Power Calculation 2

Compressor Design (Example 5):

Specifications: 35cfm free air delivered. Output pressure 6.895 Bar.

Intake air 0.97 Bar 27°C

(Assume there is an intake pressure drop and intake air has been 'warmed' up by the hot cylinder)

Driven at 500 rev/min

Clearance 5% of the swept volume

Polytropic index n=1.3

Bore-stroke ratio: 2:3

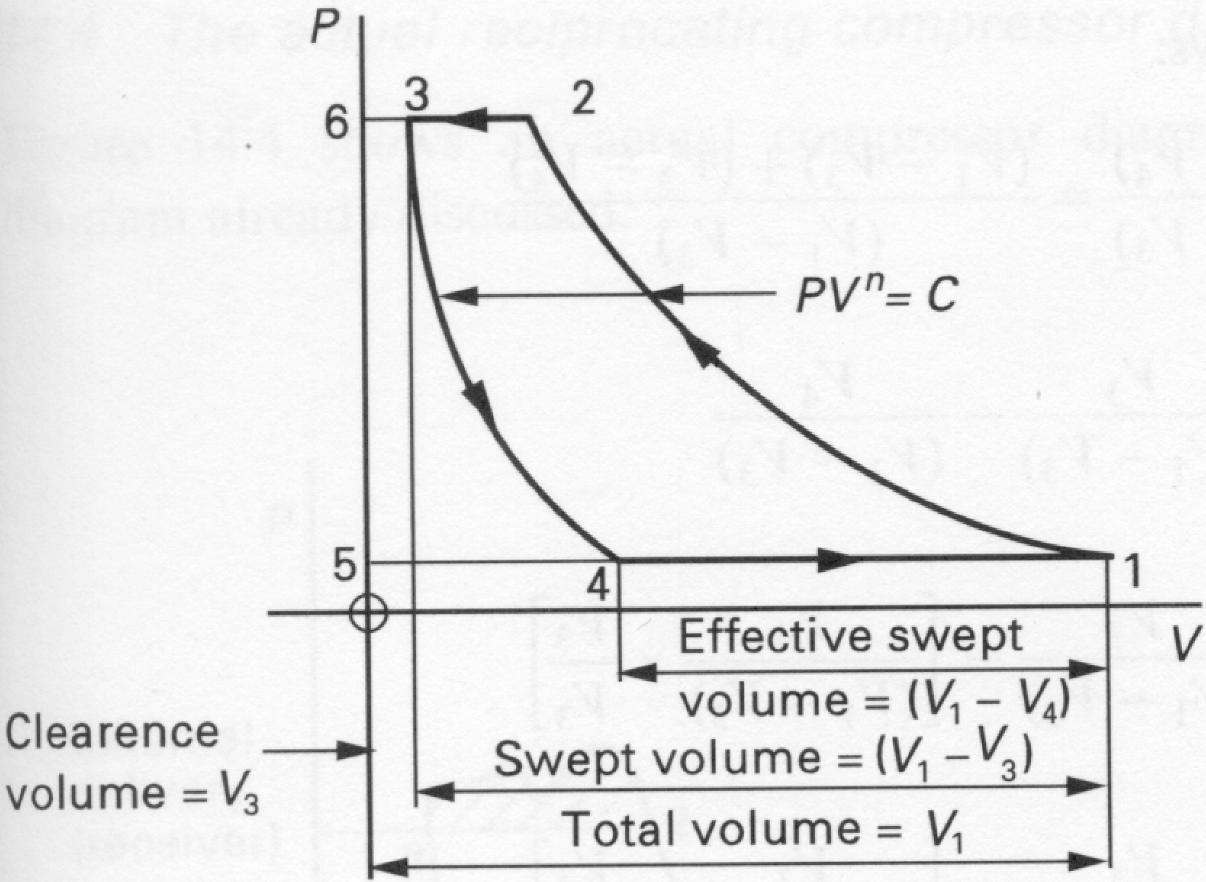
Free air delivered conditions:15 °C and pressure 1.013Bar

