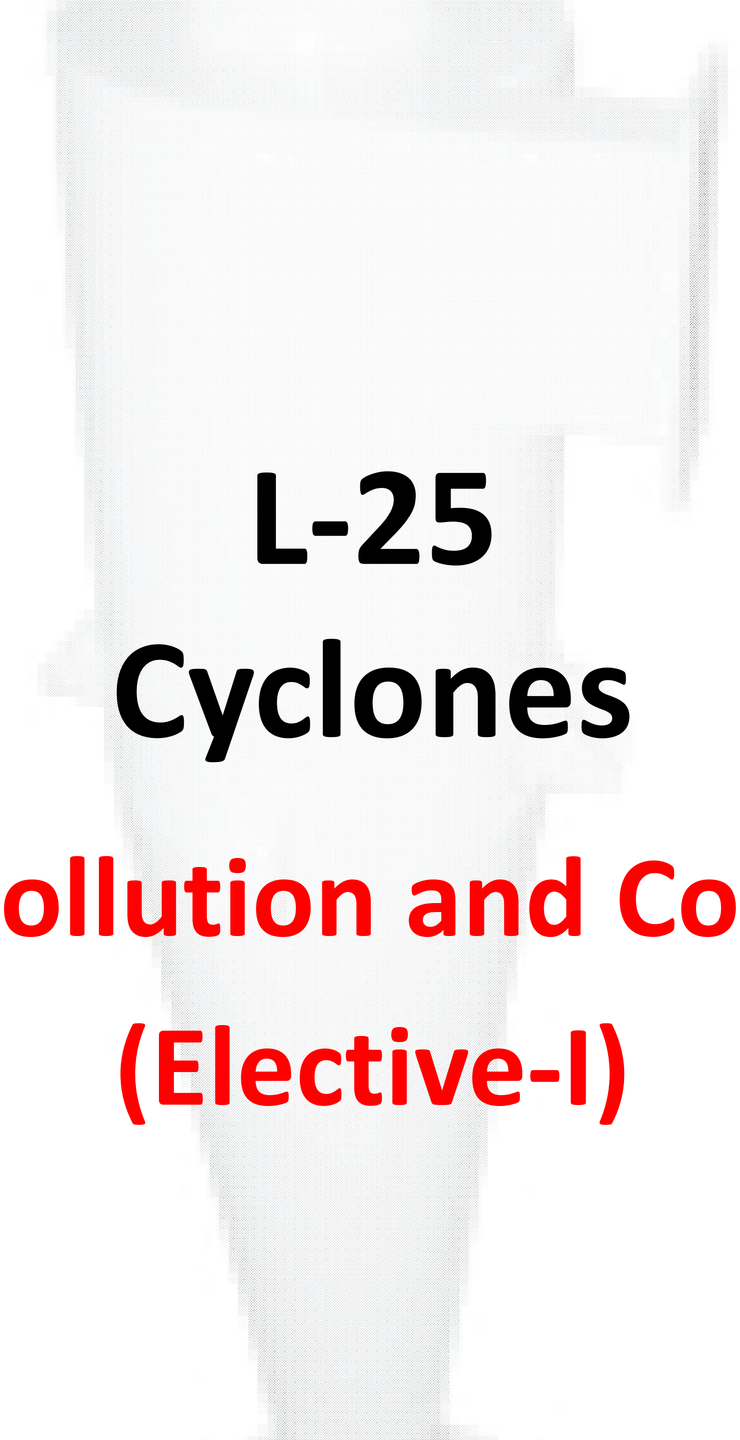


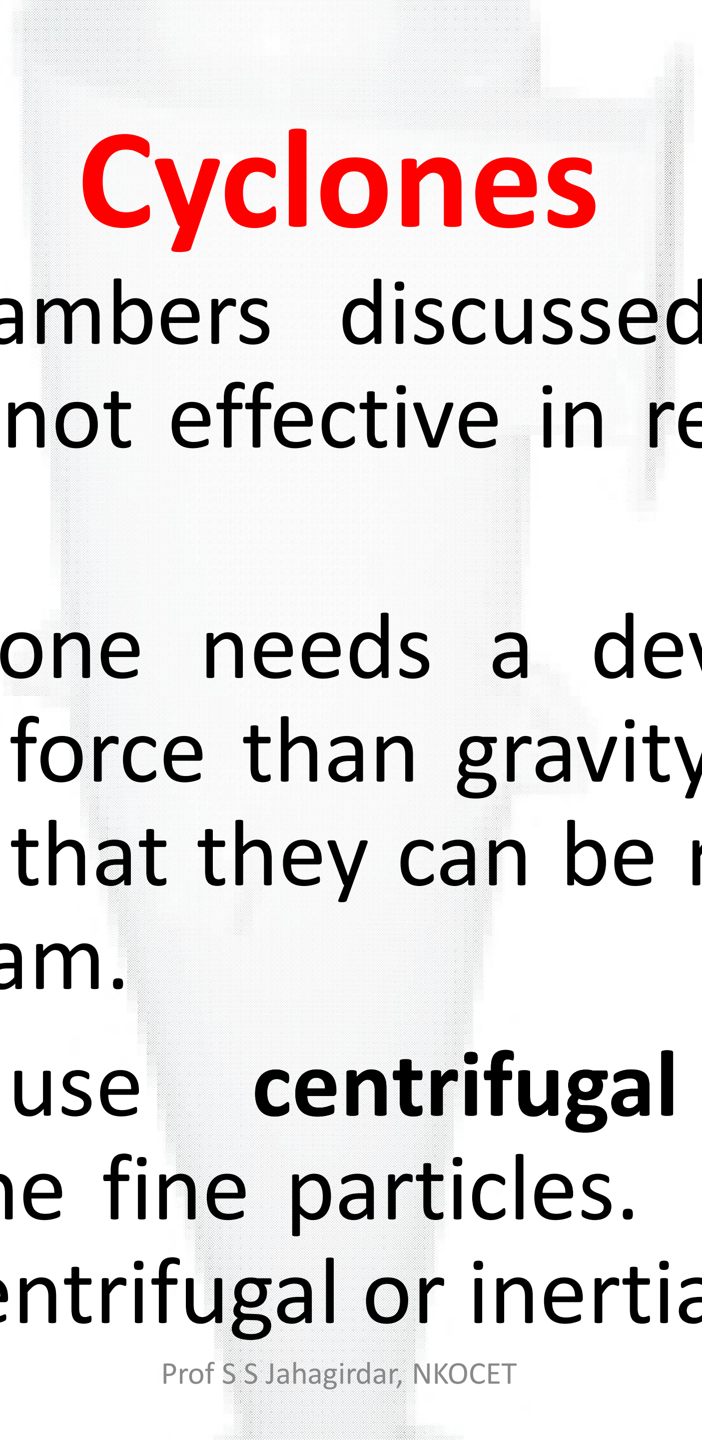
L-25

Cyclones

Air Pollution and Control

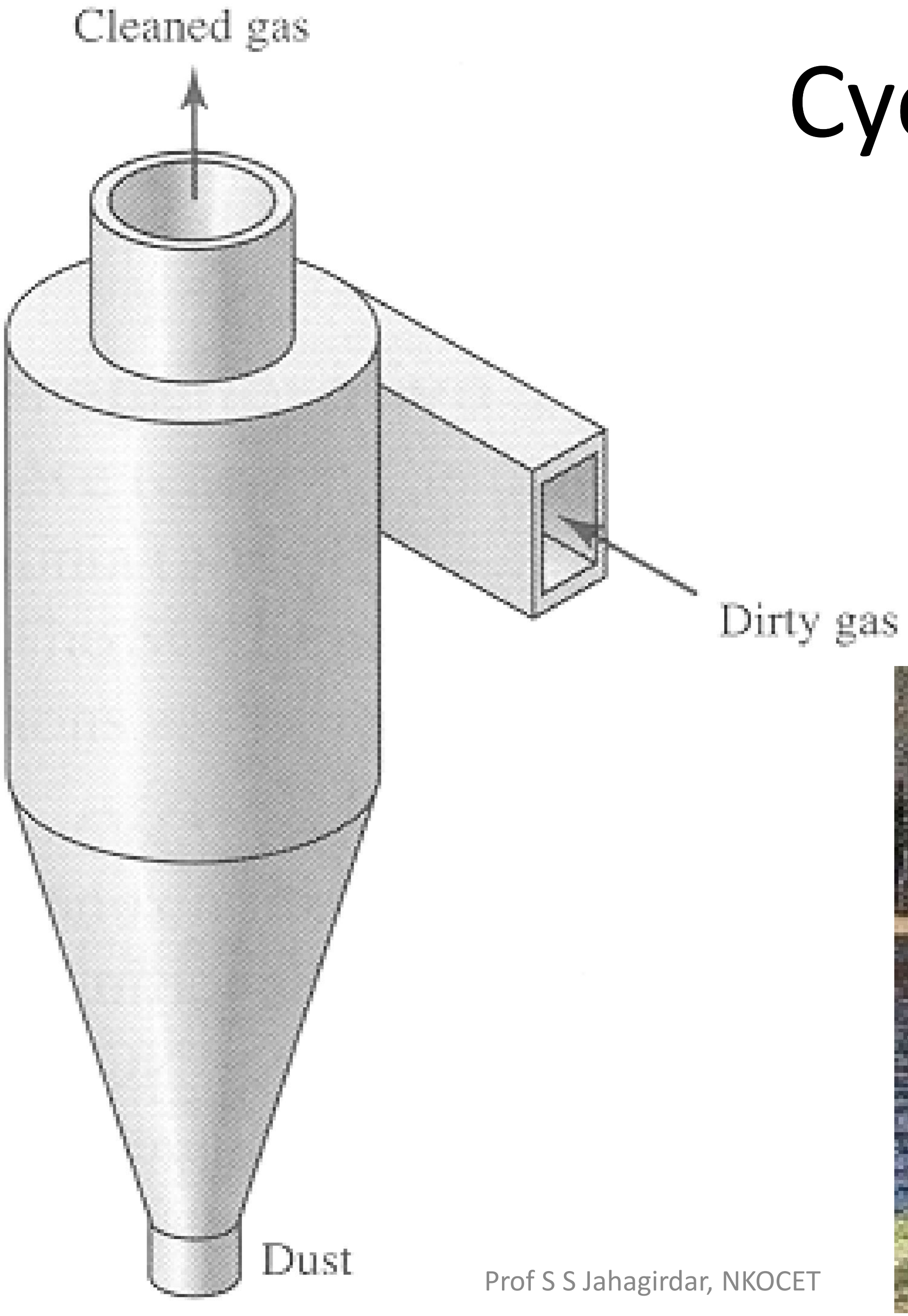
(Elective-I)

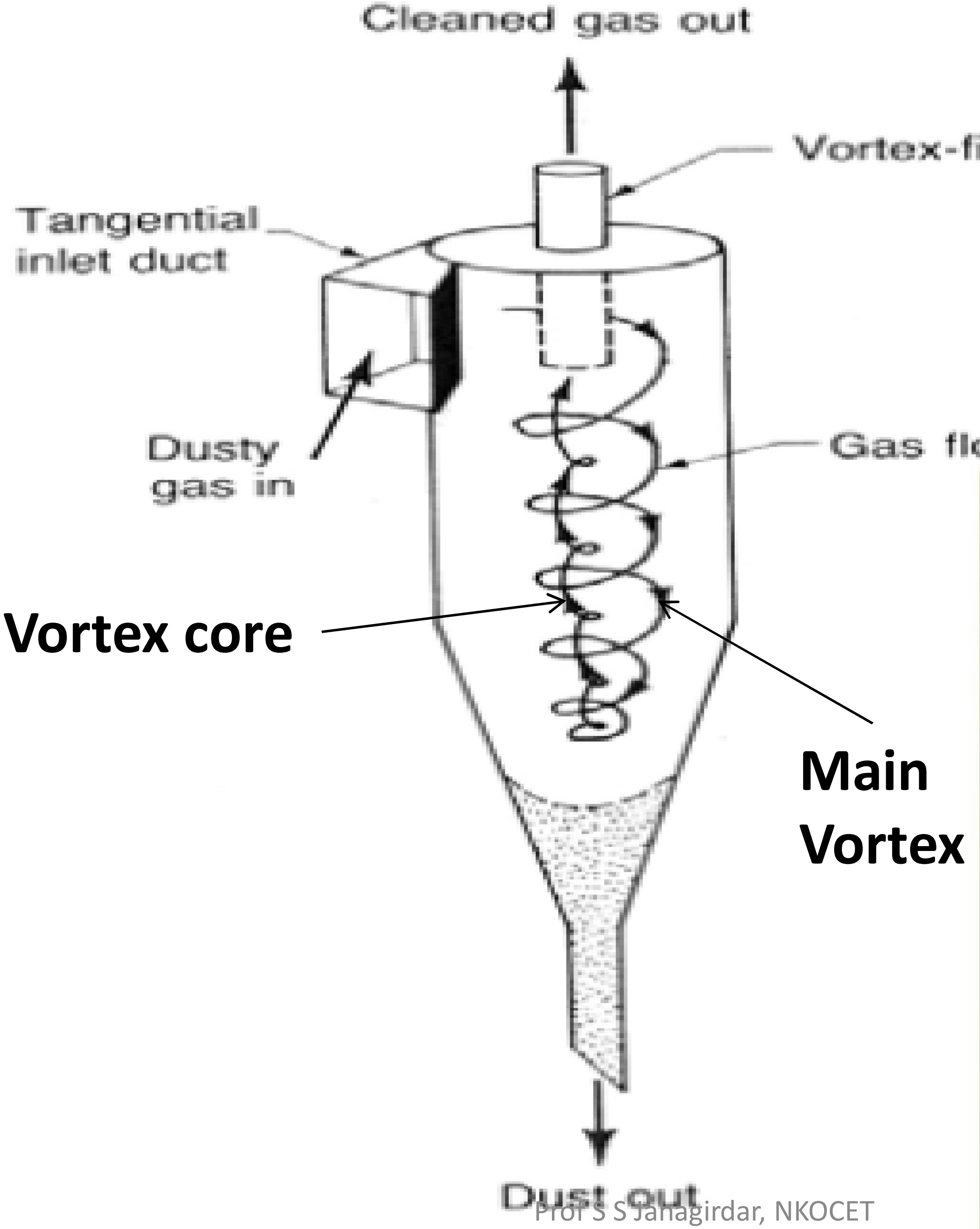
Cyclones



- Settling chambers discussed in previous lecture are not effective in removing small particles.
- Therefore, one needs a device that can exert more force than gravity force on the particles so that they can be removed from the gas stream.
- Cyclones use **centrifugal forces** for removing the fine particles. They are also known as centrifugal or inertial separators.

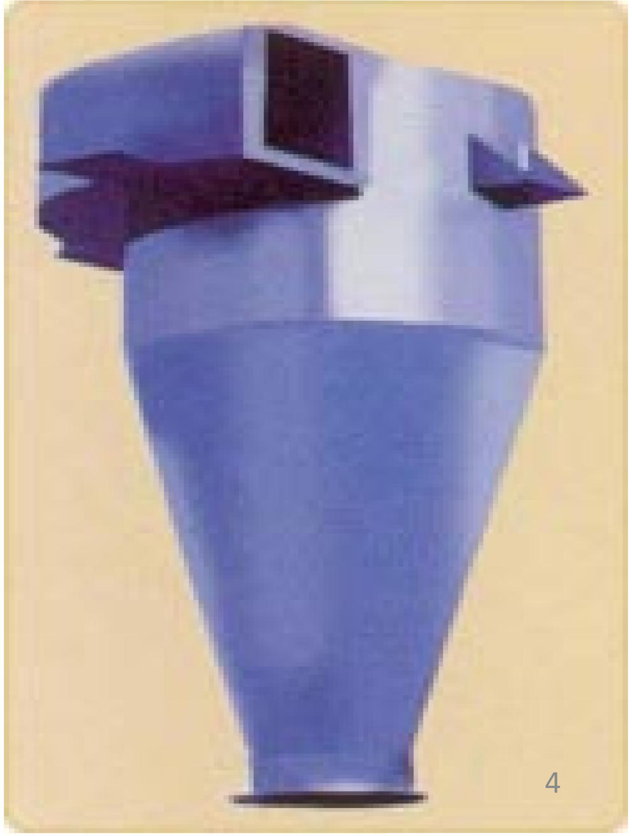
Cyclone



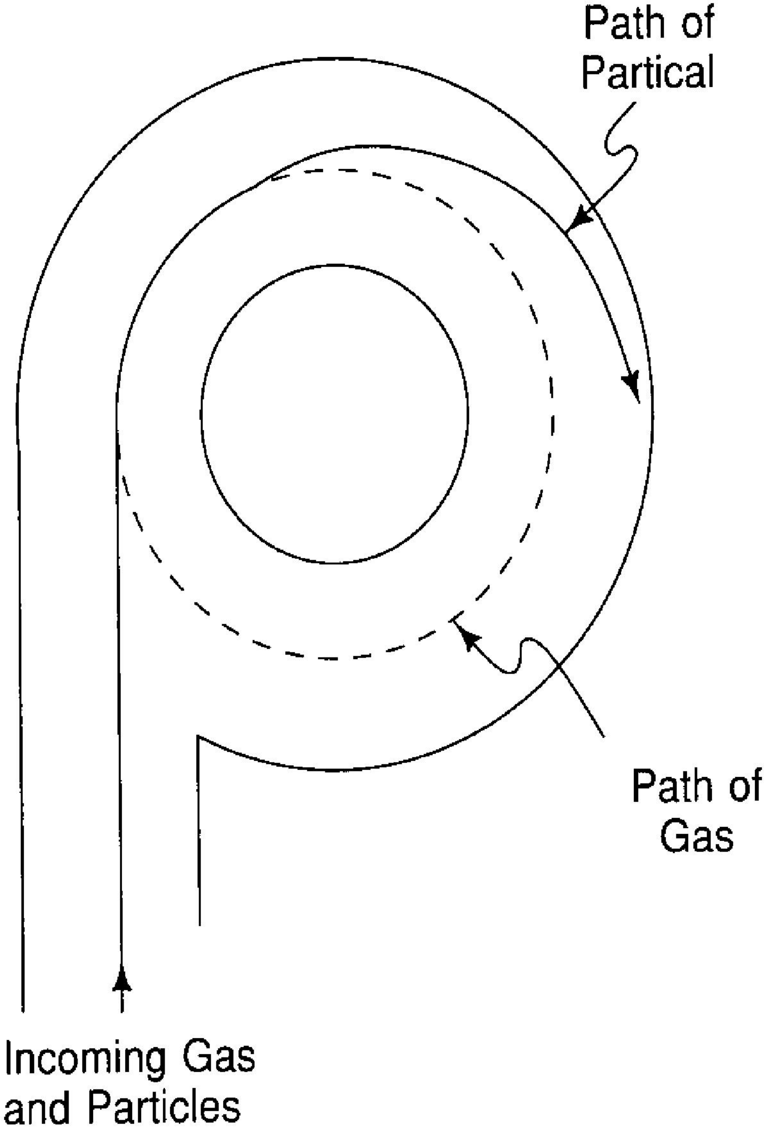


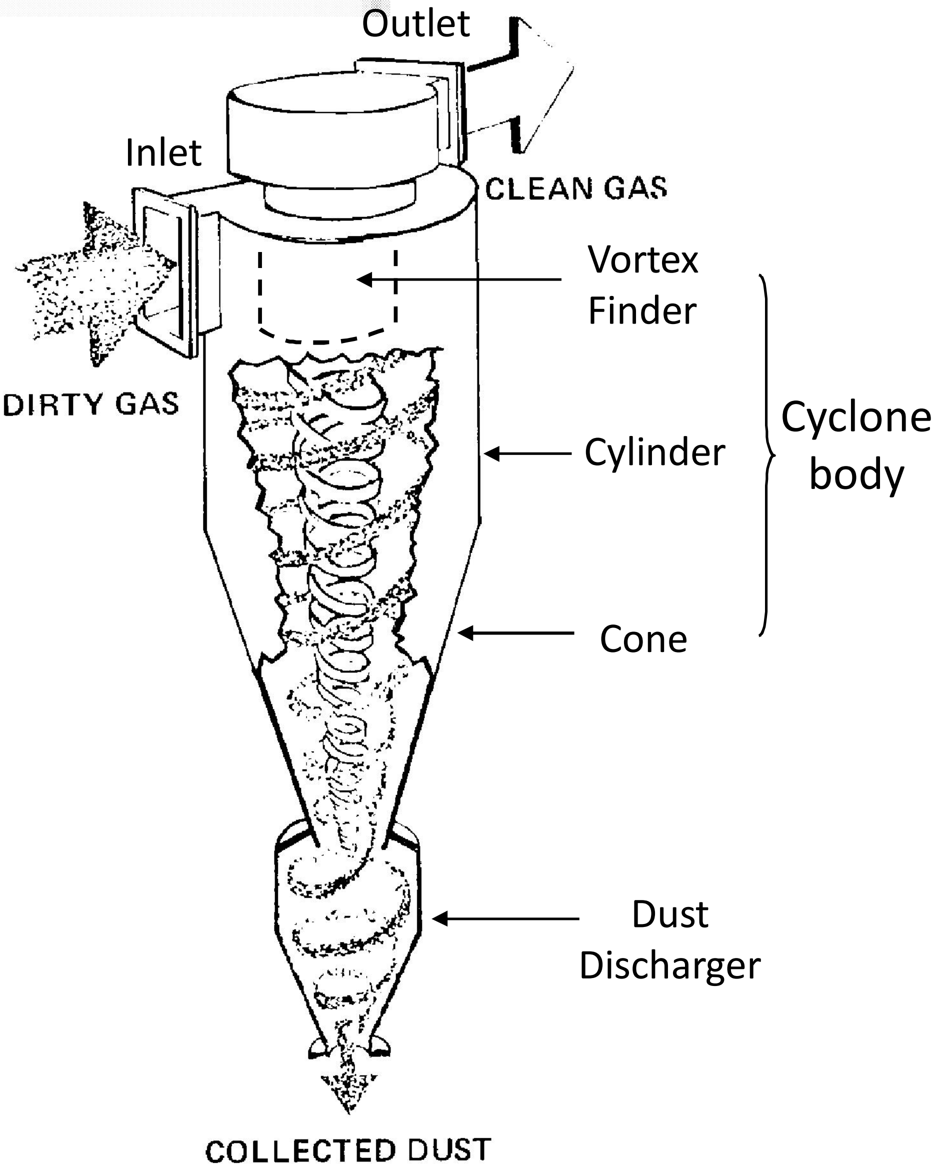
Vortex core

Main Vortex



CYCLONE





Outlet

Inlet

Vortex
Finder

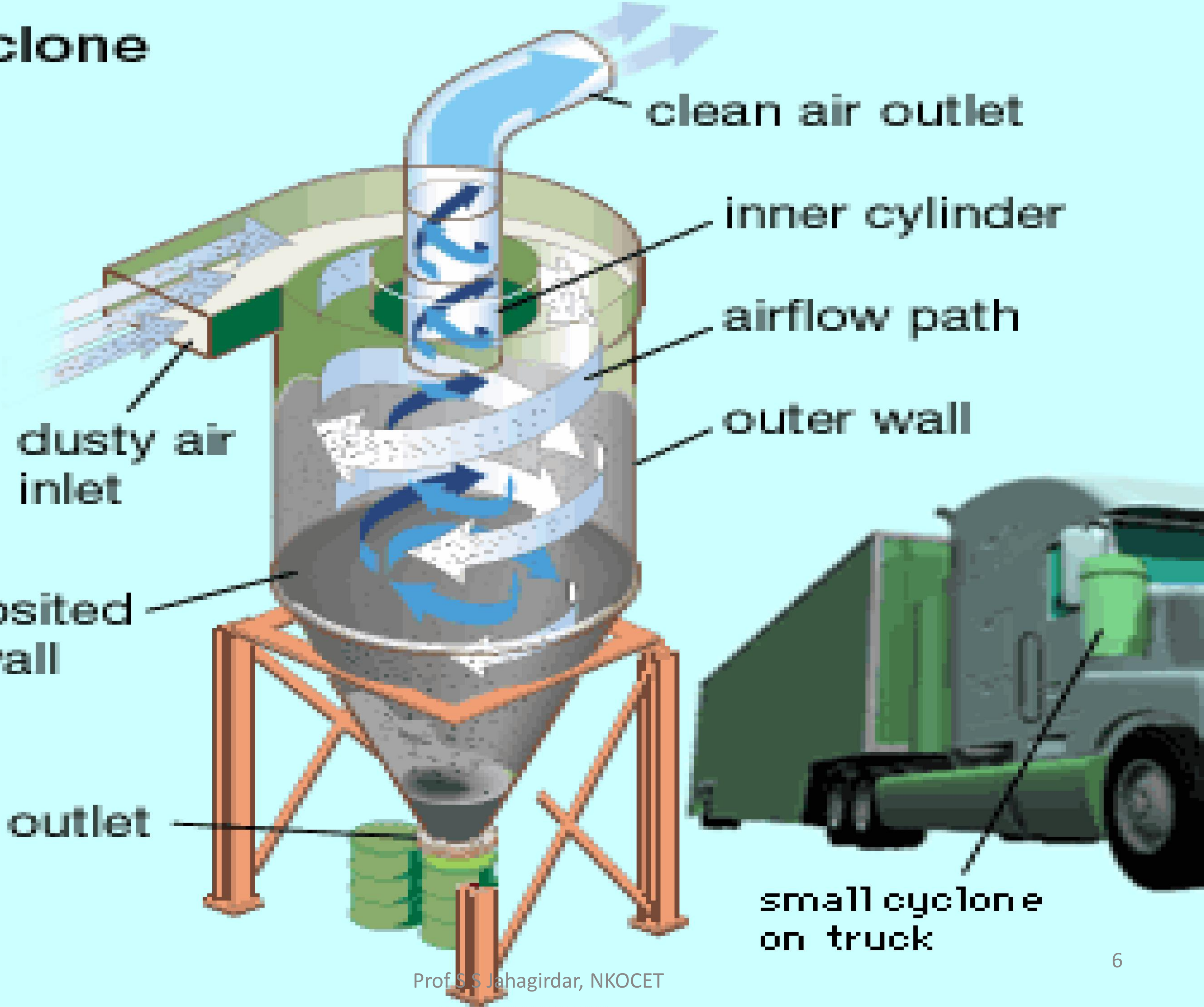
Cylinder

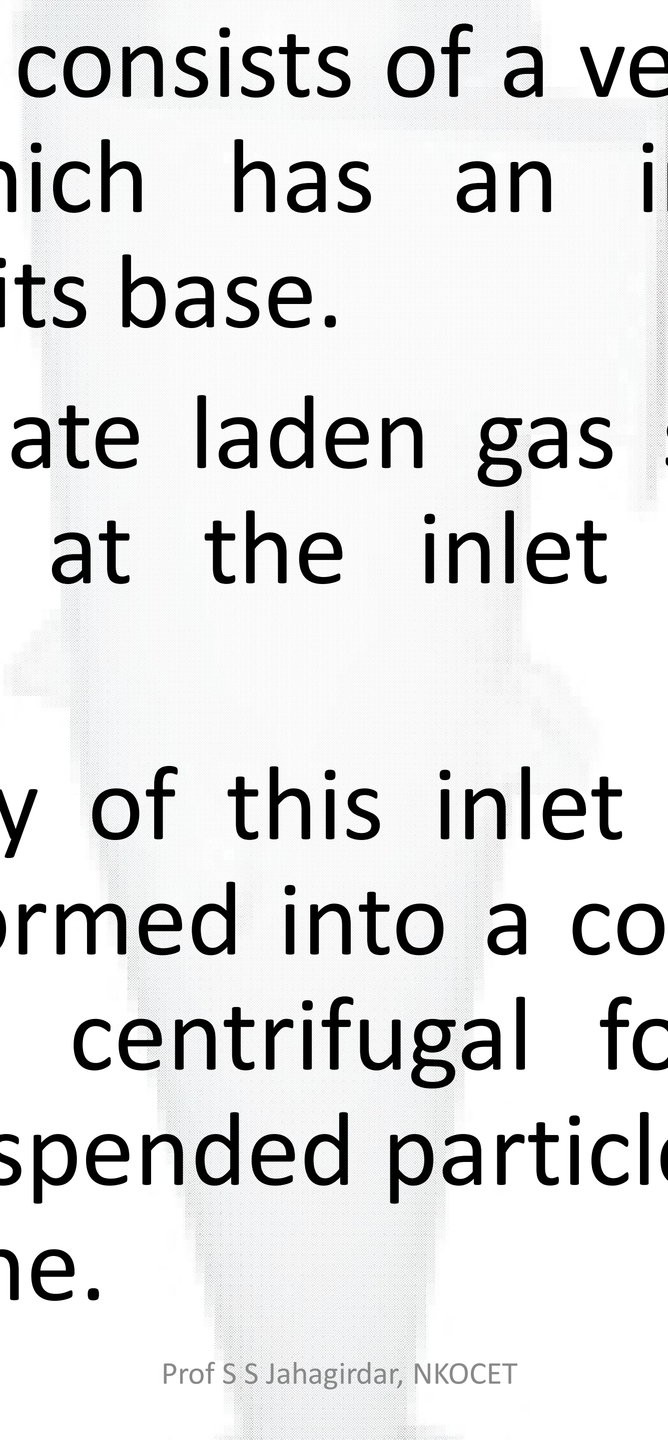
Cone

Cyclone
body

Dust
Discharger

Cyclone

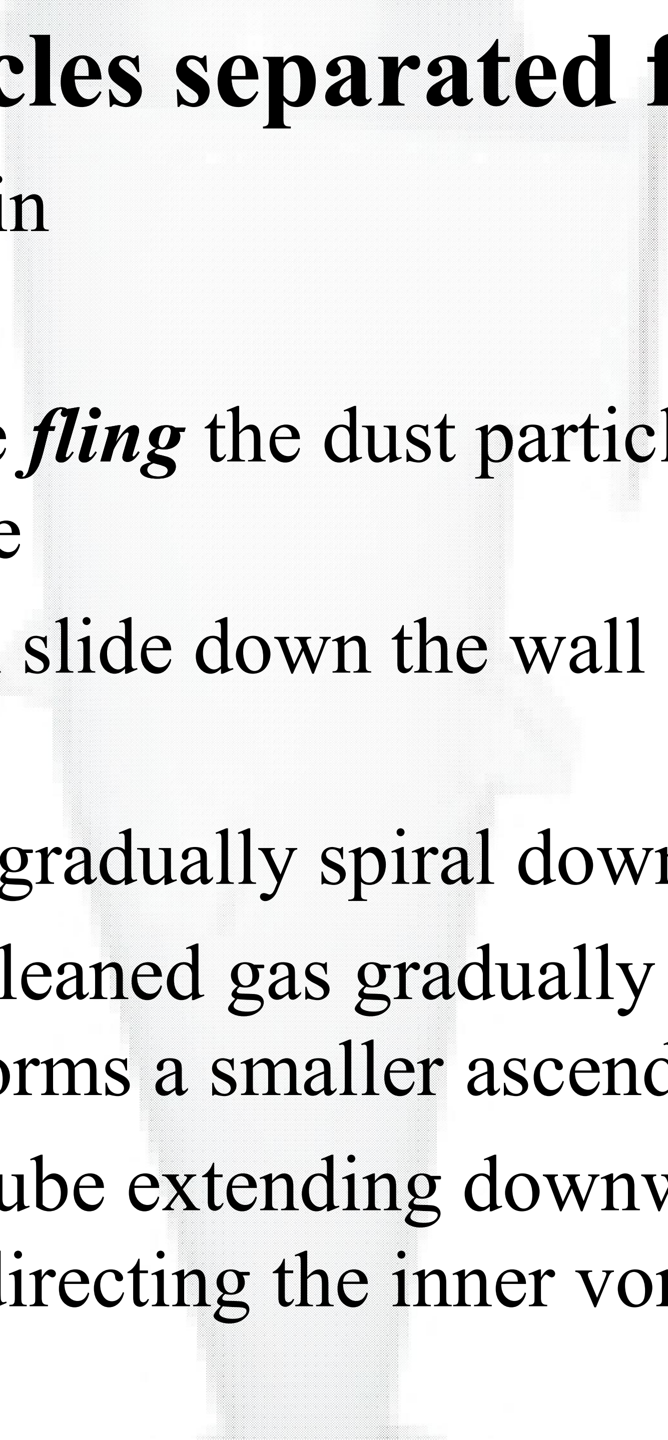

clean air outlet
inner cylinder
airflow path
outer wall
dusty air inlet
dust deposited on wall
dust outlet
small cyclone on truck



- The cyclone consists of a vertically placed cylinder which has an inverted cone attached to its base.
- The particulate laden gas stream enters tangentially at the inlet point to the cylinder.
- The velocity of this inlet gas stream is then transformed into a confined vortex, from which centrifugal forces tend to drive the suspended particles to the walls of the cyclone.

- The vortex turns upward after reaching at the bottom of the cylinder in a narrower inner spiral.
- The clean gas is removed from a central cylindrical opening at the top, while the dust particles are collected at the bottom in a storage hopper by gravity.

How particles separated from gas?



- A high rate of spin

→Spinning gas

→Centrifugal force ***fling*** the dust particles to the walls of cylinder and cone

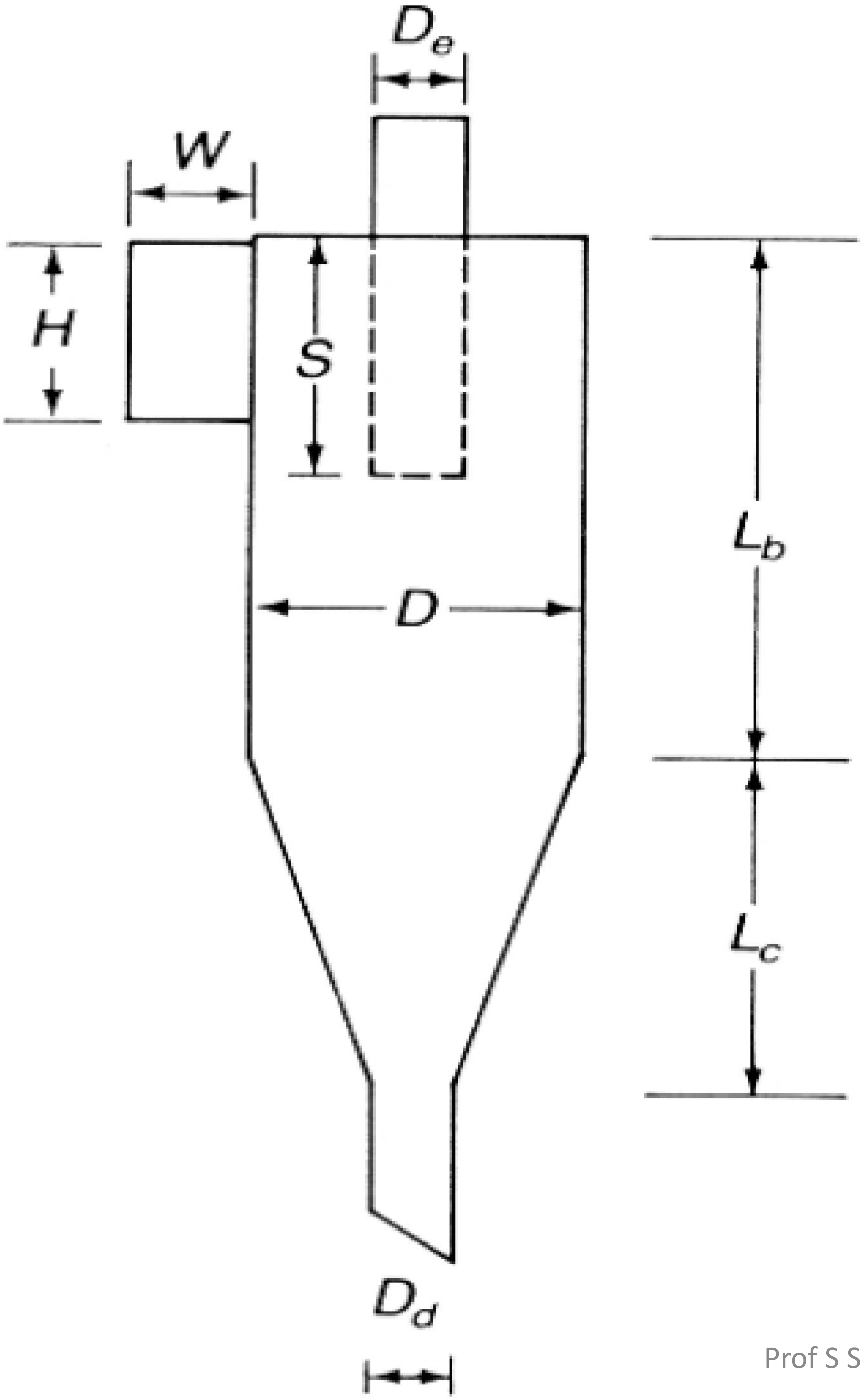
→The particle then slide down the wall and into the storage hopper

→The cleaned gas gradually spiral downward …

→The downward cleaned gas gradually reversed its downward and forms a smaller ascending spiral

→A vortex finder tube extending downward into the cylinder aids in directing the inner vortex out of the device

Cyclone Dimensions



D= Body diameter

H= Height of inlet

W= width of inlet

L_c= Length of cone

L_b= Length of body

S= Length of vortex finder

D_e= Diameter of exit

D_d= Diameter of dust outlet

Effective turns

$$N_e = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right)$$

where

N_e = number of effective turns

H = height of inlet duct (m or ft)

L_b = length of cyclone body (m or ft)

L_c = length (vertical) of cyclone cone (m or ft).

Equation for d_p

$$d_p = \left[\frac{9\,\mu W}{\pi N_e V_i (\rho_p - \rho_g)} \right]^{1/2}$$

where **V_i = Gas Velocity at inlet (m/s or ft/s)**

V_t = terminal velocity (m/s or ft/s)

d_p = diameter of the particle (m or ft)

ρ_p = density of the particle (kg/m^3)

ρ_g = gas density (kg/m^3)

μ = gas viscosity (kg/m.s).

- ***dp*** *is the size of the smallest particle that will be* collected if it starts at the inside edge of the inlet duct.

- Thus, in theory, all particles of size *dp or larger should be collected with 100% efficiency.*

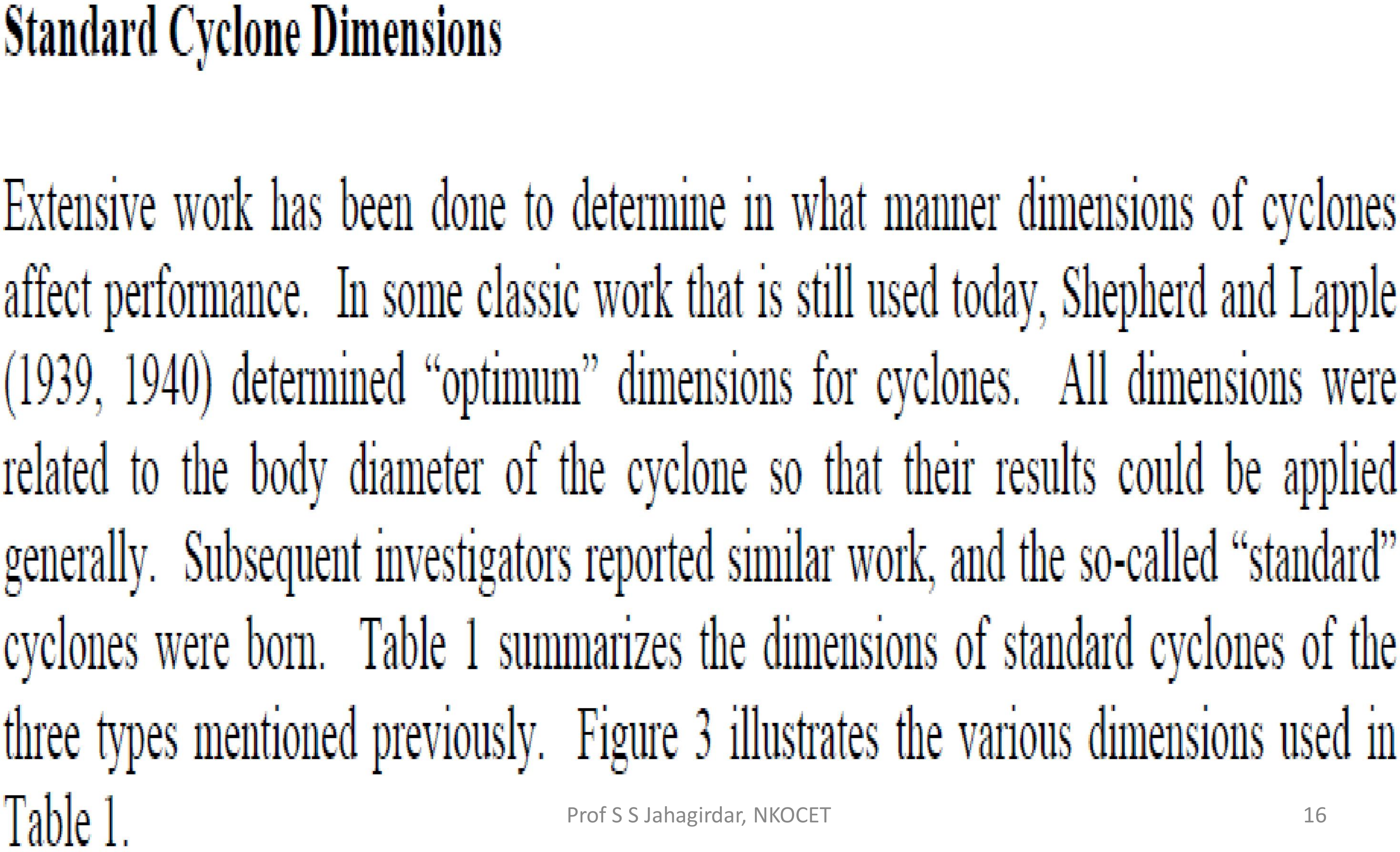
Equation for Cut Size diameter

Lapple (1951) developed a semi-empirical relationship to calculate a “50% cut diameter” d_{pc} , which is the diameter of particles collected with 50% efficiency. The expression is

$$d_{pc} = \left[\frac{9\,\mu W}{2\pi N_e V_i (\rho_p - \rho_g)} \right]^{1/2}$$

where d_{pc} = diameter of particle collected with 50% efficiency.

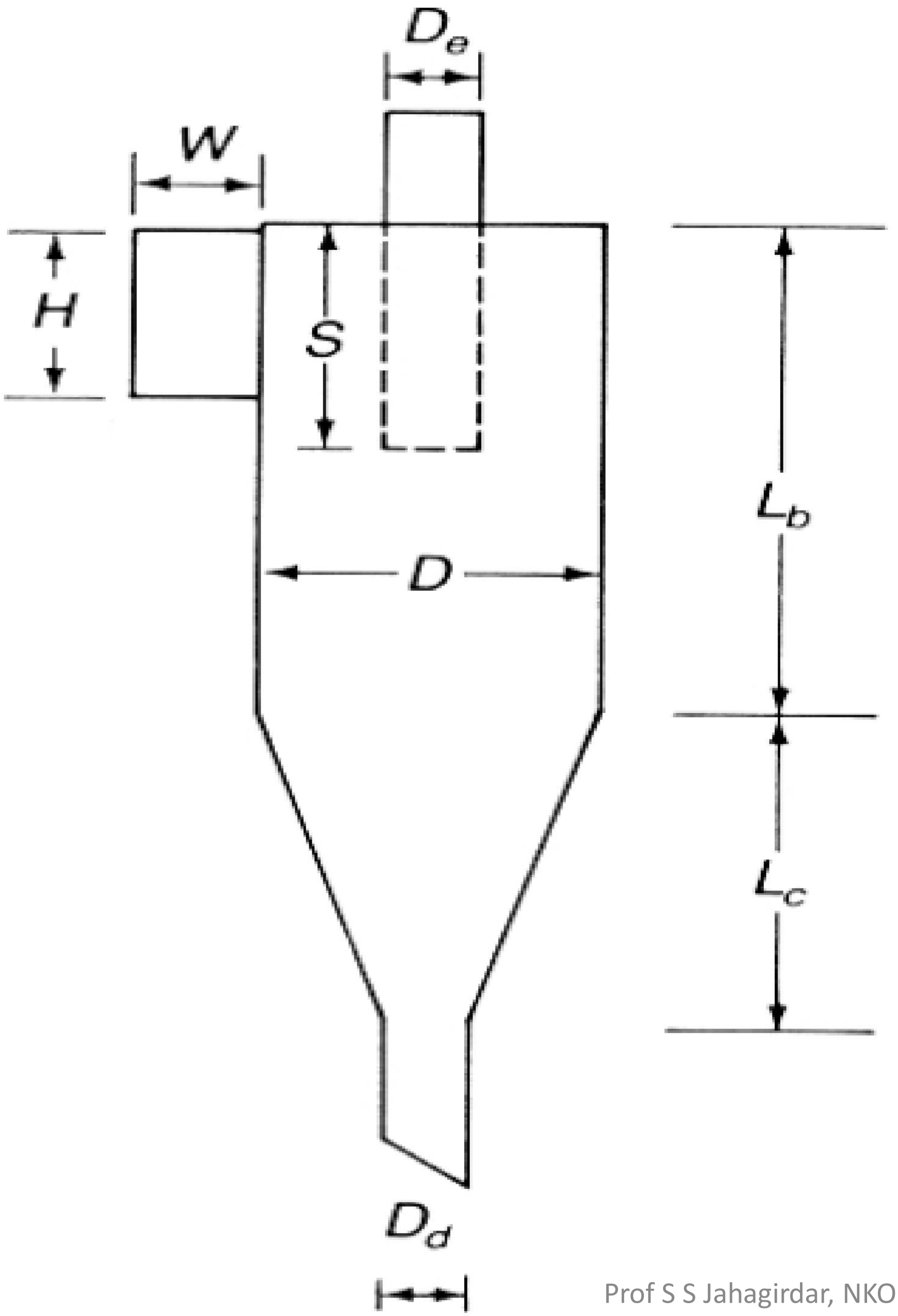
Standard Cyclone



Standard Cyclone Dimensions

Extensive work has been done to determine in what manner dimensions of cyclones affect performance. In some classic work that is still used today, Shepherd and Lapple (1939, 1940) determined "optimum" dimensions for cyclones. All dimensions were related to the body diameter of the cyclone so that their results could be applied generally. Subsequent investigators reported similar work, and the so-called "standard" cyclones were born. Table 1 summarizes the dimensions of standard cyclones of the three types mentioned previously. Figure 3 illustrates the various dimensions used in Table 1.

Standard Cyclone



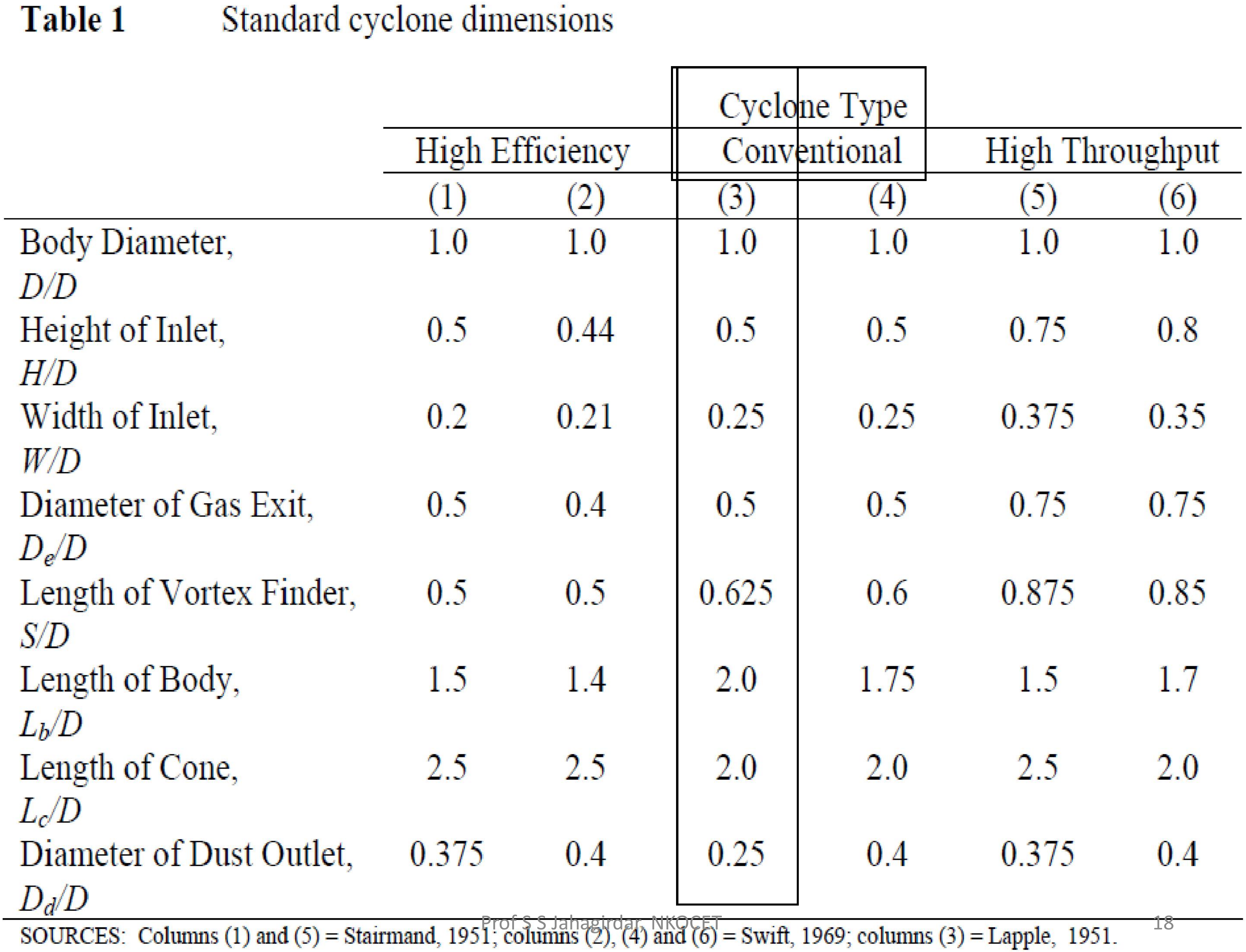


Table 1 Standard cyclone dimensions

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, *D/D*	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, *H/D*	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, *W/D*	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, *S/D*	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4

SOURCES: Columns (1) and (5) = Stairmand, 1951; columns (2), (4) and (6) = Swift, 1969; columns (3) = Lapple, 1951.

Equation of Cyclone

- **Lapple** then developed a general curve for standard conventional cyclones to predict the collection efficiency for any particle size.
- If the size distribution of particles is known, the overall collection efficiency of a cyclone can be predicted by using above graph.
- **Theodore and DePaola (1980)** have fitted an algebraic equation to above graph, which makes Lapple’s approach more precise and more convenient for application to computers.

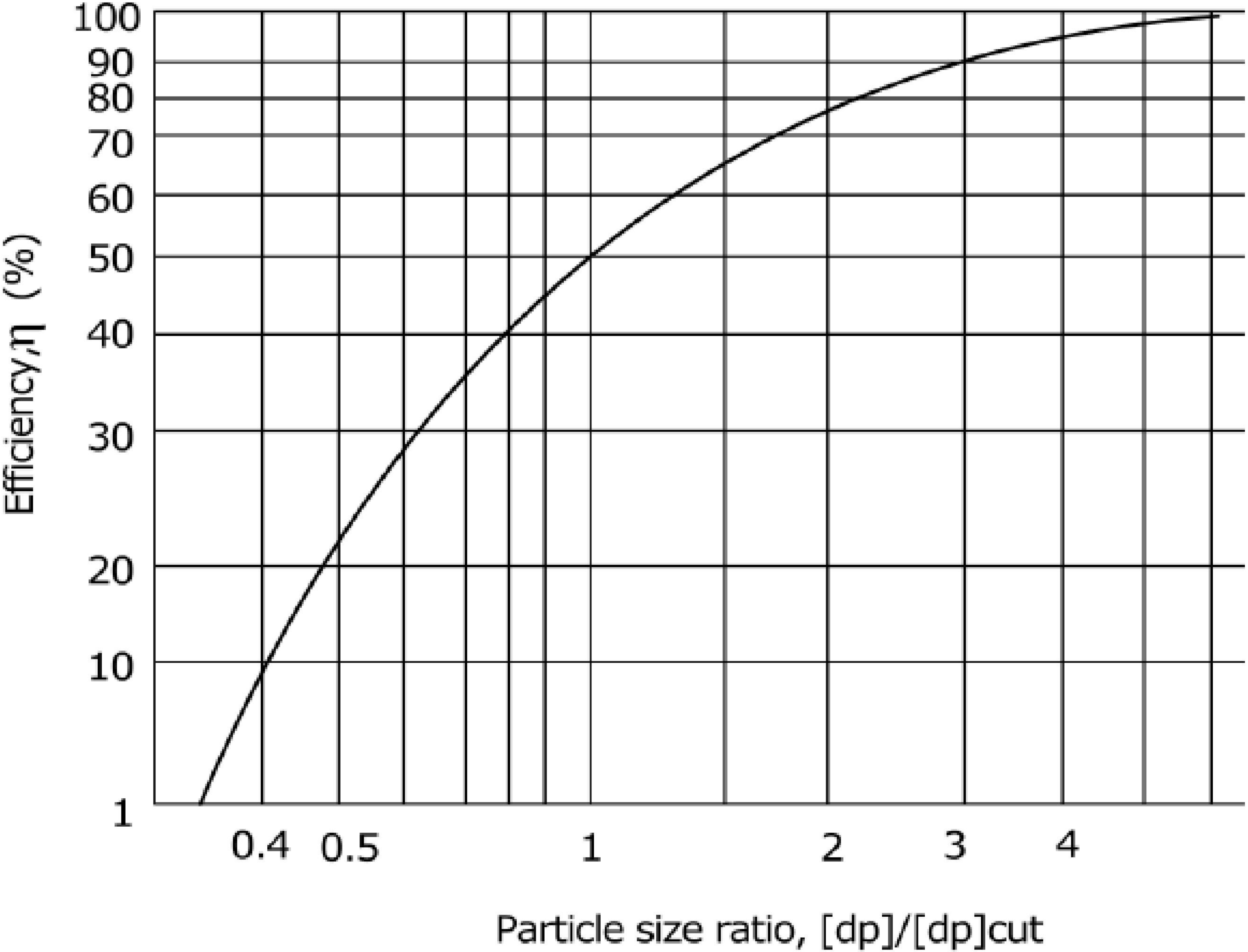


Figure 6-10. Lapple cyclone efficiency curve

Equation for efficiency

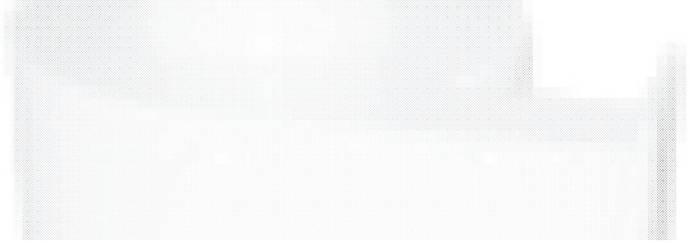
The efficiency of collection of any size of particle is given by

$$\eta_j = \frac{1}{1+\left(d_{pc}/d_{pj}\right)^2} \text{ X } 100$$

where

η_j = collection efficiency of particles in the *j*th size range ($0 < \eta_j < 1$) **in %**

d_{pj} = characteristic diameter of the *j*th particle size range (in µm).



The overall efficiency of the cyclone is a weighted average of the collection efficiencies for the various size ranges, namely

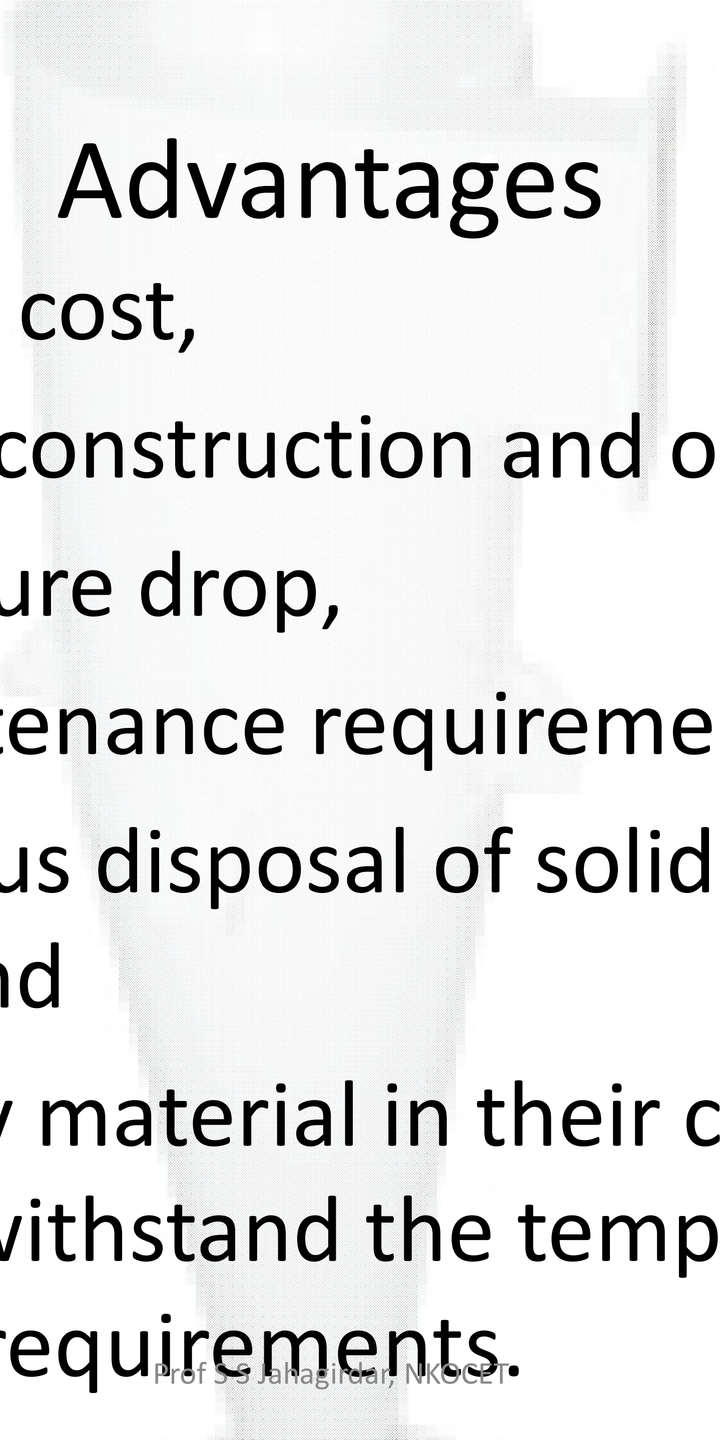
$$\eta = \frac{\sum \eta_j m_j}{M}$$

where

η = overall collection efficiency ($0 < \eta < 1$)

m_j = mass of particles in the jth size range

M = total mass of particles.



Advantages

i) low initial cost,

ii) simple in construction and operation,

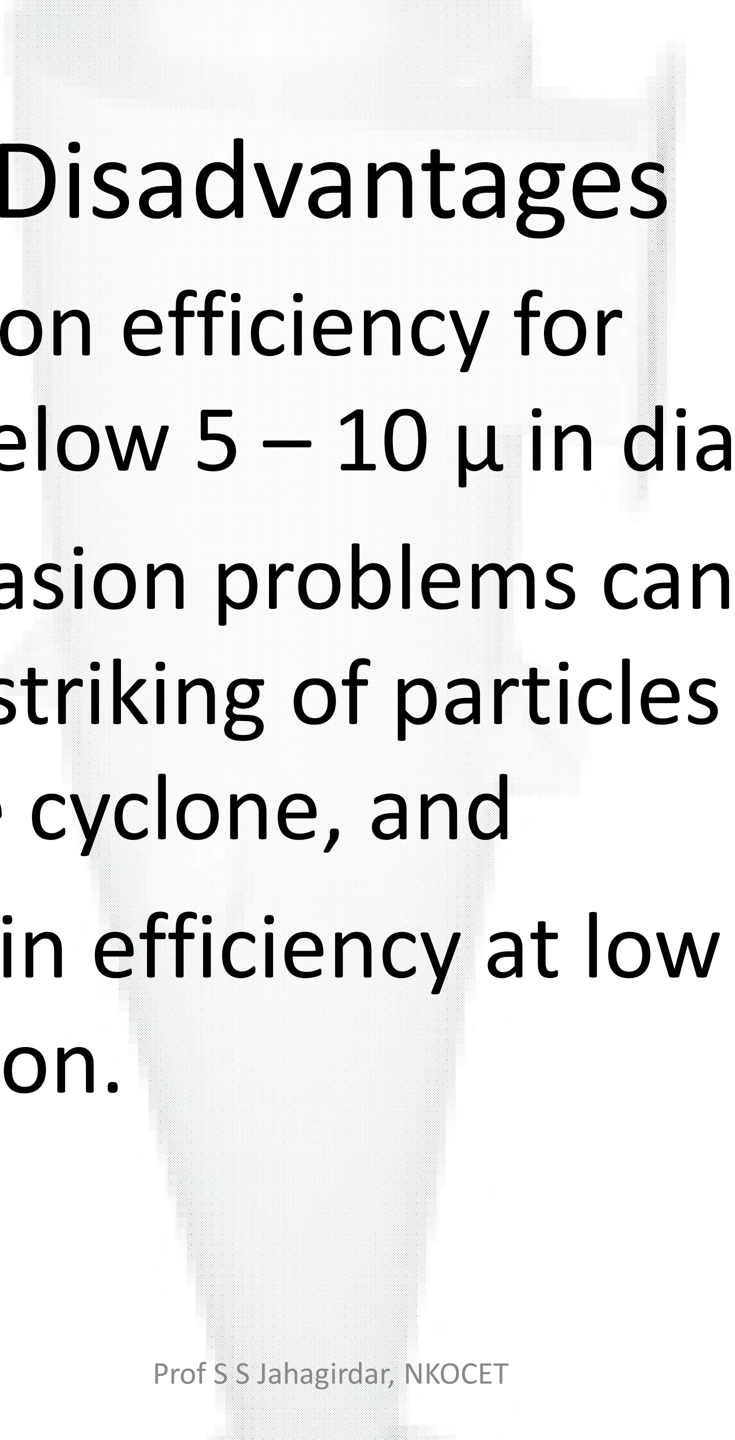
iii) low pressure drop,

iv) low maintenance requirements,

v) continuous disposal of solid particulate matter, and

vi) use of any material in their construction that can withstand the temperature and pressure requirements.

Disadvantages

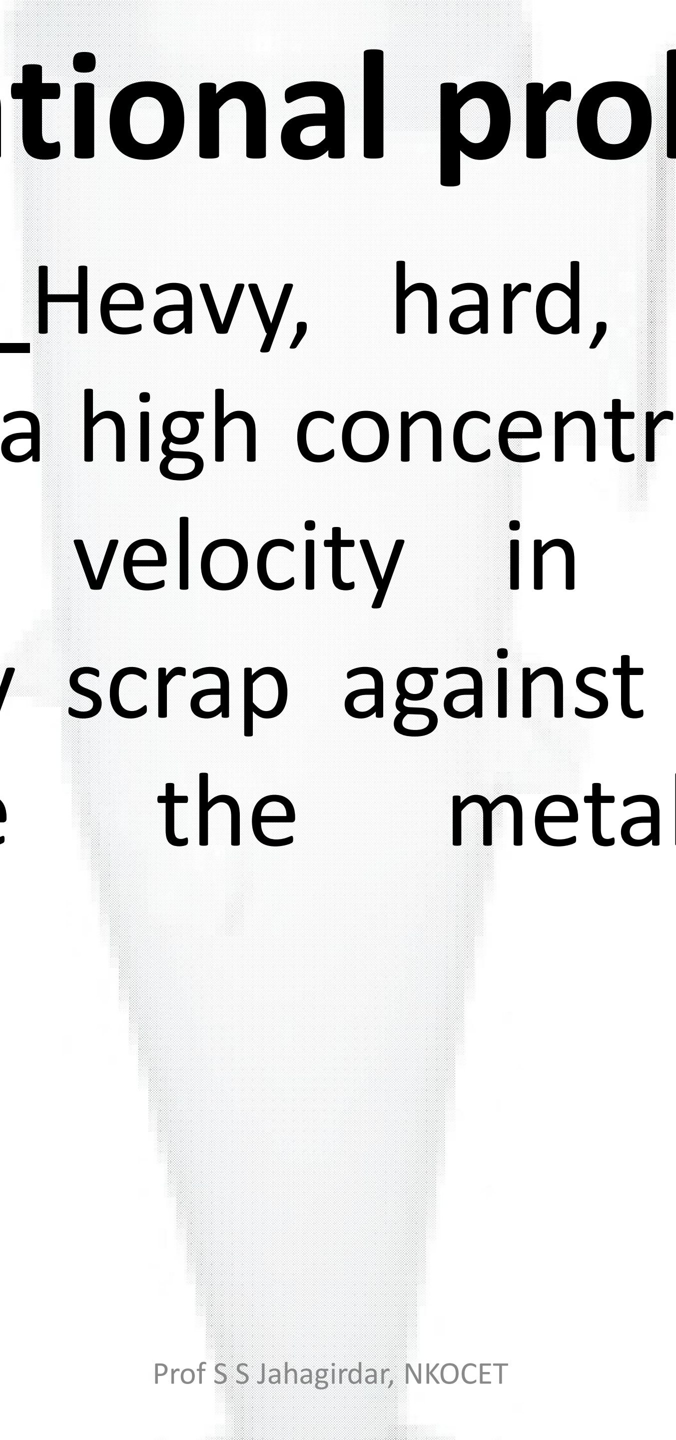


i) low collection efficiency for particles below 5 – 10 μ in diameter,

ii) severe abrasion problems can occur during the striking of particles on the walls of the cyclone, and

iii) a decrease in efficiency at low particulate concentration.

Operational problems



- **<u>i) Erosion: </u>**Heavy, hard, sharp edged particles, in a high concentration, moving at a high velocity in the cyclone, continuously scrap against the wall and can erode the metallic surface.

- **ii) Corrosion:** If the cyclone is operating below the condensation point, and if reactive gases are present in the gas stream, then corrosion problems can occur. Thus the product should be kept above the dew point or a stainless steel alloy should be used.
- **iii) Build – up**: A dust cake builds up on the cyclone walls, especially around the vortex finder, at the ends of any internal vanes, and especially if the dust is hygroscopic. It can be a severe problem.

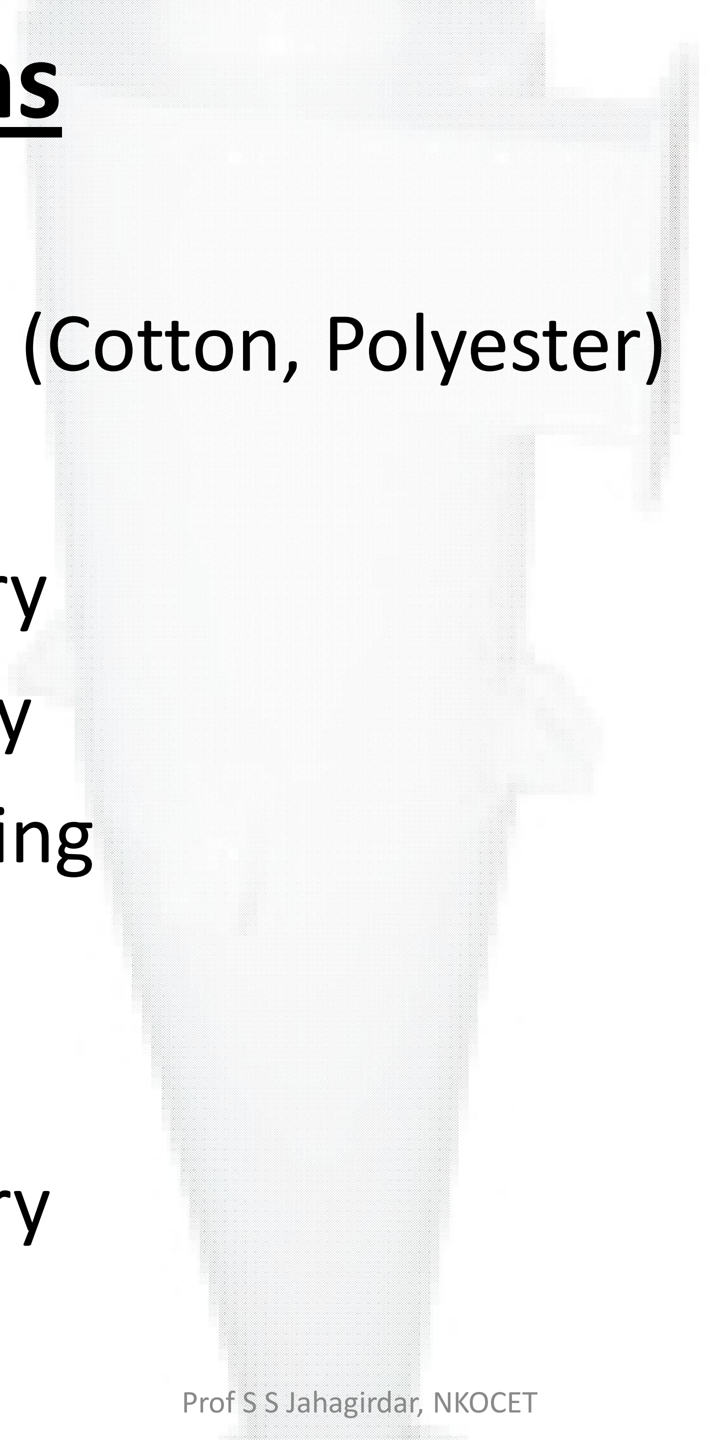
Applications of cyclones

i) For the control of gas borne particulate matter in industrial operations such as **cement manufacture, food and beverage, mineral processing and textile industries.**

ii) To separate dust in the disintegration operations, such as **rock crushing, ore handling and sand conditioning in industries.**

iii) To recover catalyst dusts in the **petroleum industry.**

iv) **To reduce the fly ash emissions.**



- **Applications**
- Power Plant
- Textile industry (Cotton, Polyester)
- Stone Crusher
- Mineral Industry
- Rubber Industry
- Material Handling
- Fly Ash
- Lead Industry
- Cement Industry
- Steel Industry

Objective Questions

Q1. In cyclone particulate separation takes place because of ____________________ force.

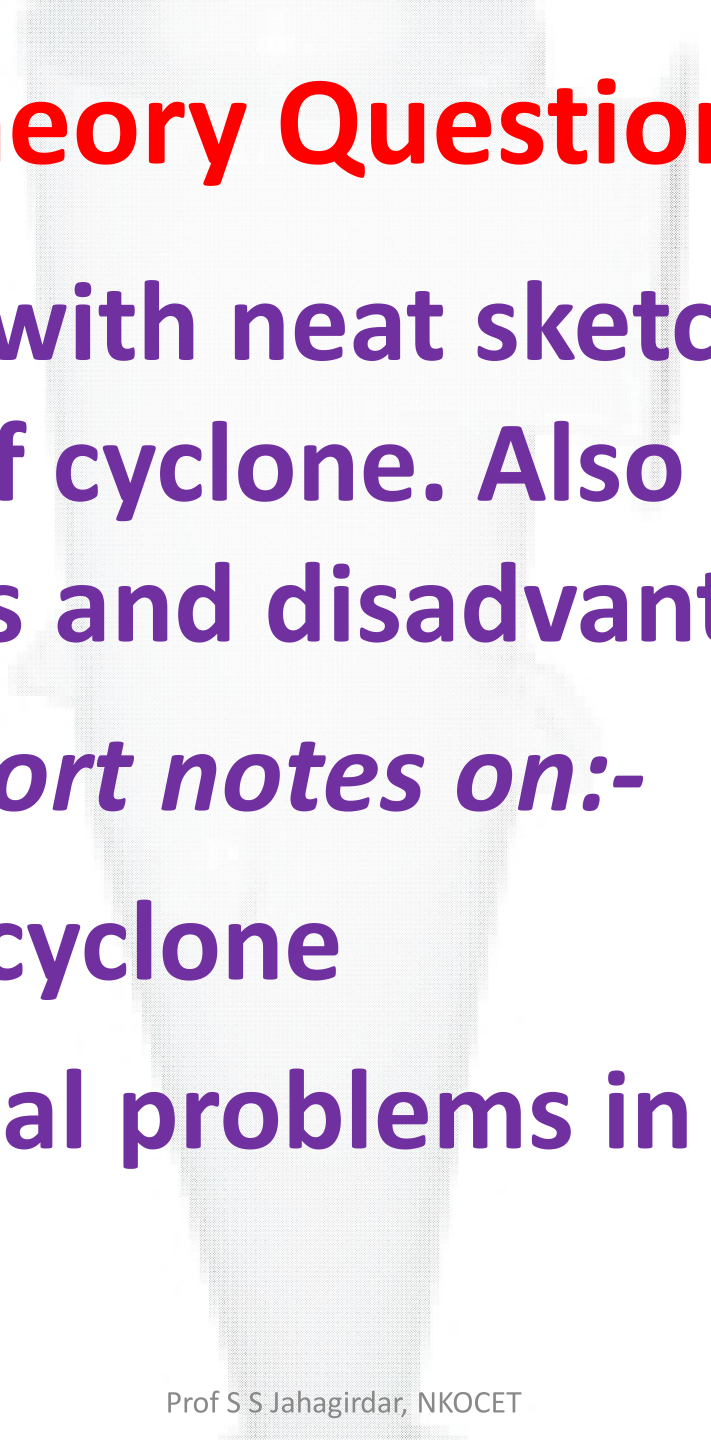
Q2. Cyclone separator has ______________ inlet.

Q3. In case of cyclone equation for effective turns is given by ___________________.

Q4. Cut size diameter in case of cyclone can be computed by using equation ___________________.

Q5. In case of a standard cyclone length of conical part is given by ____________________. *(similar questions on dimensions of cyclone)*

Theory Questions



Q1. Discuss with neat sketch working principle of cyclone. Also list its advantages and disadvantages.

Q2. write short notes on:-

1. **Standard cyclone**
2. **Operational problems in cyclone.**

Example of Cyclone Analysis

Given:

Conventional type (standard proportions)
D = 1.0 m
Flow rate = Q = 150 m^3/min
Particle density = ρ_p = 1600 kg/m^3
Particle size distribution (see below)

Particle size (d_p)	% mass in that size range (m/M)
0-2 μm	1.0%
2-4 μm	9.0%
4-6 μm	10.0%
6-10 μm	30.0%
10-18 μm	30.0%
18-30 μm	14.0%
30-50 μm	5.0%
50-100 μm	1.0%
	100%

Question:

What is the collection efficiency?

Solution

$$N = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right) = 6 \qquad V_i = \frac{Q}{WH} = \frac{Q}{0.125\,D^2} = 1200\ \text{m/min} = 20\ \text{m/s}$$

$$d_{pc} = \sqrt{\frac{9}{2\pi}\,\frac{\mu W}{N V_i(\rho_p - \rho_a)}} = \sqrt{\frac{9}{2\pi}\,\frac{0.25\,\mu D}{6 V_i(\rho_p - \rho_a)}} = 5.79\times10^{-6}\,\text{m} = 5.79\ \mu\text{m}$$

Size range (in μm)	Average size d_p (in μm)	Collection efficiency η	Mass fraction m/M	Contribution to performance $\eta \times m/M$
0 – 2	1	2.9%	0.01	0.029%
2 – 4	3	21.1%	0.09	1.903%
4 – 6	5	42.7%	0.10	4.268%
6 – 10	8	65.6%	0.30	19.678%
10 – 18	14	85.4%	0.30	25.613%
18 – 30	24	94.5%	0.14	11.953%
30 – 50	40	97.9%	0.05	4.897%
50 - 100	75	99.4%	0.01	0.994%
			1.00	**70.6%**