8.Compressor

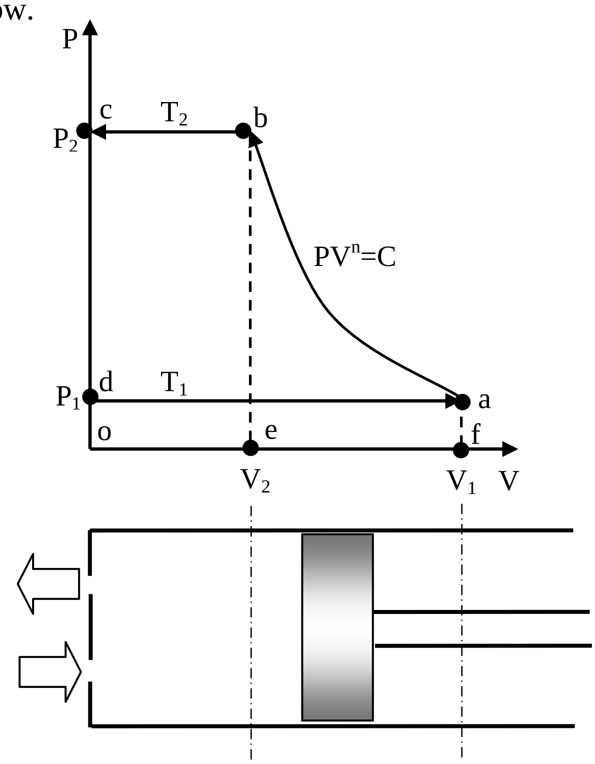
The job of this devise is to take a defined quantity of fluid (usually a gas, or air) and deliver it at a required pressure. The most efficient machine is one which will accomplish this minimum input of mechanical work. Both reciprocating and rotary positive displacement machines are used for variety of purpose.

On the basis of performance a general distinction can be made between the two types; the reciprocating type has a low mass flow rate and high pressure ratio, and the rotary compressor has a high mass flow and low pressure ratio.

Reciprocating Machines

The mechanism involved is the basic: piston, connecting rod, crank, and cylinder arrangement. By considering the clearance volume negligible and the working fluid is a perfect gas. The cycle takes one revolution of the crankshaft for completion as shown in the figure below.

Line d-a represents the suction stroke. The mass in the cylinder increases from zero at d to that required to fill the cylinder at a. the temperature is constant at T_1 for this process and there is no heat exchange with the surrounding. Line a-b-c represents the compression and delivery stroke. Line a-b the pressure rise continuously through until the delivery valve opened. Line b-c represents the process where the delivery takes place, i.e. constant temperature and pressure at T_2 and P_2 zero heat exchange and decreasing the mass.



Indicated work done on the gas per cycle=area abcd

=area abef+area bcoe-area adof

$$W_{in} = \int pdv = \frac{p_2v_b - p_1v_a}{n-1} + p_2v_b - p_1v_a$$

$$W_{in} = (p_2v_b - p_1v_a)\left(\frac{1}{n-1} + 1\right) = (p_2v_b - p_1v_a)\left(\frac{1+n-1}{n-1}\right)$$

$W_{in} = \frac{n}{n-1}(p_2 v_b - p_1 v_a)$

$p_1 v_a = mRT_1$ $\quad\quad$ $p_2 v_b = mRT_2$

m: is the mass induced and delivered per cycle.

Thus, $W_{in} = \frac{n}{n-1} m^o R(T_2 - T_1)$ is the work done per cycle

$Work\ done\ per\ unit\ time = work\ done\ per\ cycle \times no.of\ cycles\ per\ unit\ time$

Example (8.1) *A single-stage reciprocating compressor takes 1 m^3 of air per minute at 1.013 bar and 15^o C and delivers it at 7 bar. Assuming that the law of compression is [$pv^{1.35} = constant$], and the clearance is negligible, calculate the indicated power.*

Solution: mass delivered per minute is $m^o = \frac{p_1 v_1}{RT_1} = \frac{1.013\times10^5\times1}{287\times(15+273)} = 1.226\ kg/min$

Delivery temperature $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n} \rightarrow T_2 = (15+273)\left(\frac{7}{1.013}\right)^{0.35/1.35}$

$T_2 = 475.2\ K$

$$W_{in} = \frac{n}{n-1} mR(T_2 - T_1) = \frac{1.35}{1.35-1} \times 1.226 \times \frac{287}{1000} \times (475.2 - 288)$$

$W_{in} = 254\ kJ/min$

$i.p = \frac{254}{60} = 4.23\ kW$

Actual Work

Because of the friction losses, the actual work input to the compressor is larger than the indicated work.

$shaft\ work = indicated\ work + friction\ work$

$$s.p. = i.p. + f.p.$$

The mechanical efficiency of the compressor is;

$\eta_{comp,mech} = \frac{indicated\ work\ (\ i.p.)}{shaft\ work\ \ (s.p.)}$

To determine the power input required, the efficiency of the motor must be taken into account in addition to the mechanical efficiency.

$$input\ power = \frac{s.p.}{efficiency\ of\ motor\ and\ drive}$$

Example (8.2) *If the compressor in the example (8.1) is to be driven at 300 rev/min and is a single-acting, single-cylinder machine, calculate the cylinder bore required, assuming a stroke to bore ratio of 1.5:1. Calculate the power of the motor required to drive the compressor if the mechanical efficiency of the compressor is 85% and that of the motor transmission is 90%.*

Solution:

Volume per minute at inlet=1 m^3/min.

Volume drawn in per cycle =$\frac{1}{300} = 0.00333\ \ m^3/cycle$

Thus, the cylinder volume is 0.00333 $m^3 = \frac{\pi}{4} d^2 l$ where d: bore & l:stroke

$l = 1.5d$

Sub. into volume $\frac{\pi}{4} d^2(1.5d) = 0.00333 \rightarrow d^3 = 0.00283\ \ m^3 \rightarrow d = 141.5\ \ mm$

$power_{input} = \frac{4.23}{0.85} = 4.98\ \ kW$

$motor\ power = \frac{4.98}{0.9} = 5.53\ \ kW$

Other expression for the indicated work can be derived as follows:

$i.p. = \frac{n}{n-1} m^o R(T_2 - T_1) = \frac{n}{n-1} m^o R T_1 \left(\frac{T_2}{T_1} - 1\right)$

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n}$

$$i.p. = \frac{n}{n-1} m^o R T_1 \left\{\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right\}$$

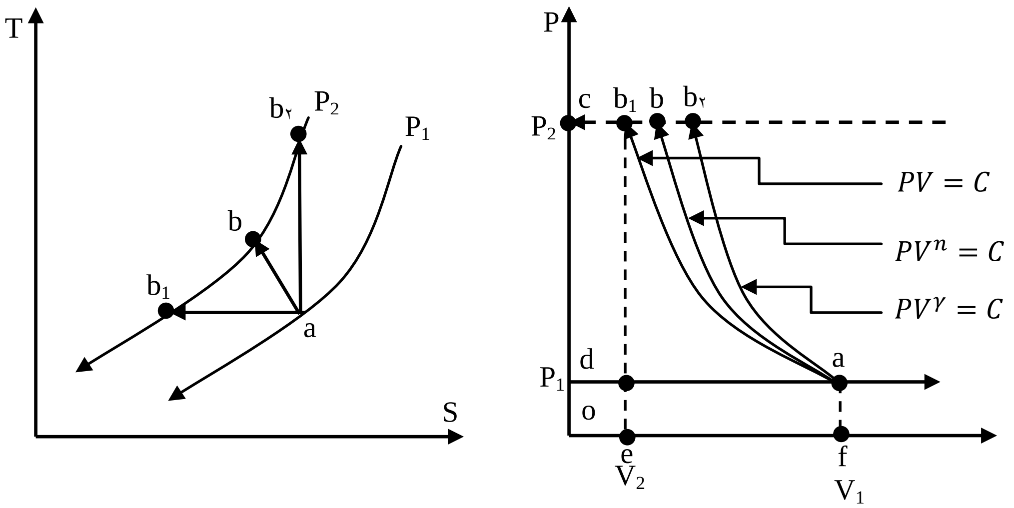
$$i.p. = \frac{n}{n-1} p_1 v^o \left\{\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right\}$$

v^o is the volume induced per unit time.

Minimum Work Conditions

The work done on the working fluid is the area of the indicator diagram. The minimization of the work done would carry out by minimizing the area of the indication diagram. The highest of the diagram is fixed by the required pressure ratio

$\left(\frac{P_2}{P_1}\right)$, moreover the length of the line $\overline{da}$ is fixed by the cylinder volume "according to the induction gas required". Thus, to decreasing the area "work done" it must be carry out by the line $\overline{ab}$. The position taken by this line is depending on the value of the index n in the relation $[PV^n = C]$ as shown in the figure below.



- Line ab_1: isothermal compression.
- Line ab: polytropic compression.
- Line ab_2: adiabatic compression.

From the figure it can be concluded that the isothermal compression consumed the minimum work. The indicated work done when the gas is compressed isothermally is given by the area $\mathbf{ab_1cd}$.

$$area\ (ab_1cd) = area\ (ab_1ef) + area\ (b_1coe) - area\ (adof)$$

$$area\ (ab_1ef) = P_2V_{b1}\ln\frac{P_2}{P_1}$$

$$indicated\ work\ per\ cycle = P_2V_{b1}\ln\frac{P_2}{P_1} + P_2V_{b1} - P_1V_a$$

$P_1V_a = P_2V_{b1} = C$ where the process is isothermal

$$\therefore indicated\ work\ per\ cycle = P_2V_{b1}\ln\frac{P_2}{P_1} = P_1V_a\ln\frac{P_2}{P_1} = m^oRT\ln\frac{P_2}{P_1}$$

Where, V_a & m^o are the mass and volume induced respectively per unit time then these above equations give the isothermal power.

Therefore, it can be concluded that; the least desirable form of compression in reciprocating compressors is that given by the isentropic process. The actual form of compression will usually be one between these two limits represented in the above figure (adiabatic and isothermal compression processes). For reciprocating air compressor the value of index n is usually (1.2 - 1.3).

Isothermal Efficiency

By definition on the indicator diagram,

$$Isothermal\ Efficiency = \frac{isothrmal\ work}{indicated\ work}$$

Examples (8.3) calculate the isothermal efficiency for the compressor in example (8.1)?

Solution:

$$isothermal\ power = m^o RT \ln\frac{P_2}{P_1} = 1.226 \times 0.287 \times 288 \times \ln\frac{7}{1.013}$$

$$isothermal\ power = 196\ \ kJ/min$$

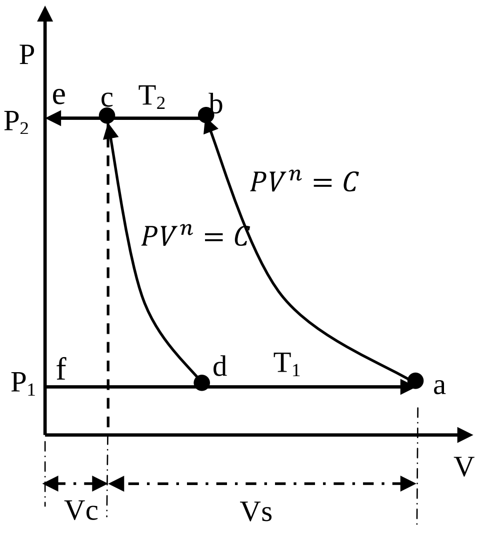
From example (9.1) $indicated\ power = 254\ \ kJ/min$

$$Isothermal\ Efficiency = \frac{196}{254} = 77.2\ \%$$

Reciprocating Compressor Including Clearance

Clearance is necessary for the compressor to give the mechanical freedom for the working parts. For the good quality machines the clearance volume about 6% of the swept volume. Moreover, machines with 30-35% are also common.

The figure represents the P-v diagram for the compressor with clearance volume.



- The delivery stroke (bc) is completed, when the clearance volume V_c is full of gas at P_2 and T_2.
- Then the piston moved to next induction stroke the air expands to P_1 (d).
- When the pressure inside the compressor cylinder reaches P_1 the induction process will begin (d) and continue to the end of this stroke (a).
- The gas is then compressed according to the law [$Pv^n = C$] (in general) process (a-b). After that the delivery process begins from (b) to (c) as controlled by valves.

