Basic Environmental Engineering and Pollution Abatement
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Lecture: 25
Air Pollution Control 5

Hello everyone, now we will have a tutorial class and in this class we will discuss on some problems related to the discussion, we have made in the last four classes.

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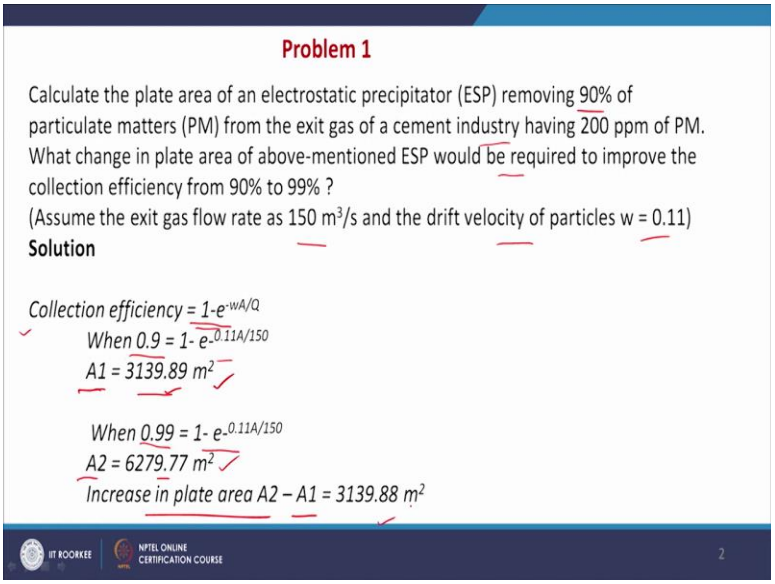

First problem the statement is, calculate the plate area of an electrostatic precipitator removing 90 % of particulate matter from the exit gas of a cement industry having 200 ppm of particulate matter. What change in plate area of above mentioned ESP would be required to improve the collection efficiency from 90 % to 99 %? Assume the exit gas flow rate as 150 m^3/s and the drift velocity of particles w is equal to 0.11.

So, this is the problem of electrostatic precipitator. Already we have made discussion on it in our previous classes and here we see that collection efficiency for ESP can be determined by this expression

Collection efficiency = $1-e^{-wA/Q}$

When $0.9 = 1- e^{-0.11A/150}$

$A_1 = 3139.89\ m^2$

So, this is the area which is required to get 90 % efficiency for these applications using the ESP. Now if the efficiency we need to increase from 90 to 99 %, so then the final efficiency will be 0.99

$0.99 = 1- e^{-0.11A/150}$

$A_2 = 6279.77\ m^2$

So, this is the area required for the second case that is for 99 % efficiency

Increase in plate area $A_2 – A_1 = 3139.88\ m^2$

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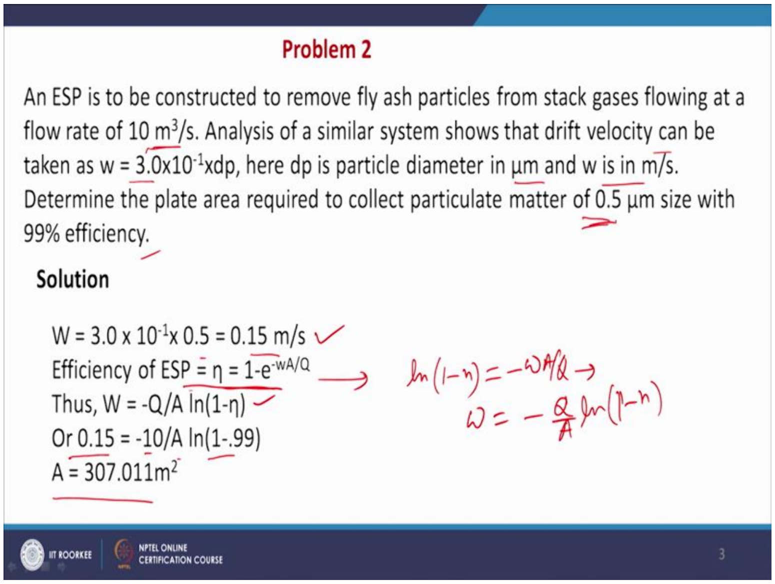

