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108.3 / 250

Research based Questions. All the Questions are compulsory!

Word Limit in questions should be adhered to.

Section A

1. Answer the following Questions in not more than 150 words. Each Question carries 10 Marks.

A. Discuss the impact of different types of duct fittings (e.g., elbows, reducers, take-offs) on the overall system pressure drop. Explain how the friction and dynamic losses are accounted for during the design process.

Key strengths:

1. The answer correctly identifies the two main components of pressure drop: friction and dynamic losses.

2. The structure is logical, addressing the two parts of the question sequentially with clear headings.

3. The use of bullet points and numbering enhances the readability of the answer.

Areas of improvement:

Introduction:

1. The introduction correctly defines the types of losses but could be more concise for a 10-mark question.

Total pressure drop in a duct system is sum of two distinct types of losses

① friction losses

② Dynamic losses (or minor losses) takes place when air flow changes direction (eg. elbows), velocity (eg. reducers) or cross sectional area (eg. take offs)

Impact of different types of duct fitting.

① Elbows – significantly create a pressure drop across duct.
ex:- 90° elbow bend drops more pressure than 45°

4.2

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Greater the angle, greate pressure drop

(2) Reducers :- cause a relatively small pressure drop as they efficiently accelerate air

(3) Take offs (Branches) used to divert a portion of airflow from a main duct into branch duct.

How friction and dynamic losses are accounted for in design

to ensure the selected fan has enough power to overcome the total system pressure drop

method used

(1) equal friction method

(2) concept of equivalent length

(3) loss coefficient (C) method

these all are method used.

Body:

1. The 'discuss' part of the question is not adequately addressed. For each fitting, explain why the pressure drop occurs. For Elbows, mention flow separation and turbulence as the primary causes of dynamic loss.

2. The explanation for Reducers is too simplistic. It is important to differentiate between a contraction (reduce and an expansion (diffuser), as the latter can cause significant losses if the angle is too steep.

3. For Take-offs, instead of defining them, you should hav explained that they cause significant junction losses, which vary based on the angle and design of the branch connection.

4. The second part of the answer, which requires an 'explanation' of how losses are accounted for, only lists the methods without any explanation. You needed to briefly describe how each method works.

5. For instance, you could explain the Equivalent Length Method as a technique where the dynamic loss from a fitting expressed as the frictional loss of a hypothetical length of straight duct.

6. Similarly, for the Loss Coefficient Method, you shoul have mentioned that it uses a dimensionless factor (K for each fitting to calculate pressure drop using the formu loss directly to the fluid's kinet energy.

Conclusion:

1. The answer lacks a conclusion. A concluding statement is necessary to summarize the key points.

2. A suitable conclusion could be: 'Accurate calculation of these losses i paramount for selecting an appropriately sized fan, ensuring the HVAC system operates at peak energy efficiency ar delivers the required airflow, thereby minimizing operational costs and environmental impact.'

Marks: 4.2 / 10

Answer word count: 140

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Key strengths:

1. The introduction provides a clear and accurate definition of the equal friction method, directly addressing the core concept of the question.

2. The answer is well-structured, logically progressing from definition to procedure and then to advantages and disadvantages, which enhances readability.

3. Including a section on advantages and disadvantages is a good value addition, as it provides a more comprehensive overview of the method.

4. The use of headings, numbered points, and bullet points makes the presentation clear and easy to follow.

B. Briefly explain the 'Equal friction method' of air conditioning duct design procedure.

The equal friction method of air conditioning is standard duct designe approach that aim to maintain a uniform pressure loss per unit length throughout the entire duct system.

Areas of improvement:

Introduction:

1. To make the definition more technically precise, you could mention the typical units used, for instance: 'This method aims to maintain a constant pressure loss, typically expressed in inches of water gauge per 100 feet of duct length.'

Procedure

① Determine a friction rate suitable friction rate select based on the available fan pressure and system's total equivalent length

Body:

1. The 'Procedure' section is too brief and lacks explanatory detail. Each step should be elaborated upon to explain 'how' it is performed.

2. For step 1, specify the typical range for the friction rate, such as 0.08 to 0.15 inches of water gauge per 100 feet for main ducts in commercial applications.

3. For steps 2 and 3, you should explain that duct sizing is performed using tools like a friction loss chart or a ductulator, which correlate airflow (in CFM), friction rate, and duct diameter.

4. In step 4, clarify that 'equivalent length' is used to account for dynamic pressure losses from fittings like elbows, tees, and transitions, not just friction.

② Size the main duct. by this method, select suitable main duct size

3.5

③ Size branch duct by using friction rate for all respective air flow.

(4) accounting for fitting

account for all pressure drop of all types friction and dynamic by using their equivalent length

following are key advantages and disadvantages

(1) Advantages
- simplicity and speed
- Inherent balance
  ↳ as constant friction rate prevent excessive pressure build up
- standard pratice

(2) disadvantages
- oversizing potential
  ↳ leading to higher material costs
- potentially causing audible noise

All are above advantages and disadvantages of this method

Conclusion:

1. The answer ends abruptly after listing disadvantages. A concluding sentence is needed to summarize the method's overall utility.

2. A suitable conclusion could be: 'Despite its potential for oversizing, the equalfriction method remains a widely used and practical approach for designing simple to moderately complex HVAC systems due to its straightforward application and inherent balancing properties.'

Marks: 3.5 / 10

Answer word count: 135

C. Explain the effect of impeller blade shape on the performance of a centrifugal compressor with the help of an exit velocity diagram and pressure ratio mass flow rate curve.

Areas of improvement:

Introduction:

1. To strengthen the introduction, define a centrifugal compressor's impeller and its primary function of transferring kinetic energy to the working fluid.

Impeller blades are usually ~~are~~ 3 types

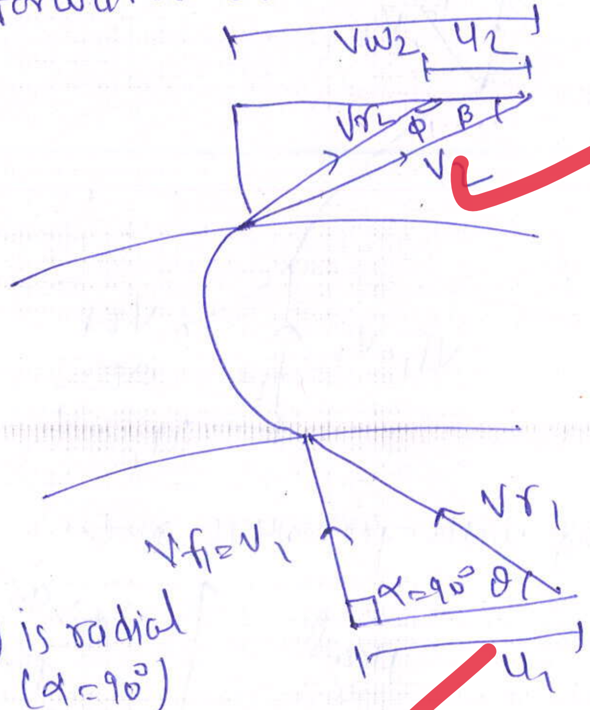
(1) forward curve

(2) Radial

(3) Backward

Velocity triangle

(1) forward curve



$P = \dot{m}(V_{w_2}u_2 - V_{w_1}u_1)$ $[V_{w_1}=0]$

$= \dot{m}V_{w_2}u_2$

4.1

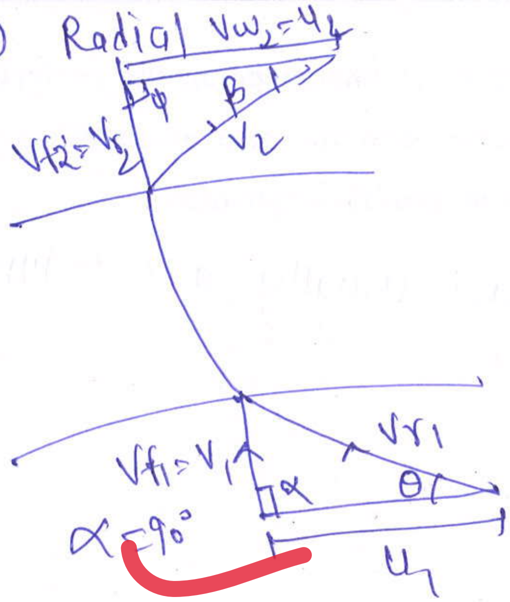
Body:

1. The answer lacks the required explanation. You must explicitly connect the velocity diagrams to the performance curves using the Euler turbomachine equation.

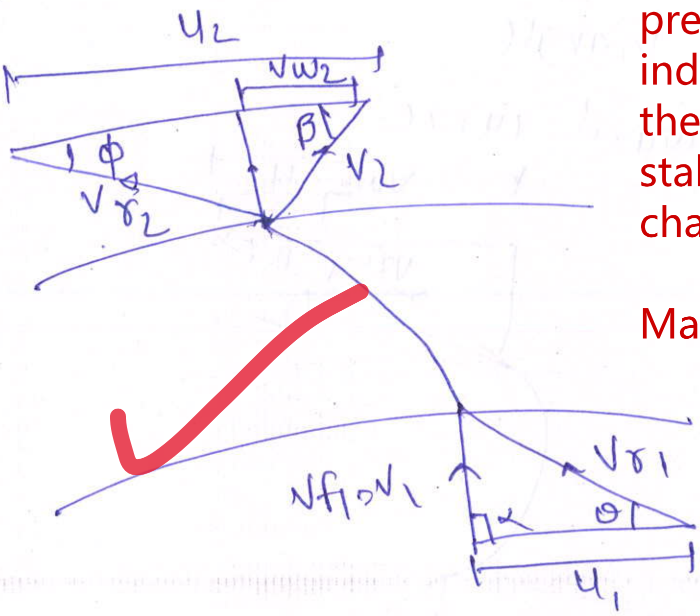
2. Explain how the blade angle (β) affects the whirl velocity (Vw2). For instance, for backward-curved blades (β < 90°), Vw2 is less than the blade speed u2, resulting in a lower pressure head but higher stability.

3. A crucial performance aspect, stability, is missing. You should have explained that the downward-sloping characteristic of the backward-curved blade provides a stable operating range, preventing the phenomenon of 'surging', which is a risk with forward-curved blades.

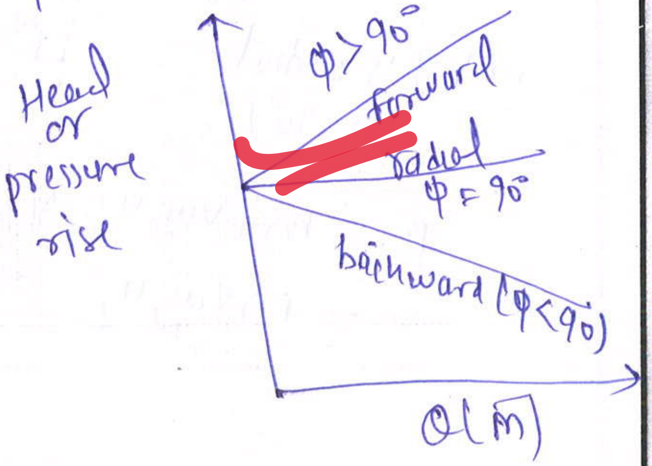
(2) Radial



(3) Backward curved



Relationship with pressure rise



Conclusion:

1. The conclusion could be strengthened by summarizing that despite offering a lower theoretical pressure rise, backward-curved blades are predominantly used in industrial applications due to their superior efficiency and stable, surge-free operating characteristics.

Marks: 4.1 / 10

D. Write in detail including your opinions and views. Discuss the effect of the following parameters on the performance of a vapour compression refrigeration system with the help of p - h diagram.

Key strengths:

1. The answer correctly identifies the impact of each parameter on the refrigeration effect and work input.

2. The use of p-h diagrams for each case is a significant strength, as it directly addresses a core requirement of the question and visually clarifies the thermodynamic changes.

3. The structure is logical, with each parameter discussed separately, making the answer easy to follow.

Vapour compression refrigeration system comprises four stage that includes compression, condensation, expansion and evaporation.

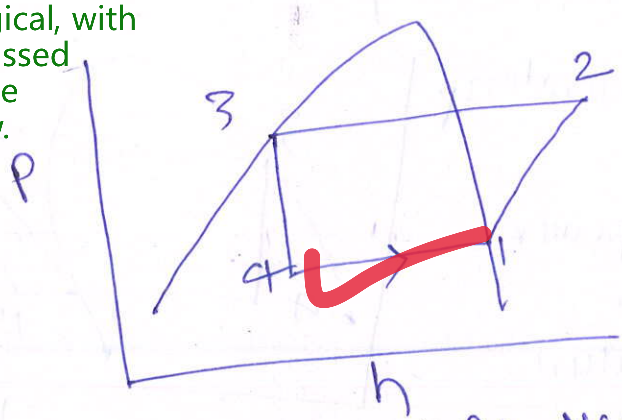


fig :- standard P-h VCRS cycle

Areas of improvement:

introduction:

1. To strengthen the introductio begin by defining the primary performance metric of a VCRS. For example: 'The performance of a Vapour Compression Refrigeration

System (VCRS) is measured by its Coefficient of Performance (COP), defined as the ratio of the refrigeration effect to the work input.'

effect of following parameter on performance

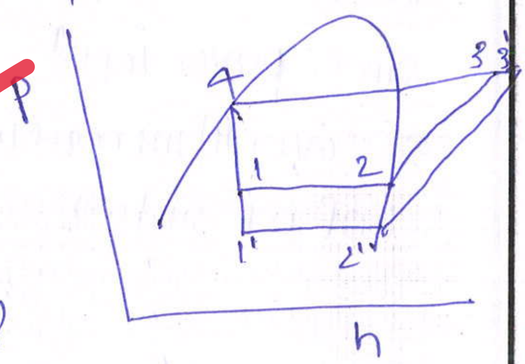
① Reducing evaporator pressure

↓ Refrigeration effect

↑ Power input

~~overall ↓ in COP~~

overall decrease in COP



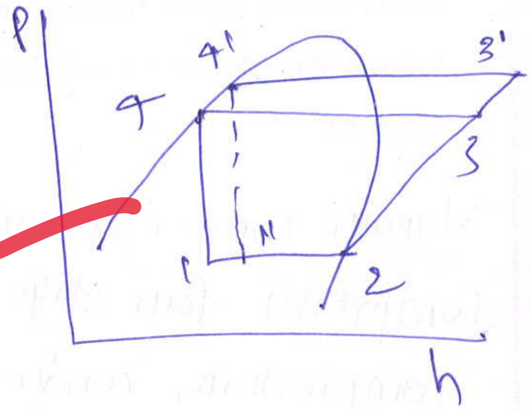
4.2

(2) condenser pressure increase

decrease refrigeration effect

increase in work input

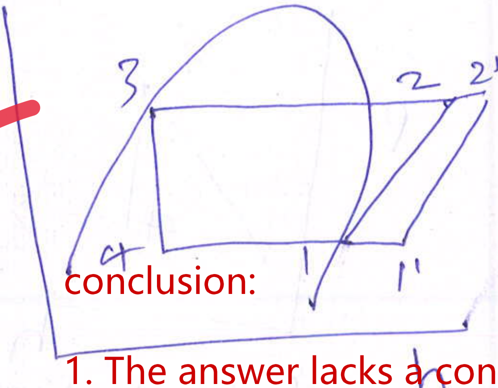
So, COP will reduce



(3) effect of superheating

increase refrigeration effect

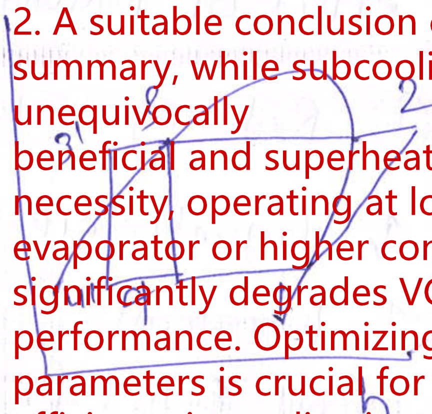
increases in power input due to higher temperature



(4) effect of subcooling

Refrigeration effect increases and same ~~power~~ input

So overall increase in COP of system



Body:

1. The explanations are too brief for a question asking to 'discuss in detail'. Expand the points into full sentences explaining the reasoning. For instance, for 'Reducing evaporator pressure', explain that it increases the pressure ratio, thus increasing the specific work of compression.

2. The discussion on superheating is incomplete. You should state the effect on COP, which can be variable depending on the refrigerant, but also add the practical importance: 'While the effect on COP is marginal, superheating is crucial to ensure that only vapour enters the compressor, preventing damage from liquid slugging.'

3. The directive 'including your opinions and views' was not addressed. This could be fulfilled by adding practical implications. For example, under subcooling, you could add that it is always desirable as it improves COP and reduces flash gas at the expansion valve inlet.

conclusion:

1. The answer lacks a conclusion. A concluding paragraph is needed to summarize the key takeaways.

2. A suitable conclusion could be: 'In summary, while subcooling is unequivocally beneficial and superheating is a practical necessity, operating at lower evaporator or higher condenser pressure significantly degrades VCRS performance. Optimizing these parameters is crucial for enhancing energy efficiency in applications like cold storage and air conditioning, contributing to SDG 7 (Affordable and Clean Energy).'

Marks: 4.2 / 10

E. Explain the difference between sensible heating and cooling, including how each process affects the dry-bulb temperature, specific humidity, and relative humidity of the air.

Introduction:

1. The introduction is concise and directly relevant to the question, which is appropriate for a technical explanation. Need to improve.

Sensible heating and sensible cooling are the process that change the temperature of air without changing its moisture content.

Sensible heating

Body:

1. In the 'sensible cooling' section, you have missed mentioning the effect on relative humidity. To complete the analysis, you should have stated that relative humidity increases as the air temperature drops closer to the dew point.

2. While the differences are implied, a small comparative table could have explicitly highlighted the contrasting effects of heating and cooling on the parameters for greater clarity.

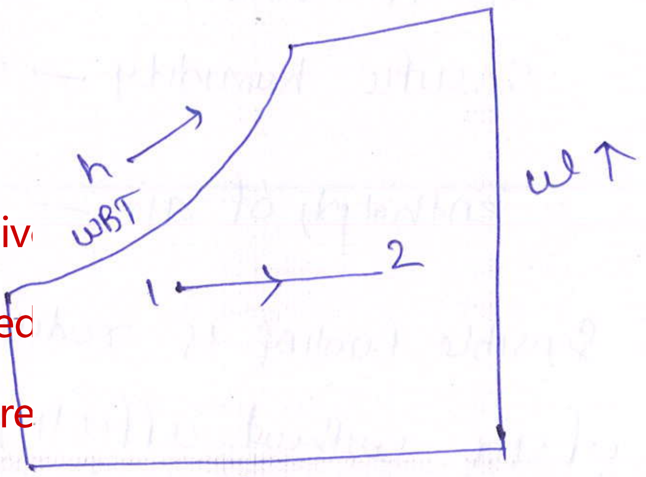


fig:- psychometric chart

Dry bulb temperature – increases
Specific humidity – remains same
relative humidity – decreases
enthalpy of air – increases
Specific volume – increases
heating the air without changing its moisture content

3.6

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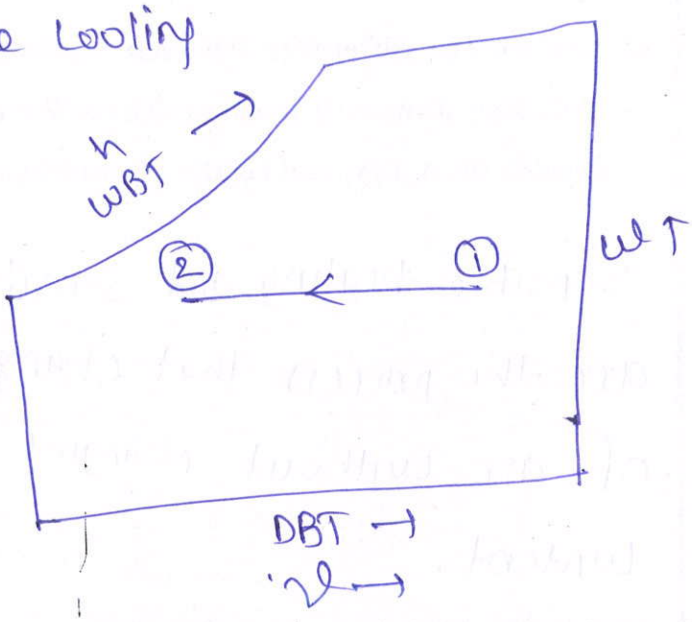
(2) sensible cooling



Dry bulb temperature — decreases
Specific volume — decreases
Specific humidity — remains same
enthalpy of air — decreases

Sensible cooling is reduce temperature of air without affecting its moisture content.

conclusion:

1. The answer ends abruptly. A concluding sentence would provide a more complete structure. For instance, you could add: 'In essence, both processes a the air's energy level and capacity to hold moisture without changing its actua moisture content, making them fundamental concepts in HVAC and meteorology.'

Marks: 3.6 / 10

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2. Answer the following Questions in not more than 250 words. Each Question carries

A. Write in detail including your opinions and views. The amount of air supplied to an air conditioned halls is 300 m3/min. The atmospheric conditions are 35 °C DBT and 55 % RH. The required conditions are 20 °C DBT and 60% RH. Find out the sensible heat and latent heat removed from the air per minute. Also find sensible heat factor for the system. 15 marks

Key strengths:

1. The answer is well-structured for a numerical problem, systematically presenting the given data, formulas, and step-by-step calculations.

2. The use of diagrams to represent the psychrometric process and the system layou is a good practice that enhances clarity.

3. The values for enthalpy (h), specific humidity (w), and specific volume (v) extracted from psychrometric data are accurate for the given conditions.

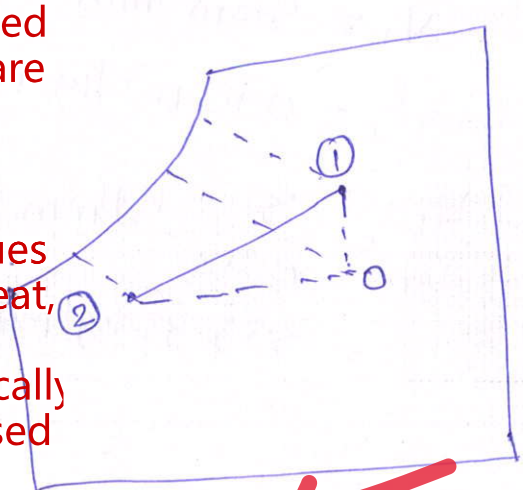
4. The final calculated values for sensible heat, latent heat, and the Sensible Heat Factor (SHF) are arithmetically consistent and correct based on the data used.

Given

atmospheric condition = 35°C DBT
55% RH

Required condition = 20°C DBT
60% RH

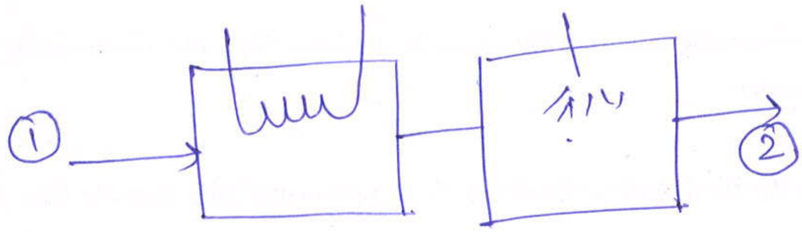
Required conditions are achieved through Cooling and humidification



① = outside condition

② = inside condition

fig :- psychometric chart



Out side condition ①

$\omega_1 = 0.0115$ kg/kg of d.a

$h_1 = 87$ KJ/kg of d.a

$v_1 = 0.90$ m³/kg of d.a

7.8

Room condition ②

$\omega_2 = 0.0088$ kg/kg of d.a

$h_2 = 43$ KJ/kg of d.a

Condition ⓞ

$\omega_0 = 0.0088$ kg/kg of d.a

$h_0 = 58.5$ KJ/kg of d.a

Volume at atmospheric condition

$V_1 = 300 m^3/min$

$v_1 = 0.90 m^3/kg$ of d.a

$m_1 = \frac{V_1}{v_1} = \frac{300}{0.90}$ kg/min

$= 333.33$ kg/min

① ~~Sensible heat removed from air~~

~~$= m_1 (h_0 - h_2)$~~

~~$= 333.33 (87 - 43)$ KJ/min~~ (58.5)

~~$= 14666.66$ KJ/min~~ 9499.905

(or) ~~$= 244.44$ KW~~ 158.33 KW

② latent heat removed

$= m_1 (h_1 - h_0)$

$= 333.33 (87 - 58.5)$ KJ/min

$= 9499.05$ KJ/min [ans]

① sensible heat removed

$= m (h_0 - h_2)$

$= 333.33 (58.5 - 43)$ KJ/min

$= 5166.615$ KJ/min [ans]

③ Sensible heat factor for system

$$SHF = \frac{\text{Sensible heat}}{\text{Sensible heat} + \text{latent heat}}$$

$$= \frac{5166.615}{5166.615 + 9499.05}$$

$= 0.352$ [ans]

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B. Write in detail including your opinions and views. A moist air sample has dry bulb temperature of 30°C and specific humidity of 11.5 gm of water vapour per kg dry air. If the saturation vapour pressure of water at 30°C is 4.24 kPa and the total pressure is 90 kPa then what is the relative humidity of the air sample? 15 marks

Given

DBT = 30°

$\omega = 11.5 \times 10^{-3}$ kg wv/kg da

$P_{vs} = 4.24$ kPa

$P = 90$ kPa

$\phi = ?$

Specific humidity $(\omega) = 11.5 \times 10^{-3}$ kg wv/kg da

$$\frac{m_v}{m_a} = \frac{0.622 P_v}{P - P_v}$$

$$11.5 \times 10^{-3} = \frac{0.622 P_v}{90 - P_v}$$

$$P_v = \frac{90 \times 11.5 \times 10^{-3}}{0.622 + 11.5 \times 10^{-3}}$$

$$= 1.63378 \text{ kPa}$$

Key strengths:

1. The answer demonstrates a strong understanding of the topic by correctly identifying and applying the appropriate formulae for specific and relative humidity.

2. The step-by-step calculation is presented with exceptional clarity, making the entire process logical and easy to follow.

3. All numerical calculations are accurate, leading to the correct final answer.
4. The initial summary of 'Given' data is a good practice that enhances the readability and organization of the solution.

5

Relative humidity (ϕ) $= \frac{P_v}{P_{vs}}$

$= \frac{1.63378}{4.24}$

$= 0.3853$

or $= 38.53\ \%$ ans

conclusion:

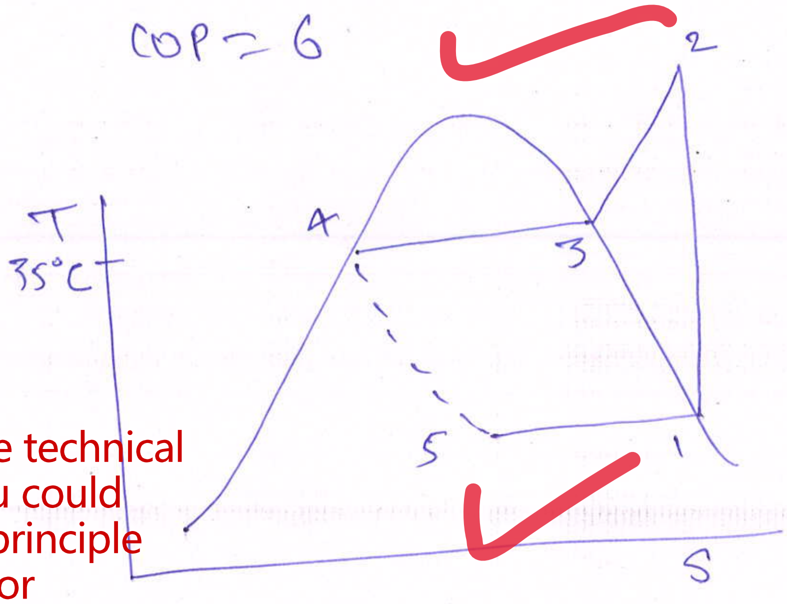
A concluding statement is not expected for a purely computational questi
final answer is sufficient.

