Measurement of cyclone separator

1. Aim of the measurement

Cyclones are widely used in industry (in food and chemical industry, in energy technology and in buildings) to remove dust and other particles from an air or gas stream. Aim of the measurement is to get acquainted with the experimental test rig built in the laboratory of the Department of Hydrodynamic Systems and to determine the following characteristics of the cyclone:

\[ \Delta p_{co} = f(v_{pipe}) \]  
Pressure drop in the unloaded cyclone as a function of air velocity,

\[ \Delta p_c = f(v_{pipe}) \]  
Pressure drop in the cyclone as a function of air velocity during particle transport,

\[ v_t = f(R) \]  
Tangential velocity distribution along the radius.

where, \( v_{pipe} \) means the average velocity at cyclone inlet.

2. General description of the test rig

The sketch of the experimental test rig is presented in Figure 1. The mixture enters the system at the feeder (2) and comes in the cyclone (3) through a pipe. The pipe is connected to the cyclone in tangential direction therefore a circular flow develops inside the cyclone. Behind the inlet the air flows in spiral pattern downwards along the wall of the cyclone. Larger particles in the circulatory stream have too much inertia to follow the tight curve of the flow so they strike the outside wall, where by friction they are broken and finally fall to the bottom of the cyclone. The transport medium (air) flows through the outlet pipe towards the filter (5), where the fine dust fraction is separated. The air leaves the filter through the orifice (6), streams through the fan (1), then through the butterfly valve (7) out to the environment. The flow-rate in the system can be set by the butterfly valve.

3. Technical data of the test rig

Fan

<table>
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<th>Type:</th>
<th>KNV 50</th>
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<tr>
<td>Production number:</td>
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</table>
Driving electric motor for the feeder

Type: HZFP-63B-4DR/2061-1
Production number: 300-462-6

Manometer

Type: ROSENMÜLLER
Production number: 42386

Orifice

Diameter of the pipe: D=80 [mm]
Diameter of the orifice throat: d=50 [mm]

4. The measured and computed quantities

4.1 Pressure drop in the cyclone

The pressure drop in the cyclone (Δp_c) will be determined by a U-tube manometer connected to the inlet and discharge of the cyclone. The pressure drop will be calculated from the deviation of manometer (Δh_c) in the following manner:

\[ Δh_c = h_{cj} - h_{cb} \] [m]
\[ Δp_c = \rho_{vz} \cdot g \cdot Δh_c \] [Pa]

where

- \( Δh_c \) [m]: total displacement of water column in the manometer
- \( Δp_c \) [Pa]: pressure drop in the cyclone
- \( g \) [m/s²]: gravitational acceleration \( g=9.81m/s^2 \)
- \( ρ_{water} \) [kg/m³]: density of medium in the manometer \( ρ_{water}= 1000 \text{ kg/m}^3 \)

4.2 Flow-rate measurement

The flow rate will be measured by a flange tap orifice (the ratio of orifice throat diameter to the diameter of the pipe is \( \beta = d / D = 50 / 80 = 0.625 \)). Measuring tube of the inclined micro manometer will be set vertically during the measurements both for unloaded operation and transport. It means, that \( sin\gamma = 1 \). The pressure difference on the orifice can be calculated from the manometer reading \( l \) as follows:

\[ Δp_p = \rho_{alcohol} \cdot g \cdot l \cdot sin\gamma \] [Pa]
where

\[ \Delta p_p \quad [\text{Pa}]: \quad \text{pressure difference between pressure-taps} \]

\[ \rho_{\text{alcohol}} \quad [\text{kg/m}^3]: \quad \text{density of alcohol in manometer (9): } \rho_{\text{alcohol}} = 800 \text{ kg/m}^3 \]

\[ l \quad [\text{m}]: \quad \text{liquid level in the manometer tube (9)} \]

\[ \gamma \quad [\text{m}]: \quad \text{angle between manometer tube and horizontal plane} \]