Next we will see problem number 2. The statement is, an ESP is to be constructed to remove fly ash particles from stack gases flowing at a flow rate of 10 m^3/s. Analysis of a similar system shows that drift velocity can be taken as $W = 3*10^{-1}*dp$, here dp is the particle diameter in µm and W is in m/s. So, determine the plate area required to collect particulate matter of 0.5 µm size with 99 % efficiency.

So, we have to calculate the area requirement again, in this case the efficiency is 99 % for the particle size of 0.5 µm. And the drift velocity here it is given as then function of dp that is the particle diameter see in our case dp value is 0.5 µm. So, we will be calculating W

$W = 3*10^{-1}*0.5 = 0.15$ m/s, so this is our drift velocity.

So, this W value will use in our efficiency expression that is

$\eta = 1-e^{-wA/Q}$

Ln(1- η) = -WA/Q

W= -Q/A Ln(1- η)

Now in this case after putting values

0.15= -10/Aln(1-0.99)

A = 307.011 m^2.

So, this is the area of the collector which is required to get 99 % efficiency for the separation of the particle having 0.5 μm size. So, now we are able to solve the problem.

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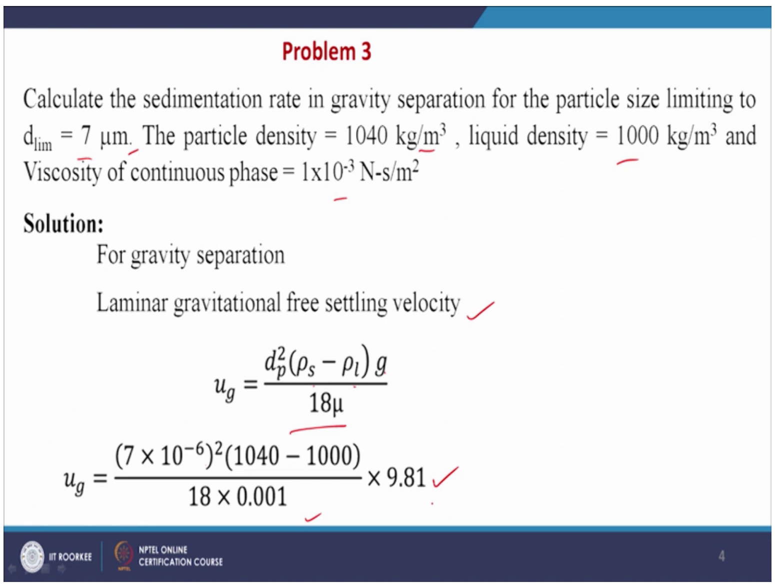

Next, we will have problem number 3, The statement is, calculate the sedimentation rate in gravity separation for the particle size limiting to $d_{limiting}$ = 7 μm. The particle density = 1040 kg/m^3, and liquid density = 1000 kg/m^3, and viscosity of continuous phase = $1*10^{-3}$ N-s/m^2.

So, this is the problem related to gravity separation, so in case of gravity separation, if we assume that laminar flow regime is applicable then laminar gravitational free settling velocity will be

$$u_g = \frac{d_p^2(\rho_s - \rho_l)\, g}{18\mu}$$

$$u_g = \frac{(7 \times 10^{-6})^2(1040 - 1000)}{18 \times 0.001} \times 9.81$$

Ug = $1.068*10^{-6}$ m/s

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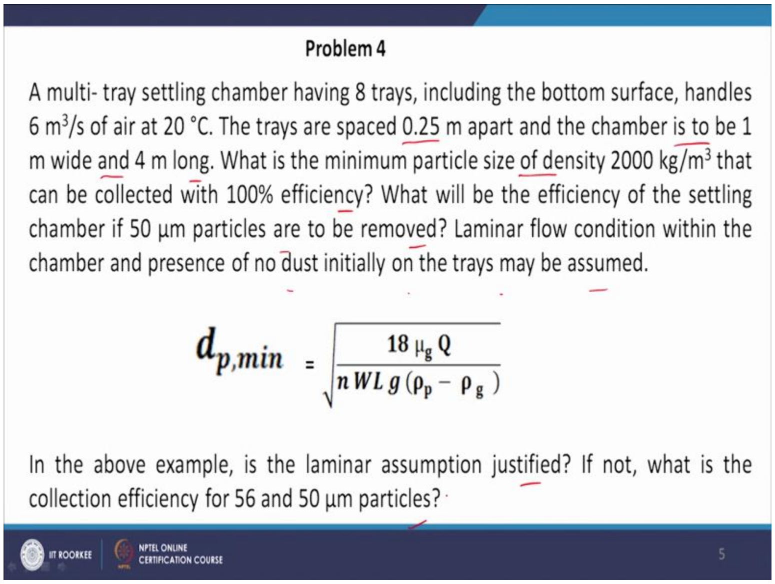

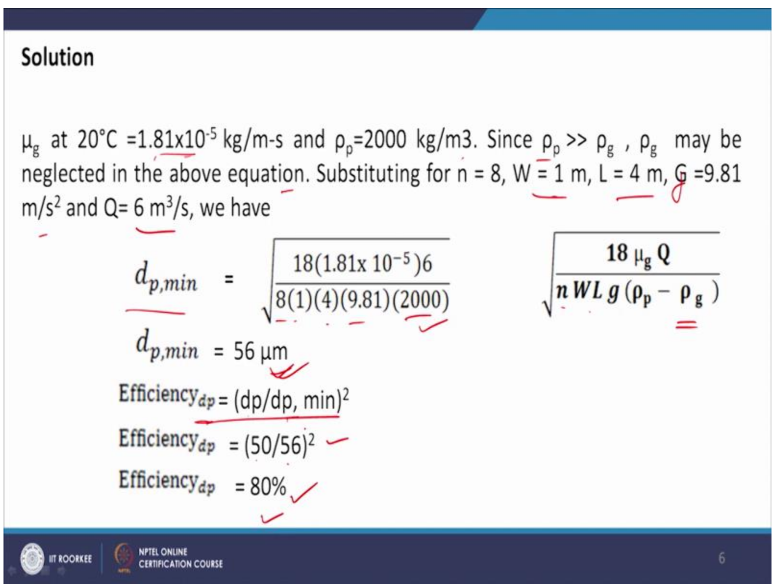

So, then problem number 4, the statement is, a multi tray settling chamber having 8 trays including the bottom surface, handles 6 m^3/s of air at 20 ºC. The trays are spaced 0.25 m apart and the chamber is to be 1 m wide and 4 m long. What is the minimum particle size of density 2000 kg/m^3 that can be collected with 100 % efficiency? What will be the efficiency of the settling chamber if 50 µm particles are to be removed? Laminar flow condition within the chamber and presence of no dust initially on the trays may be assumed.

So, this is given and dp minimum,

$$d_{p.min} = \sqrt{\frac{18\mu_g Q}{nWLg(\rho_p - \rho_g)}}$$

In the above example is the laminar assumption justified. We have to check it and then if not, what is the collection efficiency for 56 and 50 µm particles? So, this which we have written here dp minimum that is for laminar flow regime.

And if we want to get the solution, so we will get the value of dp minimum, so we will be using this expression. And these expressions we need to get the values of all these parameters which is given in the statement. Here $\rho_p >> \rho_g$, ρ_g may be neglected

$$d_{p.min} = \sqrt{\frac{18(1.81 * 10^{-5})6}{8(1)(4)(9.81)(2000)}}$$

$d_{p.min}$ = 56 µm.

So, this minimum diameter is 56 µm when the flow is in laminar regime.

Now efficiency for dp this is equal to for any other particle size, if we get any other particle size and want to calculate the efficiency of other particle size, so in that case it is proportional to dp^2.

Efficiency $_{dp} = (d_p/d_{p\ min})^2$

So, this is the first part. First part we had to calculate, what will be the efficiency of the settling chamber if 50 micrometer particles are to be removed and then laminar conditions within the chamber are presence and no dust initially on the tray may be assumed. So, on the basis of that assumptions we can get the for 50 µm particles. Because this is our 56 is the minimum diameter, so this minimum diameter particle size means we will be getting 100 percent removal.

Now the diameter is less than this 56 µm that is 50 µm so efficiency

Efficiency $_{dp} = (50/56)^2$ = 80%.

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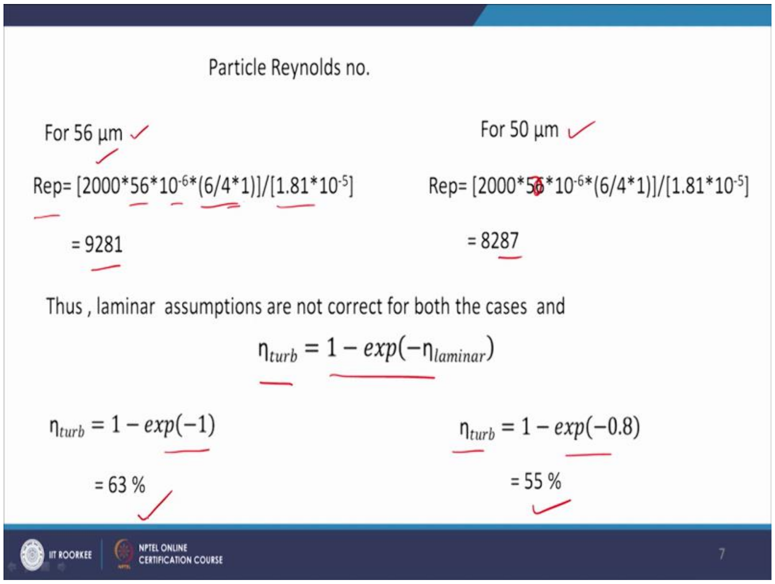

Now second part we have to calculate, the flow is in laminar regime or not. So, for 56 µm particle and for 50 µm particle, we will be calculating the particle Reynolds number.

$Rep = [2000*56*10^{-6}*(6/4*1)]/[1.81*10^{-5}] = 9281$

So, particle Reynolds number so very high. So, this is not in the laminar flow. So for the same case for 50 µm we are getting

$Rep = [2000*50*10^{-6}*(6/4*1)]/[1.81*10^{-5}] = 8287$

So, here also the particle Reynolds number 8287 is very higher, so in this case the laminar assumptions which we have considered are not correct for both the cases and efficiency turbulence will be different from the efficiency which we have got in the previous slide.

So, that efficiency in case of turbulent flow

$\eta_{turb} = 1 - \exp(-\eta_{laminar})$

For the first case when we are having 56 µm particle size then we have 100 % efficiency.

$\eta_{turb} = 1 - \exp(-1) = 63\%$

But in the second case for 50 µm particle efficiency was 80 %.

$\eta_{turb} = 1 - \exp(-0.8) = 55\%$

So, actual efficiency will be 55 % for 50 µm particle and this for 56 µm this will be 63 %. Now we are able to solve the problem.

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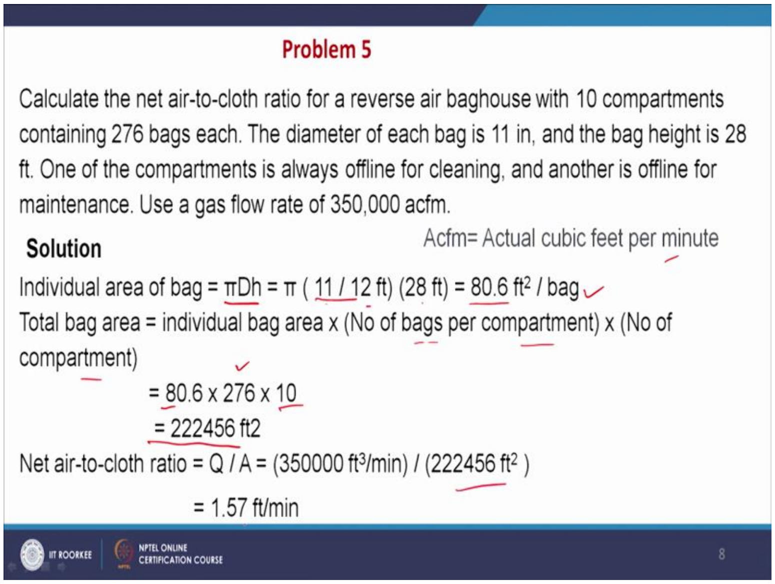

Now problem number 5, The statement is, calculate the net air to cloth ratio for a reverse air bag house with 10 compartments containing 276 bags each. The diameter of each bag is 11 inch, and the bag height is 28 ft. One of the compartments is always offline for cleaning and another is offline for maintenance. Use a gas flow rate of 350,000 acfm. acfm is actual cubic feet per minute.

So, this is a statement so this is a problem of bag filter. So, in this case we have to calculate the area

Individual area of bag = $\pi Dh = \pi$ (11 / 12 ft) (28 ft) = 80.6 ft^2 / bag

Total bag area = individual bag area x (No of bags per compartment) x (No of compartment)

= 80.6 x 276 x 10

= 222456 ft^2

Net air-to-cloth ratio = Q / A = (350000 ft^3/min) / (222456 ft^2)

= 1.57 ft/min

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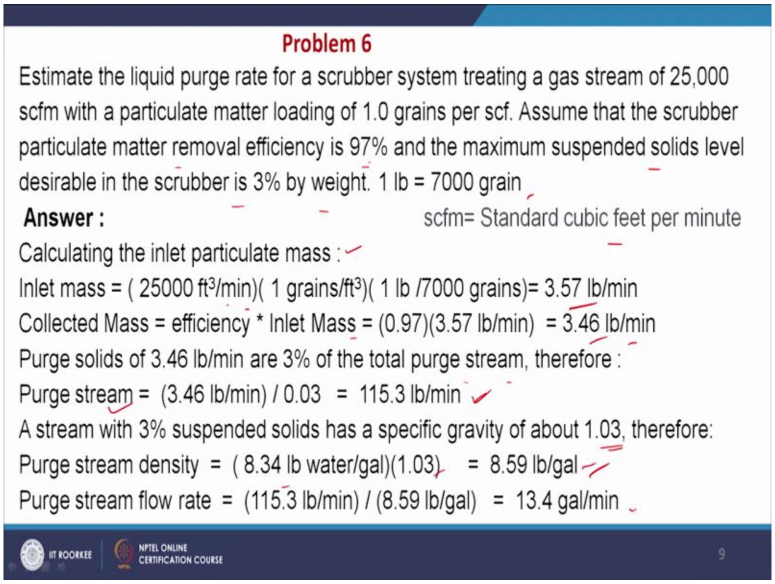

Next problem number 6, statement is, Estimate the liquid purge rate for a scrubber system treating a gas stream of 25,000 scfm with a particulate matter loading of 1 grains per scf. Assume that the scrubber particulate matter removal efficiency is 97 % and the maximum suspended solids level described in the scrubber is 3 % by weight. And it is given 1lb = 7,000 grain and scfm is standard cubic feet per minute.

So, we can solve like this say calculating the inlet particulate mass.

Calculating the inlet particulate mass :

Inlet mass = (25000 ft^3/min)(1 grains/ft^3)(1 lb /7000 grains) = 3.57 lb/min

Collected Mass = efficiency * Inlet Mass = (0.97)(3.57 lb/min) = 3.46 lb/min

Purge solids of 3.46 lb/min are 3% of the total purge stream, therefore :

Purge stream = (3.46 lb/min) / 0.03 = 115.3 lb/min

A stream with 3% suspended solids has a specific gravity of about 1.03, therefore: Purge stream density = (8.34 lb water/gal)(1.03) = 8.59 lb/gal

Purge stream flow rate = (115.3 lb/min) / (8.59 lb/gal) = 13.4 gal/min

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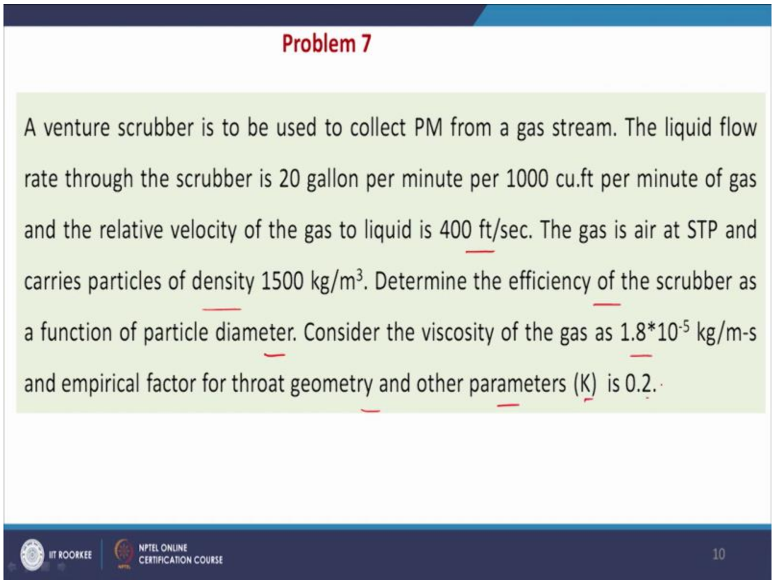

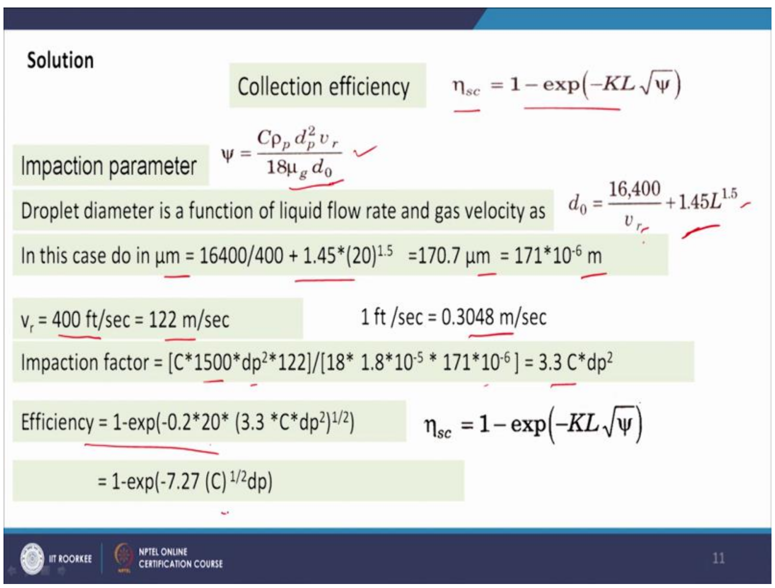

Next problem number 7, statement is, a Venturi scrubber is to be used to collect particulate matter from a gas stream, the liquid flow rate through the scrubber is 20 gallon per minute per 100 cubic feet per minute of gas and the relative velocity of the gas to liquid is 400 feet per second. The gas is here at STP and carries particles of density 1500 kg/m^3. Determine the efficiency of the scrubber as a function of particle diameter. Consider the viscosity of the gas as 1.8*10^{-5} kg/m-s and empirical factor for throat geometry and other parameters k is 0.2.

So, this is a problem of Venturis scrubber. And for this case we know that

Collection efficiency of scrubber $\eta_{sc} = 1 - \exp(-KL\sqrt{\Psi})$

$$\Psi = \frac{C\rho_p\, d_p^2\, v_r}{18\mu_g\, d_0}$$

Droplet diameter is a function of liquid flow rate and gas velocity as $d_o = (16400/v_r) + 1.45L^{1.5}$ where L is nothing but the liquid flow rate and that v is the relative velocity in the duct.

So, droplet diameter is a function of liquid flow rate and gas velocity as this one

In this case do in µm = $16400/400 + 1.45*(20)^{1.5}$ =170.7 µm = $171*10^{-6}$ m

v_r = 400 ft/sec = 122 m/sec and 1 ft /sec = 0.3048 m/sec

Impaction factor = $[C*1500*dp^2*122]/[18* 1.8*10^{-5} * 171*10^{-6}] = 3.3\ C*dp^2$

Efficiency = $1-\exp(-0.2*20* (3.3 *C*dp^2)^{1/2})$

= $1-\exp(-7.27\ (C)^{1/2}dp)$

So, this is the expressions it was asked to calculate and now we are able to solve the problem.

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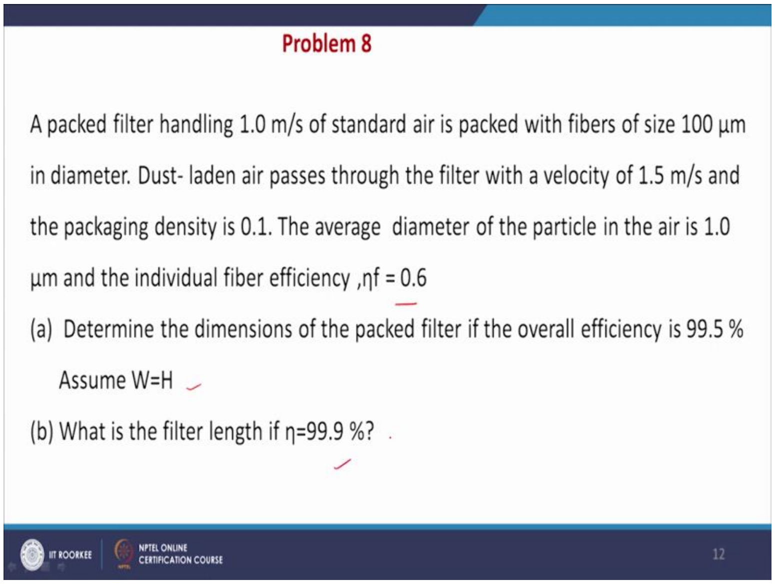

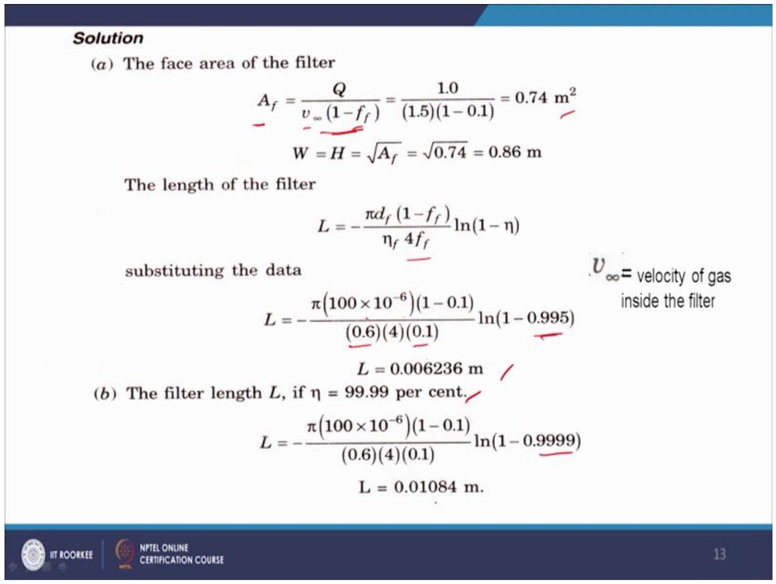

Problem number 8, A packed filter having 1.0 m/s of standard air is packed with fibers of size 100 µm in diameter. Dust laden air passes through the filter with a velocity of 1.5 m/s and the packaging density of 0.1. The average diameter of the particle in the air is 1 µm and the individual fiber efficiency η_f is equal to 0.6.

So, determine the dimensions of the packed filter if the overall efficiency is 99.5 %

Assume W = H.

And what is the filter length, if η = 99.9 %?

So, this is a problem of bag filter and we know that

(a) The Face area of the filter

$A_f = Q/v(1 – f_f) = 1.0/(1.5)(1-0.1) = 0.74\ m^2$

$W = H = (A_f)^{1/2} = 0.86$ m

The length of the filter L

$$L = \frac{\pi d_f (1 - f_f)}{\eta_f 4 f_f} \ln(1 - n)$$

Substituting the data

$$L = \frac{\pi(100 * 10^{-6} (1 - 0.1)}{(0.6)(4)(0.1)} \ln(1 - 0.995)$$

L= 0.006236 m

(b) The filter length L, if η = 99.99 %.

$$L = \frac{\pi(100 * 10^{-6} (1 - 0.1)}{(0.6)(4)(0.1)} \ln(1 - 0.9999)$$

L = 0.01084 m.

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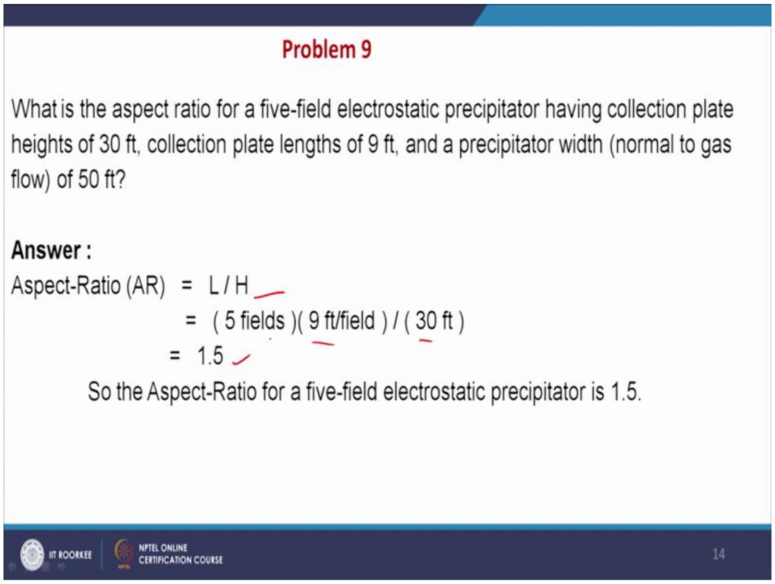

Problem number 9, the statement is, what is the aspect ratio for a five-field electrostatic precipitator having collection plate heights of 30 feet, collection plate lengths of 9 feet and a precipitator with normal to gas flow of 50 feet.

So, this is a problem of again ESP.

So, here aspect ratio (AR) = L/H

$$= (5\ \text{field})(9\text{ft/field})/(30\text{ft}) = 1.5$$

So, the aspect ratio for a five-field electrostatic precipitator is 1.5. So, now the problem is solved. So, up to this in this class thank you very much for your patience.