C. Write in detail including your opinions and views. A VCR cycle refrigerator driven by a 60 kW compressor ha a COP of 6.0. the enthalpies of saturated liquid and saturated vapour refrigerant at condenser temperature of 35°C are 114.95kj/kg and 283.89kj/kg respectively. The saturated refrigerant vapour leaving evaporator has an enthalpy of 275.76kj/kg. Find the temperature of refrigerant at the exit of compressor. The Cp of refrigerant is 0.62kj/kg - K. 20 marks

Given

$P_{input} = 60\,kW$

$COP = 6$



$h_4 = 114.95\,KJ/kg = h_f$

$h_3 = 283.89\,KJ/kg$

$h_1 = 275.76\,KJ/kg$

$(C_p)_{vapour} = 0.62\,KJ/kg\,K$

Body:

1. To enhance the technical presentation, you could briefly state the principle behind each major calculation, such as 'Applying the energy balance for the compressor (Steady Flow Energy Equation)...'.

2. While the calculation for T2 is correct, explicitly stating the assumption that the process from state 3 to state 2 occurs at constant pressure would add technical rigor to the solution.

→ ∴ $COP = \frac{\text{Desired effect}}{\text{Power input}}$

$6 = \frac{\text{Desired effect (Refrigeration capacity)}}{60}$

$\dot{m}_{ref}(h_1 - h_5) = RC = 6 \times 60$

$m_{ref}(275.76 - 114.95) = 6 \times 60$

$m_{ref} = 2.2386 \text{ kg/sec}$

→ Power input $= \dot{m}(h_2 - h_1) = 60$

$2.2386(h_2 - 275.76) = 60$

$h_2 = 302.56 \text{ kJ/kg}$

5.9

Let temperature at the exit of compressor be T_2

enthalpy of exit of compressor is h_2

So

$h_2 = h_3 + (C_p)_{vapour}(T_2 - T_3)$

$302.56 = 283.69 + 0.62(T_2 - 35°C)$

$T_2 = 65.1155°C$ ans

Temperature at the exit of compressor is 65.11°C

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3. **Answer the following Questions in not more than 250 words. Each Question carries**

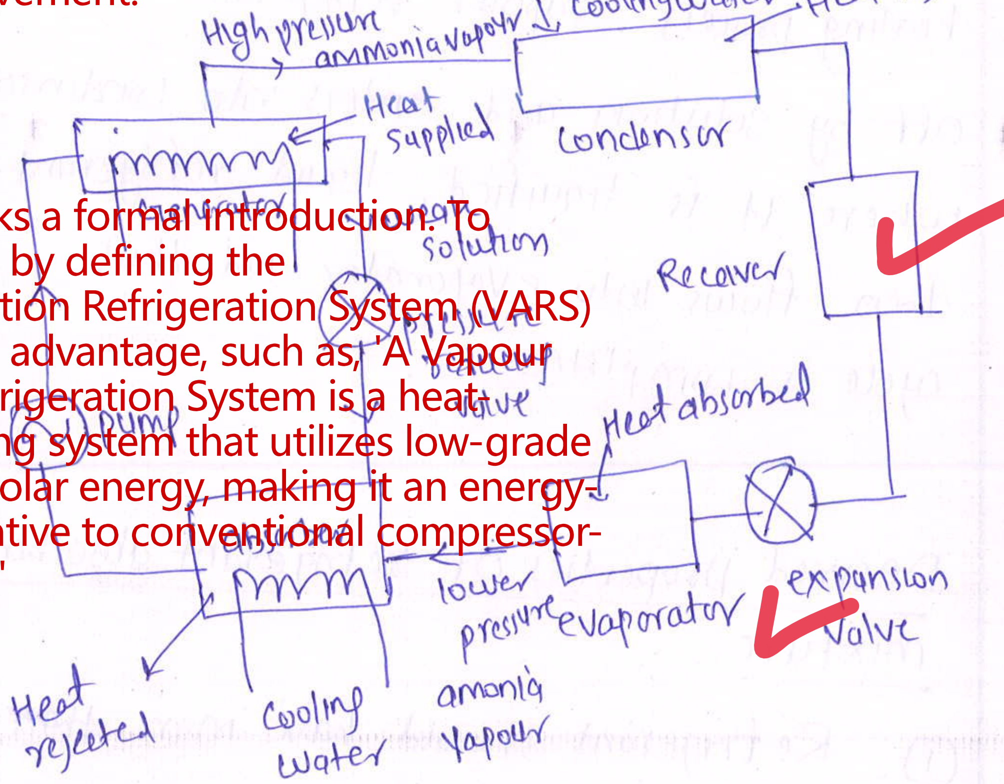
A. **Explain NH3 - water vapour refrigeration system with a neat diagram. What are the desired properties of refrigerant absorber combination? 15 marks**

NH_3 - water vapour refrigeration system

Areas of improvement:

introduction:

The answer lacks a formal introduction. To improve, begin by defining the Vapour Absorption Refrigeration System (VARS) and its primary advantage, such as, 'A Vapour Absorption Refrigeration System is a heat-operated cooling system that utilizes low-grade waste heat or solar energy, making it an energy-efficient alternative to conventional compressor-based systems.'



In. Vapour absorption system, compressor is replaced by an absorber, pump, generator and pressure reducing valve

In this system, vapour refrigerat from the evaporator is drawn into an absorber where it is absorbed by weak solution of refrigerant forming a strong solution. this strong solution is pumped to the generator where it is heated by external source. During heating process. vapour refrigerant is driven off by solution and enters into condenser where it is liquified, liquid refrigerant flows into evaporator and thus cycle is complete

Body:

1. The explanation of the cycle is concise. To add depth, you could briefly mention the practical applications, such as its use in industrial processes where waste heat is abundant, thereby reducing electricity consumption.

2. The points on desired properties could be better organized to avoid repetition. For instance, 'low viscosity' is mentioned in points 3 and 6; these could be consolidated into a single point for better clarity.

3. To enhance the explanation, explicitly differentiate between the 'strong solution' (rich in ammonia) and 'weak solution' (lean in ammonia) in your text to better trace the fluid's journey through the cycle.

Desired properties of refrigerant absorbent mixture

① Refrigerant should have more than Raoult's law solubility in absorbent so that strong solution highly rich in refrigerant is formed in absorber.

② there should be larger difference in normal boiling points of the two substance

7

So, almost absorbent free refrigerant is boiled off from generator.

(3) refrigerant – absorbent mixture – low viscosity to minimise pump work
- low freezing point
- good chemical and thermal stability

(4) refrigerant should have high affinity for absorber at low temp and less affinity at high temp

(5) combination should have high degree of negative deviation from raoult's law

(6) mixture should have low specific heat and low viscosity.

(7) should have low freezing point

Conclusion:

The answer ends abruptly. A forward-looking conclusion would strengthen it. For example, 'By optimizing these properties, VARS technology can significantly enhance energy efficiency in industrial and commercial cooling, contributing to sustainable industrialization and climate action goals (SDG 9 and SDG 13).'

Marks: 7 / 15

Answer word count: 364

Out of many combination, only two combination are commonly used

(1) ammonia-water [NH_3 – refrigerant, H_2O – absorbent]

(2) lithium-bromide water combination [H_2O – refrigerant, LiBr – absorbent]

B. Answer the following: 20 marks

a) Explain the concept of balance point between the compressor and the capillary tube in refrigeration system.

b) Discuss the concept of volumetric efficiency for a reciprocating compressor. Explain how various factors, such as clearance volume, affect the volumetric efficiency.

Key strengths:

1. The explanation of the 'balance point' in part (a) is precise, correctly identifying it as the equilibrium of mass flow rates between the compressor and capillary tube.

2. The use of a diagram (as described) to show the intersection of compressor and capillary tube performance curves is a highly effective method to explain the balance point concept.

3. In part (b), the answer correctly identifies a comprehensive range of factors affecting volumetric efficiency, including clearance volume, pressure ratio, and polytropic index.

(a) Balance point between compressor and capillary tube

this refers to operating condition where mass flow rate of refrigerant passing through both components become equal under steady state pressure.

