AL - MUSTAQBAL UNIVERSITY COLLEGE
Iraq – Babylon

Refrigeration and Air conditioning Engineering.

3rd year – refrigeration and Air conditioning Course

Lecture -8- Part 1

Fans

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CHAPTER THREE

FANS

3-1 Introduction:

A person's health can be seriously impaired by inadequate ventilation — the quality, temperature and movement of the air. Condensation and the growth of mold is a risk to buildings. Air freshness should be controlled with the removal of odors, pollutants and excessive moisture. The essence of the correct air motion is a matter of identifying the correct system, selecting the correct terminations, controls and duct routing and, perhaps most importantly, selecting the correct fan. It is a common perception that the fan is simply an air extraction device; a tool to move air between given points, e.g between the bathroom and outdoors. Fans are not only used to enhance personal comfort and well-being. Many uses of fans go unnoticed such as cooling a personal computer or the special fans used to extract hazardous fumes from industrial processes.

There are two main categories of fan: axial and centrifugal. The difference between the two is the way in which the air passes through the fan. Axial fans are in line with the airflow. They are mainly used in low pressure, high volume applications with efficiencies in the 60 to 75% range. Noise can be a problem. Centrifugal fans resemble a construction similar to a water wheel. The air enters in line with the drive shaft and exits at 90° to the entering air. Centrifugal fans are the most commonly used in air-conditioning systems for medium to high pressure applications, with efficiencies in the 50 to 85% range. There are different types of centrifugal fans determined by the type of blade and configuration. The following describes the two most common types.

3.2 Types of fans:

3.2.1 Axial fans:

The axial flow fan increases the air velocity through rotational or tangential force which produces velocity pressure (VP), kinetic energy, with a very small increase in static pressure (SP) and potential energy.

Axial fans come in various shapes and sizes including:

3.2.1.1 Propeller Fans:

Propeller fans can be placed in two categories:

a- Air Circulator or Free Fans: A free fan is one that rotates in a common unrestricted air space. Examples of free fans include ceiling fans, desk fans, and pedestal fans. Low technology, low cost designs function to move and stir the air, but are not necessarily the most efficient of designs. Shown in Fig 1.

b- Orifice Panel or Orifice Ring Fans: These are the fans most associated with applications referred to as ventilating fans. There are many variations of these arrangements, some with long shaft extensions, direct connection to a motor, arranged with bearings and sheaves for belt drive and close coupled belted arrangements. These fans are designed to transfer air from one large space to another. Shown in Fig. 2.

Fig. 1 Air Circulator or Free Fans

Fig. 2 Orifice Panel or Orifice Ring Fans

3.2.1.2 Tube axial Fans:

The tube axial fan (Figure 3) is a propeller fan mounted in a cylindrical tube or duct and is often called a duct fan. Fans of this type employ a variety of impeller designs similar to those already described under the industrial panel fan. The tube axial fan can operate in pressure ranges up to 4" water gauge primarily because its strong construction allows for higher speeds and horsepower.

Fig. 3 **Tube axial Fans**

3.2.1.3 Vane axial fans

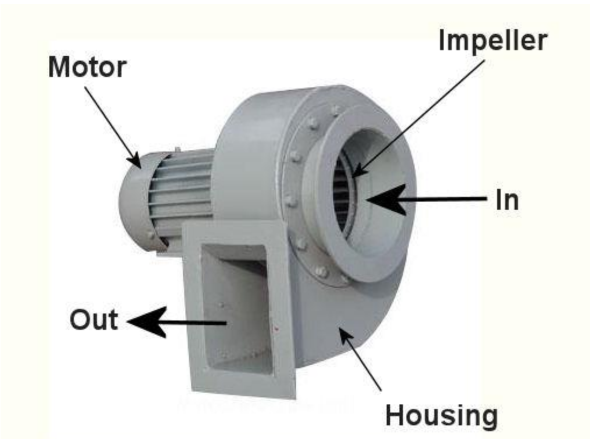
The vane axial fan (Figure 4) is a variation of the duct fan design which operates in the medium-to-high pressure ranges. The guide vanes are usually located at the discharge of the impeller. The function of the vanes is to recover the energy of rotation and convert this into useful work.

Fig. 4 Vane axial fan

3.2.2 Centrifugal fans:

The centrifugal fan induces airflow by the centrifugal force generated in a rotating column of air producing potential energy (SP) and also by the rotational (tangential) velocity imparted to the air as it leaves the tip of the blades producing kinetic energy (VP). Fig. 5 illustrates the components that make up a typical centrifugal fan and covers the common terminology of these components.

Centrifugal fans may be classified into three basic types according to blade configuration: 3-2-2-1. Forward curved 3-2-2-2 . Backward curved 3-2-2-3. Radial or straight blade.



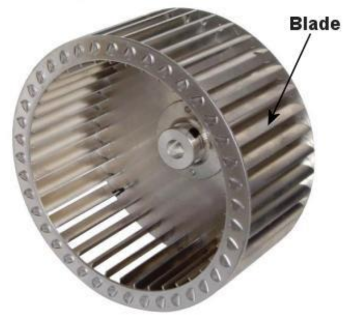


Figure 5 components that make up a typical centrifugal fan

3.2.2.1 Forward curved fan (multi vane):

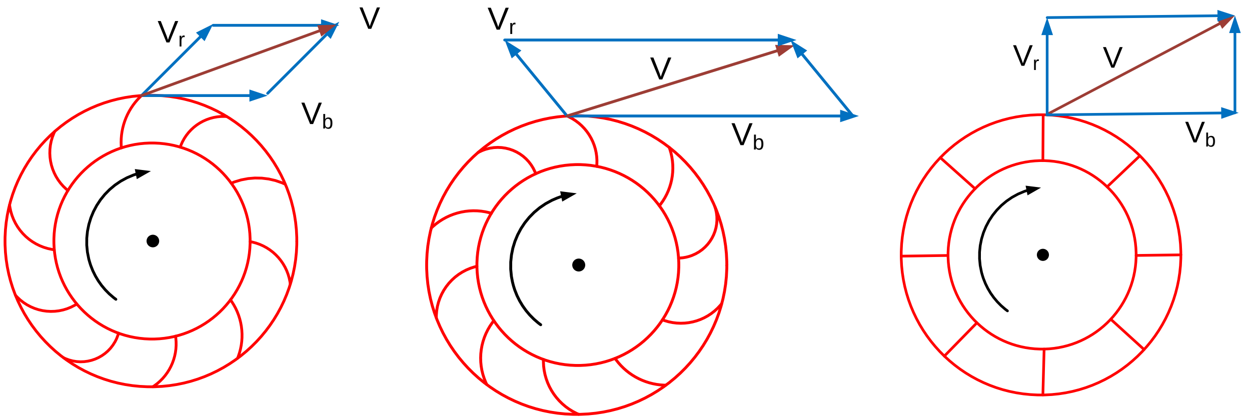
Many small blades mounted with the tips, inclined to the direction of rotation. Commonly used as they can move the largest volume of air for the fan and are quiet. They do have a severely rising power characteristic. See Fig. 6.

3.2.2.2 Backward curved fans:

Tips of blades mounted at an incline away from the direction of rotation. Normally the impeller is fitted with 10 or 16 blades. These fans are not as compact as forward-curved fans but are more efficient and have a non-overloading characteristic. They are used in systems where a high or varying pressure is needed.

3.2.2.3 Radial Blade Fans

"Steel plate" or "paddle wheel" are two of the common names for radial blade fans. The impeller blades are generally narrower, deeper and heavier than forward curve and backward inclined blades. A radial blade impeller usually comprises six to twelve equally spaced flat blades extending radially from the center of the hub.



a- Forward curved b- Backward curved c- Radial or straight blade

Fig. 6 Centrifugal wheel types

3.3 Fan laws:

Various fan laws show the relationships between pressure, flow rate, efficiency and power. These can be used to calculate each factor:

$$\frac{Q_2}{Q_1} = \frac{rpm_2}{rpm_1} \quad (3\text{-}1)$$

$$\frac{p_2}{p_1} = \left(\frac{rpm_2}{rpm_1}\right)^2 \quad (3\text{-}2)$$

$$\frac{P_2}{P_1} = \left(\frac{rpm_2}{rpm_1}\right)^3 \quad (3\text{-}3)$$

$$\frac{p_2}{p_1} = \frac{\rho_2}{\rho_1} \quad (3\text{-}4)$$

$$\frac{Q_2}{Q_1} = \left(\frac{D_2}{D_1}\right)^3 \quad (3\text{-}5)$$

$$\frac{p_2}{p_1} = \left(\frac{D_2}{D_1}\right)^2 \quad (3\text{-}6)$$

$$\frac{P_2}{P_1} = \left(\frac{D_2}{D_1}\right)^5 \quad (3\text{-}7)$$

3.4 Fan Characteristic:

The fan supplies energy to the air stream which replaces the energy lost due to friction. The energy supplied by the fan is measured in terms of pressure just as the energy lost due to friction is measured in terms of pressure loss. Fan sizing involves selecting a tail which will provide just enough pressure energy to produce the design air flow rate. Over-sizing the fan will inject more energy than necessary into the air stream resulting in excessive flow rate or the need to add additional resistance during balancing to absorb this energy. Energy is also wasted. The pressure produced by a fan depends upon the volume flow rate of air which in turn depends upon the resistance of the ductwork. So, in order to select a fan, the pressure/volume characteristic of both fan and ductwork needs to be known. Fan characteristics vary depending upon fan design, (centrifugal, axial etc); fan size and fan speed. This information is usually given in the form of data in graphs from the manufacturer.

The ductwork system characteristic follows a quadratic law:

$$\Delta p = R.Q^2 \qquad (3\text{-}8)$$

Where:

Δp: Pressure loss (kPa.)
R: Constant (is found from the calculated pressure loss at design flow rate (duct sizing)
Q: Volume flow rate (lit/s)
When system and fan curves are superimposed on one graph, as shown in Fig. 8., the fan performance with in the system can be found from the intersection of the two curves.

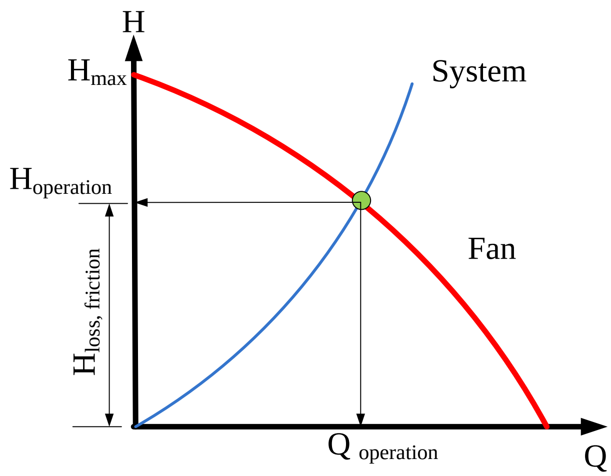


Fig. 7 Fan and system curve

Fan total pressure equals fan static pressure plus fan velocity, In theory, the tan total pressure is available but much of this can be lost at the fan exit (and entry) which will not have been allowed for in the duct sizing calculations. It is usual therefore to select the fan on fan static pressure rather than fan total pressure. Fan static pressure is the measured pressure difference between the fan inlet and the fan outlet.

$$P_s = P_t - P_v \qquad (3\text{-}9)$$

Where:

: Velocity pressure (Pa.)
: Total pressure (Pa)
: Static pressure (Pa.)

3.5 Dual fans:

Sometimes dual fans are used either in series or parallel. When comparing the fan characteristics of a single fan and dual fans in series (all identical) the pressure is doubled for a given volume flow rate.
When the system curve is plotted on the same graph the new operating point can be determined and compared with pressure that of a single fan as shown in Fig. 9.
The same applies with parallel fans where the volume flow rate is doubled for a given pressure. As shown in Fig. 10.

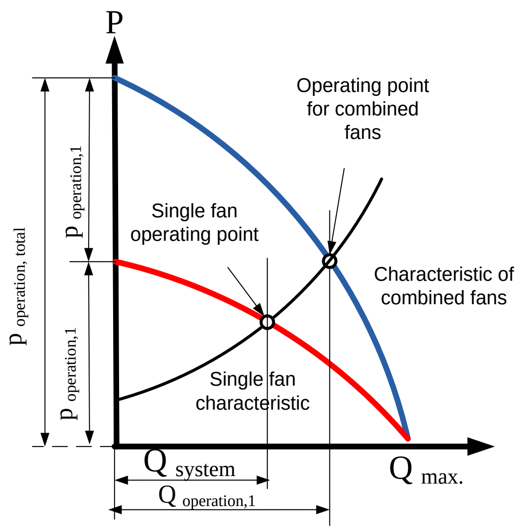


Fig. 9 two fans in series

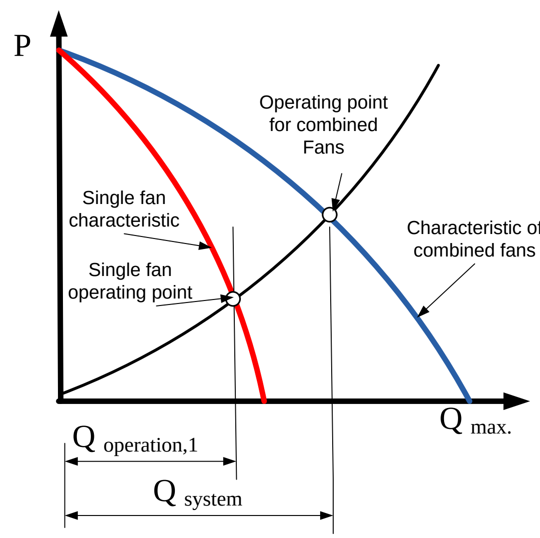


Fig. 10 two fan in parallel

3.6 Fan sizing:

Calculation procedure:

Step I. If not already available, calculate the ductwork index run pressure-drop and total system flow rate.

Step 2. Determine system equations for constant R. This can be done by substituting the Δp required and Q into the equation (4-8) and then solving for R.

Step 3. Select a tan that appears to operate within the required parameters and plot the system and fan characteristics on the same graph.

Step 4. Determine the operating point. Identify the operating pressure and flow rate.

Step 5. If there is a mismatch (for example the flow rate is too high), then either select another fan or change the fan output by either varying the speed (if necessary obtain new fan data and re-draw the graph) or restrict the flow by means of a damper.
Step 6. If a damper is required, calculate the pressure drop needed to achieve the system requirements.

Example 4

A system has a volume flow rate requirement of **2 lit/s** with an index run of 100 Pa. the fan speed is 15 rps. Find an appropriate fan. Pressure drop and volume flow rate are available in the units required. The fan characteristic is as shown in the table bellows:

ftp	197·5	190	177·5	160	137·5	110	77·5
Q	0·5	1	1·5	2	2·5	3	3·5

Step 2. The constant R in the system characteristic curve equation can be calculated as show below:

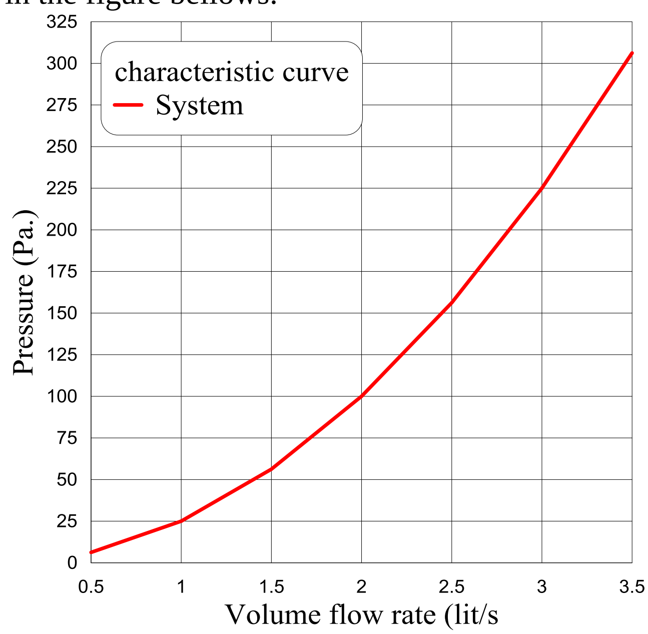
$$\Delta p = R.Q^2 \Longrightarrow R = \frac{\Delta p}{Q^2} = \frac{100}{2^2} = 25$$

Rewrite the equation above as:

$$\Delta p = 25.Q^2$$

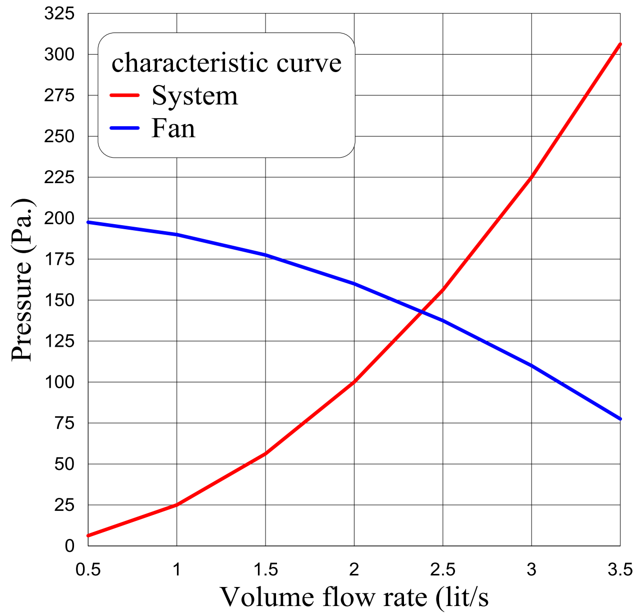
Draw the system characteristic curve as shown in the figure bellows:

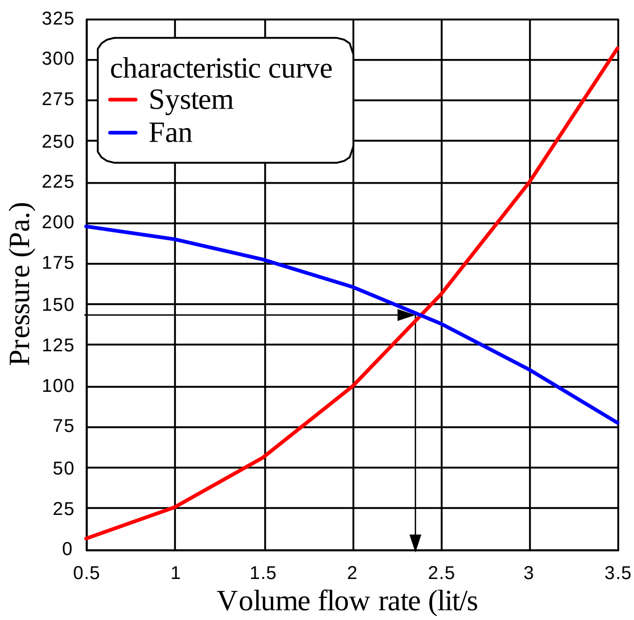
Q	$\Delta p = 25.Q^2$
0.5	6.25
1	25
1.5	56.25
2	100
2.5	156.25
3	225
3.5	306.25



Then draw the fan characteristic curve on the same graph, using manufacturer's catalogue, as shown bellows:

Q	Δp
0.5	197.5
1	190
1.5	177.5
2	160
2.5	137.5
3	110
3.5	77.5

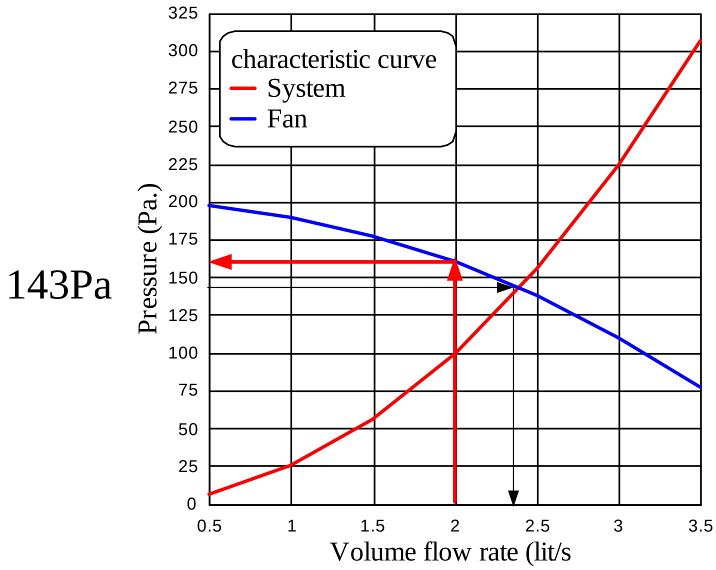




The operating point occurs when the two curves intersect, 2.39 lit/s, and 1 43 Pa.

As 2.39 lit/s is too high, the fan will need to be either slowed down or restricted in order to achieve the required flow rate. Alternatively, a different fan may give a closer value; this is worth considering when comparing the efficiency of different fans at different speeds and pressures.
If a damper were to be installed, what would the pressure drop be in order to achieve the requirements of the system?

Using 2 lit/s determine the Δp of the fan from the graph, Δp = 160 Pa > 100 Pa.



The fan is therefore developing more pressure than is required by the system. In order to match the fan to the system either the system characteristics must change (for example by adding a damper) or the fan characteristics must change (for example by changing the fan speed). The pressure drop required in the ducting is 100 Pa. Here a damper has been added therefore the pressure drop across the damper would need to be: 160 Pa - 100 Pa = 60 Pa The pressure drop required over the damper adds 60% to the system resistance that is effectively wasted energy ie the fan develops 160 Pa, 60 Pa of which are absorbed by the damper.
Alternatively the speed of the fan can be reduced to match the required volume flow rate.

$$\frac{Q_2}{Q_1} = \frac{rpm_2}{rpm_1} \qquad (3\text{-}1)$$

$$rpm_2 = rpm_1 \frac{Q_2}{Q_1} = 15 \times \frac{2}{2.39} = 12.5\ rps$$

This can also be achieved by using equation (5-8) for example:

$$\frac{p_2}{p_1} = \left(\frac{rpm_2}{rpm_1}\right)^2 \qquad (3\text{-}8)$$

$$rpm_2 = rpm_1.\left(\frac{p_2}{p_1}\right)^{0.5} = 15 \times \left(\frac{100}{143}\right)^{0.5} = 12.5\ rps$$

Design tip: Always review the pressure required if a damper is used to match fan and system and consider other approaches as required for example speed control, change of fan, or use of a variable speed fan etc.

Design tip: Using a damper to reduce the output is inefficient as it wastes fan energy. Varying the speed is preferred.