LECTURE 34 – PRODUCTION OF COMPRESSED AIR

SELF EVALUATION QUESTIONS AND ANSWERS

1: The bore and stroke of a single acting air compressor are both 10 cm. Clearance volume 80 cc, index of compression and expansion 1.23. Suction pressure 1 bar, delivery pressure 7 bar , speed 4000 RPM. If the temperature at the beginning of the compression is 22℃. Find the amount of free air dealt with by the compressor per minute at a pressure of 1.05 bar and temperature of 16℃

2: A single acting stage air compressor is required to deal with 17 m3/min of air measured at 1bar and 15℃. The pressure and temperature at the end of suction is 0.98 bar and 30 ℃ . the delivery pressure is 6.3 bar. The RPM of the compressor is 500. Assuming a clearance volume of 5% of the stroke volume, laws of compression and expansion as) $\mathbf{p\,V^{1.32} = Constant}$, calculate the necessary stroke volume, temperature of the air delivered and power of the compressor.

3: A single stage , single cylinder air compressor has a cylinder diameter 15 cm, and a stroke of 22.5 cm. Air is drawn into the cylinder at a pressure of 1.05 bar and a temperature of 15 . It is then compressed adiabatically to 6.3 bar. Find the theoretical power required to drive the compressor if its speed is 100 RPM. Find also the weight of the air compressed per minute.

4: A two stage air compressor compresses 1 kg/min of air from 1 bar to 42.18 bar. Initial temperature is 15℃ . At the intermediate pressure the intercooling is perfect. The compression takes place according to law $\mathbf{p\,V^{1.35} = Constant}$. Neglecting the effect of clearance determine the minimum power required to run the compressor. Also find the mass of cooling water required in the intercooler, if the temperature rise of water is limited to 5℃

Q1 Solution

$n\ is\ the\ polytropic\ = 1.23\ for\ air$
$d = L = 10\ cm$

$\mathrm{N} = 400\ \mathrm{RPM}\ , p_2 = 7bar$

$p_1 = 1\ bar\ \ T_1 = 22\ ℃$

$T_a = 16\ ℃$
$P_a = 1.05\ \mathrm{bar}$

$V_c = 80\ \mathrm{cc}$

$$Swept\ volume = V_s = \frac{\pi}{4}\left(d^2\right)L = \frac{\pi \times 0.1^2 \times 0.1}{4} = 0.0007853\ \ m^3$$

$$clearance\ volume\ = V_c = 80\ cc = 0.00008\, m^3/cycle$$

$$clearance\ ratio = \frac{V_c}{V_s} = \frac{0.00008}{0.0007853} = 0.1018$$

$$\eta_{volumetric} = \frac{Actual\ volume\ of\ air\ taken\ referred\ to\ free\ air\ conditions}{swept\ volume\ of\ the\ compressor}$$

$$\eta_{volumetric} = \frac{p_1(T_a)}{p_a T_1}\left[1 + \mathrm{k} - \mathrm{k}\left(\frac{p_2}{p_1}\right)^{\frac{1}{\mathrm{n}}}\right]$$

$$\eta_{volumetric} = \frac{1 \times 289}{1.05 \times 295}\left[1 + 0.101 - 0.1018\left(\frac{7}{1}\right)^{\frac{1}{1.23}}\right] = 0.5659 = 56.59\%$$

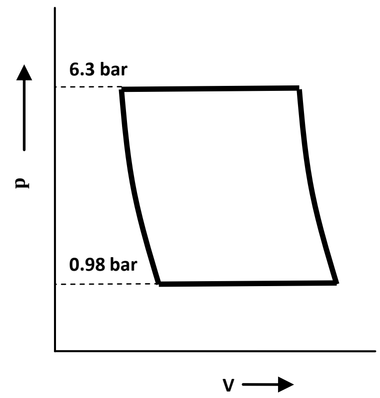
$$Volume\ \ of\ air\ V_a = 0.5659 \times 0.0007853 = 0.000444\, m^3/cycle$$

$$Volume\ \ of\ air\ V_a = 0.000444 \times 400 = 0.17776\, m^3/min$$

$$mass\ of\ air = \frac{p_a V_a}{RT_a} = \frac{1.05 \times 100 \times 0.1776}{0.287 \times 289} = 0.225\, kg/cycle$$

Thus, $V_2 = 520.5\ cm^3$

Q2 Solution



$n \; is \; the \; polytropic \; = 1.32 \; for \; air$

$N = 500 \; RPm$

$p_2 = 6.3 \; bar$

$p_{\text{a}} = 1 \; bar \;\; T_1 = 30 \text{ °C}$

$T_a = 15\text{°C}$

$V_c = 17 \text{ m}^3/\text{min}$

$$clearance \; ratio = \text{k} = \frac{V_c}{V_s} = \frac{5}{100} = 0.05$$

$$\eta_{volumetric} = \frac{Actual \; volume \; of \; air \; taken \; referred \; to \; free \; air \; conditions}{swept \; volume \; of \; the \; compressor}$$

$$\eta_{volumetric} = \frac{p_1(T_a)}{p_a T_1}\left[1 + \text{k} - \text{k}\left(\frac{p_2}{p_1}\right)^{\frac{1}{\text{n}}}\right]$$

$$\eta_{volumetric} = \frac{0.98 \times 288}{1 \; \times 303}\left[1 + 0.05 - 0.05\left(\frac{6.3}{0.98}\right)^{\frac{1}{1.32}}\right] = 0.8452 = 84.52\%$$

$$\eta_{volumetric} = \frac{V_a}{V_s}$$

$$V_s = swept \; volume = \frac{17}{0.452} = 20.11 \; m^3/min$$

$$V_s == \frac{20.11}{500} = 0.0402 \; m^3/cycle$$

$$mass \; of \; air = \frac{p_a V_a}{RT_a} = \frac{1 \times 100 \times \; 17}{0.287 \times 288} = 20.56 \; kg/min$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{\mathrm{n}-1}{\mathrm{n}}} = 303\left(\frac{6.3}{0.98}\right)^{\frac{0.32}{1.32}} = 475.71\mathrm{K}$$

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

$$power = \frac{1.32}{1.32-1} \times 0.3427 \times 0.287 \times (465.71 - 303) = 70\frac{\mathrm{kJ}}{\mathrm{s}}\,\text{or 70 kW}$$

Q3Solution

γ *is the polytropic* $= 1.4$ *for air*
$N = 100\ RPm\ d = 15cm, l = 22.5\ cm$

$p_1 = 1.5\ bar$

$p_2 = 6.3\ bar$

$T_1 = 15\ °\mathrm{C}$

Solution

$$Swept\ volume = V_s = \frac{\pi}{4}(d^2)\ L$$

$$Swept\ volume = V_s = \frac{\pi \times 1.5^2 \times 0.225}{4} = 0.003976\ m^3$$

$$mass\ of\ air = \frac{p_a V_a}{RT_a} = \frac{1.05 \times 100 \times\ 0.003976}{0.287 \times 288} = 0.00505\ kg/cycle$$

$$weight\ \ of\ air\ per\ minute = 0.00505 \times\ 100 = 0.505\ kg/min$$

$$V_1 =\ 0.003976\ m^3/cycle$$

$$V_1 =\ 0.003976\frac{m^3}{cycle\,\frac{100}{60}} = 0.006626\ m^3/sec$$

$$Power = \frac{\gamma\ p_1 V_1}{\gamma - 1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{\mathrm{n}-1}{\mathrm{n}}} - 1\right]$$

$$Power = \frac{1.4 \times 1.05 \times 100 \times 0.006626}{1.4 - 1}\left[\left(\frac{6.3}{1.05}\right)^{\frac{1.4-1}{1.4}} - 1\right] = 1.62\ \mathrm{kW}$$

$$power = \frac{\gamma}{\gamma - 1}\mathrm{mR}(T_2 - T_1)$$

$$power \;= \frac{1.3}{1.3\;-1} \times 0.294 \times 0.287 \times (492.7 - 313) = 65.7\,\frac{\mathrm{kJ}}{\mathrm{s}}\,\text{or } 65.7\ \mathrm{kW}$$

$$\text{Isothermal power } = \mathrm{p_1\ V_1 \ln\left(\frac{p_2}{p_1}\right)} = \mathrm{mR}T_1 \ln\left(\frac{\mathrm{p_2}}{\mathrm{p_1}}\right)$$

$$Isothermal\ power \;= 0.294 \times 0.287 \times 313 \times \ln\left(\frac{7}{0.98}\right) = 51.92\ \mathrm{kW}$$

$$\text{Isothermal efficiency } = \frac{51.92}{65.7} = 0.79 = 79\%$$

Q4 Solution

$n\ is\ the\ polytropic \;= 1.2\ for\ air$

$$m = 1\,\frac{kg}{min} = \frac{1}{60} = 0.0166\ kg/sec$$

$p_1 = 1\ bar\ \ T_1 = 15\ ℃$

$p_3 = 42.18\ bar$

Solution

For perfect intercooling

$$p_2 = \sqrt{\mathrm{p_1 p_3}} = \sqrt{1 \times 42.18} = 6.49\ \mathrm{bar}$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{\mathrm{n-1}}{\mathrm{n}}} = 288\left(\frac{6.49}{1}\right)^{\frac{0.35}{1.35}} = 467.7\mathrm{K}$$

Minimum power required

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

$$W \;= \frac{1.35 \times 0.0166 \times 0.287}{1.35 - 1}(467.7 - 288) = 3.3\ kW$$

Heat rejected in the intercooler

$$Q_{rejected} = m_w c_{pw}(\Delta T)$$

$$2.99 = 0.0166 \times 4.187(5)$$

Solving we get

$$m_w = 0.1432\ kg/sec$$