Areas of improvement:

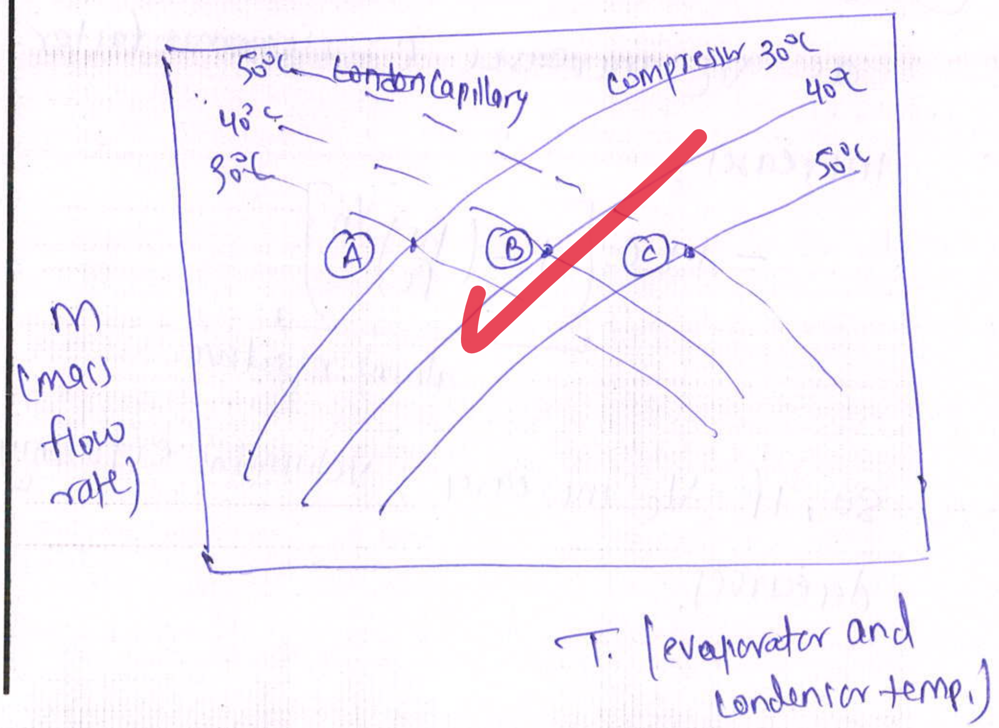
Introduction:

part (a) could begin with 'The stable operation of a refrigeration system depends on the matching of its key components, primarily the compressor and the expansion device.

- compressor moves refrigerant through the system by creating a pressure difference between the evaporator (low pressure) and condenser (High pressure)

- capillary tube acts as an expansion device, reducing refrigerant pressure while offering resistance based on its length and inner diameter.

- flow through capillary tube depends entirely on the pressure difference between condenser and evaporator
- when mass flow rate delivered by compressor matches the rate that capillary tube supplies to the evaporator the system operates at its "balance point". at this moment, the pressure at the condenser and evaporator stabilize, resulting in consistent cooling performance
- If the load changes, balance point shifts.



Body:

1. In part (b), the initial definition of volumetric efficiency is imprecise. A more accurate definitio is the ratio of the actual volume of gas drawn ir the cylinder during suction to the piston displacement volume.

2. In the discussion on pressure ratio, suggestin a 'multi-stage compressor' is more technically accurate than a 'multi-cylinder compressor' for improving efficiency at high-pressure ratios.

3. To visually supplement the explanation in par (b), including a Pressure-Volume (P-V) diagram showing the effect of clearance volume on the actual suction volume would be a significant addition.

(B) Volumetric efficiency

$$\eta_{vol} = \frac{\text{actual mass of air pumped}}{\text{theoretical piston displaced occurred}}$$

$$= \frac{(m_{refri})_{entry\ to\ compressor} \times v}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times K}$$

K = no of cylinder

$$= 1 + C - C\left(\frac{P_H}{P_L}\right)^{1/n}$$

C = clearance factor

$$= \frac{V_c}{V_s}$$

factor affecting volumetric efficiency

(1) clearance volume (V_c)

as V_c increases, C = clearance factor increases,

$$= 1 + C\left[1 - \left(\frac{P_H}{P_L}\right)^{1/n}\right]$$

always negative

So, if V_c increases, volumetric efficiency decreases.

8.8

Date:

Question No.

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Remarks

(2) pressure ratio $\left(\frac{P_H}{P_L}\right)$

if pressure ratio increases then volumetric efficiency decreases, hence multi cylinder reciprocating compressor preffered

(3) poly tropic index (n)

if n decreases then volumetric efficiency decreases.

(4) Higher inlet temperature of air decreases volumetric efficiency

(5) Piston ring leakage will reduce volumetric efficiency.

conclusion:

The answer ends abruptly after listing the factors. A concluding statement for part (b) could summarize the practical importance, such as: 'Maximizing volumetric efficiency is crucial for reducing the power consumption and increasing the capacity of a reciprocating compressor, thereby improving overall system performance.'

Marks: 8.8 / 20

Answer word count: 302

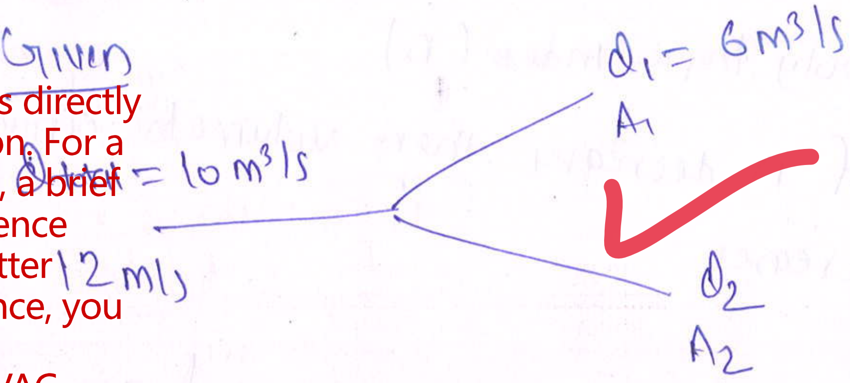
C. An air-conditioning system has a main supply duct carrying a total airflow of 10m3/s at an initial velocity of 12m/s. The duct branches into two smaller ducts. One branch carries 6m3/s of air..Using the principle of conservation of mass, calculate the mean velocity of air in the second branch if its cross-sectional area is known. Assume air density is constant. Discuss how the choice of duct design method (e.g., Equal Friction vs. Static Regain) would affect the sizing of the branches downstream. 15 marks

Areas of improvement:

introduction:

The answer begins directly with the calculation. For a 15-mark question, a brief introductory sentence would provide better context. For instance, you could start with: 'Duct design in HVAC systems is governed by fundamental fluid dynamics principles like mass conservation and utilizes specific sizing methodologies to ensure balanced and efficient air distribution.'

Given



$Q_{total} = Q_1 + Q_2$

$10 = 6 + Q_2$

$Q_2 = 4\ m^3/s$

$Q_1 = A_1 V_1$

$$V_1 = \frac{6}{A_1}$$

$Q_2 = A_2 V_2$

$$V_2 = \frac{4}{A_2}$$

duct design method → affect the sizing of branches downstream

Body:

1. To add more depth to the discussion, you could specify the ideal applications for each method. For example, mention that the Equal Friction method is best suited for simple, symmetrical layouts, whereas the Static Regain method is more energy-efficient for complex systems with long duct runs.

2. You could also explicitly state that in the Static Regain method, the branch with the higher pressure loss (typically the longer one or the one with more fittings) is designed first, and other branches are sized to match its static pressure, thus avoiding oversizing.

① equal friction method

select the duct size so that pressure drop per unit length is constant through out the system

6.7

· Simpler, but may lead to imperfect pressure balance at branches

for our branch ducts, both branches would be sized to have same friction rate, so their velocities may differ if flow rates differ.

· Results in smaller total static pressure fan requirement but may need balancing damper.

(b) Static Regain method

- sizes ducts so that static pressure is regained in downstream section after a branch, by reducing velocity (increasing area).
- aims to have static pressure at each branch inlet nearly equal, minimizing need for dampers.
- main duct before branch would be sized to reduce velocity gradually, branch 2 might have larger diameter relative to equal friction method, to match static pressure at both branch

conclusion:

The answer ends abruptly after discussing the second method. A conclud
statement is needed to summarize the key trade-offs. A suitable conclusi
could be:
'In conclusion, the choice between the Equal Friction and Static Regain methods involves a trade-off between design simplicity and initial cost ve
operational energy efficiency and system balance. The Static Regain meth
though more complex, aligns better with modern energy conservation gc
building infrastructure, contributing to SDG 7 (Affordable and Clean Ener
and SDG 11 (Sustainable Cities and Communities).'

Marks: 6.7 / 15

Answer word count: 190

4. Answer the following Questions in not more than 250 words. Each Question carries

A. A low-velocity HVAC system is being designed for a commercial building. The design specification calls for an Equal Friction Method. Describe the step-by-step procedure to design a simple branched duct system using this method. How would you balance the system to ensure adequate airflow to all terminals? Explain the role of dampers in this process. 15 marks

Areas of improvement:

Introduction:

To enhance the introduction, you could briefly mention the primary advantage of this method, which is it design simplicity, and its main drawback, which is that it is not inherently the most energy-efficient for complex layouts.

Equal friction method is an HVAC duct design technique that maintain a constant friction loss per unit length of ductwork throughout the system. It is commonly used for low-velocity, low-pressure system in commercial building.

Step by step procedure for a branched duct system

① Determine air flow requirements map the supply and return air terminal on floor plan

② sketch the duct layout.

③ choose a suitable friction rate

④ select a suitable size of main duct

⑤ select a size of branch duct

· select the air flow for each branch duct

⑥ account of all fittings and equivalent length

· account of friction and dynamic losses

⑦ account of total pressure loss.

⑧ Select the fan accordingly.

Equal friction method does not inherently balance a system, especially if the duct runs are of unequal length, which is common in branched design.

Body:

1. The step-by-step procedure for the Equal Friction Method lacks the core technical detail. The steps are too generic. A crucial step is missing: 'Using a duct sizing chart or a tool like a Ductulator, determine the friction loss rate (e.g., inches of water gauge per 100 feet) for the main duct. This specific friction rate is then held constant to size all subsequent main and branch duct sections based on their respective airflow requirements.'

2. In the section on balancing, you could add value by mentioning the specific tools used for measurement, such as a capture hood (balometer) or a pitot tube, to demonstrate a more practical understanding.

3. When discussing dampers, you could differentiate between manual balancing dampers, which are set once during commissioning, and automated control dampers (like those in VAV systems) that modulate airflow continuously.

Balancing the system for adequate airflow

(1) before balancing, all dampers should be opened completely to allow maximum flow

(2) take measurement

(3) Identify critical path (longest run) will receive least airflow and is left untouched

(4) adjust the damper on shorter run

(5) Iterate and fine-tune the airflow across all terminals.

Role of dampers in the process

damper, essentially a plate or series of blades, installed inside ductwork to regulate or restrict the flow air.

- Balancing air flow
- mixing air
- Preventing backdraft
- Improving energy efficiency
- ensuring safety.

these all are functions of damper.

6.5

conclusion:

1. The answer ends abruptly and lacks a conclusion. A suitable conclusion could summarize the method's utility for simple, low-velocity systems and reiterate that proper balancing using dampers is critical to achieving the intended design performance, occupant comfort, and energy efficiency.

2. For a futuristic outlook, you could mention that while simple, this method's energy performance can be enhanced with modern variable speed fans, contributing to SDG 7 (Affordable and Clean Energy) in building operations.

Marks: 6.5 / 15

Answer word count: 223

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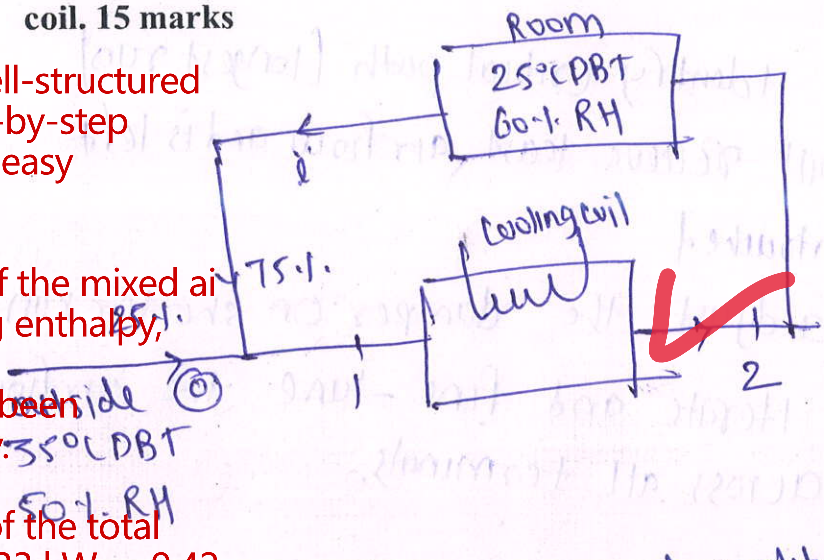
B. For a summer air-conditioning system, the outside air is at 35°C dry-bulb temperature (DBT) and 50% relative humidity (RH). The required room conditions are 25°C DBT and 60% RH. If 25% of the total air supplied to the room is fresh air, and the remaining is recirculated, calculate the sensible heat factor and the refrigeration load of the cooling coil. 15 marks

Key strengths:

1. The answer is well-structured with a logical, step-by-step progression that is easy to follow.

2. The properties of the mixed air (state '1'), including enthalpy, humidity ratio, and temperature, have been calculated correctly.

3. The calculation of the total refrigeration load (33 kW or 9.42 TR) is accurate based on the clearly stated assumption
4. The inclusion of a block diagram is a good practice that enhances the clarity of the process described.



Outside condition (o)
ω_o = 0.0178 kg/kg da
h_o = 82 KJ/Kg da

Inside condition (i)
ω_i = 0.0119 kg/kg da
h_i = 56 KJ/kg da

let assume mass of air circulated to coil is m_1 = 1 kg/s.

So m_o = 0.25 kg/s $\quad m_i$ = 0.75 kg/s

$$\omega_1 = \frac{m_o \omega_o + m_i \omega_i}{m_o + m_i}$$

$$= 0.013375 \text{ kg/kg da}$$

$h_1 = \frac{M_o h_o + M_i h_i}{M_o + M_i}$

$= 62.5$ kJ/kg da

$t_1 = \frac{M_o t_o + M_i t_i}{M_o + M_i}$

$= 27.5°C$ DBT

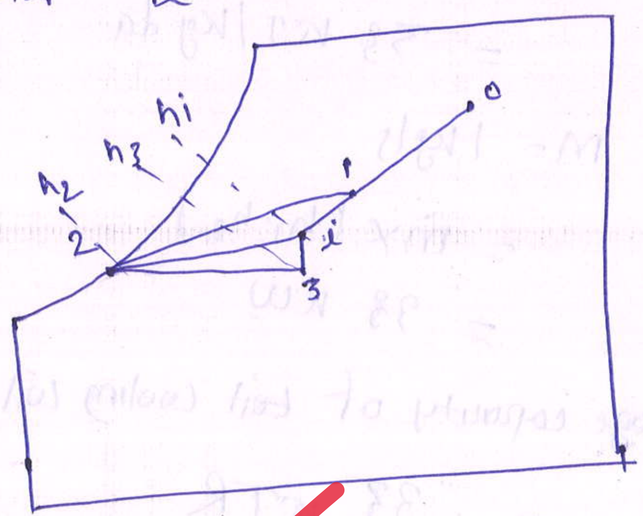
ADP of coil is not given, lets assume ADP of coil as 10°C and by pass factor is 0.

$t_{ADP} = t_2 = 10°C$

$h_{ADP} = h_2 = 29.5$ kJ/kg da

$\omega_{ADP} = \omega_2 = 0.0075$ kg/kg da

7.7



$h_3 = 45$ kJ/kg da

Room sensible heat factor

$$= \frac{RSH}{RSH + RLH}$$

$$= \frac{h_3 - h_2}{h_1 - h_2}$$

$$= \frac{45 - 29.5}{56 - 29.5}$$

$$= 0.5849$$

Cooling coil capacity per kg of air

$$= h_1 - h_2$$

$$= 62.5 - 29.5$$

$$= 33 \text{ KJ/kg da}$$

if $M = 1$ kg/s

$$= \dot{m} \times (h_1 - h_2)$$

$$= 33 \text{ KW}$$

tonnage capacity of ~~coil~~ cooling coil

$$= \frac{33}{3.5} \text{ TR}$$

$$= 9.42 \text{ TR}$$ ans

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C. **Answer the following:** 20 marks

a) "The design of a duct system involves a trade-off between installation cost and operating cost." Justify this statement with respect to the velocity and pressure drop considerations in duct sizing.

b) Derive the expression for the heat rejection ratio of a condenser. Discuss the impact of condenser temperature on the overall performance and COP of a refrigeration system.

design of a duct system involves a tradeoff between installation cost and operating cost primarily through the relation ship between air velocity, pressure drop and duct size

Trade-off

① High velocity, high pressure drop (smaller duct)

- designing for high air velocity allow for smaller, cheaper ducts, which reduces initial installation cost

- smaller cross section are increase resistance

- high pressure drop.

② low velocity, low pressure drop
(larger ducts)

- lower air velocity require larger, more expensive duct
- larger cross section area reduces air-resistance
- lower pressure drop.

Body:

1. To add more technical depth in part (a), you could explicitly. mention the Darcy-Weisbach equation to mathematically ground the relationship betwee pressure drop, velocity, and duct diameter.

2. In part (b), while the s diagram is described, including a simple, labeled T-s diagram would visually support the derivation and analysis, which is a standard practice for such questions.

Velocity and pressure drop consideration

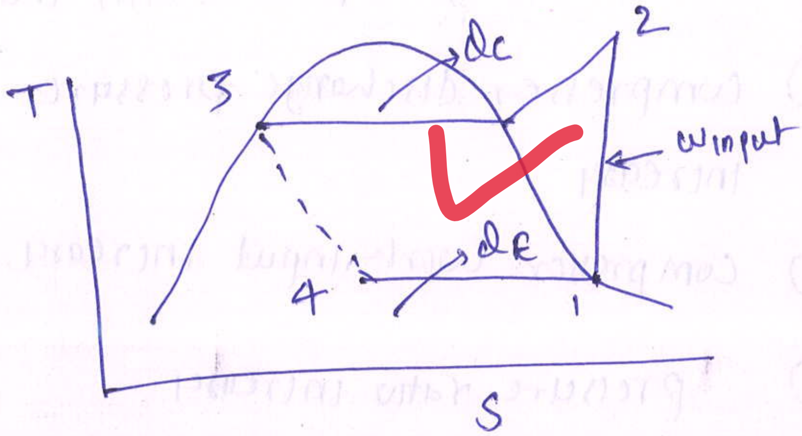
$\Delta P \propto v^2$

small increases in air velocity results in much larger increase in pressure drop.

Velocity	High	Slow
Duct size	smaller	larger
pressure drop	Higher	lower
Installation cost	lower (less material)	Higher (more material)
operating cost	Higher (more fan power)	lower (less fan power)

(B) Heat Rejection ratio (HRR)

$$HRR = \frac{\text{heat rejected in condenser}}{\text{Refrigeration effect}} = \frac{Q_C}{Q_E}$$



From energy balance (neglecting heat loss to surrounding)

7.7

$$Q_C = Q_E + W_{input}$$

$$\frac{Q_C}{Q_E} = 1 + \frac{W_{input}}{Q_E}$$

$$HRR = 1 + \frac{1}{COP}$$

$\therefore COP = \frac{Q_E}{W_{input}}$

$$HRR = 1 + \frac{1}{COP}$$

Impact of condenser temperature on performance

* as condensing temperature (T_H) increases

(1) compressor discharge pressure increases

(2) compressor work input increases

(3) pressure ratio increases

(4) Refrigeration effect decreases

(5) COP decreases because W_{input} ↑ and RE ↓ (50) COP ↓

$HRR = 1 + \frac{1}{COP}$

So relationship crucial in designing.

Conclusion:

The answer lacks concluding statements for either part. A summary sentence would provide a better sense of closure. For part (b), a suitable conclusion wo[u]
'Therefore, optimizing condenser temperature is a key strategy for enhancing the energy efficiency and operational effectiveness of refrigeration systems, directly impacting sustainability goals like SDG 7 (Affordable and Clean Energy).'

Marks: 7.7 / 20

Answer word count: 240

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5. **Answer the following Questions in not more than 150 words. Each Question carries.**

A. A mixture of air and water vapor is cooled below its dew-point temperature. Explain what happens to the air in this process, including the role of the apparatus dew point temperature

Areas of improvement:

introduction:

To enhance the introduction, you could begin with a precise definition: 'The dew-point is the temperature to which air must be cooled to become saturated with water vapor, assuming constant air pressure and water content.'

When a mixture of air and water is cooled below its dew-point temperature, the air becomes saturated and condensation occurs.

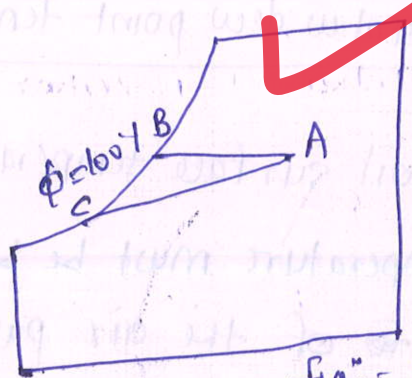

fig:- psychometric chart

AB - sensible cooling

AC - cooling and dehumidification

What happens to the air

(1) Saturation is reached

↳ air becomes 100% saturated

(2) Condensation occurs

↳ Cooling below its dew-point then condensation occurs.

5

③ Release of ga~~s~~ energy
↳ phase change water vapour (gas) to liquid water is exothermic process, release of latent heat

④ Dehumidification
↳ Moisture is removed from air in this process, humidity ratio decreases.

Role of apparatus dew point temperature (ADP)

① It is coil surface temperature
surface temperature must be below the dew point ~~fo~~ of the air passing over it for ~~form~~ condensation to occur.

② By pass factor – describes fraction of air that does not comes into contact with cooling coil's surface

Hence, cooling & then condensation at dew point temperature will occure.

Body:

1. While the mention of the bypass factor is a strength, you could briefly elaborate on its implication, for instance, by stating that the final air temperature is a mix of air cooled to the ADP and the bypassed air.

2. For a 15-mark question, each point could be explained in a complete sentence
rather than using short phrases to add more depth to the explanation.

conclusion:

The answer ends abruptly. A forward-looking conclusion would strengthen it significantly. For example: 'This process of cooling and dehumidification is the fundamental principle behind modern air conditioning and refrigeration systems, which are critical for ensuring human comfort, food preservation, and various industrial processes, thereby contributing to sustainable infrastructure (SDG 9).'

Marks: 5 / 10

Answer word count: 184

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B. Explain the concept of "effective temperature" and its use in determining human thermal comfort.

Effective temperature is single value that represents the combined sensory effect of air temperature, humidity and air movement on the human body's sensation of warmth or cold.

Factors incorporated into effective temperature

(1) Air temperature – dry bulb temperature which is temperature of air around the body

(2) Humidity :- amount of water vapor in the air. High humidity hinders the body's ability to cool itself through sweat evaporation, making a person feel warmer

(3) Air movement – speed of air moving past the body. Increased air movement can enhance heat loss by convection create a cooling effect

Body:

1. The section on the 'use' of effective temperature can be expanded with specific applications. You could mention its role in designing energy-efficient HVAC (Heating, Ventilation, and Air Conditioning) systems, in urban planning to mitigate the Urban Heat Island effect, and in setting occupational health and safety standards.

2. To add technical depth, you could briefly mention the two key personal factors that influence thermal comfort: metabolic rate (related to activity level) and clothing insulation (measured in 'clo' units).

3. Consider mentioning Mean Radiant Temperature (MRT) as another crucial environmental factor that modern thermal comfort models, like the PMV/PPD model, incorporate alongside the three you listed.

5.5

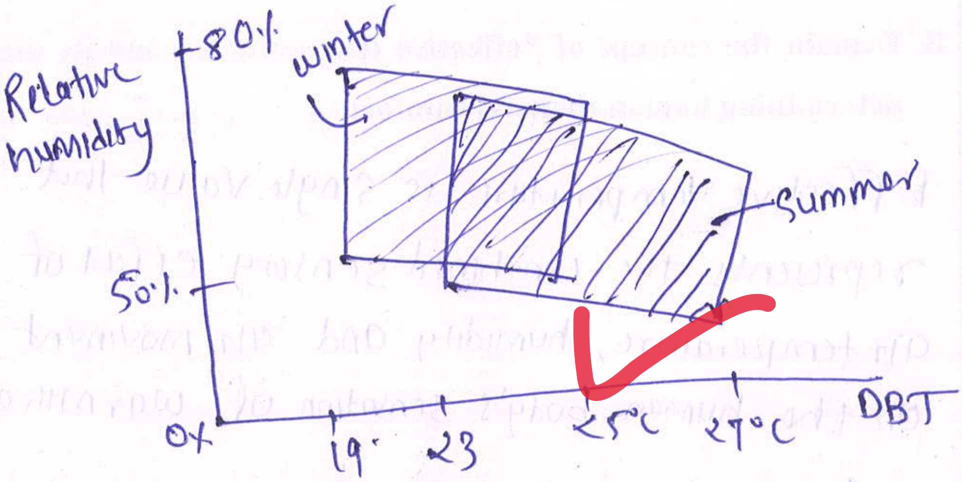


fig:- comfort zone diagram in different season.

Effective temperature is used to establish the comfort zone for most of people comfort chart zone shows, the range of condition considered comfortable for a majority of people

Charts shows humidity decreases, a higher air temperature can be tolerated while maintaining the same effective temperature

optimum effective temperature varies based on factor like climate and personal characteristic like clothing, age and activity level

Conclusion:

The answer currently lacks a conclusion. A forward-looking conclusion would strengthen the answer significantly. For example: 'Ultimately, the application effective temperature concept is crucial for creating sustainable and healthy built environments, directly contributing to the achievement of Sustainable Development Goal 11 (Sustainable Cities and Communities) and SDG 3 (Goo Health and Well-being).'

Marks: 5.5 / 10

Answer word count: 228

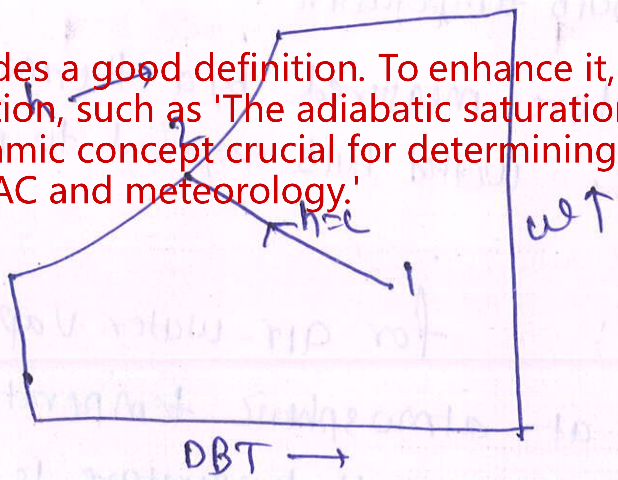
C. Describe the adiabatic saturation process. Explain how the wet-bulb temperature is related to the adiabatic saturation temperature and the significance of this relationship.

Adiabatic saturation process involves the cooling air till its saturation point ($\phi = 100\%$) along its constant enthalpy line.

Areas of improvement:

introduction:

1. The introduction provides a good definition. To enhance it, you could brief the context of its application, such as 'The adiabatic saturation process is a fundamental thermodynamic concept crucial for determining the properties moist air in fields like HVAC and meteorology.'



process 1-2 is shows as adiabatic saturation process where it reaches the saturation level. but the process involves the constant enthalpy of air. while maintaining the constant wet bulb temperature of air. and decreasing its dry bulb temperature of air.

5

Body:

1. The answer completely omits the third part of the question, which asks for the 'significance of this relationship'. This is a major gap in the content.

2. To address the missing part, you should have included a dedicated section on significance. For example, explain that the key significance is practical: it allows the easily measurable Wet Bulb Temperature (WBT) to be used as a direct substitute for the theoretical Adiabatic Saturation Temperature (AST) in psychrometric calculations.

3. You could further elaborate on the significance by mentioning its application in using a sling psychrometer and a psychrometric chart to easily determine other air properties like relative humidity, enthalpy, and specific humidity, which is vital for designing air conditioning and drying systems.

Relationship between wet bulb temperature and adiabatic ~~temper~~ Saturation temperature

- Adiabatic saturation temperature – theoretical temperature of air reaches when it is adiabatically humidified to 100% saturation

- Wet bulb temperature : equilibrium temperature measured by a thermometer with the wetted bulb exposed to moving air

for air-water vapour mixture at atmospheric temperature and pressure - wet bulb temperature is approximately equal to the adiabatic saturation temperature

physical reason for being the same is that both ~~fundamental~~ ~~process~~ process the process are governed by the same fundamental heat and mass transfer phenomenon

sensible heat lost by air is equal to the latent heat gained by the water vapor evaporating into it

Conclusion:

1. The answer lacks a concluding statement. A conclusion is necessary to summarize the answer's key points and provide a forward looking perspective.

2. A suitable conclusion could be: 'Ultimately, the congruence between the wet- bulb and adiabatic saturation temperatures is a cornerstone of psychrometry, enabling the practical design and optimization of systems for air conditioning, cooling towers, and industrial drying. This contributes to greater energy efficiency and process control, aligning with goals of sustainable industrial practices (SDG 9).'

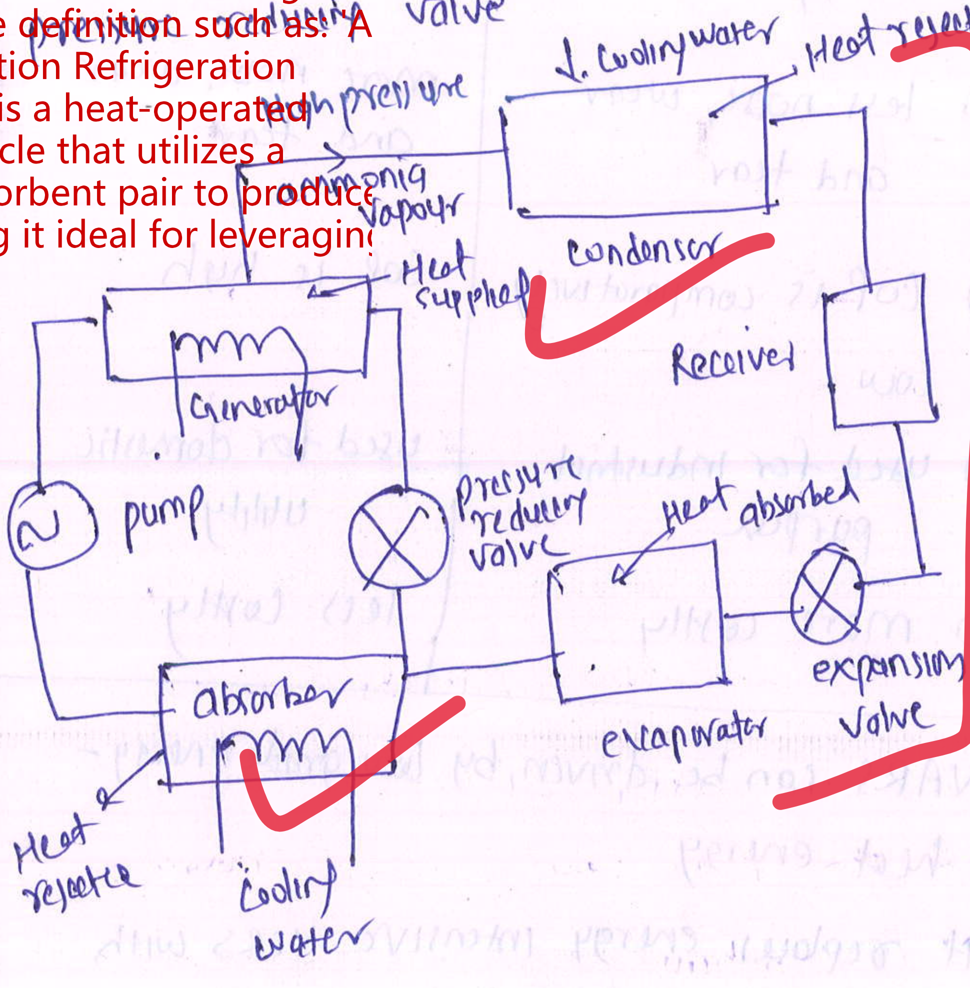
Marks: 5 / 10

Answer word count: 206

D. Explain the working principle of a simple vapor absorption refrigeration system (VARS) with a neat schematic diagram. Compare and contrast its working with a vapor compression refrigeration system (VCRS), explaining why the VARS can be driven by low-grade energy.

In Vapour absorption system, compressor is replaced by an absorber, pump, generator and pressure reducing valve

To improve the introduction, begin with a clear, one-line definition such as: 'A Vapour Absorption Refrigeration System (VARS) is a heat-operated refrigeration cycle that utilizes a refrigerant-absorbent pair to produce cooling, making it ideal for leveraging waste heat.'



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Core principle of VARS is to produce a cooling effect by using thermal compressor instead of a mechanical one.

Comparison VARS and VCRS system

VARS	VCRS
(1) thermal compression	mechanical compression
(2) use of low grade energy - Heat energy	use of high grade energy - electricity
(3) less noise, wear and tear	more noise, wear and tear
(4) CoP is comparatively low	CoP is high
(5) used for industrial purpose	used for domestic utility
(6) more costly	less costly

conclusion:

The conclusion currently restates a point from the body. A more impactful conclusion would be forward-looking. For example: 'By effectively utilizin grade energy sources, VARS offers a sustainable pathway for cooling applications, reducing reliance on fossil fuel-based electricity and contribu to goals of energy efficiency and circular economy, thereby aligning with (Affordable and Clean Energy) and SDG 13 (Climate Action).'

Marks: 5 / 10

VARS can be driven by low grade energy - waste energy

It replaces energy intensive VCRS with thermal compressor, since it can operate with low-temperature heat and require very little mechanical work.

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introduction:

The answer begins directly with the purpose, which is acceptable. To enhance it, you could frame it within the context of the refrigeration cycle, for example: 'The expansion device, a critical component situated between the condenser and the evaporator in a refrigeration system, serves two primary functions...'

E. What is the purpose of an expansion device in a refrigeration system? Explain the throttling process using T-s and p-h diagrams, and state its key assumptions.

Primary purpose of an expansion device is to create a pressure drop and to regulate refrigerant flow.

Throttling process

It is an expansion process irreversible adiabatic pressure drop.

- High pressure, medium temperature liquid refrigerant enter the valve
- forced through small orifice causing pressure drop
- low pressure, low temperature liquid-vapor mixture exits the valve and enters the evaporator

5.1

throttling process involves the constant enthalphy.

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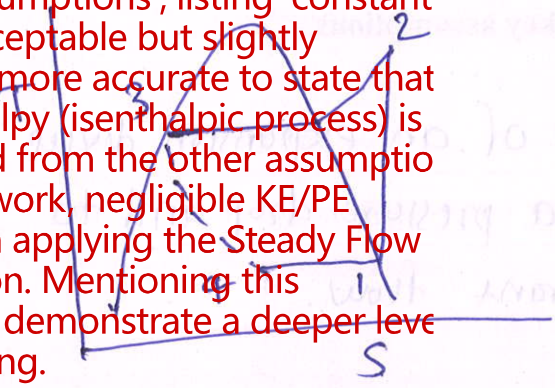
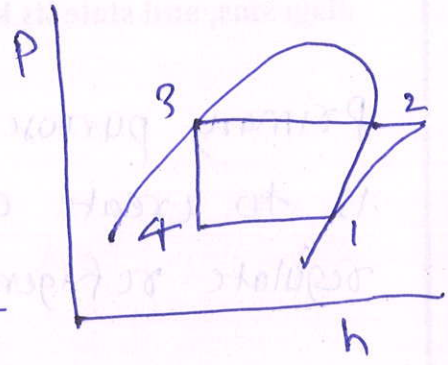
Remarks

Body:

process shown on T-s and p-h diagram.





Under 'Key assumptions', listing 'constant enthalpy' is acceptable but slightly imprecise. It is more accurate to state that constant enthalpy (isenthalpic process) is a result derived from the other assumptio (adiabatic, no work, negligible KE/PE changes) when applying the Steady Flow Energy Equation. Mentioning this distinction can demonstrate a deeper leve of understanding.

process 3-4 is throttling process, where enthalpy of refrigerant is constant.

Key assumptions

① adiabatic process - no heat transfer

② constant enthalpy

③ no work interaction
↳ no shaft work

④ negligible KE and PE changes.

follows ...

major assumption

conclusion:

1. The answer lacks a conclusion and ends abruptly. A concluding statement provide a sense of completeness. For instance: 'Thus, the throttling process is essential irreversible expansion that facilitates the sharp drop in temperature and pressure, preparing the refrigerant for effective heat absorption in the evaporator and enabling the entire cooling function of the refrigeration cycle

Marks: 5.1 / 10

Answer word count: 166

Worksheet: