

# Chapter Five

## Fans

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### 1- Types of fans:

- 1- Centrifugal fan, (fig.1)
  - backward curved impeller
  - forward curved impeller
  - radial impeller
- 2- Axial flow fan, (fig.2)
  - ducted fan
  - propeller fan
- 3- Mixed flow fan

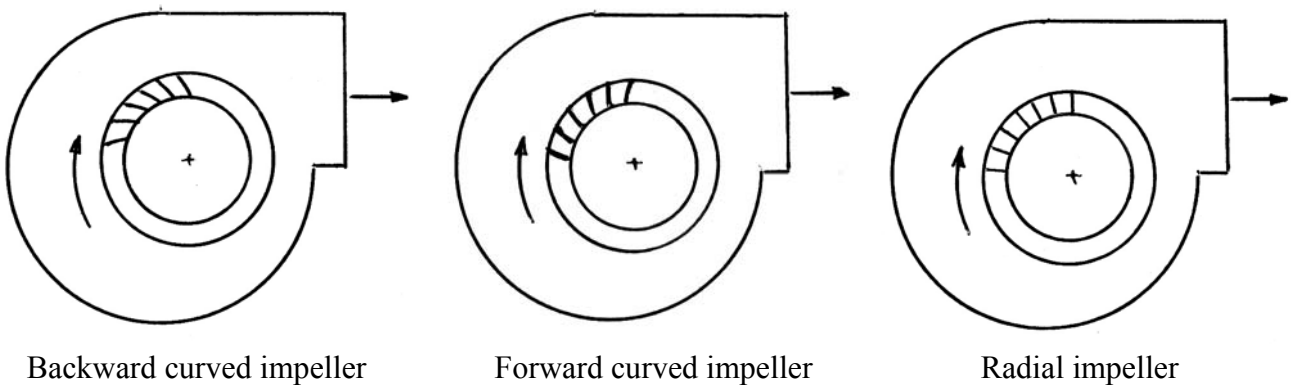


Fig.(1) Centrifugal fan

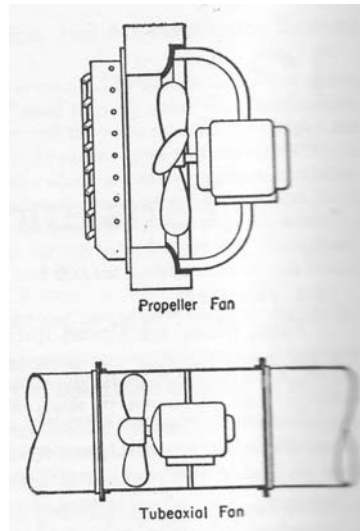


Fig.(2) Axial flow fan

## **2- Centrifugal fan:**

Centrifugal fan consists of an impeller running in a casing normally of volute shape, fig.(1). The air enters axially and is discharged at the periphery.

### **Advantages:**

- 1- quiet.
- 2- efficient operation at high pressures.
- 3- fan inlet can be connected to larger apparatus sections and its outlet to smaller supply duct sections.

### **Types:**

#### **- Backward curved impeller ( $\beta_2 < 90^\circ$ )**

This type is employed for lower pressures and lower flow rates. It has higher efficiencies than that for forward type. It must run at higher speed to develop the same pressure rise as that for forward type.

#### **- Forward curved impeller ( $\beta_2 > 90^\circ$ )**

This type is employed for higher stage pressure rise. They are also available as high volume flow fan. Forward fans are smaller and slower thus they tend to be quieter and cheaper. They are used in small air conditioners with drum-type construction.

