nozzle angle is 20oC . The blade velocity is 350m/s and the blade velocity of co-efficient is 0.85.Assuming no losses due to shock at inlet ,calculate for a mass flow of 1.5kg/s ,and symmetrical blading, (i) Blade inlet angle, (ii)

Driving force on the wheel, (iii) Axial thrust on the wheel and (iv) Power developed by the turbine.

(b) Differentiate between impulse and reaction turbine. **[April/May 2013]**

1. In a single stage impulse turbine the blade angles are equal and nozzle angle is 20o.the velocity coefficient for the blade is 0.83 find the maximum blade efficiency possible. If the actual blade efficiency is 90% of maximum blade efficiency, find the possible ratio of blade speed to steam speed. **[Nov/Dec 2017]**
2. In one stage of a reaction steam turbine, both the fixed and moving blades have

inlet and outlet blade tip angles of 35º and 20º respectively. The mean blade speed is 80 m/s and the steam consumption is 22 500 kg per hour. Determine the power developed In the pair, if the isentropic heat drop for the pair is 23.5 kJ per kg.

1. A Parson's reaction turbine, while running a 1400 r.p.m. consumes 30 tonnes of steam per hour. The steam at a certain stage is at 6 bar with dryness fraction of

0.9 and the stage develops 10 kW. The axial velocity of flow is constant and equal to 0.75 of the blade velocity. Find mean diameter of the drum and the volume of steam flowing per second. Take blade tip angles at inlet and exit as 35º and 20º respectively.

1. A Parson’s reaction turbine has mean diameter of blades as 1.6 m and rotor moving at 1500 rpm. The inlet and outlet angles are 80°C and 20°C respectively. Turbine receives steam at 12 bar, 200°C and has isentropic heat drop of 26 kJ/kg. 5% of steam supplied is lost through leakage. Determine the following considering horse power developed in stage to be 600 hp.(a) the stage efficiency and (b) the blade height.

# PART – C (C301.3)

1. A convergent-divergent nozzle for a steam turbine has to deliver steamunder a supply condition of 11 bar with 100ºC superheat and a back pressure of 0.15bar. if the outlet area of the nozzle is 9.7cm2, determine using steam tables, the mass of steam discharged per hour. If the turbine converts 60% of the total enthalpy drop into useful work, determine the power delivered by the turbine. Neglec the effect of friction in the nozzle. Take CP of superheated steam as 2.3 kJ/kg.k

# [Nov/Dec 2018]

1. A 50% reaction turbine (with symmetrical velocity triangles) running at 400

r.p.m. has the exit angle of the blades as 20º and the velocity of steam relative to the blades at the exit is 1.35 times the mean blade speed. The steam flow rate is

8.33 kg/s and at a particular stage the specific volume is 1.381m3 /kg. Calculate for this stage. A suitable blade height, assuming the rotor mean diameter to be 12 times the blade height.

1. In a reaction turbine, the blade tips are inclined at 35º and 20º in direction of motion. The guide blades are of the same shape as the moving blades, but reversed in direction. At a certain place in the turbine, the drum diameter is 1 meter and the blades are 100 mm high. At this place, steam has a pressure of 1.7

bar and dryness 0.935. If the speed of the turbine is 250 r.p.m. and the steam passes through the blades without shock, find the mass of steam flow and the power developed in the ring of the moving blades

1. A reaction turbine runs at 300 r.p.m. and its steam consumption is 15400 kg/hr. The pressure of steam at certain pair is 1.9 bar; its dryness 0.93 and power developed by the pair is 3.5 kW. The discharging blade tip angle is 20° for both fixed and moving blades and the axial velocity of flow is 0.72 of the blade velocity. Find the drum diameter and blade height. Take the tip leakage steam as 8%, but neglect blade thickness.
2. **(a)** List the advantages of steam turbines over gas turbines**.**

**(b)** Determine the isentropic enthalpy drop in the stage of Parson's reaction turbine which has the following particulars: speed=1500 rpm, mean diameter of the rotor = 1m, stage efficiency =80%, speed ratio = 0.7, blade outlet angle =20o.

# UNIT-IV CO-GENERATION AND RESIDUAL HEAT RECOVERY PART-A (C301.4)

1. **What is mean by cogeneration?**

A cogeneration system is the sequential or simultaneous generation of multiple forms of useful energy (usually mechanical and thermal) in a single integrated system. Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85 %.

# What is the principle of cogeneration system?

Cogeneration is a way of generating both thermal energy and electricity. In convectional thermal power stations outlet steam needs to be cooled before pumping it to the boiler again. The heat wasted during the cooling is the highest energy loss in the whole generation process and it is the main reason why thermal power systems have such a low efficiency. Cogeneration allows for using the waste heat and thus enhancing the overall system efficiency

# Write the other known names of cogeneration?

Cogeneration is also known as ‘combined heat and power (CHP)’ and ‘total

energy system

# Why cogeneration system efficiency will be higher?

Cogeneration is the simultaneous generation of heat and power, both of which are used. Electricity generated by cogeneration plant is normally used locally and hence the transmission and distribution losses are negligible.

# What are advantages of cogeneration system? [Jul 2021]

Improves energy efficiency, Lower emissions, lower energy costs, conserve natural resources (fossil fuels), Reduces transmission and distribution losses.

# Application of cogeneration system in Industries

Wood and Agro industries, food processing, pulp and paper, steel , textile, glass and ceramic industries,

# What are the major components of a cogeneration system?

i). Prime mover (heat engine) ii). Generator

1. Heat recovery
2. Electrical interconnection

# Explain how cogeneration systems are classified.

Cogeneration systems are normally classified according to

i). The sequence of energy use (Topping cycle & Bottoming cycle) ii). The operating schemes adopted

# Explain about topping cycle.

In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.

# What are the various types of topping cycle?

i). Combined cycle topping system ii). Steam turbine topping system

iii). Heat recovery from engine exhaust iv). Gas turbine topping system

# Explain about bottoming cycle.

In a bottoming cycle, the primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures.

# What are the applications of bottoming cycle?

i). Cement industry ii). Steel industry

1. Ceramic industry
2. Petrochemical industries

# What is the main difference between “Topping Cycle” and “Bottoming Cycle”?

A topping cycle plant generates electricity or mechanical power first whereas a bottoming cycle plant generates heat first.

# Explain gas turbine cogeneration system?

In the gas turbine energy input comes from the fuel that is injected into the combustion chamber. The gas/air mixture drives the turbine with high temperature waste gases existing to the atmosphere. If steam is generated using this waste heat for the process it is called a ‘gas turbine cogeneration system’.

# State the principle of Rankine Cycle cogeneration?

The Rankine Cycle provides an ideal outlet for waste heat recovered from any process or generation situation. Instead of condensing the entire steam if the back pressure steam is utilised in the process, it is called a Rankine cycle cogeneration.

# What is the function of ‘back pressure steam turbine’?

In back pressure steam turbine steam enters the turbine chamber at high pressure and expands to low or medium pressure. Enthalpy difference is used for generating power/work.

# Mention the waste heat sources from reciprocating engines?

Waste heat sources from reciprocating engines are:

Exhaust flue gases

Engine jacket cooling water Lube oil cooler

# What are the factors influencing the choice of cogeneration system?

i). Base electrical load matching ii). Base Thermal Load Matching iii). Electrical load matching

iv). Thermal Load Matching

# List important technical parameters to be considered in a cogeneration system.

* 1. Heat to power ratio , b) Quality of thermal energy needed, c) Load pattern

d) Fuel available, e) System reliability, f) Dependent systems Vs independent system, g) Retrofit Vs new installation, h) Electricity buy back, i) Local environment consideration

# Explain about standalone system

If the thermal energy demand of the site is higher than that generated by the cogeneration system, auxiliary boilers are used. On the other hand, when the thermal energy demand is low, some thermal energy is wasted. If there is a possibility, excess thermal energy can be exported to neighboring facilities. In this operating scheme, the facility is totally independent of the power utility grid. All the power requirements of the site, including the reserves needed during scheduled and unscheduled maintenance, are to be taken into account while sizing the system.

# Describe about thermal load matching

The cogeneration system is designed to meet the thermal energy requirement of the site at any time. The prime movers are operated following the thermal demand. During the period when the electricity demand exceeds the generation capacity, the deficit can be compensated by power purchased from the grid. Similarly, if the local legislation permits, electricity produced in excess at any time may be sold to the utility.

# List out some technical parameters to be considered while selecting a

**cogeneration system**

1. Heat-to-Power Ratio
2. Quality of Thermal Energy Needed
3. Load Patterns iv). Fuels Available
4. System Reliability
5. Local Environmental Regulation

# Under what circumstances the cogeneration system is most likely to be

**attractive**

1. The demand for both steam and power is balanced i.e. consistent with the range of steam - power output ratios that can be obtained from a suitable cogeneration plant.
2. A single plant or group of plants has sufficient demand for steam and power to permit economies of scale to be achieved.
3. Peaks and troughs in demand can be managed or, in the case of electricity, adequate backup supplies can be obtained from the utility company.

# Why regenerators are normally preferred for high pressure ratio gas turbine

**cycle ? [Jul 2021]**

The high pressure air leaving the compressor can be heated by transferring heat from exhaust gases in a counter-flow heat exchanger which is called a regenerator. As an exhaust-gas heat exchanger, a regenerator recovers heat from the exhaust and uses it to preheat the compressed air before the compressed air enters the combustor. Preheating of the compressed air permits a small heat input to the combustor for a given power output of the engine. Thus, regenerators can be used to increase the thermal efficiencies and power outputs of gas turbines.

# Define heat to power ratio

Heat to power ratio is defined as the ratio of thermal energy to electricity required by the energy consuming facility. It is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility should match with the characteristics of the cogeneration system to be installed.

# Name some prime movers that can be used for prime movers

i). steam turbine ii). gas turbine

iii). Reciprocating engine systems

# What are the common fuels used in gas turbines?

1. LPG
2. Natural gas iii). Distillate oils

# What do you understand by the term waste heat?

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved

# Give two examples of waste heat recovery

Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered

# Explain source and utilization of residual heat

|  |  |  |
| --- | --- | --- |
| **S.No.** | **Source** | **Quality** |
| 1. | Heat in flue gases. | The higher the temperature, the greater  the potential value for heat recovery |
| 2. | Heat in vapour streams. | As above but when condensed, latent  heat also recoverable. |
| 3. | Convective and radiant heat  lost from exterior of equipment | Low grade – if collected may be used  for space heating or air preheats. |
| 4. | Heat losses in cooling water. | Low grade – useful gains if heat is  exchanged with incoming fresh water |
| 5. | Heat losses in providing chilled water or in the disposal of chilled water | 1. High grade if it can be utilized to reduce demand for refrigeration 2. b) Low grade if refrigeration unit   used as a form of heat pump. |
| 6. | Heat stored in products leaving  the process | Quality depends upon temperature |
| 7. | Heat in gaseous and liquid  effluents leaving process | Poor if heavily contaminated and thus  requiring alloy heat exchanger |

1. **What are the direct and indirect benefits of waste heat recovery? Direct Benefits:**

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost.

# Indirect Benefits:

* 1. Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.
  2. Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.
  3. Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc..

# How will you go about developing a waste heat recovery system?

**Understanding the process**

* 1. Sources and uses of waste heat , b) Upset conditions occurring in the plant due to heat recovery, c) Availability of space, d) Any other constraint, such as dew point occurring in an equipments etc. After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipments to recover and utilise the same.

# Economic Evaluation of Waste Heat Recovery System

It is necessary to evaluate the selected waste heat recovery system on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition the advice of experienced consultants and suppliers must be obtained for rational decision

# What do you meant by Recuperator?

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. There are no moving parts in direct transfer type heat exchangers. This type of exchanger is designated as a recuperative heat exchanger or simply as a Recuperator.

# Explain the various types of recuperators

Metallic Radiation Recuperator, Convective Recuperator, Convective Radiative Recuperator, Ceramic Recuperator

# Explain the operating principle of a regenerator

A regenerative heat exchanger, or more commonly a regenerator, is a type of heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid.

# What are heat wheels? Explain with sketch.

|  |  |
| --- | --- |
| Heat Wheel is the rotary regenerator where the matrix is in a cylinder rotating across the waste gas and air streams. The heat or energy recovery wheel is a rotary gas heat regenerator, which can transfer  heat from exhaust to incoming gases. |  |

1. **What is Heat Pipe?**

Heat pipes are Heat transfer devices. They are Hollow cylindrical pipes filled with a small amount of fluid that evaporates to produce heat. This heat is then rejected from another end for its application on industrial processes. For example, it is used in Air Conditioning and Refrigeration application.

# Explain the principle of operation of a heat pipe

Heat pipe is generally self-heat recovery devices that are used to transfer heat from one end (heat injection) to another (destination) with minimum temperature differences and also to pass the heat across internal surface. Many terms have to be taken into consideration while choosing a pipe for application on industrial devices. They are manufactured in different shapes such as round or flat shapes.

# What are the typical applications of a heat pipe in heat exchangers?

* Preheating of boiler combustion air
* Recovery of Waste heat from furnaces
* Reheating of fresh air for hot air driers
* Recovery of waste heat from catalytic deodorizing equipment
* Preheating of boiler feed water with waste heat recovery from flue gases in the heat pipe economizers.
* Drying, curing and baking ovens
* Heating, ventilating and air-conditioning systems

# Explain the operating principle of a heat pump with examples

A heat pump is a device that transfers heat energy from a source of heat to what is called a [heat sink.](https://en.wikipedia.org/wiki/Heat_sink) Heat pumps move [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) in the opposite direction of spontaneous heat transfer, by absorbing heat from a cold space and releasing it to a warmer one. A heat pump uses a small amount of external power to accomplish the work of transferring energy from the heat source to the heat sink. The most common design of a heat pump involves four main components – a [condenser](https://en.wikipedia.org/wiki/Condenser_(heat_transfer)), an [expansion valve](https://en.wikipedia.org/wiki/Thermal_expansion_valve), an [evaporator](https://en.wikipedia.org/wiki/Evaporator) and a [compressor](https://en.wikipedia.org/wiki/Compressor). The heat transfer medium circulated through these components is called [refrigerant](https://en.wikipedia.org/wiki/Refrigerant).

# Explain the operation of an economizer.

Economizer can be provided to utilize the flue gas heat for preheating the boiler feed water. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler. For every 22°C reduction in flue gas temperature by passing through an economizer or a pre-heater, there is 1% saving of fuel in the boiler

# How does a shell and tube heat exchanger work? Give typical examples.

A shell and tube exchanger consists of a number of tubes mounted inside a cylindrical shell. Two fluids can exchange heat, one fluid flows over the outside of the tubes while the second fluid flows through the tubes. The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement.

Typical applications is condensates from refrigeration and air-conditioning systems, condensate from process steam, coolants from furnace doors, grates, and pipe supports, coolants from engines, air compressors, bearings, and lubricants and the condensates from distillation processes

# How does a plate heat exchanger work?

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

# What are wheeling and its types?

Wheeling is the transportation of [electric energy](https://en.wikipedia.org/wiki/Electric_energy) (megawatt-hours) from within an [electrical grid](https://en.wikipedia.org/wiki/Electrical_grid) to an [electrical load](https://en.wikipedia.org/wiki/Electrical_load) outside the grid boundaries. Two types of wheeling are 1) wheel-through, where the [electrical power generation](https://en.wikipedia.org/wiki/Electrical_power_generation) and the

load are both outside the boundaries of the transmission system and 2) a wheel- out, where the generation resource is inside the boundaries of the transmission system but the load is outside.

# PART – B (C301.4)

1. Explain the Cogeneration system with neat sketch
2. Explain about the types of topping cycle cogeneration system
3. Compare the Topping cycle and Bottoming cycle cogeneration system
4. With suitable circuit, explain the function wise differences between topping and bottoming cycle **[Jul 2021]**
5. Explain briefly about the sources and utilization of residual heat.
6. Discuss the various applications of Residual heat recovery system
7. Enumerate the Economic aspects of Cogeneration and Residual Heat Recovery
8. Explain the operating principle of a waste heat recovery boiler with examples.
9. Explain about heat pump and heat pipes.
10. Explain about recuperative & regenerative heat exchangers along with their advantages disadvantages. **[Jul 2021]**
11. Explain about Economic Considerations in Heat Exchanger Selection
12. Explain the operating principle of regenerator?
13. Explain the various types of recuperators.

# PART – C (C301.4)

1. Explain the operating principle of a heat pump with examples.
2. What are the typical applications of a heat pipe in heat exchangers?.
3. Give two examples of residual heat recovery sources, What are the direct and indirect benefits of residual heat recovery system?.
4. A textile factory requires 10t/h of steam for process heating at 3 bar saturated and 1000 kW of power, for which a back pressure turbine of 70% internal efficiency is used. Find the steam condition required at inlet of the turbine.

[**Jul 2021]**

# UNIT-V REFERIGERATION AND AIR -CONDITIONING PART-A (301.5)

1. **Define refrigeration. [NOV/DEC 2018, Jul 2021]** Refrigeration is the branch of science which deals with the transfer of heat from a low temperature region to a high temperature region, to maintain a space or region at a temperature lower than that of surroundings.

# Define Tonne of Refrigeration. [May 2015]

One tonne of refrigeration is the amount of refrigerating effect (heat removed) produced by melting 1 tonne (1000 kg) of ice at 0°C in 24 hours. 1 TR = 210

kJ/min = 3.5 kW

1. **What is refrigerant? Give examples of commonly used refrigerant. [Nov 2017]** The refrigerant is a heat carrying medium, which undergoes thermodynamic cycles of refrigeration. In a refrigeration system, refrigerant absorbs heat from a

low temperature medium and discards the absorbed heat to a high temperature environment. Commonly used refrigerants are air, water, carbon-di-oxide, ammonia, Freon-12(R12) and Freon-22(R22).

# Give the properties of a good refrigerant. [Dec 2013, June 2014, Dec 2014]

* + The saturation pressure of the refrigerant (at low temperature) should be above or equal to the atmospheric pressure.
  + The latent heat of evaporation (at low temperature) should be as high as possible.
  + The specific volume of the refrigerant should be low to reduce compressor size.
  + Refrigerant should have low boiling point and low freezing point.
  + Refrigerant should have high thermal conductivity to reduce heat transfer in condenser and evaporator.
  + Refrigerant should be chemically stable.
  + Refrigerant should be non-toxic, non-flammable and non-explosive.
  + Refrigerant should give high COP to reduce the running cost of the system.
  + Refrigerant must be cheap and must be readily available.

# What is refrigerating effect?

The amount of heat extracted from a space or region in a given time is known as refrigerating effect.

# Define COP of a refrigerator.

The performance of a refrigerator is expressed in terms of coefficient of performance (COP), which is defined as the ratio of refrigerating (cooling) effect to the work input required to achieve that cooling effect.

# List the components of vapour Compression refrigeration system.

1. Compressor
2. Condenser.
3. Expansion Valve.
4. Evaporator.

# List the advantages and disadvantages of vapour compression refrigeration system.

Advantages:

1. VCR system has high value of COP.
2. It approaches reversed Carnot cycle except for expansion of refrigerant in expansion device.
3. The size of refrigeration system per tonne of refrigeration is smaller.
4. It has less running cost. Disadvantages:
5. It has high initial cost.
6. Leakage of refrigerant may cause harmful effect.
7. The production of some refrigerant may be hazardous to the refrigerant.

# What is the function of the throttling valve in vapour compression refrigeration

**system ?**

Throttling valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator. **[Jul 2021]**

# List out the components of in the vapour absorption refrigeration system.

**[Dec 2013]**

1. Absorber, 2. Generator, 3. Condenser, 4. Evaporator, 5. Pump

# List the advantages and disadvantages of vapour absorption refrigeration system.

Advantages:

1. As there is no moving part in the system, the operation is quiet and there is very little wearing.
2. The maintenance cost is low.
3. The system does not depend upon electric power.
4. It can be built in capacities well above 1000 TR.
5. Absorption refrigeration system can operate at reduced evaporator temperature by increasing the steam which is supplied to generator with little decrease in capacity.

Disadvantages:

1. The COP of the system is poor since it uses low grade energy.
2. The lowest temperature attained is above 0°C, since water is used as the refrigerant.

# Differentiate VCR and VAR System. [May 2018]

|  |  |  |
| --- | --- | --- |
| **Sl.**  **No** | **Vapour Compression Refrigeration**  **System** | **Vapour Absorption Refrigeration System** |
| 1 | Due to compressor and fan, more wear  and tear. | Only moving part is liquid pump and  so less wear and tear. |
| 2 | Electrical power is essential to operate the system. | Electrical power is not essential to operate the system (heat energy is  used). |
| 3 | Compressor is used to compress the  refrigerant. | Compressor is replaced by absorber  and generator. |
| 4 | Freon 12, Freon 22, NH3, Propane, Iso butane are used as refrigerants. | NH3 water vapour system and  Lithium Bromide water vapour system are used. |

1. **Define air-conditioning [May 2018, Jul 2021]** Air conditioning is the process of treating air in an internal environment to achieve and maintain required standards of temperature, humidity, motion and cleanliness of air regardless of surrounding conditions.

# Give the applications of air-conditioning.

1. Used in residential buildings, stores, hotels & restaurants to promote human health & comfort.
2. Used in transportation of goods and human beings.
3. Used in operation theatres and intensive care units.
4. Also used in offices, libraries, theatres and auditoriums.

# Classify air-conditioning system.

According to season:

1.Summer a/c system 2.Winter a/c system 3.Year-round a/c system.

According to purpose:

1.Comfort a/c system 2.Industrial a/c system.

According to equipment arrangement:

1.Unitary a/c system 2.Central a/c system.

# Differentiate refrigeration and air-conditioning.

|  |  |
| --- | --- |
| **Refrigeration** | **Air-conditioning** |
| Process of removing heat from a lower temperature region to a higher temperature region to maintain a space  lower than its surroundings. | Process of treating air in an internal environment to achieve and maintain required standards of temperature,  humidity, cleanliness and motion of air. |

1. **What do you mean by dry air, moist air and moisture?**

Dry air is the mixture of oxygen, nitrogen, carbon-di-oxide, argon, etc. Moist air is the mixture of dry air and water vapour.

Moisture is the amount of water vapour present in dry air.

# Define saturated air and degree of saturation.

Saturated air is the moist air which contains maximum possible water vapour. Degree of saturation is defined as the ratio of actual humidity ratio to the humidity ratio of saturated air at the same temperature and total pressure.

# What do you mean by humidity and absolute humidity?

Humidity or moist is the amount of water vapour in air.

Absolute humidity is the ratio of the mass of water vapour (mv) in a given volume to the mass of dry air in a given volume (ma).

# Define relative humidity.

Relative humidity is defined as the ratio of actual mass of water vapour (mw) to the mass of saturated vapour (ms) produced in a mixture of air and water vapour at the same temperature and pressure (or)

Relative humidity is defined as the ratio of partial pressure of water vapour (pw) in a mixture to the saturation pressure (ps) of pure water at the same temperature of mixture.

# Define DBT and WBT.

Dry Bulb Temperature (DBT) of the mixture is the temperature measured by an ordinary thermometer placed in the air-vapour mixture.

Wet Bulb Temperature (WBT) is the temperature measured by a thermometer whose bulb is covered by a thoroughly wetted cotton wick.

# Define dew point temperature and dew point depression. [Dec 2010]

Dew Point Temperature (DPT) of an air-vapour mixture is a temperature at which the vapour starts to condense, when the mixture is cooled at constant pressure.

Dew Point Depression (DPD) is the difference between dry bulb temperature (DBT) and dew point temperature (DPT) of air vapour mixture.

# Define sensible heat factor. [Dec 2014]

The Sensible Heat Factor (SHF) is the ratio between total sensible heat to total heat (sum of total sensible heat and total latent heat).

# List the requirements of conditioned air for human comfort?

Temperature - 22°C to 25°C, Relative humidity - 40% to 60% and Air velocity - 5 to 8 m/min.

# Define RSHF. [June 2014, Nov 2017, Nov 2018]

RSHF is defined as the sensible heat load in the room divided by the total heat load in room.

# Define effective sensible heat factor. [May 2015, Nov 2018]

Effective Room Sensible Heat (ERSH) is the sum of all sensible heat gain that occurs in the room including the gain due to the portion of the ventilation air which is bypassed.

Effective Room Latent Heat (ERLH) is the sum of all latent heat gain that occurs in the room including the gain due to the portion of the ventilation air which is bypassed.

Effective Room Total Heat (ERTH) is ERSH + ERLH

**Effective Sensible Heat Factor** (ESHF) is the ratio ERSH/(ERSH + ERLH)

# Define the terms gross sensible heat factor and effective sensible heat factor.

**[May 2015]**

Gross sensible heat factor is defined as the gross sensible heat to the gross total heat. Effective sensible heat factor is defined as the effective room sensible heat to the effective room total heat

# PART – B (C301.5)

1. Explain working of vapour compression refrigeration cycle with neat sketch.

# [Dec2013, Nov 2017, Nov 2018]

1. Explain the working principle of vapour absorption refrigeration cycle with neat sketch. **[Dec 2014, May 2018]**
2. A refrigeration machine is required to produce i.e., 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 a dryness fraction of 0.6. Specific heat of water is 4.187 kJ/kgK and the latent heat of ice is 335 kJ/kg. Calculate the amount of ice produced on 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/kgK) |
| 298 | 59.7 | 138.0 | 0.2232 |
| 268 | 31.4 | 154.0 | 0.1251 |

1. A F12 vapour compression refrigeration system has a condensing temperature of 50 ºC and evaporating temperature of 0ºC. The refrigeration capacity is 7 tons. The liquid leaving the condenser is saturated liquid and compression is isentropic. Determine i)The refrigerant flow rate ii) The power required to run the compressor iii) The heat rejected in the plant and iv) COP of the system use the properties of F12 as listed in the table. **[Nov 2018]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Temp  (ºC) | Pressure  (bar) | hf  (kJ/kg) | hg  (kJ/kg) | Sf  (kJ/kg.K) | Sg  (kJ/kg.K) |
| 50 | 12.199 | 84.868 | 206.298 | 0.3034 | 0.6792 |
| 0 | 36.022 | 187.397 | 187.397 | 0.1418 | 0.6960 |

1. 28 tonnes of ice from and at 0°C is produced per day in an ammonia refrigerator. The temperature range in the compressor is from 25°C to – 15°C. The vapour is dry and saturated at the end of compression and an expansion valve is used. Assuming a co-efficient of performance of 62% of the theoretical, calculate the power required to drive the compressor.
2. An ammonia refrigerator produces 30 tons of ice at 0oC in a day of 24 hours. The temperature range in the compressor is from 25o C to -15oC. The vapour is dry saturated at the end of compression. Assume a COP of 60 % of theoretical value. Find power required to drive compressor. Assume latent heat of ice is 335kJ/kg. For properties of ammonia refer table below: **[May 2013]**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Temperature  (oC) | hf  (kJ/kg) | hg  (kJ/kg) | Sf  (kJ/kgK) | Sg  (kJ/kgK) |
| 25 | 298.9 | 1465.8 | 1.124 | 5.039 |
| -15 | 112.3 | 1426.5 | 1.4572 | 5.549 |

1. The temperature limits of an ammonia refrigeration system are 25o C and -10oC. If the gas is dry at the end of compression, Calculate the COP assumi8ng no-under cooling of the system. The properties of ammonia are given below. **[Dec 2013]**

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature (oC) | Liquid heat  (kJ/kg) | Latent heat  (kJ/kg) | Liquid entropy  (kJ/kgK) |
| 25 | 298.90 | 1166.94 | 1.2420 |
| -10 | 0.5443 | 135.37 | 1297.68 |

1. Explain briefly various absorption systems, and give the comparison vapour compression system and vapour absorption system. **[June 2014]**
2. Explain various types of air conditioning systems with neat sketch.
3. Explain various psychrometric processes with the help of psychrometric chart.

# [Jul 2021]

1. The sling psychrometer in a laboratory test recorded the following readings: Dry bulb temperature = 35°C Wet bulb temperature = 25° Atmospheric pressure = 1.0132 bar Calculate, (i) Specific humidity, (ii) Relative humidity, (iii) Vapour density in air, (iv) Dew point temperature and (v) Enthalpy of mixture per kg of dry air.
2. An air-water vapour mixture enters an air-conditioning unit at a pressure of 1.0 bar. 38°C DBT and a relative humidity of 75%. The mass of dry air entering is 1

kg/s. The air-vapour mixture leaves the air-conditioning unit at 1.0 bar, 18°C, 85% relative humidity. The moisture condensed leaves at 18°C. Determine the heat transfer rate for the process.

1. Saturated air at 3ºC is required to be supplied to a room where the temperature must be held at 22ºC with a relative humidity of 55%. The air is heated and then water at 10ºC is sprayed to give the required humidity. Determine, (i) The mass of spray water required per m3 of air at room conditions.
2. A small-size cooling tower is designed to cool 5.5 liters of water per second, the inlet temperature of which is 44ºC. The motor-driven fan induces 9 m3/s of air through the tower and the power absorbed is 4.75 kW. The air entering the tower is at 18ºC, and has a relative humidity of 60%. The air leaving the tower can be assumed to be saturated and its temperature is 26ºC. Calculate, (i) the amount of cooling water (make-up) required per second. (ii) The final temperature of the water. Assume that the pressure remains constant throughout the tower at 1.013 bar
3. An office is to be air- conditioned for 50 staff when the outdoor conditions are 30o C DBT and 75% RH if the quantity of air supplied is 0.4 m3/ min / person, find the following: (i) Capacity of the cooling coil in tones of refrigeration, (ii) Capacity of the heating coil in kW, (iii) Amount of water vapour removed per hour. Assume that required inlet conditions are 200 C DBT and 60% RH. Air is first conditioned by cooling and dehumidifying and then by heating. Describe the factors that affect human comfort. **[May 2013]**
4. An office is to be air-conditioned for 50 staffs when the outdoor conditions are 30°

C DBT and 75 percentage RH if the quantity of air supplied is 0.4m3/min/person find the following, i) capacity of cooling coil, ii) capacity of heating coil in KW, iii) amount of water vapour removed per hour assume the air inlet conditions are 20° C DBT and 60 percentage RH, air is conditioned first by cooling and dehumidifying and then by heating, and iv) If the heating coil temperature is 25°C, Find the by-pass factor of heating coil. **[June 2014]**

1. Explain the desirable thermodynamics properties and environmental safety

aspects of alternative refrigerants**. [Dec 2014]**

1. Saturated air leaving the cooling section of an air conditioning system at 14°C at the rate of 50 m3/ min is mixed adiabatically with the outside air at 32°C and 60% RH at the rate of 20 m3/ min. assuming that the mixing process occurs at a pressure of 1 atm, determine the specific humidity, the relative humidity, the dry bulb temperature and volume flow rate of the mixture. **[May 2015]**
2. Air at dry bulb temperature of 5oC and relative humidity of 80% is to be heated

and humidified to 24.5 ⁰C and 45% relative humidity, (i) by passing air through heated water spray washer, (ii) by preheating assembly and then passing through water spray washer with recirculated water till relative humidity rises to 95% and then again heated sensibly to final required state. Determine for (i) and (ii) the total heating required. The makeup water required in water spray air washer and humidifying efficiency of the recirculated spray washer. **[Nov 2017]**

1. The following data relates to the office air conditioning plant having maximum seating capacity of 25 occupants :

Outside design conditions = 34ºC DBT, 28ºC WBT

Inside design conditions = 24ºC DBT, 50% Rh

Solar heat gain = 9120 W

latent heat gain per occupant = 105 W

Sensible heat gain per occupant = 90 W

lightening load = 2300 W

Sensible heat load from other sources = 11630 W Infiltration load = 14 m3/min

Assuming 40% fresh air and 60% of recirculated air passing through the evaporator coil and the by-pass factor of 0.15. Estimate the capacity of the plant and the dew point temperature of the coil. **[Jul 2021]**

# PART – C (C301.5)

1. Explain design and working of summer air conditioning for Hot and Dry, Hot and Wet Weather. **[APR/MAY 2018]**
2. An ammonia refrigerator operates between evaporating and condensing temperature of -16°C and 50°C respectively. The vapour is dry saturated at the compressor inlet, the compression process is isentropic and there is no under cooling of the condensate calculate the refrigeration effect per kg, the mass flow and power input per kW of refrigeration and the COP**.**
3. Analyse the implications of high latent heat load on the design of Air conditioning

systems and on the energy efficiency of the overall system. **[May 2017]**

1. A small-size cooling tower is designed to cool 5.5 litres of water per second, the inlet temperature of which is 44ºC. The motor-driven fan induces 9 m3 /s of air through the tower and the power absorbed is 4.75 kW. The air entering the tower is at 18ºC, and has a relative humidity of 60%. The air leaving the tower can be assumed to be saturated and its temperature is 26ºC. Calculate, (i) The amount of cooling water (make-up) required per second. (ii) The final temperature of the water. Assume that the pressure remains constant throughout the tower at 1.013 bar.
2. An air conditioned auditorium is to be maintained at 27ºC dry bulb temperature and 60% relative humidity. The ambient condition is 40ºC dry bulb temperature and 30ºC wet bulb temperature. The total sensible heat load is 100000 kj/h and the total latent heat load is 40000 kj/h. 60% of the return air is recirculated and mixed with 40% of make-up air after the cooling coil. The condition of air leaving the cooling coil is at 18ºC.

Determine the following :

* 1. Room sensible heat factor
  2. The condition of air entering the auditorium
  3. The amount of make-up air
  4. Apparatus dew point

Show the processes on the psychrometric chart. **[Jul 2021]**