The effect of clearance is to reduce the induced volume at P_1 and T_1 from Va to (Va-Vd). It can be noticed that $[m_a^o = m_b^o \ \& \, m_c^o = m_d^o\,]$ and the mass delivered per cycle is $[m_b^o - m_c^o]$ or $[m_a^o - m_d^o]$

$$indicated\ work = area(abcd) = area(abef) - area(cefd)$$

$$indicated\ work = \frac{n}{n-1} m_a^o R(T_2 - T_1) - \frac{n}{n-1} m_d^o R(T_2 - T_1)$$

$$indicated\ work = \frac{n}{n-1} R(m_a^o - m_d^o)(T_2 - T_1)$$

$$indicated\ work = \frac{n}{n-1} R m^o (T_2 - T_1)$$

Where $m^o = (m_a^o - m_d^o)$: the mass induced per unit time

The indicated power of reciprocating compressor with or without clearance is identical. In addition, the work done per unit mass of gas delivered is unaffected with the size of the clearance volume.

Other expressions can be derived as before;

$$i.p. = \frac{n}{n-1} p_1 v^o \left\{ \left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1 \right\}$$

$$i.p. = \frac{n}{n-1} p_1 (v_a - v_d) \left\{ \left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1 \right\}$$

The delivered mass per unite time can be increased by designing the machine to be double acting. Where, the induction stroke for one side being the compression stroke for other side.

Example (8.4) *A single stage double acting air compressor is required to deliver 14 m^3 of air per minute measured at 1.013 bar and 15^{o}C. The delivery pressure is 7 bar and the speed 300 rev/min. Take the clearance volume as 5% of the swept volume with a compression index of n=1.3. Calculate the swept volume of the cylinder, the delivery temperature and the indicated power.*

Solution: according to the above figure

$$swept\ volume = (V_a - V_c) = V_s$$

Clearance volume; $V_c = 0.05 \times V_s \rightarrow V_a = 1.05 \times V_s$

Volume induced per cycle; $(V_a - V_d) = \frac{14}{300 \times 2} = 0.02333\ m^3$

Where, $\{cycle\ per\ min = rev\ per\ min \times cycle\ per\ rev\}$

$$V_a = 1.05 \times V_s \ \& \ \frac{V_d}{V_c} = \left(\frac{P_2}{P_1}\right)^{1/n} \rightarrow V_d = 0.05 \times V_s \times \left(\frac{7}{1.013}\right)^{1/1.3} = 0.221 \times V_s$$

$$(V_a - V_d) = 1.05V_s - 0.221V_s = 0.0233 \ m^3$$

Then $V_s = \frac{0.0233}{0.829} = 0.0281\, m^3$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n} \rightarrow T_2 = (15+273)\left(\frac{7}{1.013}\right)^{(1.3-1)/1.3} = 450\ K$$

$$i.p. = \frac{n}{n-1} p_1 (v_a - v_d)\left\{\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right\}$$

$$i.p. = \frac{1.3}{0.3} \times \frac{1.013 \times 10^5 \times 14}{10^3 \times 60}\left\{\left(\frac{7}{1.013}\right)^{(1.3-1)/1.3} - 1\right\} = 57.65\ kW$$

Or $m^o = \frac{P_1 \times V_1}{R \times T_1} = \frac{1.013 \times 14 \times 10^5}{0.287 \times 288 \times 10^3} = 17.16\ \ kg/min$

$$i.p. = \frac{n}{n-1} m^o R(T_2 - T_1) = \frac{1.3}{0.3} \times 17.16 \times 0.287(450 - 288)$$

$$i.p. = 3459\ \ kJ/min = \frac{5459}{60} = 57.65\ kW$$

Volumetric Efficiency

One the effect of the clearance volume is to reduce the induced volume to a value less than that of the swept volume. This means that for a required induction the cylinder size must be increased over that calculated on the assumption of zero clearance. The volumetric efficiency is defined as:

η_v: the mass of air delivered divided by the mass of air which would fill the swept volume at the free air conditions of pressure and temperature.

Or,

η_v: the volume of air delivered measured at the free air pressure and temperature divided by the swept volume of the cylinder.

Free air delivery (F.A.D.): the volume of air dealt with by the compressor.

If the F.A.D. is V, at P and T then $m^o = \frac{PV}{RT}$

The mass required to fill the swept volume V_S at P and T is: $m_S^o = \frac{PV_S}{RT}$

The volumetric efficiency $\eta_V = \frac{m^o}{m_s^o} = \frac{V}{V_s}$

$$induced\ volume = V_a - V_d = V_s + V_c - V_d$$

From the above figure, it can be noticed that: $\frac{V_d}{V_c} = \left(\frac{P_2}{P_1}\right)^{1/n} \rightarrow V_d = V_c \times \left(\frac{P_2}{P_1}\right)^{1/n}$

$$induced\ volume = V_s + V_c - V_c \times \left(\frac{P_2}{P_1}\right)^{1/n} = V_s - V_c\left\{\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right\}$$

Thus, $\eta_V = \frac{V_a - V_d}{V_s} = \frac{V_s - V_c\left\{\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right\}}{V_s}$

$$\eta_V = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right\}$$

Example (8.5) *A single stage, double acting air compressor has a F.A.D. of 14 m^3/min measured at 1.013 bar and 15 ^oC. The delivery pressure is 7 bar and the index of compression and expansion, n=1.3. Calculate the indicated power required and the volumetric efficiency. The clearance volume is 5% of the swept volume.*

Solution:

Mass delivered per minute, $m^o = \frac{PV}{RT} = \frac{1.013\times14\times10^5}{0.287\times288\times10^3} = 17.16\ kg/min$

Where, V is the F.A.D. at P and T.

$$T = (15 + 273) = 288\ K$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n} \rightarrow T_2 = (15 + 273)\left(\frac{7}{1.013}\right)^{(1.3-1)/1.3} = 450\ K$$

$$i.p. = \frac{n}{n-1} m^o R(T_2 - T_1) = \frac{1.3}{0.3} \times 17.16 \times 0.287(450 - 288)$$

$$i.p. = 3457\ kJ/min = \frac{3457}{60} = 57.62\ kW$$

As before, $\frac{V_d}{V_c} = \left(\frac{P_2}{P_1}\right)^{1/n} \rightarrow V_d = V_c \times \left(\frac{P_2}{P_1}\right)^{1/n}$

$$V_d = 0.05 \times V_s \times \left(\frac{7}{1.013}\right)^{1/1.3} = 0.221V_s$$

$$induced\ volume = V_a - V_d = V_a - 0.221V_s = 1.05V_s - 0.221V_s = 0.829V_s$$

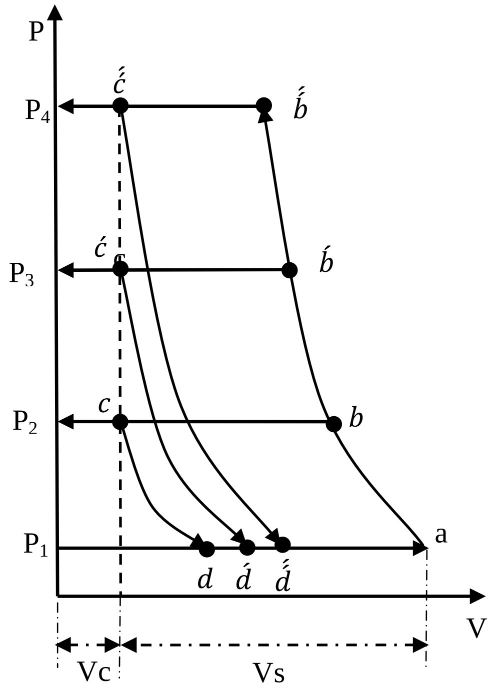
Note: if the difference in temperature and pressure between the free air conditions and suction conditions are ignored and the volumetric efficiency calculated as follows:

$$\eta_V = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right\} = 1 - \frac{0.05V_s}{V_s}\left\{\left(\frac{7}{0.95}\right)^{1/1.3} - 1\right\} = 81.7\%$$

Multi-stage Compression

Previously, we know that for minimum work conditions, the compression process should be isothermal. In general the temperature after compression is given by equation [$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n}$]. The delivery temperature increases with the pressure ratio. Further, it can be concluded that when the pressure ratio increases, the volumetric efficiency decreases.

The below figure shows: for compression from P_1 to P_2 the cycle is $(abcd)$ and the F.A.D. per cycle is$(V_a - V_d)$. For compression from P_1 to P_3 the cycle is $(a\acute{b}\acute{c}\acute{d})$ and the F.A.D. per cycle is$(V_a - V_{\acute{d}})$. For compression from P_1 to P_4 the cycle is $(a\acute{\acute{b}}\acute{\acute{c}}\acute{\acute{d}})$and the F.A.D. per cycle is$\left(V_a - V_{\acute{\acute{d}}}\right)$. Therefore, for the required F.A.D. the cylinder size would have to increase as the pressure ratio increases.

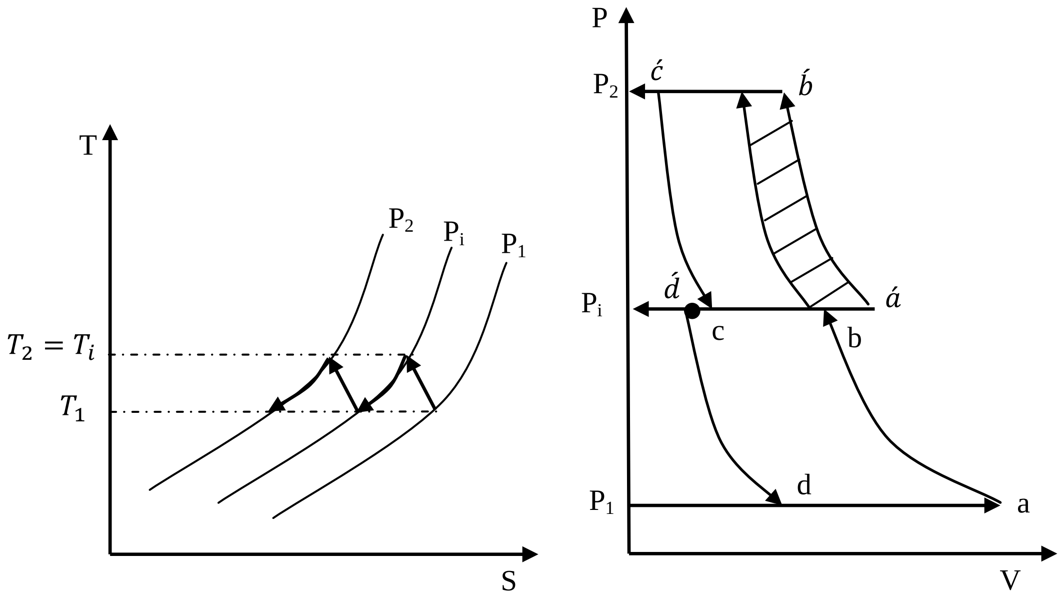


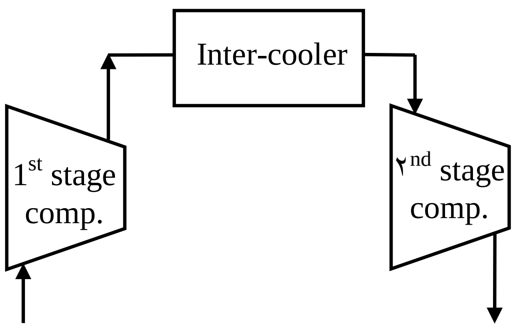
The volumetric efficiency can be improved by carrying out the compression in two stages. After the first stage of compression the fluid is passed into a smaller cylinder in which the gas is compressed to the required final pressure. If the machine has two stages, the gas will be delivered at the end of this stage, but it could be delivered to a third cylinder for higher pressure ratios. The cylinders of the successive stages are proportioned to take the volume of gas delivered from the previous stage.

The indicator diagram for the two-stage machine is shown in the figure below. In this diagram it is assumed that the delivery process from the first or low-pressure stage and the induction process of second or high-pressure stage are at the same pressure.

The ideal isothermal compression can be only obtained if ideal cooling is continuous. This is difficult to obtain during normal compression. With multi-stage compression the opportunity presents itself for gas to be cooled as it is being transferred from one cylinder to the next, by passing it through an intercooler. If inter-cooling is complete, the gas will enter the second stage at the same temperature at which it entered the first stage. The saving in the work obtained by inter-cooling is shown by shaded area in the figure.

To evaluate the indicated power, its equation can be applied to each stage separately and the results added together.





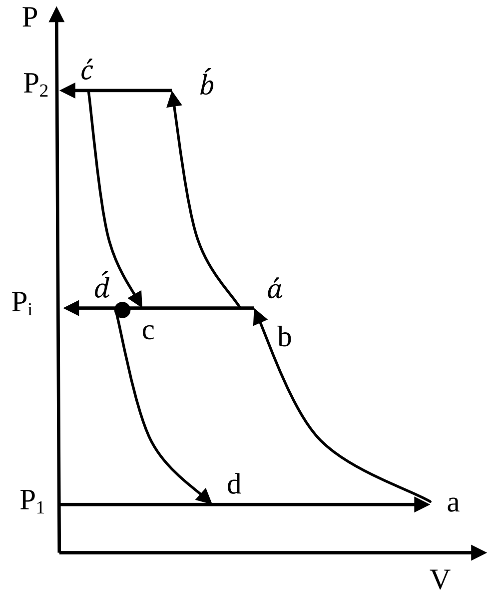
Example (8.6) *In a single acting two-stage reciprocating air compressor 4.5 kg of air per min are compressed from 1.013 bar and 15°C through a pressure ratio of 9 to 1. Both stages have the same pressure ratio, and the law of compression and expansion in both stages is* $[PV^{1.3} = C]$. *If the inter-cooling is complete, calculate the indicated power and the cylinder swept volumes required. Assuming that the clearance volumes of both stages are 5% of their respective swept volumes and that the compressor runs at 300 rev/min.*

Solution:

The two indicator diagrams are shown superimposed in the figure. The low pressure stage cycle is $(abcd)$ and the high-pressure cycle is $(\acute{a}\acute{b}\acute{c}\acute{d})$.

Now $\frac{P_2}{P_1} = 9 \rightarrow P_2 = 9P_1$ and $\frac{P_i}{P_1} = \frac{P_2}{P_i}$ $\therefore P_i^2 = P_1 \cdot P_2 = 9 \times P_1 \cdot P_1$

$\frac{P_i}{P_1} = \sqrt{9} = 3$



$\frac{T_i}{T_1} = \left(\frac{P_i}{P_1}\right)^{(n-1)/n} \rightarrow T_i = (15 + 273)(3)^{(1.3-1)/1.3} = 371\ K$ is the temperature of the air interring the inter-cooler.

The work done in each stage is the same, where n, m°, and the temperature difference are the same for both stages.

$The\ total\ power\ required\ per\ min = i.p.$

$i.p. = 2 \times \frac{n}{n-1} m^o R(T_i - T_1) = 2 \times \frac{1.3}{0.3} \times 4.5 \times 0.287(371 - 288) = 930\ kJ/min$

$i.p. = \frac{930}{60} = 15.5\ kW$

The mass induced per cycle is, $m^o = \frac{4.5}{300} = 0.015\ kg/cycle$

This mass is passed through each stage in turn.

For the low-pressure cylinder:

$$V_a - V_d = \frac{m^o R T_1}{P_1} = \frac{0.015 \times 287 \times 288}{1.013 \times 10^5} = 0.0122\ m^3/cycle$$

$$\eta_V = \frac{V_a - V_d}{V_s} = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_i}{P_1}\right)^{1/n} - 1\right\} = 1 - \frac{0.05V_s}{V_s}\left\{(3)^{1/1.3} - 1\right\} = 93.4\ \%$$

$$V_s = \frac{V_a - V_d}{\eta_V} = \frac{0.0122}{0.934} = 0.0131\ \ m^3/cycle$$

Thus, $the\ swept\ of\ low - pressure\ cylinder = 0.0131\ m^3$

For the high-pressure stage, a mass of 0.015 kg/cycle is drawn in at 15°C and pressure of $P_i = 3 \times 1.013 = 3.039\ bar$

i.e. $volume\ drawn\ in = \frac{0.015 \times 287 \times 288}{3.039 \times 10^5} = 0.00406\ \ m^3/cycle$

For the high-pressure stage $\eta_V = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right\} = 93.4\%$

Since $\frac{V_c}{V_s}$ is the same as for low-pressure stage, and also $\frac{P_i}{P_1} = \frac{P_2}{P_i}$

$$Swept\ volume\ of\ high - pressure\ stage = \frac{0.00406}{0.934} = 0.00436\ m^3$$

Note: that the clearance ratio is the same in each cylinder, and the suction temperature are the same since inter-cooling is complete, therefore the swept volumes are in the ratio of suction pressures.

i.e. $V_H = \frac{V_L}{3} = \frac{0.0131}{3} = 0.00436\ m^3$

Exercises

Problem (8.1) Air is to be compressed in a single-stage reciprocating compressor from 1.013 bar and 15^{o}C to 7 bar. Calculate the indicated power required for free air delivery of 0.3 m^3/min, when the compression process is:

a) Isentropic;
b) Reversible isothermal;
c) Polytropic, with n=1.25.

What will be the delivery temperature in each case? [*reference: Applied Thermodynamics, by Estop, prob. 9.1,p-285*]

Ans. *:(1.31 kW; 0.98 kW; 1.19 kW; 228^{o}C ;15^{o}C ;151^{o}C)*

Problem (8.2) The compressor in problem 9.1 is to run at 1000 rev/min. if the compressor is single-acting and has a stroke/bore ratio of 1.2/1, calculate the bore size required. [*reference: Applied Thermodynamics, by Estop, prob. 9.2,p-285*]

Ans.: *(68.3 mm)*

Problem (8.3) a single-stage, single-acting air compressor running at 1000 rev/min delivers air at 25 bar. For this purpose the induction and free air conditions can taken as 1.013 bar and 15^{o}C, and the free air delivery as 0.25 m^3/min. The clearance volume is 13% of the swept volume and the stroke/bore ratio is 1.2/1. Calculate the bore and stroke and the volumetric efficiency of this machine. Take the index of compression and expansion as 1.3. Calculate also the indicated power and the isothermal efficiency. [*reference: Applied Thermodynamics, by Estop, prob. 9.3,p-28*6]

Ans.: *(73.2 mm; 87.84 mm; 67.6%; 2 kW; 67.5%)*

Problem (8.4) A single-acting compressor is required to deliver air at 70 bar at a rate of 2.4 m^3/min measured, where the free-air conditions are 1.013 bar and 32^{o}C. Calculate the indicated power required if the compression is carried out in two stages with an ideal intermediate pressure and complete inter-cooling, the index of compression for both stages is 1.25. What is the saving in power over single-stage compression?

If the clearance volume is 3% of the swept volume in each cylinder, calculate the swept volume of the cylinders. The speed of the compressor is 750 rev/min.

If the mechanical efficiency of the compressor is 85%, calculate the power output in kilowatts of the motor required. [*reference: Applied Thermodynamics*, *by Estop, prob. 9.5,p-28*6]

Ans.: *(22 kW; 6 kW; 0.00396 m^2; 0.000474 m^3; 26.75 kW)*

Problem (8.5) A single-cylinder, single acting air compressor running at 300 rev/min is driven by a 23 kW electric motor. The mechanical efficiency of the drive between motor and compressor is 87%. The air inlet conditions are 1.013 bar and 15^oC and the delivery pressure is 8 bar. Calculate the free air delivery in m^3/min, the volumetric efficiency, and the bore and stroke of the compressor. Assuming that the index of compression and expansion is n=1.3, that the clearance volume is 7% of the swept volume and that the bore is equal to the stroke. [*reference: Applied Thermodynamics, by Estop, prob. 9.8,p-28*7]

Ans.: *(4.47 m^3/min; 73%; 296mm)*

Problem (8.6) Air is compressed steadily by a reversible compressor from an inlet state of 100 kPa and 300 K to an exit pressure of 900 kPa. Determine the compressor work per unit mass for (a) isentropic compression with k=1.4, (b) polytropic compression with n=1.3, (c) isothermal compression, and (d) ideal two-stage compression with inter-cooling with a polytropic exponent of 1.3. [*reference: Thermodynamics an Engineering Approach, by Michael A. Boles, Ex:7-13,p-368*]

Ans.: *(263.2kJ/kg; 246.4 kJ/kg; 189.2 kJ/kg; 215.3 kJ/kg)*