Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 34
Packed bed adsorber design (Contd.)

Good day to all. So, therefore, we are now in the third lecture on the Packed bed adsorber design. So, if you remember if you recall in the last class we had discussed the packed bed adsorber, we had decided or rather we had fixed on the contacted dimensions, the mass of adsorbent that we require and also we had decided upon the cycle time and we were about to start the evaluation of the pressure drop. So, today we start with discussions on estimation of pressure drop and after that we will be going into two illustration problems.

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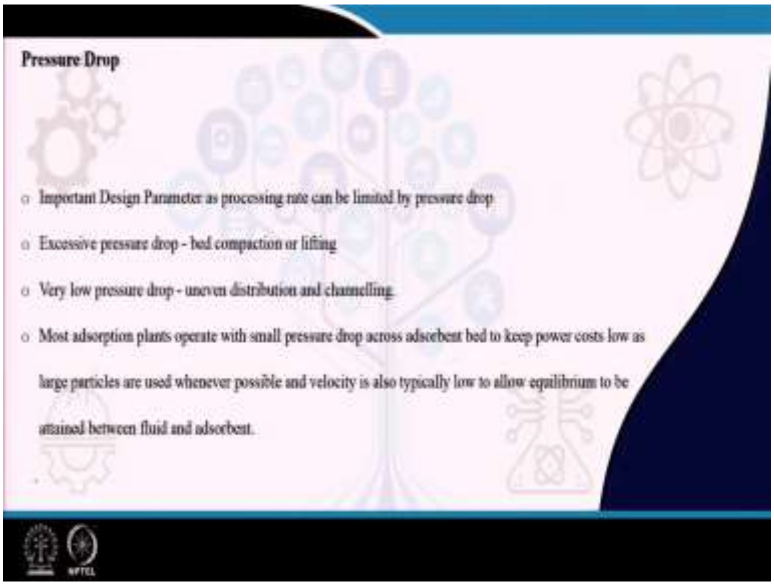

Pressure Drop

- Important Design Parameter as processing rate can be limited by pressure drop
- Excessive pressure drop - bed compaction or lifting
- Very low pressure drop - uneven distribution and channelling.
- Most adsorption plants operate with small pressure drop across adsorbent bed to keep power costs low as large particles are used whenever possible and velocity is also typically low to allow equilibrium to be attained between fluid and adsorbent.

Now, this pressure drop as I had mentioned in the last class, it is something a very important parameter because the processing rate it can be limited by pressure drop and if you recall, if you have a very high pressure drop what happens? It can result in the lifting of the bed or it can result in the bed compaction depending upon the direction of the fluid flow.

Again suppose if you would go for very low pressure drop, then there are chances of uneven distribution and channelling. So, therefore, we find that to keep the power cost as low as possible, generally most of the adsorption plants are operated with a very small pressure drop and we would always like to go for larger particles in order to reduce the pressure drop.

And we would also like to keep the velocity low not only from pressure drop considerations, but to ensure that equilibrium is attained between the fluid and the adsorbent and so, therefore, maximum adsorption is possible under the particular operating conditions.

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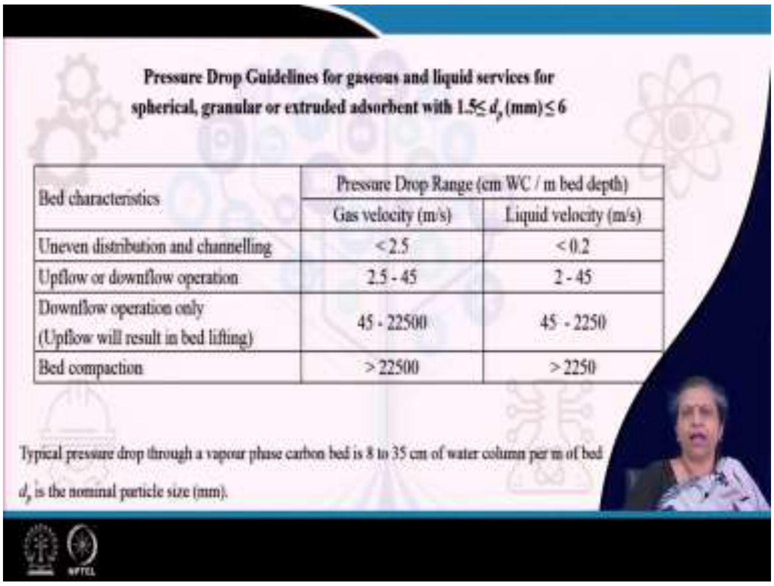

Pressure Drop Guidelines for gaseous and liquid services for spherical, granular or extruded adsorbent with $1.5 \leq d_p\,(\mathrm{mm}) \leq 6$

Bed characteristics	Pressure Drop Range (cm WC / m bed depth)	
	Gas velocity (m/s)	Liquid velocity (m/s)
Uneven distribution and channelling	< 2.5	< 0.2
Upflow or downflow operation	2.5 - 45	2 - 45
Downflow operation only (Upflow will result in bed lifting)	45 - 22500	45 - 2250
Bed compaction	> 22500	> 2250

Typical pressure drop through a vapour phase carbon bed is 8 to 35 cm of water column per m of bed

d_p is the nominal particle size (mm).

So, usually there are certain guidelines you have. You must have found that during the entire course of the discussion on the design. I have given you several guidelines which you might consider and also several checks.

So, there are certain guidelines which are provided here for the gaseous and the liquid services using spherical granular or the extruded adsorbent particles when the size lies within a particular range and this particular size it is defined in terms of the nominal particle size.

And we find that typically when the vapour phase is flowing through a carbon bed adsorption is going on, there the pressure drop typically lies between 8 to 35 centimeters of water column per meter of bed and more or less I have also listed down the pressure drop range as a function of the fluid velocity under which we can have uneven distribution both upflow and down flow are possible only down flow operation is possible.

Because when we go for upflow, the particular velocity, it is going to result in the lifting of the bed. It is important for you to remember that the velocity for lifting is less than the velocity which brings about bed compaction now in. So, therefore, what we do? We first find out the pressure drop, then we see whether it falls within the ranges which has been specified here.

How do you go to find out pressure drop? This is basically flow through packed bed. You would recall that in your fluid flow classes you have studied that for estimating the pressure drop through packed bed what do we do? We use Ergun equation.

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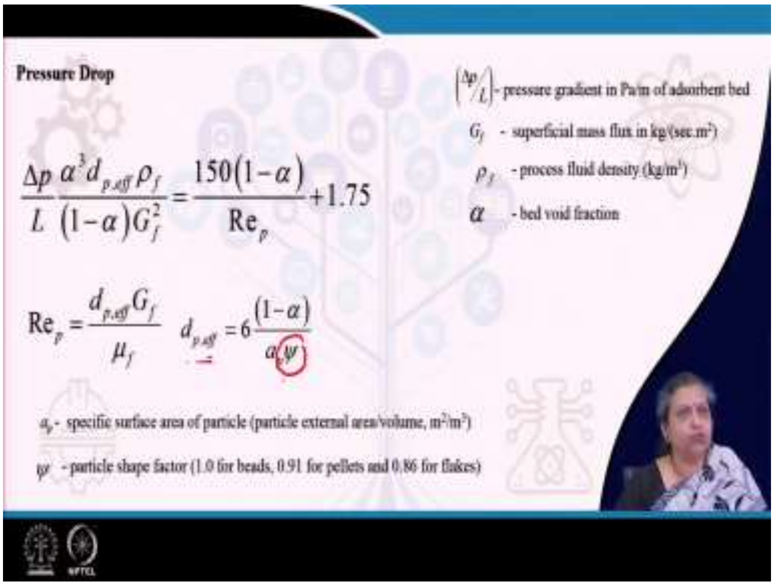

Pressure Drop

$$\frac{\Delta p}{L}\frac{\alpha^3 d_{p,eff}\rho_f}{(1-\alpha)G_f^2} = \frac{150(1-\alpha)}{\mathrm{Re}_p} + 1.75$$

$$\mathrm{Re}_p = \frac{d_{p,eff}G_f}{\mu_f} \qquad d_{p,eff} = 6\frac{(1-\alpha)}{a\psi}$$

$\left(\Delta p/L\right)$ - pressure gradient in Pa/m of adsorbent bed

G_f - superficial mass flux in kg/(sec.m^2)

ρ_f - process fluid density (kg/m^3)

α - bed void fraction

a_p - specific surface area of particle (particle external area/volume, m^2/m^3)

ψ - particle shape factor (1.0 for beads, 0.91 for pellets and 0.86 for flakes)

So, therefore, in this particular case also we use Ergun equation. I have listed down the nomenclatures of each and every terms that have been used here along with the relevant dimensions.

Because since it is an empirical equation it is important that use the same units that have been specified here so that these constants are applicable and naturally for this particular case the Reynolds number it is defined as shown and for non-spherical particles the

Reynolds number term through the dp effective it contains a term on the particle shape factor as well.

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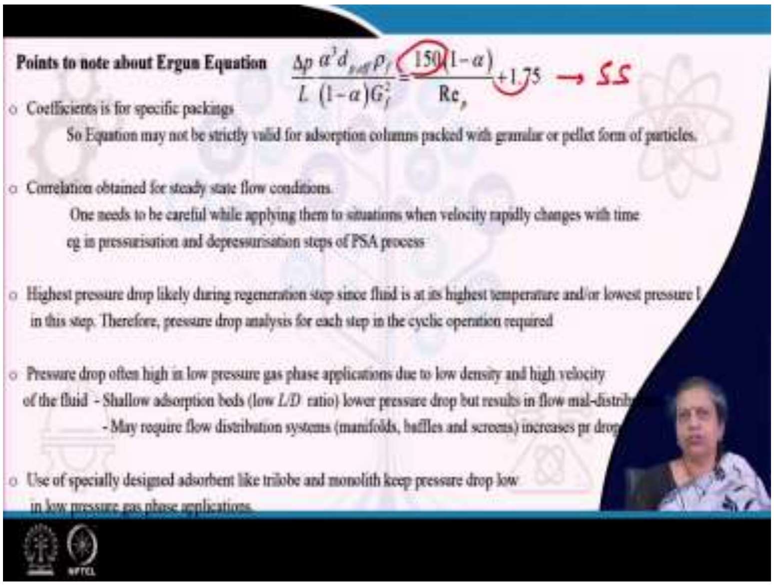

Points to note about Ergun Equation

$$\frac{\Delta p\,\alpha^3 d_{p,eff}\rho_f}{L\,(1-\alpha)G_f^2}=\frac{150(1-\alpha)}{\mathrm{Re}_p}+1.75 \rightarrow SS$$

- Coefficients is for specific packings
  So Equation may not be strictly valid for adsorption columns packed with granular or pellet form of particles.
- Correlation obtained for steady state flow conditions.
  One needs to be careful while applying them to situations when velocity rapidly changes with time
  eg in pressurisation and depressurisation steps of PSA process
- Highest pressure drop likely during regeneration step since fluid is at its highest temperature and/or lowest pressure in this step. Therefore, pressure drop analysis for each step in the cyclic operation required
- Pressure drop often high in low pressure gas phase applications due to low density and high velocity of the fluid - Shallow adsorption beds (low L/D ratio) lower pressure drop but results in flow mal-distrib
  - May require flow distribution systems (manifolds, baffles and screens) increases pr drop
- Use of specially designed adsorbent like trilobe and monolith keep pressure drop low in low pressure gas phase applications.

Now when we go to use this Ergun equation, there are certain things that we need to keep in mind when you are using. Definitely we have to use it, but there are certain things which you need to keep in mind.

First thing is the constants. These constants are applicable for certain conditions, they have been derived for certain specific packings. So, therefore, when we are using granular or pellet form of particles this equation may not be very strictly valid for adsorption columns.

The other important thing is this particular equation, it is applicable for steady state conditions. So, therefore, when the velocity is changing rapidly with time one needs to be careful. The other thing is the highest pressure drop when do you expect that you are going to going to get? When the fluid is at the highest temperature and the lowest pressure under what condition this happens? This happens generally during the desorption or the regeneration step.

We get the highest temperature during the TSA the desorption step of the TSA cycle and the lowest pressure during the desorption step of the PSA cycle. So, therefore, when you are finding out pressure drop it is important that you find out the pressure drop both for the adsorption as well as for the desorption process. Often we find that the pressure drop it is high for low pressure gas phase application.

For such cases one can opt for a shallow adsorption column which means that one can go for a low L by D ratio the diameter is larger the length is smaller under this case the lower pressure drop can result.

But be very careful because moment you go for a low L by D, it results in maldistribution. Therefore, in order to ensure uniform distribution, we might have to use manifolds baffle screens, etc. which again increases the pressure drop.

And definitely we need to keep in mind that there is certain special shape of the adsorbent particles which are being increasingly used now in industries particularly to keep the pressure drop low in low pressure gas phase applications, these typical shapes are say monolith particles trilobe particles etcetera which can be adopted in order to ensure a low pressure drop.

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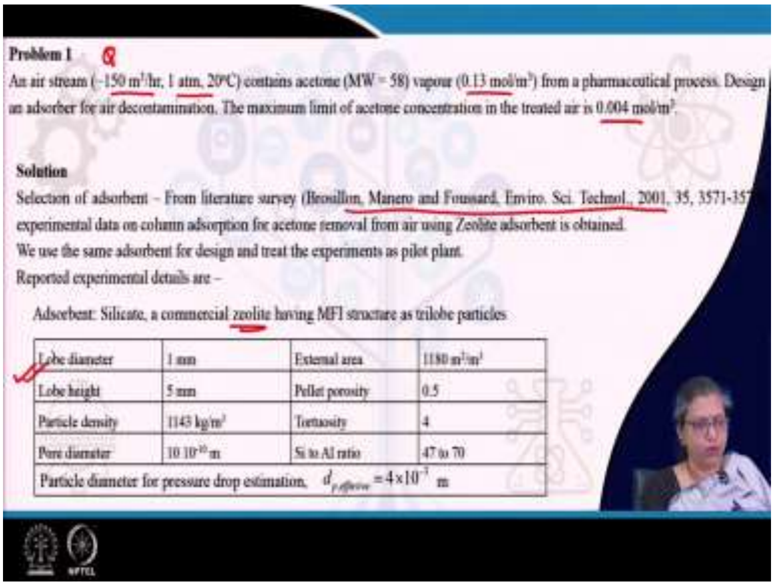

Problem 1 Q

An air stream (~150 m^3/hr, 1 atm, 20°C) contains acetone (MW = 58) vapour (0.13 mol/m^3) from a pharmaceutical process. Design an adsorber for air decontamination. The maximum limit of acetone concentration in the treated air is 0.004 mol/m^3.

Solution

Selection of adsorbent – From literature survey (Brosillon, Manero and Foussard, Enviro. Sci. Technol., 2001, 35, 3571-357
experimental data on column adsorption for acetone removal from air using Zeolite adsorbent is obtained.
We use the same adsorbent for design and treat the experiments as pilot plant.
Reported experimental details are –

Adsorbent: Silicate, a commercial zeolite having MFI structure as trilobe particles

Lobe diameter	1 mm	External area	1180 m^2/m^3
Lobe height	5 mm	Pellet porosity	0.5
Particle density	1143 kg/m^3	Tortuosity	4
Pore diameter	$10 \ 10^{-10}$ m	Si to Al ratio	47 to 70
Particle diameter for pressure drop estimation, $d_{p,effective} = 4\times10^{-3}$ m			

Well. So, with all these things now I think we are in a position to just look into a typical problem of adsorber bed design we start with the gas phase adsorption. What do we have? What is our feed? Our feed is an air stream, the flow rate of the air stream is provided, the feed condition is provided.

If you recall in the beginning of the class I had said that normally we have the feed condition, the feed flow rate, we also have the adsorbent concentration in the feed and we also specified what can be the maximum adsorbent concentration in the effluent, based on this we have to proceed. If you recall in the last class what did we say? First step will be selection of adsorbent.

Now, when you select adsorbent definitely we have to keep in mind that which adsorbent is conventionally used for such a system along with that if by some chance you have some particular adsorbent for which the breakthrough curve or the breakthrough data are available, it is going to be additionally useful for you.

So, therefore, considering these things what we did? We selected as commercial zeolite adsorbent silicate and from the literature data the reference is there which you can refer for further references.

In this particular paper we found that they have provided experimental data on column adsorption for acetone removal from air. So, fortunately we take up the properties of the adsorbent that they have provided and we also take up the breakthrough curve that they have given us.

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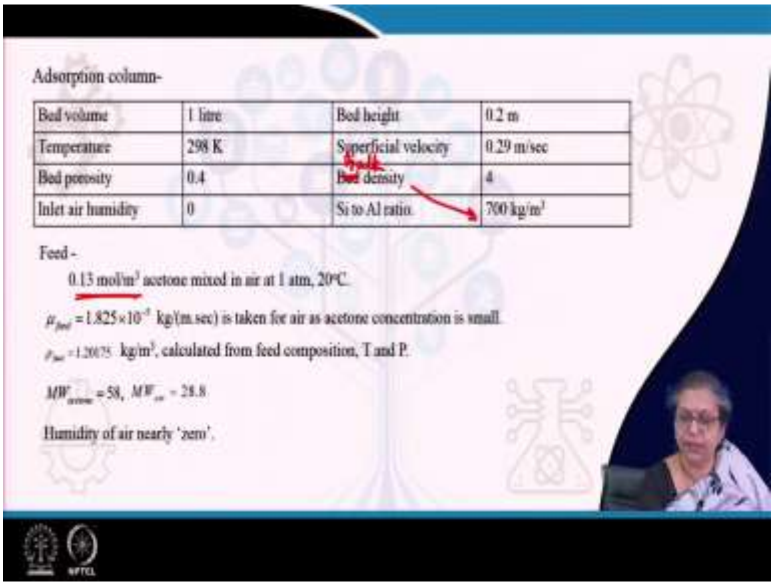

Adsorption column-

Bed volume	1 litre	Bed height	0.2 m
Temperature	298 K	Superficial velocity	0.29 m/sec
Bed porosity	0.4	~~Bed~~ Bulk density	4
Inlet air humidity	0	Si to Al ratio	700 kg/m^3

Feed -

0.13 mol/m^3 acetone mixed in air at 1 atm, 20°C.

$\mu_{feed} = 1.825 \times 10^{-5}$ kg/(m.sec) is taken for air as acetone concentration is small.

$\rho_{feed} = 1.20075$ kg/m^3, calculated from feed composition, T and P.

$MW_{acetone} = 58$, $MW_{air} = 28.8$

Humidity of air nearly 'zero'.

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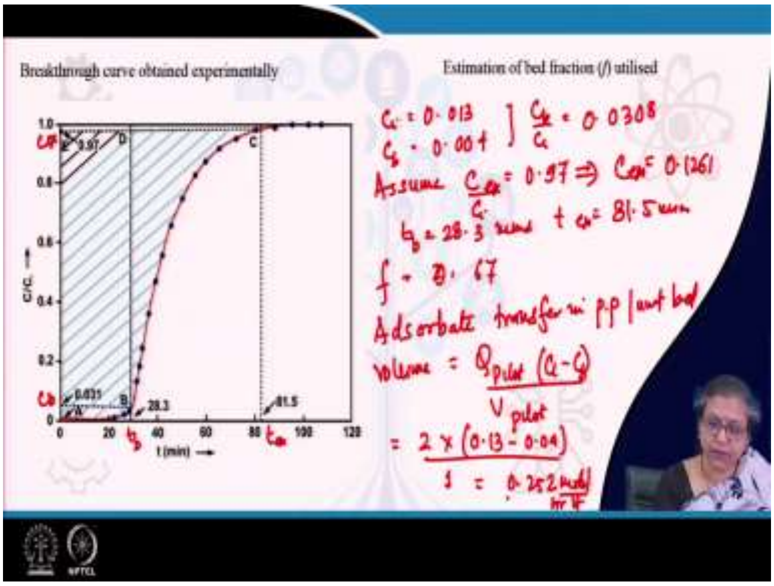

Breakthrough curve obtained experimentally

Estimation of bed fraction (*f*) utilised

$C_i = 0.013$
$C_b = 0.004$ $\Big]$ $\frac{C_b}{C_i} = 0.0308$

Assume $\frac{C_{ex}}{C_i} = 0.97 \Rightarrow C_{ex} = 0.1261$

$t_b = 28.3$ min $t_{ex} = 81.5$ min

$f = 0.67$

Adsorbate transfer in p.p / unit bed volume $= \frac{Q_{pilot}(C_i - C_b)}{V_{pilot}}$

$= \frac{2 \times (0.13 - 0.04)}{1} = 0.252$ mol/hr ft

So, therefore, with this particular breakthrough curve and with the adsorption column details that they have provided, the adsorbent details that we have provided, we proceed with the design of the adsorber for the feed concentration which has been provided under the conditions which are given here.

So, to start with what do we do? To start with the first thing that we do is that using this particular breakthrough curve. Here we know C i this is equal to 0.013, C breakthrough, if you see I have marked all of these, this is 0.004. So, therefore, from here I can find out what is C b by C i. I will just write down the values you can check it up for yourself we assume the that we can operate the bed till C i about 0.97.

We can operate it. So, therefore, this gives you the C e x value. This is the C e x value, this is the C break point value, this is the t b and this is the t exhaustion. So, therefore, from here we get C e x equals to 0.1261, t b we know, if you see it carefully, t b is 28.3 minutes, t exhaustion is 81.5 minutes. So, naturally from there we are in a position to find out f; f is what? Just like I had told you this particular area divided by the total area.

So, therefore, in this particular case it is naturally equal to 26. So, for this particular case more or less this is equal to if you find out this particular shaded area from t equals to 0 to t equals to 28.3 divided by the area from t equals to 0 to t equals to 81.5 more or less we are going to get f equals to you can check it out f equals to 0.67 which is slightly less definitely, but we are going to proceed with this. Now from here what do we get?

Suppose, once we have known f, we can find out the adsorbate transfer in the pilot plant. So, therefore, for what do I get this? This is naturally equal to Q pilot C i minus C b divided by V pilot. This if you can check it up the Q pilot was the change in concentration I have already written it down.

So, you can check it for yourself the volume of the pilot plant if you remember it was given. So, from there we find out this is 0.252 moles per hour liter of bed. In the same particular way we know that 67 of the bed it gets utilized.

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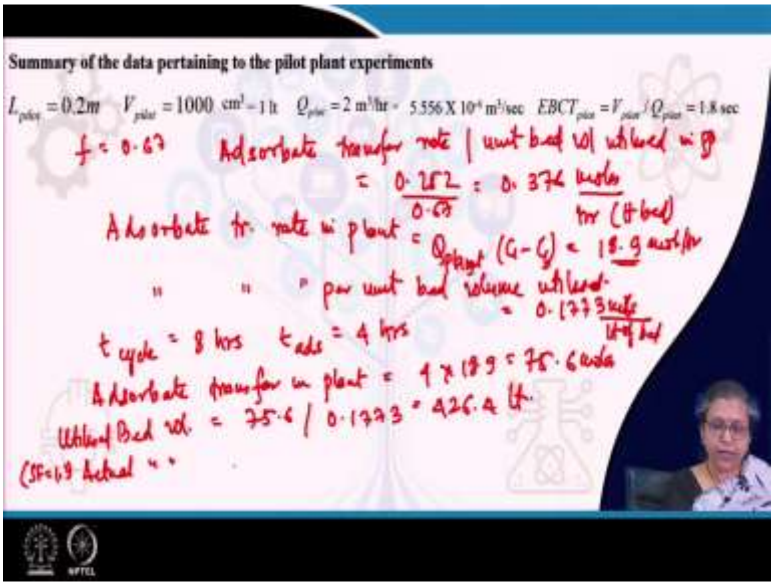

Summary of the data pertaining to the pilot plant experiments

$L_{pilot} = 0.2m$ $V_{pilot} = 1000$ cm^3 = 1 lt $Q_{pilot} = 2$ m^3/hr = 5.556 X 10^{-4} m^3/sec $EBCT_{pilot} = V_{pilot} / Q_{pilot} = 1.8$ sec

f = 0.67 Adsorbate transfer rate / unit bed vol utilized in pp

$= \frac{0.252}{0.67} = 0.376 \frac{\text{moles}}{\text{hr (lt bed)}}$

Adsorbate tr. rate in plant $= Q_{plant} (C_i - C_b) = 18.9$ moles/hr

" " " per unit bed volume utilized $= 0.1773 \frac{\text{moles}}{\text{lt of bed}}$

$t_{cycle} = 8$ hrs $t_{ads} = 4$ hrs

Adsorbate transfer in plant = 4 × 18.9 = 75.6 moles

Utilized Bed vol. = 75.6 / 0.1773 = 426.4 lt.

(SF=1.3 Actual " "

So, here the data of the pilot plant they are already provided, we know that the 67 percent f equals to 0.67. So, therefore, we can also find out the total amount of adsorbate transfer rate per unit bed volume utilized in pilot plant. You can definitely find this out, this is nothing but equal to the things which you have to found it out which gives you to be 0.376 moles per hour liter of bed volume.

So, from that you know that what is the adsorbate transfer rate in the plant, the Q of the plant it is provided to you. So, from here it is nothing but the Q plant C i minus C b, you can find this out and then you can also find out the adsorbate transfer rate per unit volume of the bed utilized. So, adsorbate transfer rate per unit bed volume utilized this also you can find this out. So, therefore, from all these things more or less the adsorbate loading could be found out.

Now, suppose we assume a t cycle. Normally for such operations it is 8 hours from where we can find out that the adsorption part usually it can be assumed to be 4 hours. So, therefore, during this particular 4 hours how much amount of adsorbate transfer has happened per hour we know.

So, therefore, the adsorbate transfer in the plant for one cycle that you can very well find it out.

So, the adsorbate transfer rate in the plant you can find out, the adsorbate transfer rate it is roughly equals to 18.9 moles per hour and. So, from there we can find out what was the adsorbate transfer rate in the plant definitely that can be find out this is 4 hours into so, much amount of moles which gives you around 76 75.6 moles.

So, therefore, the bed volume that gets utilized that is how much was that going to be? That is going to be 75.6 by the adsorbate loading per unit of bed volume which was equal to 0.1773 moles per liter of bed.

So, therefore, from there we can find out the adsorbate transfer in the plant and from there we can find out the bed volume that gets utilized. Now once we can find out the bed volume that gets utilized we can find out the actual bed volume.

So, this is the utilized bed volume we can find out the actual bed volume. How do we find the actual bed volume? We consider this and then we also take a safety factor of 1.3. So, using all those things we can find out the adsorbent volume in the plant for operation up to the breakthrough point.

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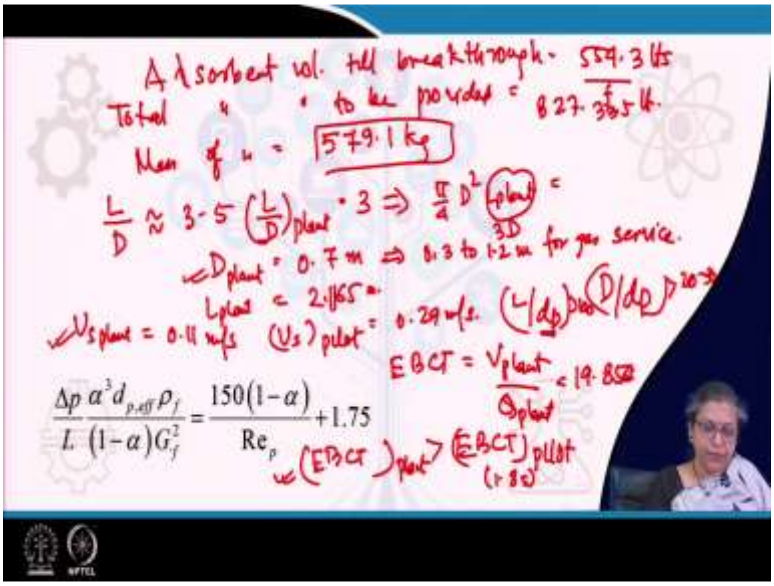

Adsorbent vol. till breakthrough = 554.3 lts

Total " " to be provided = $\frac{554.3}{f}$ = 827.335 lt.

Mass of " = $\boxed{579.1\ kg}$

$\frac{L}{D} \approx 3\text{-}5 \quad \left(\frac{L}{D}\right)_{plant} = 3 \Rightarrow \frac{\pi}{4} D^2 (L_{plant}) =$ 3D

$D_{plant} = 0.7\ m \Rightarrow$ 0.3 to 1.2 m for gas service.

$L_{plant} = 2.1165\ m$

$V_{s\,plant} = 0.11\ m/s \quad (V_s)_{pilot} = 0.29\ m/s. \quad (L/d_p) > 100 \quad (D/d_p) > 20\text{-}30$

$EBCT = \frac{V_{plant}}{Q_{plant}} = 19.85$

$$\frac{\Delta p}{L} \frac{\alpha^3 d_{p,eff} \rho_f}{(1-\alpha) G_f^2} = \frac{150(1-\alpha)}{Re_p} + 1.75$$

$(EBCT)_{plant} > (EBCT)_{pilot}$ (~8s)

So, from this if you can find out the adsorbent volume which is necessary till breakthrough. We can find this out and once we can find this out we can also find out total adsorbent volume to be provided. What will that be? That is going to be suppose the adsorbent volume till breakthrough it is near about equals to say 554.3 liters just check up these particular quantitative measures.

So, then in that case this is going to be this value divided by f into 1.3 and from there you are going to get the total adsorbent volume which will be coming to as 827.335 liters. Once you know the total adsorbent volume that has to be provided you can definitely find out the mass of adsorbent that is required this is just the volume into the bulk density.

And as I had already mentioned I think the bulk density was equal to. There is a small mistake here this bulk density this is equal to 700 this has got interchanged. So, therefore, from there we can find out the total mass of adsorbent that will be required and finally, if you do it you are going to find that the total adsorbent mass required will be something of this sort. So, therefore, what we did? We used the breakthrough curve we found out the f.

Once we found out the f, then we tried to find out what was the adsorbate transfer rate in the pilot plant and for per unit volume of bed utilized and then we found out what is the actual adsorbate transfer rate in the plant per liter of bed utilized and from there we know that how long this this particular adsorption process will occur, from there we found out the total adsorbent volume that has to be required in the plant and also the total amount of the total mass of adsorbent that will be required.

Once this is done, next thing we would like to find out or finalize the dimensions. Now normally for finding out the dimensions if since we will be operating with a vertical column. So, definitely for a vertical column you will be learning more about this when we go for discussions on pressure vessels etcetera generally this lies between say three to 4 or 3 to 5. So, accordingly we assume that for the actual contactor L plant by L by D of the plant we have assumed this to be 3, you can go you can also assume it for 4.

So, from there what do we get? We get pi by 4 D square into the L plant where this L plant is nothing, but 3 D. So, from there we know the entire volume of the adsorbent volume we know what is the total volume that is required. So, from there using this particular equation we can find out the D plant and we can find out the L plant. For our particular case what we have obtained is D plant it is nearly equals to 0.7 meters, L plant it is near about equals to 2.1165 meters.

So, therefore, we find that more or less for gas services, the diameter of the plant it lies between 0.3 to 1.2 meters for gas services and we find that. In fact, just to accommodate this we had done this calculation and now we find that this is fine. Once we have found this out now we need some checks if you remember what are the checks what is U s plant you need to find out under this condition.

More or less we have found out that the U s plant is 0.11 meters per second. What was the U s pilot that we had found out that was 0.29 meters per second. So, what do we find? That in the plant the velocity is lower if the velocity is lower there is no problem we are going to get sufficient contact between them and it also provides a sufficient residence sign. So, definitely we can go ahead with this particular situation.

We also need to check L by d p and D by d p this is the pilot diameter. If you can check you will find that both of this, this is also greater than 100 this is also greater than 20 to 30. So, these things are also fine. So, we have checked the superficial velocity we find we can go ahead, we have checked that channelling mixing everything is ensured next we need to check the EBCT. The EBCT in this particular case we found find that this is nothing, but the V plant by the Q plant.

So, this we find its more or less say 19.856 seconds. Now we find that this particular EBCT, the EBCT for the plant this is greater the much much greater than the EBCT for the pilot scale. For the pilot scale the EBCT was 1.8 seconds and we find that it is not only greater if you remember we had said that more or less EBCT should vary between there was some particular limit and so, we find that more or less it is less than 30 seconds which is the permissible limit.

So, therefore, the EBCT is also greater than the EBCT that we had obtained from the pilot plant data, but since this ensures a better contact and so, therefore, we go ahead with this and we and after that we try to evaluate the pressure drop.

If you try to evaluate the pressure drop you will find that more or less all the data are given, you can find it out and I had calculated it that also falls within the permissible limits that were there. The bed pressure drop was much small compared to the total pressure of one atmospheres and therefore, we find that this is fine we can go ahead with this.

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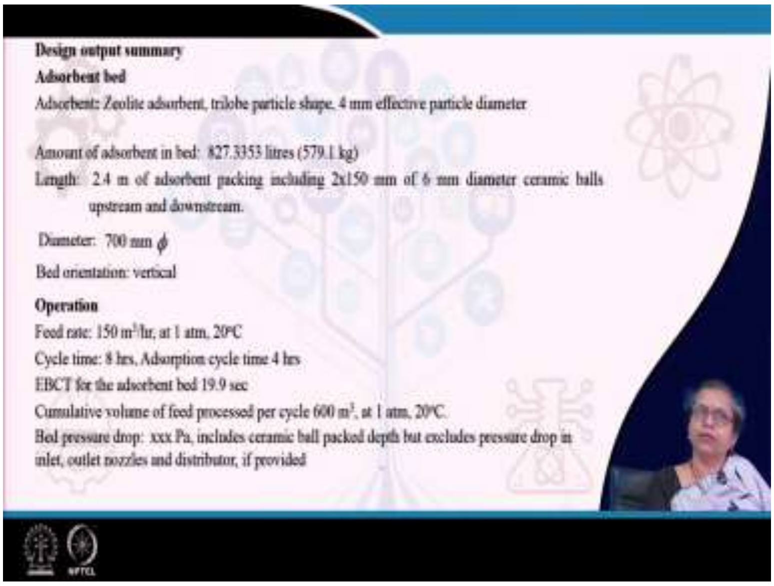

Design output summary

Adsorbent bed

Adsorbent: Zeolite adsorbent, trilobe particle shape. 4 mm effective particle diameter

Amount of adsorbent in bed: 827.3353 litres (579.1 kg)

Length: 2.4 m of adsorbent packing including 2x150 mm of 6 mm diameter ceramic balls upstream and downstream.

Diameter: 700 mm ϕ

Bed orientation: vertical

Operation

Feed rate: 150 m^3/hr, at 1 atm, 20°C

Cycle time: 8 hrs, Adsorption cycle time 4 hrs

EBCT for the adsorbent bed 19.9 sec

Cumulative volume of feed processed per cycle 600 m^3, at 1 atm, 20°C

Bed pressure drop: xxx Pa, includes ceramic ball packed depth but excludes pressure drop in inlet, outlet nozzles and distributor, if provided

After it was completed then more or less the design summary has been put up in this particular form where the total amount of adsorbent the length and diameter etcetera etcetera etcetera all those things are there, the only thing which is remaining is the design of nozzles etcetera which we will be taking up when we go for the discussion on the pressure vessels. So, this was a typical problem for gas adsorption.

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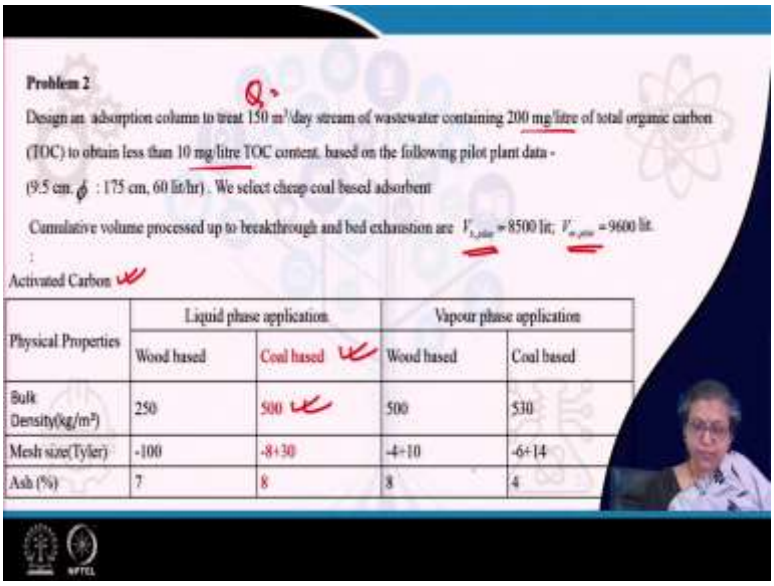

Problem 2

Q

Design an adsorption column to treat 150 m^3/day stream of wastewater containing 200 mg/litre of total organic carbon (TOC) to obtain less than 10 mg/litre TOC content, based on the following pilot plant data -

(9.5 cm ϕ : 175 cm, 60 lit/hr). We select cheap coal based adsorbent

Cumulative volume processed up to breakthrough and bed exhaustion are $V_{b,pilot}$ = 8500 lit; $V_{e,pilot}$ = 9600 lit.

Activated Carbon ✓

Physical Properties	Liquid phase application		Vapour phase application	
	Wood based	Coal based ✓	Wood based	Coal based
Bulk Density(kg/m^3)	250	500 ✓	500	530
Mesh size(Tyler)	-100	-8+30	-4+10	-6+14
Ash (%)	7	8	8	4

In the same way I had I will just touch upon another adsorption problem for waste water treatment. Again in this particular case the total Q is provided, the initial concentration is provided, the permissible concentration is provided. Since this is wastewater treatment if you recall that activated carbon was a potential source. So, we select activated carbon and from the table that I had shown you, I go for a coal based activated carbon from where I select this particular bulk density.

And in this particular case we found that the data which are available, they are in terms of cumulative volume. We do not have a breakthrough curve, but we have a cumulative volume in this particular case.

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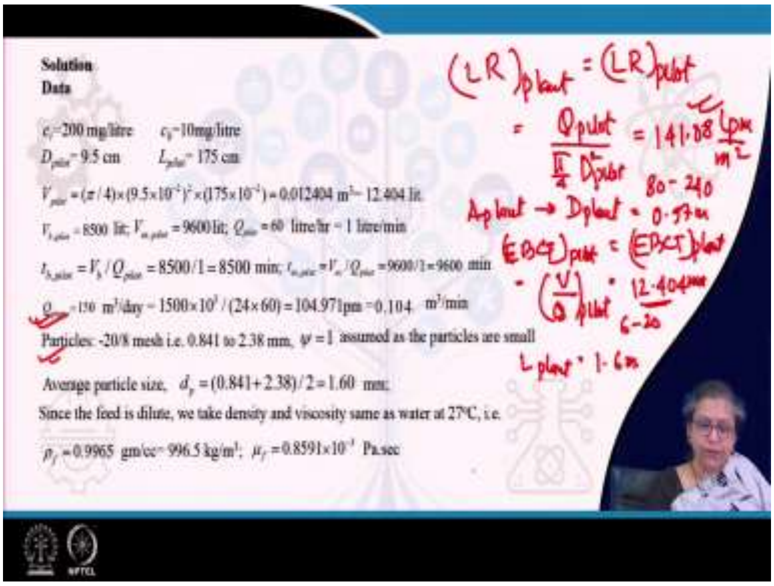

Solution

Data

c_i = 200 mg/litre c_b = 10mg/litre

D_{pilot} = 9.5 cm L_{pilot} = 175 cm

$V_{pilot} = (\pi/4)\times(9.5\times10^{-2})^2\times(175\times10^{-2}) = 0.012404\ m^3 = 12.404$ lit.

$V_{b,pilot}$ = 8500 lit; $V_{e,pilot}$ = 9600 lit; Q_{pilot} = 60 litre/hr = 1 litre/min

$t_{b,pilot} = V_b/Q_{pilot} = 8500/1 = 8500$ min; $t_{e,pilot} = V_e/Q_{pilot} = 9600/1 = 9600$ min

Q_{plant} = 150 m³/day = $1500\times10^3/(24\times60) = 104.97$ lpm = 0.104 m³/min

Particles: -20/8 mesh i.e. 0.841 to 2.38 mm, $\psi = 1$ assumed as the particles are small

Average particle size, $d_p = (0.841+2.38)/2 = 1.60$ mm;

Since the feed is dilute, we take density and viscosity same as water at 27°C, i.e.

ρ_f = 0.9965 gm/cc = 996.5 kg/m³; $\mu_f = 0.8591\times10^{-3}$ Pa.sec

$(LR)_{plant} = (LR)_{pilot}$

$= \dfrac{Q_{pilot}}{\frac{\pi}{4} D^2_{pilot}} = 141.08\ \dfrac{lpm}{m^2}$

80 - 240

$A_{plant} \rightarrow D_{plant} = 0.97m$

$(EBCT)_{pilot} = (EBCT)_{plant}$

$= \left(\dfrac{V}{Q}\right)_{pilot} = 12.404$ min

6-20

$L_{plant} = 1.6m$

So, therefore, here I have listed down all the different data which are available for the pilot plant and also the flow rate etcetera the particle dimensions everything has been put down here. From there first what I will do? I find out the LR plant. LR plant what is the LR plant? This is equals to the LR pilot what is the LR pilot? It is Q pilot by the cross sectional area of the pilot plant.

We find that more or less if you calculate it is going to be 141.08 LPM per meter square if you recall the limits that I had placed the limit was between 80 to 240. So, therefore, this limit is fine. Now we would like to keep this LR for our case. So, if we want to keep this LR from there we can find out the A plant. From the A plant we can find out the D plant. We know the Q plant we know the LR plant.

So, therefore, we can find out the D plant. This particular case we found that the D plant we had obtained it as say 0.97 meters which we will be taking it as one meters after that what we do? We go to find the EBCT pilot and we take it as same as the EBCT plant. What is the EBCT pilot? It is V by Q for the pilot plant and this we obtain as 12.404 minutes. Taking this particular EBCT we find that the L we can find out the L plant in this particular case as well.

We find that the EBCT that we get that is also within the permissible limits of 6 to 20 minutes. So, therefore, from there we find out the L plant L plant is actually 1.6 meters now this is slightly less. As I had said for vertical columns we would like to have 1 to 2 meters.

So, the L plant by D plant should be between 3 to 5. Anyhow let us proceed and then we might change from there we find out the V plant and then we would like to find out the fraction utilized of the adsorbent bed. So, for that the we would need to have the data which I have already shown you.

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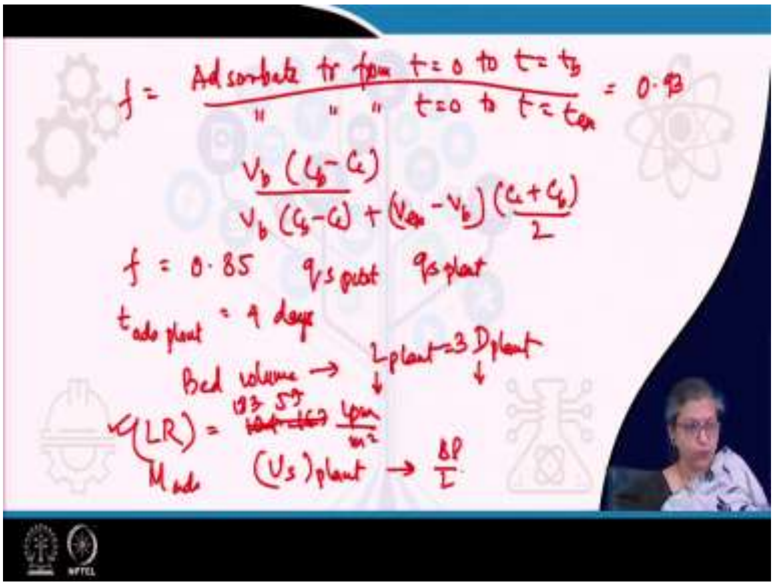

$$f = \frac{\text{Adsorbate tr from } t=0 \text{ to } t=t_b}{\text{" " " } t=0 \text{ to } t=t_{ex}} = 0.93$$

$$\frac{V_b\,(C_b - C_i)}{V_b\,(C_b - C_i) + (V_{ex} - V_b)\left(\frac{C_i + C_b}{2}\right)}$$

$f = 0.85$ $\quad q_{s\,\text{pilot}} \quad q_{s\,\text{plant}}$

$t_{\text{ads plant}} = 4$ days

Bed volume $\rightarrow$ $L_{\text{plant}} = 3\,D_{\text{plant}}$

$q\,(LR) = \overset{193.59}{\cancel{[illegible]}}\ \frac{\text{kg}}{\text{m}^2}$

$M_{\text{ads}} \quad (V_s)_{\text{plant}} \rightarrow \frac{\Delta P}{L}$

If we assume that the curve was more or less symmetric then in that case we can find out the f from the adsorbate transfer from t equals to 0 to t equals to t b divided by adsorbate transfer from t equals to 0 to t equals to t exhaustion. From there if you find it out you will find that it is nearly equal to 0.93. This adsorbate transfer this is nothing, but V b into C b minus C i divided by V b into C b minus C i plus V exhaust minus V b.

We assume that the average concentration is the arithmetic mean from there you can find it out this is actually quite high. So, therefore, for the actual plant what we do? We assume the f to be equal to 0.85 and we proceed because naturally when the adsorbent bed it starts operating and also due to other uncertainties little amount of maldistribution the larger bed the f utilized will naturally be much less.

And after that we also find out the adsorbate loading in the pilot plant we also find out the adsorbent loading in the actual plant. We assume that the adsorption in the time of adsorption is equal to equal to 4 days and in this particular way we proceed.

Once we have found this out we can find out the total bed volume, we can consider f equals to 0.85 take up a safety factor and then finally, we can find out the bed volume. When we find out the bed volume in this way we find that it is slightly higher than the bed volumes which we had found out from the pilot plant data.

Anyhow we proceed with this and in this from this bed volume considering L plant equals to equals to 3 times the D plant we recalculate the length and the diameter of the column and finally, arrive at the dimensions.

Once we have arrived at the dimensions, it was important to check the loading rate in this particular case. We found that the loading rate in this particular case it was around say 183.57 liters per minute per meter square which is again within the permissible limits.

So, we proceed with this, find out the mass of the adsorbent that is required and we also check up the superficial velocity in the plant. After every design we need to check up LR the U s plant these things we need to check up and then we go ahead with the pressure drop calculations.

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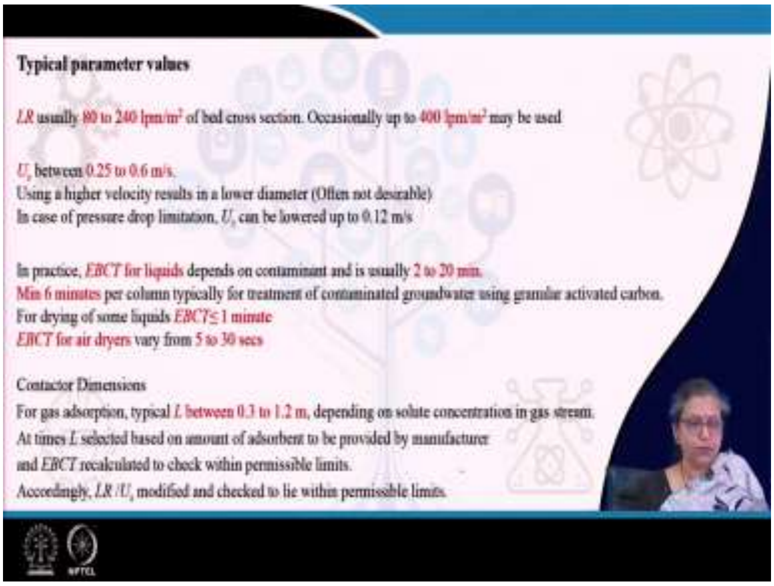

Typical parameter values

LR usually 80 to 240 lpm/m^2 of bed cross section. Occasionally up to 400 lpm/m^2 may be used

U_s between 0.25 to 0.6 m/s.
Using a higher velocity results in a lower diameter (Often not desirable)
In case of pressure drop limitation, U_s can be lowered up to 0.12 m/s

In practice, *EBCT* for liquids depends on contaminant and is usually 2 to 20 min.
Min 6 minutes per column typically for treatment of contaminated groundwater using granular activated carbon.
For drying of some liquids *EBCT* ≤ 1 minute
EBCT for air dryers vary from 5 to 30 secs

Contactor Dimensions
For gas adsorption, typical *L* between 0.3 to 1.2 m, depending on solute concentration in gas stream.
At times *L* selected based on amount of adsorbent to be provided by manufacturer
and *EBCT* recalculated to check within permissible limits.
Accordingly, *LR* / U_s modified and checked to lie within permissible limits.

So, once if you proceed with these particular calculations and these checks also I have written down for your convenience.

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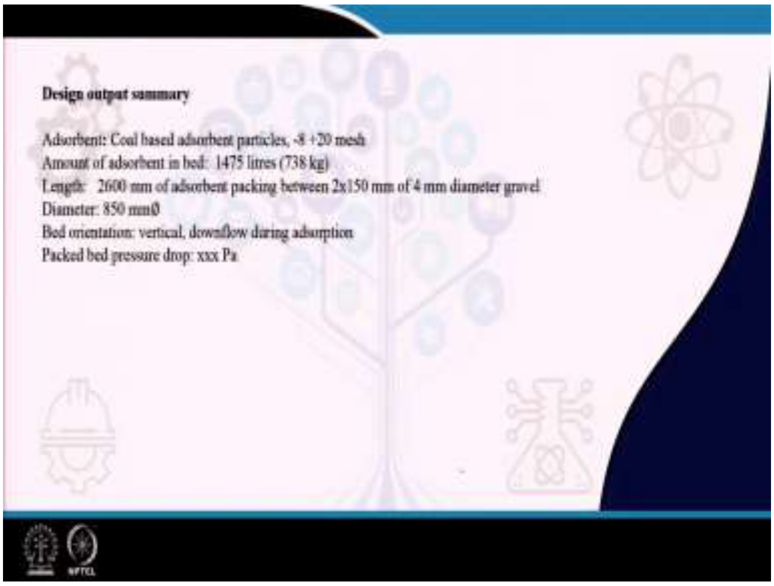

Design output summary

Adsorbent: Coal based adsorbent particles, -8 +20 mesh
Amount of adsorbent in bed: 1475 litres (738 kg)
Length: 2600 mm of adsorbent packing between 2x150 mm of 4 mm diameter gravel
Diameter: 850 mmØ
Bed orientation: vertical, downflow during adsorption
Packed bed pressure drop: xxx Pa

So, once you have done more or less the design output is as shown in this particular case. You can proceed for yourself, in case you have any doubts regarding the illustration problems we will be happy to address those doubts and with this I conclude my discussions on adsorber design.

Thank you very much for today.