#### **- Radial impeller ( $\beta_2 = 90^\circ$ )**

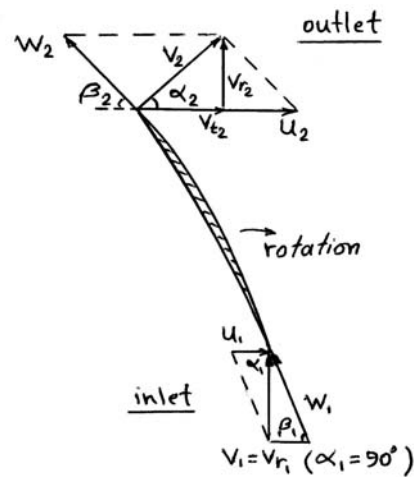
This type is ideal for handling dust-laden air because it is less prone to blockage, dust erosion and failure

### **Theory:**

Total pressure developed by fan,  $p_t$

$$(\Delta p_t) \text{ or } p_t = \gamma H$$

where H is the theoretical total head.



$$H = \frac{(u_2 V_2 \cos \alpha_2 - u_1 V_1 \cos \alpha_1)}{g}$$

for entry of air to the blade passage being radial without pre whirl ( $\alpha_1=90^\circ$ ) we have:

$$H = \frac{(u_2 V_2 \cos \alpha_2)}{g}$$

and

$$p_t = \rho u_2 V_2 \cos \alpha_2$$

Then fan static pressure,  $p_s$

$$p_s = p_t - p_d$$

$p_d$  is the dynamic pressure.

Form the continuity equation:

$$Q = \pi d_1 b_1 V_{r1} = \pi d_2 b_2 V_{r2}$$

where  $d_1$ = impeller diameter at inlet.

$d_2$ = impeller diameter at outlet.

$b_1$ = width of blade at inlet.

$b_2$ = width of blade at outlet.

$$\text{Fan total efficiency: } \eta = \frac{\gamma Q H}{\text{shaft power}} = \frac{Q p_t}{\text{shaft power}}$$

The following **dimensionless design parameters** are used for fans:

Flow coefficient:  $\phi = \frac{Q}{\frac{\pi d_2^2}{4} u_2}$

Pressure coefficient:  $\psi = \frac{p_t}{\frac{1}{2} \rho u_2^2}$

Power coefficient:  $\lambda = \frac{\phi \psi}{\eta}$

### **Similarity laws:**

For any series of geometrically similar fans and for any point on the characteristic curves, the following relationships hold:

$$\frac{Q}{ND^3} = \text{constant} \quad (Q \propto N) \text{ and } (Q \propto D^3)$$

$$\frac{gH}{N^2 D^2} = \text{constant}$$

$$\frac{p_t}{\rho N^2 D^3} = \text{constant}$$

$$\frac{\text{power}}{\rho N^3 D^5} = \text{constant}$$

## Characteristics of centrifugal fan:

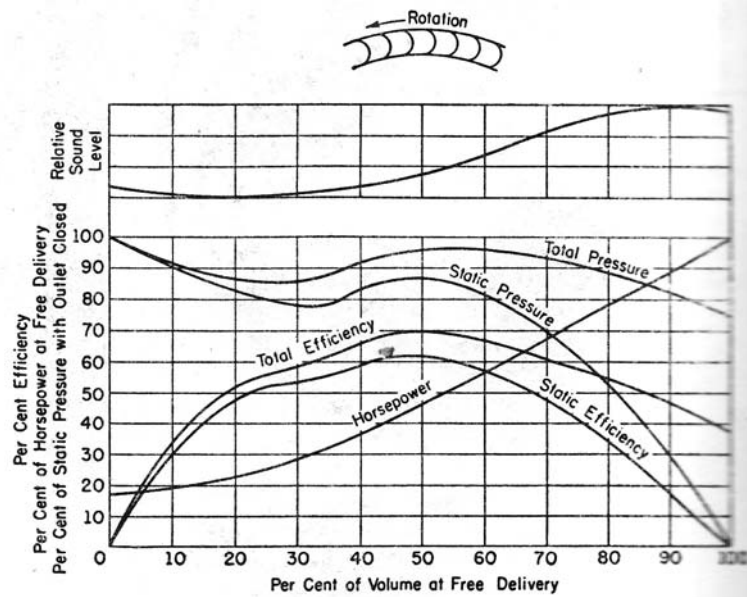


FIG. 13-4. Forward-tip-fan characteristics.

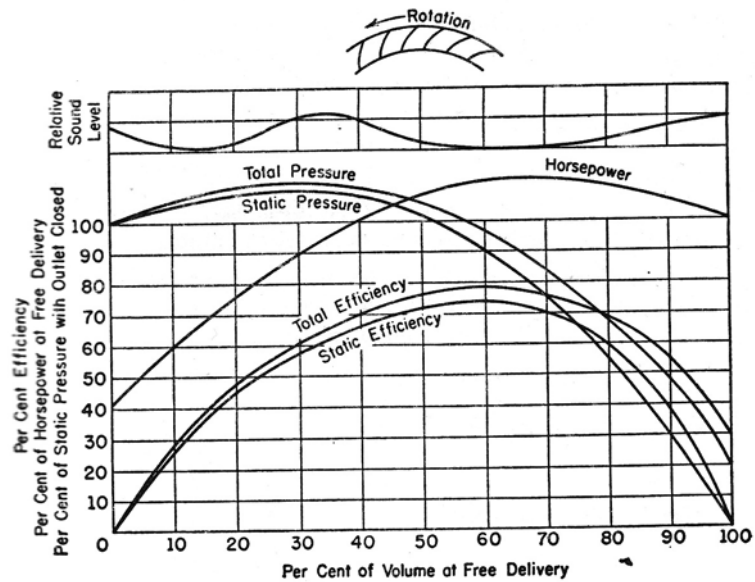


FIG. 13-5. Backward-tip-fan characteristics.

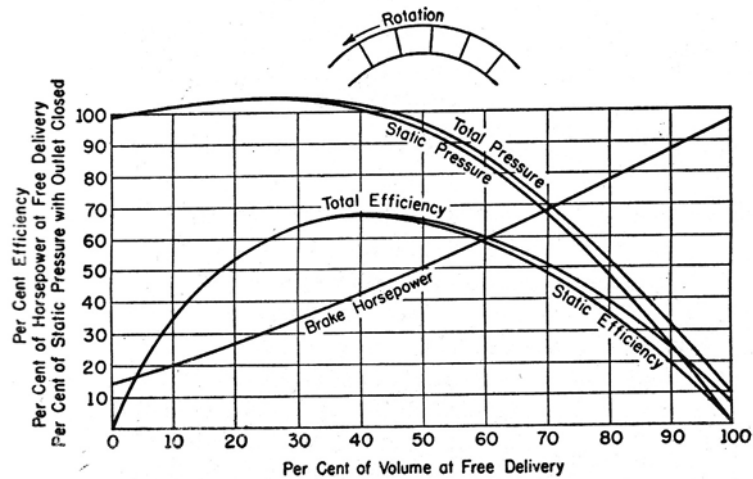


FIG. 13-6. Radial-tip-fan characteristics.

### **3- Axial flow fan:**

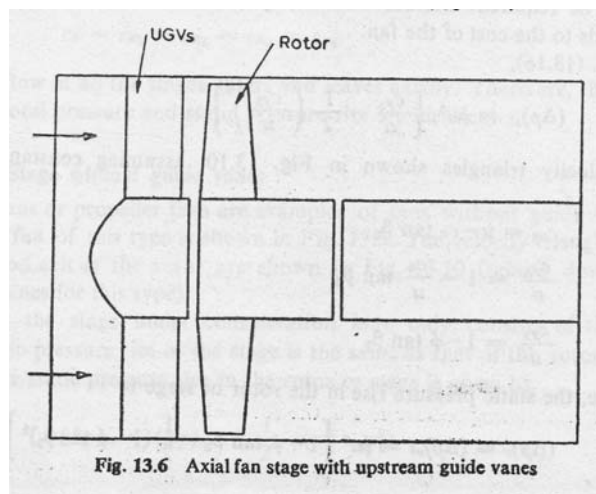
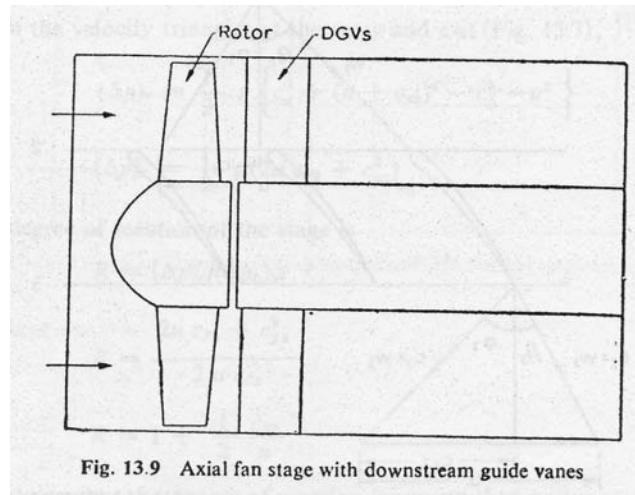
Axial flow fan consists of a rotor made up of a number of blades fitted to the hub, fig.(2). In the ducted type fan, a cylindrical casing encloses the rotor. Unenclosed or open fans are called propeller fan. The flow of air is substantially parallel to the axis of the impeller.

**Advantages:** 1- suitable for handling large volume..  
2- used in industrial ventilation and air conditioning systems.

#### **Types:**

- *ducted fan*
- *propeller fan*

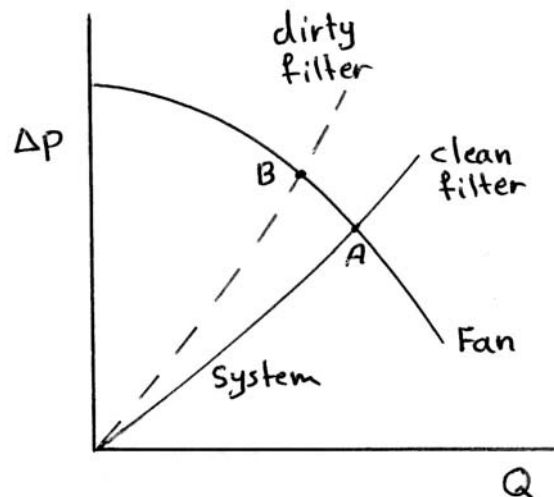
Some designs have guide vanes down stream which remove the rotational components converting some excess velocity into more useful static pressure. Another designs have up stream guide vanes, as shown in the following figures.



#### 4- Fan and system characteristics:

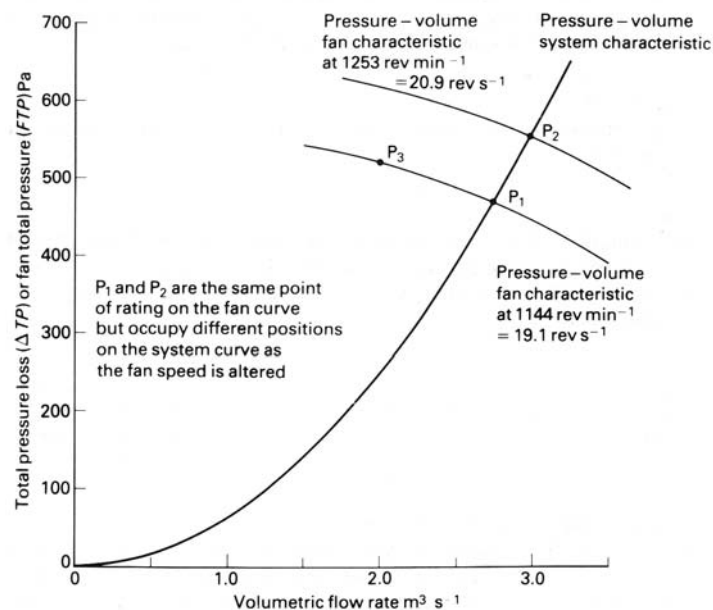
##### Effect of change in system resistance:

Point (A) represent the point of operation. If the system resistance change say due to unclean filters, the system curve will move and the operating point will then shift to (B) resulting in decreased flow.



##### Effect of change in fan speed:

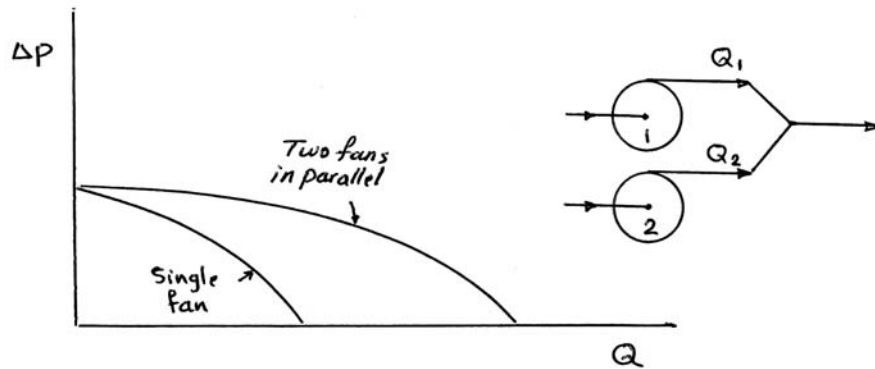
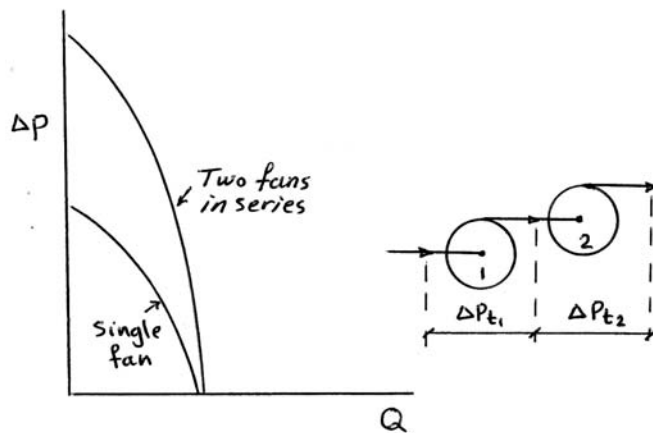
If the fan speed increase the operating point will shift from point (1) to point (2).



**Figure 15.20** The point of rating on a fan characteristic curve is fixed but it slides down the system characteristic curve as the fan speed is reduced

## Fan Arrangements

The figures show the characteristic curves for two identical fans in series and for two identical fans in parallel.



- fans in series tend to increase the total pressure.

$$\Delta p_{t \text{ double}} = \Delta p_{t1} + \Delta p_{t2}$$

- fans in parallel tend to increase the volume flow rate.

$$Q_{\text{double}} = Q_1 + Q_2$$



### 5- Example:

A backward-swept centrifugal fan develops a pressure of (75 mm H<sub>2</sub>O). It has an impeller diameter of (89 cm) and runs at (720 rpm). The blade air angle at tip is (39°) and the width of the impeller (10 cm). Assuming a constant radial velocity of (9.15 m/s) and density of (1.2 kg/m<sup>3</sup>), determine the fan efficiency, discharge, power required and pressure coefficient.

Solution:

$$\begin{aligned} Q &= \pi d_2 b_2 V_{r2} \\ &= \pi \times 0.89 \times 0.1 \times 9.15 \\ &= 2.558 \text{ m}^3/\text{s} \quad (\text{Ans}) \end{aligned}$$

$$u_2 = \frac{\pi d_2 N}{60} = \frac{\pi \times 0.89 \times 720}{60} = 33.55 \text{ m/s}$$

$$\begin{aligned} \text{input power} &= \rho Q u_2 V_2 \cos \alpha_2 \\ &= \rho Q u_2 V_{t2} \\ &= \rho Q u_2 \left( u_2 - \frac{V_{r2}}{\tan \beta_2} \right) \\ &= 1.2 \times 2.558 \times 33.55 \left( 33.55 - \frac{9.15}{\tan 39} \right) \\ &= 2291.5 \text{ W} \quad (\text{Ans}) \end{aligned}$$

$$\begin{aligned} \text{output power} &= \gamma Q H \\ &= 9810 \times 2.558 \times 0.075 \\ &= 1882.05 \text{ W} \end{aligned}$$

$$\text{Fan efficiency: } \eta = \frac{\text{output power}}{\text{input power}} = \frac{1882.05}{2291.5} \times 100 = 82\% \quad (\text{Ans})$$

$$\begin{aligned} \text{Pressure coefficient: } \psi &= \frac{p_t}{\frac{1}{2} \rho u_2^2} = \frac{\gamma H}{\frac{1}{2} \rho u_2^2} \\ \psi &= \frac{9810 \times 0.075}{\frac{1}{2} \times 1.2 \times 33.55^2} = 1.09 \quad (\text{Ans}) \end{aligned}$$

1- A centrifugal fan (blower) with a radial impeller produces a pressure equivalent to 100 cm column of water. The pressure and temperature at its entry are (0.98 bar, 310 K). The electric motor driving the blower runs at 3000 rpm. The efficiency of the fan and drive are 82% and 88% respectively. The velocity at the inlet eye is  $0.4 u_2$ . If the blower handles  $200 \text{ m}^3/\text{min}$  of air at the entry conditions; determine the power required by the electric motor, the impeller diameter, and the inner diameter of the blade ring.

[45.31 kW; 66.4 cm ; 31.9 cm]

2- A fan running at 1480 rpm, takes in  $6 \text{ m}^3/\text{min}$  of air at inlet conditions of ( $p=950 \text{ mbar}$ ,  $t=15^\circ\text{C}$ ). If the fan impeller diameter is 40 cm and the blade tip air angle  $20^\circ$ ; determine the fan total pressure, and the width of the impeller at exit. Take the radial velocity at the exit as 0.2 times the impeller tip speed.

[497.9 N/m<sup>2</sup>; 1.28 cm ]

3- A backward-swept ( $\beta_2=30^\circ$ ,  $d_2=46.6 \text{ cm}$ ) centrifugal fan is required to deliver  $3.82 \text{ m}^3/\text{s}$  ( $4.29 \text{ kg/s}$ ) of air at a total pressure of  $618.05 \text{ N/m}^2$ . The flow coefficient at the impeller exit is 0.25 and the power supplied to the impeller is 3 kW. Determine the fan efficiency, pressure coefficient, and rotational speed.

[78.7% ; 0.895 ; 1440 rpm]

4- A fan has a pressure-volume characteristic given by the following information obtained from a test at ( $t=0^\circ\text{C}$  and  $p_{\text{atm}}=101.325 \text{ kPa}$ ), when running at 1144 rpm.

Q (m <sup>3</sup> /s)	1.5	2	2.5	3	3.5
P <sub>t</sub> (N/m <sup>2</sup> )	542	520	488	443	388

a- determine the quantity of air handled if it is installed in a system of the following data:

Q (m <sup>3</sup> /s)	0.5	1	1.5	2	2.5	2.75	3	3.25
$\Delta P_t$ (N/m <sup>2</sup> )	15	61	138	245	383	464	552	648

b- determine the fan input power, if the fan total efficiency is 84%.

c- determine the air quantity handled, the fan total pressure and the fan input power, if the air temperature is  $35^\circ\text{C}$  and the barometric pressure is 85 kPa.

d- at what speed must the fan run to deliver  $3 \text{ m}^3/\text{s}$ .

[2.74 m<sup>3</sup>/s ; 1.504 kW ; 2.74 m<sup>3</sup>/s ; 343 N/m<sup>2</sup> ; 1.118 kW ; 1253 rpm]