Flow-rate is proportional with the square root of pressure drop through the orifice:

\[ Q = \alpha \cdot \varepsilon \cdot \frac{d \cdot \pi}{4} \cdot \sqrt{\frac{2 \cdot \Delta p_p}{\rho_{\text{air}}}} \]

where

\[ d \quad [\text{m}]: \quad \text{orifice throat diameter} \]

\[ \alpha: \quad \text{orifice flow coefficient} \]

\[ \varepsilon: \quad \text{expansion factor (} \varepsilon \approx 1, \text{because of low pressure drop)} \]

\[ \rho_{\text{air}} \quad [\text{kg/m}^3]: \quad 	ext{air density (upstream of orifice for inlet pressure } p_1 \text{ and temperature } T_1) \]

\[ \rho_{\text{air}} = \rho_{\text{norm}} \cdot \frac{p_1}{p_{\text{norm}}} \cdot \frac{T_{\text{norm}}}{T_1} \]

we assume that \( T_1 = T_0 \).

\[ T_{\text{norm}} = 273 \text{ K} \]

\[ b_{\text{norm}} = 760 \text{ mmHg} \rightarrow p_{\text{norm}} = 101396 \text{ Pa} \]

\[ \rho_{\text{norm}} = 1.293 \text{ kg/m}^3 \]

According to MSZ ISO 5167-1 the orifice flow coefficient (\( \alpha \)) is can be calculated as:

\[ \alpha = \frac{C}{\sqrt{(1 - \beta^4)}} \]

where \( C \) is the discharge coefficient, which can be determined by the Stolz formula:

\[ C = 0.5959 + 0.0312 \beta^{0.5} - 0.0184 \beta^2 + 0.0029 \beta^{0.75} \quad (10^6 / \text{Re})^{0.75} \]

The Reynolds-number above is:

\[ \text{Re} = \frac{\nu \cdot D}{\nu} \]

where

\[ D \quad [\text{m}]: \quad \text{inner pipe} \]

\[ \nu \quad [\text{m/s}]: \quad \text{fluid velocity through the pipe} \]

\[ \nu \quad [\text{m}^2/\text{s}]: \quad \text{kinematic viscosity of air} \]
Applying the above written relations, the flow rate can be obtained in an iterative manner. First the air velocity \( (v_1) \) will be approached (say \( v = 1 \, \text{m/s} \)), then the Reynolds number \( (Re) \), the discharge coefficient \( (C) \), and the orifice flow coefficient \( (\alpha) \) will be calculated. Then a new velocity will be approached as:

\[
v_2 = \alpha \cdot \sqrt{\frac{2 \cdot \Delta p_p}{\rho_{air}} \cdot \frac{d^2}{D^2}}
\]

This method has to be applied repeatedly until the relative error between consecutive velocities becomes less than 1%. As the velocity is given, the flow rate will be determined using the above written formula.

Density and viscosity for actual pressure and temperature are:

\[
\rho_{air} = \rho_{norm} \cdot \frac{p}{p_{norm}} \cdot \frac{T_{norm}}{T}
\]

\[
v = \frac{p_{norm}}{p} \left(10^6 \cdot v_{norm} + 0.1 \cdot t\right) \cdot 10^{-6}
\]

\( p \) and \( p_{norm} \) - absolute pressure in [Pa]

\( T \) and \( T_{norm} \) - temperature in [K]

\( t \) - temperature in [°C]

\( v_{norm} = 13.3 \times 10^{-6} \, \text{m}^2/\text{s} \)

The pressure drop characteristic curves depend on the inlet velocity \( (v_{pipe}) \). To obtain the inlet velocity, the flow rate through the orifice has to be reduced to the inlet pressure:

\[
Q_{in} = Q_j \frac{p_j}{p_{in}}
\]

where

\[
p_{in} = p_0 + \rho_{water} g \Delta h_{el}
\]

Then the inlet velocity can be calculated by substituting \( D_{in} = 55 \, \text{mm} \).

\[
v_{pipe} = \frac{Q_{in}}{D_{in}^2 \pi / 4}
\]
4. 3 Measurement of tangential velocity distribution in the cyclone

The tangential velocity distribution in the cyclone will be measured by a three holes gauge. The central stagnation pressure-tap of the gauge will be connected to the positive port of an inclined micro manometer, while the twin pressure taps on both sides of the central hole are united and connected to the negative tap, so the pressure difference between the streamwise central hole and the slanted holes are measured. The butterfly valve will be fully opened. A constant flow rate will be set and the gauge will be pulled out by steps of 5 mm. The micromanometer displacement has to be read for each gauge position. Attention should be paid that the gauge is directed facing the flow. During the measurement micromanometer tube has to be set to \( \frac{1}{2} \) position \((\sin \gamma = 0.5)\).

The deviation of the inclined micromanometer has to be corrected according to the Figure 2. The pressure difference and velocity can be calculated as written above using the corrected manometer deviation.