R=287

Compressor mechanical efficiency $\eta c=80\%$

Motor and transmission efficiency $\eta d=85\%$

Design a single cylinder, single-acting reciprocating compressor



Clearance volume: effect on reciprocating compressor

Solution:

Free air delivered per min

$$V_{fad} = 35 \times 0.028317 = 0.9911 m^3 / \min, \quad (1\ cube\_foot = 0.028317\, m^3)$$

Free air delivered per cycle

$$V_{free} = V_{fad} / 500 = 0.0020 m^3 / cycle$$

Effective Swept volume:

$$V_1 - V_4 = \frac{p_{free} V_{free} T_1}{T_{free} p_1} = \frac{1.013 \times 0.0020 \times (273 + 27)}{(273 + 15) \times 0.97} = 0.0022 m^3 \qquad \text{(A)}$$

Expanded clearance air volume:

$$V_4 = V_3 \left(\frac{p_3}{p_4} \right)^{1/n} = V_3 \left(\frac{1.013}{0.97} \right)^{1/1.3} = 4.5232 V_3 \qquad \text{(B)}$$

Clearance 5% of swept volume:

$$V_3 = 0.05(V_1 - V_3) \qquad \text{(C)}$$

From simultaneous Eqs (A), (B) and (C), find

$$V_1 = 0.0027, \quad V_3 = 0.000131, \quad V_4 = 0.000592\, m^3$$

Calculate cylinder sizes:

$$\frac{\pi b^2 s}{4} = V_1 - V_3 \qquad or \qquad \frac{\pi b^2 (3/2) b}{4} = V_1 - V_3$$

$$bore : b = 0.1305 m \qquad stroke : s = 0.1957 m$$

Compressed air temperature

$$T_2 = T_1 \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} = (273+27) \left(\frac{6.9}{0.97} \right)^{\frac{1.3-1}{1.3}} = 471.7963 K$$

Free air mass density

$$\rho = \frac{p_{free}}{RT_{free}} = \frac{1.013 \times 10^5}{287(273+15)} = 1.2256 kg/m^3$$

Power absorbed by the free air delivered (energy per second)

$$W = \frac{n}{n-1} \dot{m} R (T_2 - T_1) = \frac{n}{n-1} V_{free} \rho R (T_2 - T_1)$$

$$= \frac{1.3}{1.3-1} 0.0020 \times 1.2256 \times 287(471.8 - 300) \times \frac{500}{60} = 4.3253 KW$$

Motor power required:

$$W_m = \frac{W}{\eta_c \eta_d} = \frac{4.3253}{0.80 \times 0.85} = 6.361 KW$$

or

$$W_m = 6.361 / 0.7457 = 8.53 hp$$

Compressed air volume

$$V_2 = \frac{P_1 V_1}{T_1} \frac{T_2}{P_2} = 0.000608$$

p-V chart can be plotted (see next page)

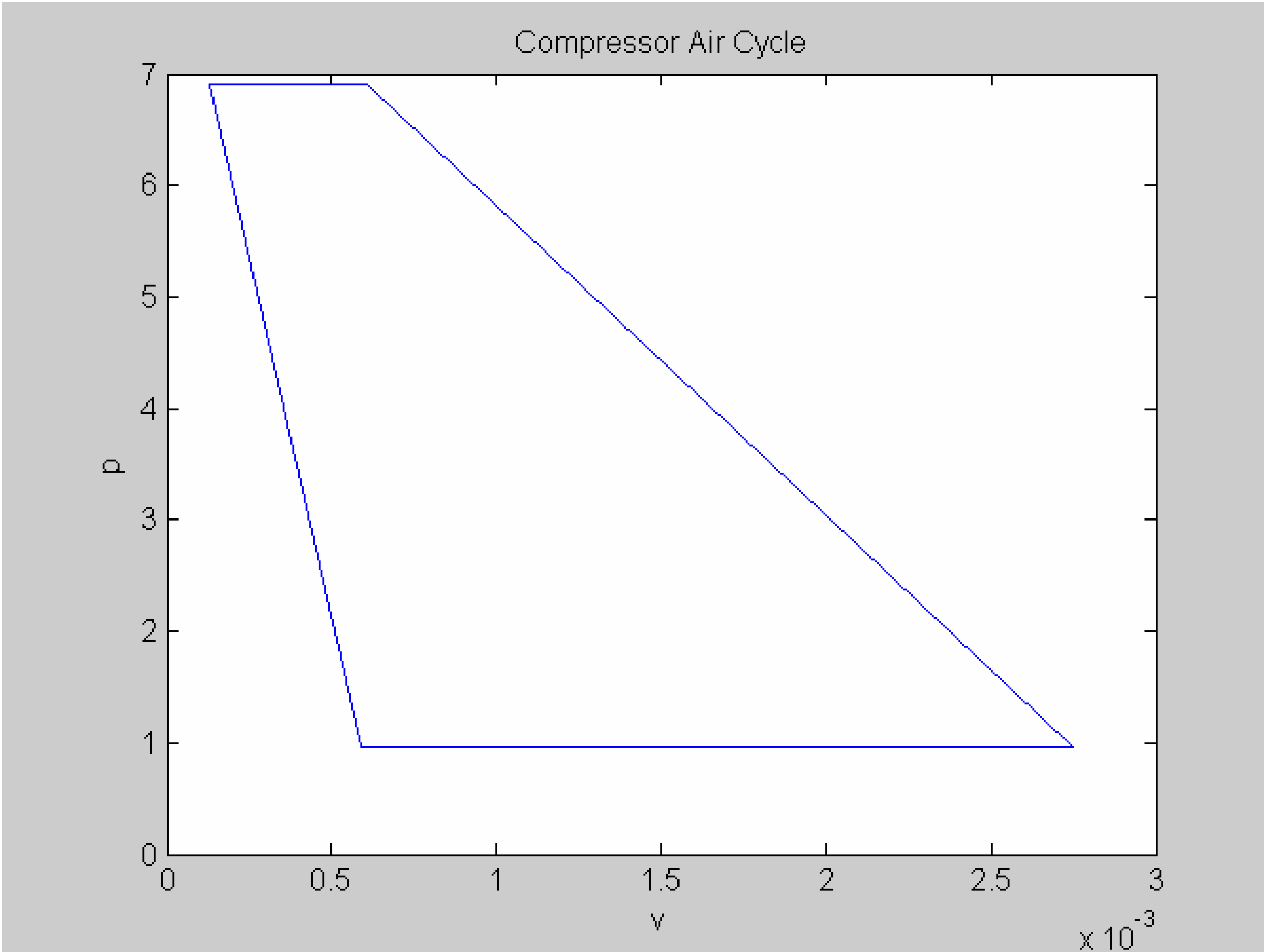
Volumetric efficiency

$$\eta_v = \frac{V_{free}}{swept\_volume} = \frac{V_{free}}{V_1 - V_3} = 75.73\%$$

Compressor indicated power (=by the free air delivered per unit time)

$$W_{indicated} = \frac{n}{n-1} p_1 (V_1 - V_4) \left[\left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} - 1 \right] f = 4.3253 KW$$

where f – cycles/s


Compressor Air Cycle
p
v
x 10^-3
0
1
2
3
4
5
6
7
0.5
1.5
2.5

Compressor design considerations

Capacity

Unusual operating conditions may require a larger unit than indicated. If you are not certain, select a larger unit to ensure adequate initial capacity and provide for future needs.

Compressor Intake

It is important to provide fresh, uncontaminated air to the compressor's intake since gross contamination of intake air will adversely affect the efficiency of the purifier. If the compressor is operated near running vehicles or close to a gas heater, the CO and CO_2 levels in the ambient air may be affected resulting in an adverse impact on the air quality of your system. If the compressor is located in a room where chemicals are stored, fumes or particles from the chemicals can be drawn into the system and affect air quality. Your compressor should never be located where volatile gases can enter the compressor.

To safeguard your system's air quality, a remote intake may need to be installed in another room, on an outside wall, or on the roof. A drip leg with drain should be provided to prevent water from entering the compressor intake.

Flow Requirements

1. The time required to fill the stack.
2. The capacity of your storage system.

Flow Rate

A compressor has two ratings for delivered flow rate: free air delivery (FAD) and average cylinder charge rate (CR). When the same compressor is rated using these two methods, the results are dramatically different - average charge rate will exceed free air delivery.

Free Air Delivery

Free air delivery (FAD) measures the compressor's output at a specific operating pressure. The result, normally expressed in actual cubic feet per minute, rates the outlet flow based on inlet conditions. This method for measuring FAD is specified by the American Society of Mechanical Engineers (ASME PTC-9) and the International Standards Association (ISO 1217).

Cylinder Charging Rate

Charging rate measures the average output of a compressor as it fills a BA cylinder. Since there are no recognized standards governing how a charging rate is determined, the method of determining the rate is left up to the individual compressor manufacturer. As a result, there are numerous ways to calculate a charging rate. The rate is usually obtained by timing how long it takes a compressor to fill a BA cylinder, perhaps an 80 cf SCUBA cylinder, from 0 to 3000 psig. The cylinder volume (80cf) is then divided by the filling time (5 minutes, for example). The result would be a charging rate of 16 cfm.

For the purposes of this document, both FAD and CR ratings are referenced. However, all cylinder refill system calculations utilize FAD.

Pressure Requirements

Choose a compressor that is rated at a higher operating pressure than is needed to complete your cylinder refill requirements. Higher operating pressures aid in the purification process as well as making it possible to store a greater volume of air in the same physical space.

Multiple Stage Compressors

Multiple stage reciprocating compressors are utilized to produce high pressure air. High pressure compressors are available in a number of configurations employing either a lubricated or a non-lubricated design. The basic difference is the presence of lubricant within the compression process. Non-lubricated compressors are designed with closer tolerances within the compressor's valve assemblies and cylinder walls. When compared to a lubricated compressor, the non-lubricated compressor will also require more frequent service intervals.

Lubricating oil is viewed as a contaminant, but it also serves many critical functions. Lubricating oil reduces the operating temperature of the compressor, reduces friction (thus increasing compressor operating efficiency and output), minimizes air leakage around piston rings, and it reduces the possibility of internal corrosion. Lubricating oil will also assist in the removal of dirt, wear particles and liquid water within the compressor.

Compressor Components and Controls

It is highly recommended that a compressor be equipped with automatic controls to prevent damage due to human error or mechanical failure.

- Magnetic starter (with overload protection)
- Belt guard (OSHA requirement)
- Intake filter
- Inter-stage coolers
- After coolers
- Pressure safety relief valve for each stage of compression
- Elapsed time recorder
- Condensate drain traps
- High temperature alarm and/or carbon monoxide alarm when using an oil-lubricated compressor (OSHA requirement).

Advanced Monitoring and Control

More automated with more elaborate controls and sophisticated components. Examples include:

- Automatic condensate drain with muffler/reservoir assembly
- Low oil level alarm and/or shutdown
- Inter and final stage pressure gauges
- Emergency stop and restart controls

Programmable Condition Monitoring and Control

With the advent of automated compressors, programmable controls have begun to replace electro-mechanical designs of the past. A programmable electronic control system will provide an operator with numerous diagnostic features monitoring all normal and abnormal operating conditions.