3. The efficiency of a piston compressor

1. Introduction

A compressor is a good (basic) example of an open thermodynamic system. The main aims of the use of it are as follows:

- to get drive medium for pneumatic devices,
- to increase the temperature for coolant in refrigerators and heat pumps,
- to grow density for easy transport of medium.

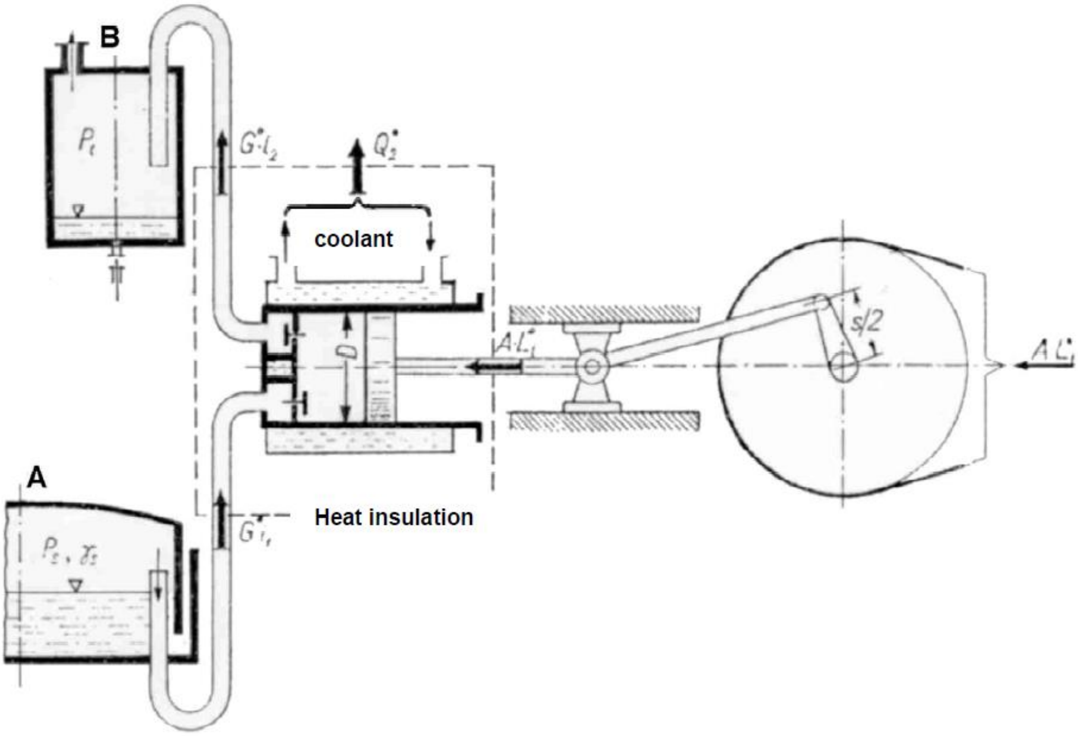

Fig. 1. Scheme of piston compressor

The piston in a compressor moves between two extreme positions called dead centres. Position closer to the cylinder head is called top dead centre TDC and the opposite one is the bottom dead centre – BTD. Considering the construction of the compressor and safety of piston operation, it is necessary that the piston crown does not reach the head of the compressor. The volume between piston and cylinder head, when the piston is in TDC position, is called clearance volume - V_c.

In theory, the compressor efficiency is the highest when there is no clearance volume ($V_c = 0$). This, however, is practically impossible. The clearance volume always exists in such devices. In consequence, the efficiency is reduced.

The reasons for the efficiency decrease are:

- When the discharge process is ended the clearance volume is still filled with some portion of air with discharge pressure higher than suction pressure ($p_d > p_s$).
- During the reverse piston movement, the new portion of the medium will not be acquired until the pressure in the cylinder drops to the value of suction pressure ($p \leq p_s$). As a result, only the part of the piston stroke is effectively used for filling, while the rest is used for depressurisation of the chamber.

2. Perfect compressor model

It is a compressor in which:

- there is no friction between the piston and the cylinder,
- valves do not create aerodynamic resistance,
- there is no clearance volume
- the medium is compressed according to a polytropic process, which is described by the equation:

$$pV^w = idem$$

2.2.Indicator diagram

Indicator diagram is a graphical representation of the process of gas pressurisation in the cylinder with respect to the position of the piston or the instantaneous value of the total gas volume. Such a graph for the ideal compressor is shown in Fig. 2, for the semi-ideal (called also the reference one) - in Fig. 3 and for the real one - in Fig. 4.

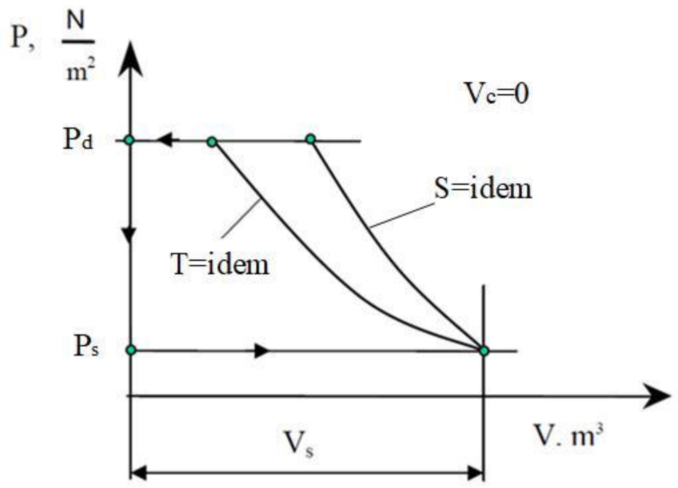

Fig. 2. 2. Indicator diagram of the ideal compressor: p_d, p_s – pressure discharge and suction pressure respectively

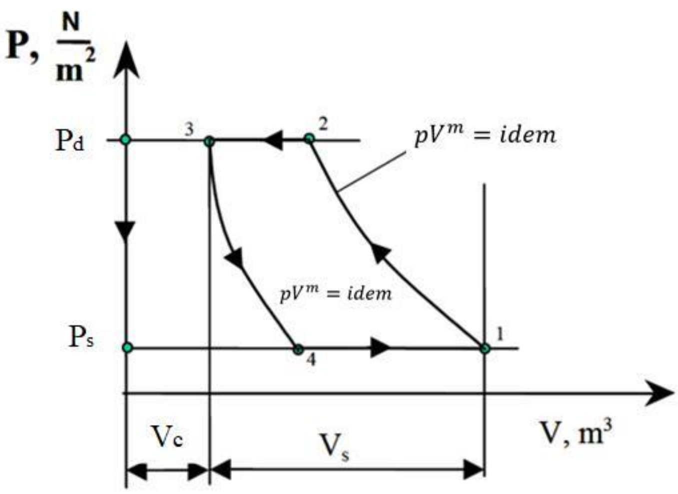

Fig. 3. Indicator diagram of semi-ideal compressor

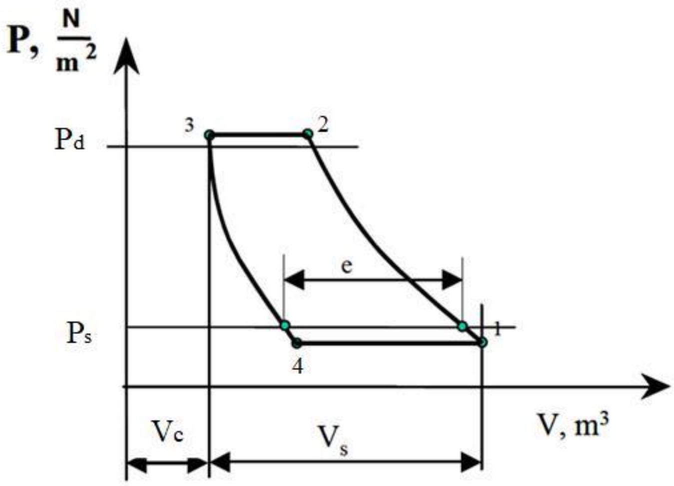

Fig. 4. Indicator diagram of real compressor.

2.3.Volumetric efficiency

The efficiency of a compressor expressed in relation to its clearance volume is called volumetric efficiency η_V. Hence, for an ideal compressor $\eta_V = 1$; for the semi-ideal compressor (see fig 3) the volumetric efficiency is given by:

$$\eta_V = \frac{V_1 - V_4}{V_S}$$

For real compressor the efficiency is:

$$\eta_V = \frac{e}{V_S}$$

Factor "e" from the denominator have to be determined using the diagram obtained experimentally.

2.4. Filling of the compressors tank

The time of the ambient air compression from ambient pressure p_0 up to final pressure p_k inside the tank with a volume of V_Z is strongly dependent on the swept volume V_S and the clearance volume V_c. During inflation of the tank, the pressure changes along with the amount of the cycles (i_{ki}). Consequently, the value of (i_{ki}) changes with respect to the time of compressor operation (τ_{ki}), and the rotational speed of the compressor (n) expressed in [rpm]. Thus:

$$i_{ki} = \frac{n \cdot \tau_{ki}}{60}$$

3. Experiment description

Fig 1 Compressor installation as a measurement position

Experiment shall be conducted for three clearance volumes V_c. The test starts with the smallest one.

The following steps have to be realised:

- check the pressure in the tank – should be equal to ambient one p_0,
- turn on the compressor and the time at the same moment,
- record the time (τ_{ki}) when the defined pressures will be reached Δp_{ki}, (i.e. from 0,05 MPa to 0,2 MPa),

Repeat these steps for three clearance volumes installed in the compressor

3.1. Elaboration of the results

1. Calculate Δm – the amount of air collected inside of the tank, after reaching pressures p_{ki}:

$$p_{ki} = p_0 + \Delta p_{ki}$$

$$p_{ki} V_Z = m_{ki} R T_0$$

$$p_0 V_Z = m_0 R T_0$$

$$\Delta m = m_{ki} - m_0$$

2. To compute mass flow for each measurement step $\dot{m}_{av(i)}$

$$\dot{m}_{av(i)} = \frac{\Delta m}{\tau_{ki}}$$

3. Draw diagram V_c, versus $\dot{m}_{av(i)}$.

Group …………………..date: …………………. hour:…………………….

p_0= ....hPa to= .... °C T_0= .... K $\boldsymbol{\varphi}$= ....%				
V_s = 107 cm^3 V_z = 100 000 cm^3 n = 1200 rpm				
$V_{c1} = 30\ cm^3$				
$\Delta p_{ki}, MPa$	0,05	0,10	0,15	0,20
τ_{ki}, s				
i_{ki}				
p_{ki}, MPa				
$\dot{m}_{av}, kg/s$				
$V_{c2} = 60\ cm^3$				
$\Delta p_{ki}, MPa$	0,05	0,10	0,15	0,20
τ_{ki}, s				
i_{ki}				
p_{ki}, MPa				
$\dot{m}_{av}, kg/s$				
$V_{c3} = 90\ cm^3$				
$\Delta p_{ki}, MPa$	0,05	0,10	0,15	0,20
τ_{ki}, s				
i_{ki}				
p_{ki}, MPa				
$\dot{m}_{av}, kg/s$				