The tangential velocity \((v_t)\) can be calculated employing the pressure difference \((\Delta p_{\text{dynamic}} \text{ [Pa]})\) measured by the PITOT-static tube as follows:

\[
\Delta p_{\text{dynamic}} = \frac{\mu_{\text{air}}}{2} v_t^2 \rightarrow v_t = \sqrt{2 \cdot \Delta p_{\text{dynamic}} \rho_{\text{air}}}
\]

4. 4 Calculation of the pressure-drop on the filter

The system contains a filter after the cyclone to catch the fine dust (which can not be separated by the cyclone) and to avoid it to get into the laboratory through the fan. A U-tube manometer is connected to the pressure-side and discharge of the filter, so the pressure-drop on the filter can be determined as follows:

\[
\Delta h_{\text{filter}} = h_{\text{filter, left}} - h_{\text{filter, right}}
\]

\[
\Delta p_{\text{filter}} = \rho_{\text{water}} \cdot g \cdot \Delta h_{\text{filter}}
\]

When this pressure difference exceeds a prescribed value, the filter has to be cleaned.

5. Starting of the equipment

1. The manometer will be set, the measuring liquid level must be set to zero
2. The discharge of the fan will be closed by the butterfly valve for minimizing the power consumption during start up
3. The fan will be started
6. The measurement

6.1 Measurement of characteristic curve of the cyclone for unloaded operation and during dust transport

1. Different operating points will be set (10-15 measuring positions have to be set in such an order, that equal pressure difference steps on the ROSENMÜLLER manometer (9 in Fig. 1) can be read)
2. The displacement of U-tube and inclined micro manometer will be recorded for each butterfly valve setting
3. The average mass flow rate will be calculated in case of transport by measuring the mass of the dust and time during the operation
4. The measurement will be evaluated
5. The resistance of cyclone will be drawn in function of inlet velocity

\[ \Delta p_{\text{co}} = f(v_{\text{pipe}}) \quad \text{unloaded operation} \]
\[ \Delta p_{\text{t}} = f(v_{\text{pipe}}) \quad \text{during transport} \]

6.2 Measurement of velocity distribution

1. The gauge and manometer will be joined with mipolan tubes
2. The manometer will be set to position „1:2” for a better accuracy
3. The butterfly valve will be opened
4. The gauge will be set in streamwise direction
5. The gauge will be positioned by pulling it out for in 5 mm steps, paying attention to the right streamwise direction
6. The displacement of the ROSENMÜLLER manometer will be recorded for each gauge position
7. The measurement will be evaluated
8. The tangential velocity distribution will be drawn as a function of the radius: \( v_t = f(R) \)

The below written geometric data can be applied for the representation:

\( D_c = 350 \text{ mm} \) \hspace{1cm} \text{inner diameter of cylindrical part of the cyclone}
\( D_\phi = 85 \text{ mm} \) \hspace{1cm} \text{diameter of vertical discharge pipe}
\( m = 23 \text{ mm} \) \hspace{1cm} \text{distance between the plate fixed to the gauge and the flange on the cyclone (R}= 52.5 \text{ mm})

(for details see Figure 3.)
7. Table of measurements

<table>
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<tr>
<th>No. of meas.</th>
<th>$h_{cb}$ [mm]</th>
<th>$h_{cj}$ [mm]</th>
<th>$l$ [mm]</th>
<th>$h_{p1b}$ [mm]</th>
<th>$h_{p1j}$ [mm]</th>
<th>$h_{c1b}$ [mm]</th>
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Constants: $b=$ mmHgo $t_0=$ °C $\sin \alpha=$

$\rho_{\text{water}}=1000$ kg/m$^3$ $\rho_{\text{alcohol}}=800$ kg/m$^3$
### Measurement of particle transport in cyclone

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**Constant data:**

- \(b=\) mmHgo
- \(t_0=\) °C
- \(\sin\alpha=\)
- \(\rho_{\text{water}}=1000\ \text{kg/m}^3\)
- \(\rho_{\text{alcohol}}=800\ \text{kg/m}^3\)
### Measurement of pressure distribution

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Constant data:

- $b =$ mmHgo
- $t_0 =$ °C
- $\sin \alpha =$
- $\rho_{\text{water}} =$ 1000 kg/m$^3$
- $\rho_{\text{alcohol}} =$ 800 kg/m$^3$
Figure 1.
Figure 2.