Compressor Inherent Characteristics

Objectives:

To obtain the ***various characteristic curves*** for a centrifugal compressor operating at inherent speed. Inherent speed is a term used to describe when the rotational speed of the impeller falls as the work being performed by the impeller increases (or vice-versa).

Theory:

In a centrifugal compressor, the air is drawn into the center of a rotating impeller and is thrown outwards. The fluid (air) is guided by fixed vanes to the next stage of the compressor, where the process repeats.

Inside the compressor, energy is transferred to the fluid in the form of kinetic, potential, and pressure energy. By applying the first law of thermodynamics to the system, the total pressure P_{total} can be expressed as:

$$P_{total} = \frac{\rho_{air}({V_1}^2 - {V_2}^2)}{2} + dP_s \qquad \text{(Eq. 1)}$$

Where dP_s is the fan differential pressure. P_{total} is equivalent to the work done on the fluid by the compressor.

The power output P_u given to the fluid can be calculated from the total pressure P_{total} and the volumetric flow rate Q_v as:

$$P_u = P_{total} \cdot Q_v \qquad \text{(Eq. 2)}$$

The overall efficiency (%) can then be calculated using the electrical power input from the wattmeter P_e :

$$\eta_{th} = \frac{P_u}{P_e} \cdot 100 \qquad \text{(Eq. 3)}$$

The best way to describe the operating characteristics of a centrifugal compressor is through the use characteristic curves (operating curves): pressure head, power input, and overall efficiency as a function of the air flow capacity, for a given compressor speed. The optimum conditions are when the required flowrate and pressure correspond with the maximum efficiency. Engineers can use these curves to select an appropriate compressor based on the required duty.

Equipment:

We are using the FM12 Centrifugal Compressor demonstration unit. The apparatus consists of an electric motor which drives 7-stage compressor. The inlet duct (D_1 = 1.25in) and outlet duct (D_2 = 1.5in) are transparent, allowing visual observation of the compressor. A set of duct end caps are provided to enable variable outlet head and flow.

The FM12 incorporates sensors which measure the following:

- Pressure head across the compressor;
- Pressure head across the orifice (to provide the flowrate)
- Inlet temperature
- Rotational speed of the compressor

Each of these readings is relayed to the computer in real-time.

The motor is powered by Armfield SWA1 Integrated Wattmeter which provides a variable voltage output. This allows the power to the compressor motor to be regulated and measured at the same time.

Experimental Procedure:

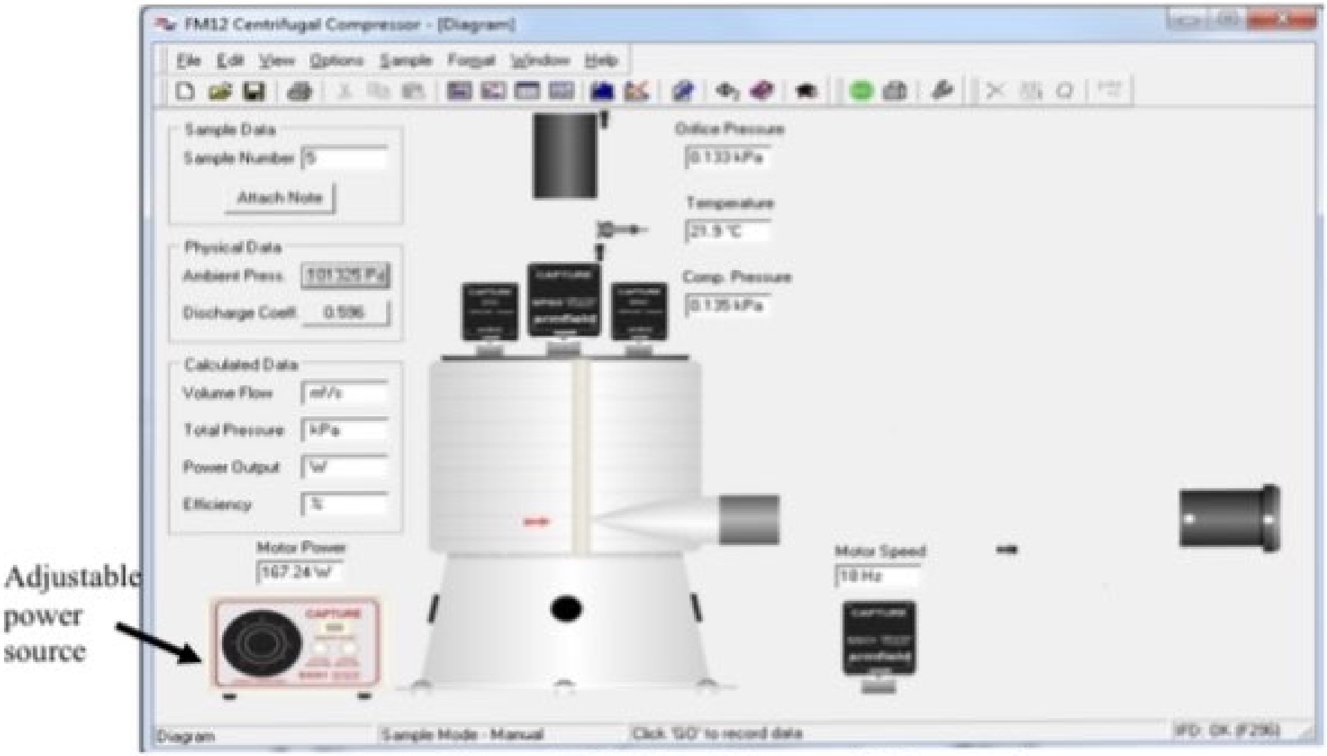

Figure 1: FM12 – Data acquisition system

Use the Centrifugal Compressor FM12. All the connections are already made and the compressor is ready for the experiment.

1. Select the maximum compressor speed ***n*** by adjusting the power controller to 100% while keeping the outlet duct fully opened and running the unit for several seconds to get steady state conditions.
2. Close the outlet duct with the duct end cap. Check the compressor speed and adjust it until reaches your previous value **n**.
3. Let running for few seconds until reaches the steady state conditions, and collect your data; This will represent the first point on the characteristic curve corresponding to No Flow.
4. Change the outlet duct end cap to **0.5in** and repeat steps 2 and 3; This point will represent your second point on the Characteristic Curves.
5. Repeat steps 2, 3, and 4, using all the duct end caps provided (1.0in, 1.5in), and fully open setting.

Collect your data under the yellow columns from Table 1.

Table 1: Collected Data

Run #	Orifice Differential Pressure dP_0 (kPa)	Fan Differential Pressure dP_s (kPa)	Motor Speed n (Hz)	Air Temperature T_a (°C)	Motor Input Power P_e (W)
1					
2					
3					
4					

Note – In the table above, add more lines as needed;

Fill-in Table 2 below using the following equations:

- Air density (ρ): $\frac{P_{atm}}{\rho} = R \cdot T_a$
- Volumetric flow rate (Q_v): $Q_v = \frac{C_d \cdot \pi \cdot D^2 \sqrt{2 \cdot dP_0 \cdot \rho}}{4 \cdot \rho}$
- Inlet velocity (V_1): $Q_v = A_1 \cdot V_1$
- Outlet velocity (V_2): $Q_v = A_2 \cdot V_2$
- Total pressure (P_{total}): Use Eq. 1
- Power Output (P_u): Use Eq. 2
- Overall efficiency (η_{th}): Use Eq. 3

Always pay attention to the units

Table 2: Calculated Data

Air Density ρ (kg/m^3)	Volumetric Flow Rate Q_v (m^3/s)	Inlet Velocity V_1 (m/s)	Outlet Velocity V_2 (m/s)	Total Pressure P_{total} (kPa)	Power Output P_u (W)	Overall Efficiency (%)

Where:

P_{atm} = 101.325KPa, D = 3.5 cm; and use C_d = 0.596

To Do:

- Plot the **Characteristic Curves** - Total Pressure, Overall Efficiency, and Power Output as function of the Volumetric Flow Rate.
- Identify the best efficiency point.
- Compare your results with other compressor characteristics curves you find in textbooks or online for similar compressors.
- Discuss your findings in Conclusions.

Conclusions: