Assignment – 6

Topic: Refrigeration & Air Conditioning.

(**Disclaimer:** The purpose of these AI-generated responses is just education and reference. Utilise them to grasp topics and structure, but always rewrite in your own words and double-check the content before submitting.)

Q-1: A single stage reciprocating compressor takes 1 m³ of air per minute at 1.013 bar and 288 K and delivers it at 7 bar. Assuming that the law of compression is $PV^{1.35} = C$ and the clearance is negligible, calculate (i) the mass delivered/min, (ii) delivery temperature, (iii) indicated power and (iv) isothermal efficiency.

Answer:

Given:

- Suction volume, $V_1 = 1 \text{ m}^3/\text{min}$
- Suction pressure, $p_1 = 1.013 \text{ bar}$
- Suction temperature, $T_1 = 288 \text{ K}$
- Delivery pressure, $p_2 = 7 \text{ bar}$
- Polytropic index, $n = 1.35$
- Clearance = negligible
- For air,

Step 1: Find Mass Delivered per minute (m)

$$m = \frac{p_1 V_1}{RT_1}$$

Ensure units: $p_1 = 1.013 \text{ bar} = 101.3 \text{ kPa}$

$$m = \frac{101.3 \times 1}{0.287 \times 288}$$

$$m = \frac{101.3}{82.656} = 1.225 \text{ kg/min}$$

∴ **(i) Mass delivered/min = 1.225 kg/min**

Step 2: Find Delivery Temperature (T_2)

For polytropic process: $\frac{T_2}{T_1} = (\frac{p_2}{p_1})^{\frac{n-1}{n}}$

$$\frac{T_2}{288} = (\frac{7}{1.013})^{\frac{0.35}{1.35}}$$
$$\frac{T_2}{288} = (6.910)^{\frac{0.35}{1.35}}$$
$$\frac{T_2}{288} = (6.910)^{0.25926}$$
$$(6.910)^{0.25926} \approx 1.62$$
$$T_2 = 288 \times 1.62 = 466.56 \text{ K}$$

∴ **(ii) Delivery Temperature,** $T_2 = 466.56 \text{ K } (193.56^{\circ}\text{C})$

Step 3: Find Indicated Power (IP)

The work done for polytropic compression (neglecting clearance) is:

$$W = \frac{n}{n-1} mR(T_2 - T_1)$$

First, convert mass flow rate to kg/s: $m = \frac{1.225}{60} = 0.020417 \text{ kg/s}$

$$W = \frac{1.35}{0.35} \times 0.020417 \times 0.287 \times (466.56 - 288)$$
$$W = 3.857 \times 0.020417 \times 0.287 \times 178.56$$
$$W = 3.857 \times 0.005857 \times 178.56$$
$$W = 3.857 \times 1.0456 = 4.033 \text{ kJ/s} = 4.033 \text{ kW}$$

∴ **(iii) Indicated Power = 4.033 kW**

Step 4: Find Isothermal Efficiency (η_iso)

Isothermal work is given by:

$$W_{iso} = mRT_1 \ln (\frac{p_2}{p_1})$$
$$W_{iso} = 0.020417 \times 0.287 \times 288 \times \ln (\frac{7}{1.013})$$
$$W_{iso} = 0.020417 \times 0.287 \times 288 \times \ln (6.910)$$
$$W_{iso} = 1.687 \times 1.933 = 3.261 \text{ kJ/s} = 3.261 \text{ kW}$$

Isothermal Efficiency is:

$$\eta_{iso} = \frac{W_{iso}}{W_{actual}} = \frac{3.261}{4.033} = 0.8086$$

∴ **(iv) Isothermal Efficiency = 80.86%**

Final Answers for Q-1 (a):
(i) Mass delivered/min = **1.225 kg/min**
(ii) Delivery Temperature = **466.56 K**
(iii) Indicated Power = **4.033 kW**
(iv) Isothermal Efficiency = **80.86%**

Q-2: A single cylinder, single acting air compressor has a cylinder diameter 150 mm and stroke length 300 mm. It draws air into its cylinder at a pressure of 1 bar and temperature 27°C. This air is then compressed to a pressure of 6.5 bar. If the compressor runs at a speed of 120 RPM determine (i) mass of air compressed / cycle (2) work required / cycle (3) Power required to drive the compressor if the compressor is adiabatic.

Answer:

Given:

- Bore, $D = 150 \text{ mm} = 0.15 \text{ m}$
- Stroke, $L = 300 \text{ mm} = 0.3 \text{ m}$
- Suction pressure, $p_1 = 1 \text{ bar} = 100 \text{ kPa}$
- Suction temperature, $T_1 = 27 + 273 = 300 \text{ K}$
- Delivery pressure, $p_2 = 6.5 \text{ bar}$
- Speed, $N = 120 \text{ RPM}$
- Compression is adiabatic, so $\gamma = 1.4$
- For air,
- Single cylinder, single acting. For single acting, power cycles per minute = N.

Step 1: Find Swept Volume per cycle (V_s)

$$V_s = \frac{\pi}{4} D^2 L$$
$$V_s = \frac{\pi}{4} (0.15)^2 (0.3)$$
$$V_s = 0.7854 \times 0.0225 \times 0.3 = 0.005301 \text{ m}^3$$

Step 2: Find Mass of air compressed per cycle (m)

Assuming the cylinder draws in its full swept volume of air at suction conditions.

$$m = \frac{p_1 V_s}{RT_1}$$
$$m = \frac{100 \times 0.005301}{0.287 \times 300}$$
$$m = \frac{0.5301}{86.1} = 0.006157 \text{ kg/cycle}$$

∴ **(i) Mass of air compressed/cycle = 0.006157 kg**

Step 3: Find Work required per cycle (W_cycle)

For adiabatic compression, work done per kg is:

$$W = \frac{\gamma}{\gamma - 1} RT_1[(\frac{p_2}{p_1})^{\frac{\gamma-1}{\gamma}} - 1]$$

First, find the temperature at the end of compression (T_2).

$$\frac{T_2}{T_1} = (\frac{p_2}{p_1})^{\frac{\gamma-1}{\gamma}}$$
$$\frac{T_2}{300} = (\frac{6.5}{1})^{\frac{0.4}{1.4}}$$
$$\frac{T_2}{300} = (6.5)^{0.2857}$$
$$(6.5)^{0.2857} \approx 1.743$$
$$T_2 = 300 \times 1.743 = 522.9 \text{ K}$$

Now, work per kg:

$$W = \frac{1.4}{0.4} \times 0.287 \times 300 \times (1.743 - 1)$$
$$W = 3.5 \times 86.1 \times 0.743$$
$$W = 3.5 \times 63.97 = 223.9 \text{ kJ/kg}$$

Work per cycle:

$$W_{cycle} = m \times W = 0.006157 \times 223.9 = 1.378 \text{ kJ/cycle}$$

∴ **(ii) Work required/cycle = 1.378 kJ**

Step 4: Find Power Required (P)

For a single-acting compressor:

$$\text{Power} = \frac{W_{cycle} \cdot N}{60}$$
$$P = \frac{1.378 \times 120}{60} = \frac{165.36}{60} = 2.756 \text{ kW}$$

∴ **(iii) Power Required = 2.756 kW**

Final Answers for Q-2:
(i) Mass of air compressed/cycle = **0.00616 kg**
(ii) Work required/cycle = **1.378 kJ**
(iii) Power Required = **2.756 kW**

Q-3: Air is to be compressed in a single stage reciprocating compressor from 1.013 bar and 15°C to 7 bar. Calculate the indicated power required for a free air delivery of 0.3 m³/min when the compression process is:
(i) Isentropic
(ii) Reversible isothermal
(iii) Polytropic with n = 1.25.
What will be the delivery temperature in each case? Neglect clearance.

Answer:

Given:

- Suction pressure, $p_1 = 1.013$ bar
- Suction temperature, $T_1 = 15 + 273 = 288$ K
- Delivery pressure, $p_2 = 7$ bar
- Free Air Delivery (FAD), $\dot{V}_1 = 0.3$ m³/min $= 0.005$ m³/s
- For air,

First, find the mass flow rate using FAD conditions (p_1, T_1):

$$\dot{m} = \frac{p_1 \dot{V}_1}{RT_1} = \frac{101.3 \times 0.005}{0.287 \times 288} = \frac{0.5065}{82.656} = 0.006126 \text{ kg/s}$$

Part (i) Isentropic Compression ($\gamma = 1.4$)

Step 1: Delivery Temperature (T_2)

$$\frac{T_2}{T_1} = (\frac{p_2}{p_1})^{\frac{\gamma-1}{\gamma}} = (\frac{7}{1.013})^{\frac{0.4}{1.4}} = (6.910)^{0.2857}$$
$$(6.910)^{0.2857} \approx 1.745$$
$$T_2 = 288 \times 1.745 = 502.56 \text{ K}$$

∴ **Delivery Temperature = 502.56 K (229.56°C)**

Step 2: Indicated Power (IP)

$$W = \frac{\gamma}{\gamma - 1} \dot{m} R (T_2 - T_1)$$
$$W = \frac{1.4}{0.4} \times 0.006126 \times 0.287 \times (502.56 - 288)$$
$$W = 3.5 \times 0.001757 \times 214.56$$
$$W = 3.5 \times 0.3769 = 1.319 \text{ kW}$$

∴ Indicated Power = 1.319 kW

Part (ii) Reversible Isothermal Compression

Step 1: Delivery Temperature (T_2)

For isothermal compression, $T_2 = T_1$
∴ Delivery Temperature = 288 K (15°C)

Step 2: Indicated Power (IP)

$$W = \dot{m} R T_1 \ln\left(\frac{p_2}{p_1}\right)$$
$$W = 0.006126 \times 0.287 \times 288 \times \ln(6.910)$$
$$W = 0.5065 \times 1.933 = 0.979 \text{ kW}$$

∴ Indicated Power = 0.979 kW

Part (iii) Polytropic Compression ($n = 1.25$)

Step 1: Delivery Temperature (T_2)

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} = \left(\frac{7}{1.013}\right)^{\frac{0.25}{1.25}} = (6.910)^{0.2}$$
$$(6.910)^{0.2} \approx 1.527$$
$$T_2 = 288 \times 1.527 = 439.78 \text{ K}$$

∴ Delivery Temperature = 439.78 K (166.78°C)

Step 2: Indicated Power (IP)

$$W = \frac{n}{n - 1} \dot{m} R (T_2 - T_1)$$
$$W = \frac{1.25}{0.25} \times 0.006126 \times 0.287 \times (439.78 - 288)$$
$$W = 5 \times 0.001757 \times 151.78$$
$$W = 5 \times 0.2666 = 1.333 \text{ kW}$$

∴ Indicated Power = 1.333 kW

Final Answers for Q-3:

Compression Process	Delivery Temperature	Indicated Power
(i) Isentropic	502.56 K (229.56°C)	1.319 kW
(ii) Isothermal	288 K (15°C)	0.979 kW
(iii) Polytropic (n=1.25)	439.78 K (166.78°C)	1.333 kW

Q-4: The following data are available for a single stage single acting reciprocating compressor without clearance.
Atmospheric air ... 1 bar, 27°C
Discharge Pressure ... 7 bar
Law of compression and expansion = $PV^{1.3} = C$
Compressor takes 1 m^3 of air/min.
Speed of the compressor = 300 RPM
L/D = 1.5
Mechanical efficiency = 85%
Motor transmission efficiency = 90%
Calculate (1) Indicated power (2) Isothermal efficiency (3) Cylinder dimensions (4) Motor power

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Answer:

Given:

- $p_1 = 1 \text{ bar}, T_1 = 300 \text{ K}$
- $p_2 = 7 \text{ bar}$
- $n = 1.3$
- $\dot{V}_1 = 1 \text{ m}^3\text{/min}$
- $N = 300 \text{ RPM}$
- $L/D = 1.5$
- $\eta_m = 0.85$
- $\eta_{trans} = 0.90$
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Step 1: Find Mass Flow Rate ($\dot{m}$)

$$\dot{m} = \frac{p_1\dot{V}_1}{RT_1} = \frac{100 \times 1}{0.287 \times 300} = \frac{100}{86.1} = 1.161 \text{ kg/min} = 0.01935 \text{ kg/s}$$

Step 2: Find Indicated Power (IP)

First, find delivery temperature T_2.

$$\frac{T_2}{T_1} = (\frac{p_2}{p_1})^{\frac{n-1}{n}} = (\frac{7}{1})^{\frac{0.3}{1.3}} = (7)^{0.23077}$$
$$(7)^{0.23077} \approx 1.544$$
$$T_2 = 300 \times 1.544 = 463.2 \text{ K}$$

Now, calculate indicated power:

$$IP = \frac{n}{n-1}\dot{m}R(T_2 - T_1)$$
$$IP = \frac{1.3}{0.3} \times 0.01935 \times 0.287 \times (463.2 - 300)$$
$$IP = 4.333 \times 0.005552 \times 163.2$$
$$IP = 4.333 \times 0.9058 = 3.925 \text{ kW}$$

∴ **(1) Indicated Power = 3.925 kW**

Step 3: Find Isothermal Efficiency (η_iso)

Isothermal work:

$$W_{iso} = \dot{m}RT_1 \ln(\frac{p_2}{p_1})$$
$$W_{iso} = 0.01935 \times 0.287 \times 300 \times \ln(7)$$
$$W_{iso} = 1.666 \times 1.9459 = 3.242 \text{ kW}$$

$$\eta_{iso} = \frac{W_{iso}}{IP} = \frac{3.242}{3.925} = 0.8261$$

∴ **(2) Isothermal Efficiency = 82.61%**

Step 4: Find Cylinder Dimensions (D, L)

Swept volume per minute, $\dot{V}_s = \dot{V}_1 = 1$ m³/min (since clearance is negligible).

For a single-acting compressor:

$$\dot{V}_s = V_s \times N$$
$$1 = V_s \times 300$$
$$V_s = \frac{1}{300} = 0.003333 \text{ m}^3 = 3333.3 \text{ cm}^3$$

$$V_s = \frac{\pi}{4} D^2 L$$

Given $L = 1.5D$

$$V_s = \frac{\pi}{4} D^2 (1.5D) = 1.1781D^3$$

$$3333.3 = 1.1781D^3$$
$$D^3 = \frac{3333.3}{1.1781} = 2830.0$$
$$D = \sqrt[3]{2830.0} = 14.15 \text{ cm}$$

$$L = 1.5 \times D = 1.5 \times 14.15 = 21.225 \text{ cm}$$

∴ **(3) Cylinder Dimensions: Bore, D = 141.5 mm; Stroke, L = 212.25 mm**

Step 5: Find Motor Power

$$\text{Brake Power (BP)} = \frac{IP}{\eta_m} = \frac{3.925}{0.85} = 4.6176 \text{ kW}$$

$$\text{Motor Power} = \frac{BP}{\eta_{trans}} = \frac{4.6176}{0.90} = 5.1307 \text{ kW}$$

∴ **(4) Motor Power = 5.13 kW**

Final Answers for Q-4:
(1) Indicated Power = **3.925 kW**
(2) Isothermal Efficiency = **82.61%**
(3) Cylinder Dimensions: **Bore = 141.5 mm, Stroke = 212.25 mm**
(4) Motor Power = **5.13 kW**

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