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Unit Operations of Particulate Matter

Lec – 15
Gas Fluidisation(Part -01)

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Welcome to the 5th lecture of week 3 of course unit operations of particulate matter in this lecture we will discuss gas fluidization if you remember in the last lecture we have started gas fluidization and we are continuing that in 5th lecture also here first of all we will discuss what is entrainment and how entrainment is consider in fluidization process and then we will discuss design of fluidizer with an example and finally we will discuss application of fluidized bed in industry.

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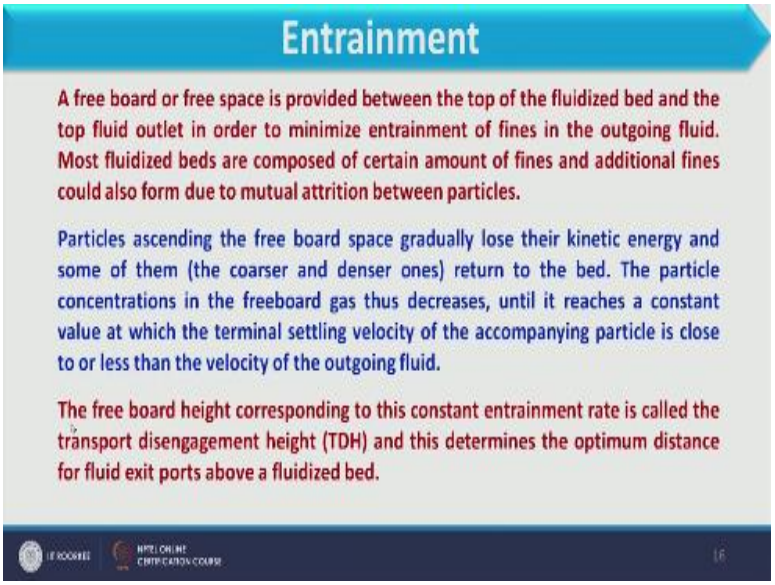

So let us start with the entrainment now what happens that a free board or free spaces provide between the top of the fluidized bed and top fluid outlet in order to minimize entrainment of the fines in the outgoing fluids, now first of all we should understand what is entrainment I guess many of us understand this and entrainment is basically caring the solid particle with the fluid and that is also possible in fluidized bed so when we are defining the fluidized bed in fluidizer after bed there are free space which is available from top of the bed and two of the column through which gas exits.

So this space is basically called as free space or free board and when this is sufficient the entrainment of solid with the gas is possible so most fluidized bed are composed of certain amounts of fines and additional fines could also form due to mutual iteration between particles so when we are dealing with fine particles fine particle can easily be entrained with the gas now when fine particle is fluidized in the fluidized bed what happens when the fine particle strike with the wall of the fluidizer or when they strike to each other further smaller fines can be made and these smaller fines can easily be entrained with the gas.

So particles are sending the free board space gradually loss there kinetic energy and some of them retune to the because particles carry some energy and when they move with the gas they loss the energy and then falls back and it usually when particles are course are desire the particles constrains in the free board gas thus decrease until it reaches a constant value at which the terminal steeling velocity of the companying particle is close to or less than the velocity of outgoing fluid so when the it will reached to the terminal steeling velocity or less than the velocity of outgoing stream till then the concentration of free board zone will be constant.

So what happens the free board height corresponding to this constant entrainment rate is called the transport disengagement height and this determines the optimum distance for fluid exit ports above the fluidized bed. So when we are dealing with the design of fluidizer bed height is important factor but along with this the height of column above bed it is also important because we have stop entrainment of the particles.

So as for as height is concerned we have to calculate transport disengagement height and then that height would be added to the bed height and other factor also to calculate total height of the fluidized.

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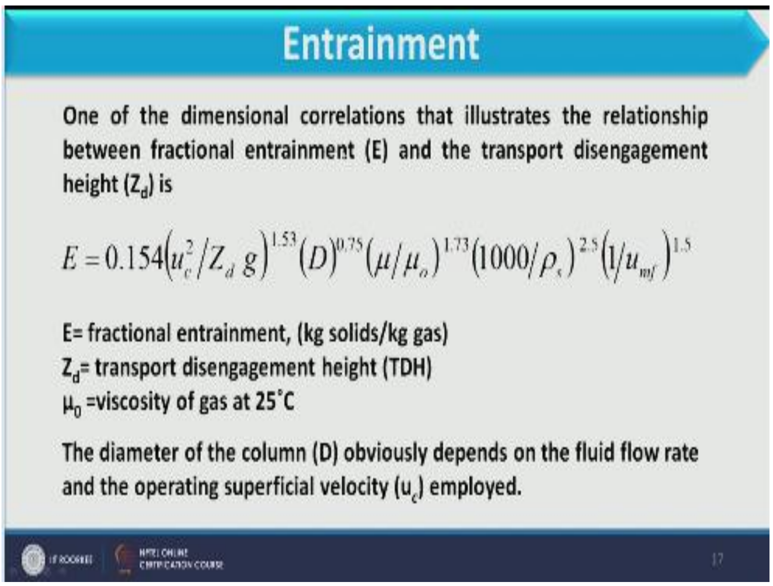

Now as for as us entrainment is concerned how we can relate this mathematically it can be done by 1 of the dimensional less coloration that illustrates the relationship between fractional entrainment and transport this engagement height that we have denoted with z_e and it is related as E = 0.154 and here we have whole expression so you see here we have u_c is the velocity of gas that is operating velocity z_d is the transport disengagement height d is the column diameter μ is the velocity of fluid and $\mu 0$ is a viscosity of fluid that is gas at 25^0C.

And other parameter are there where u_{mf} you understand this is nothing but the minimum fluidizing velocity, so E is basically fractional entrainment that is kg of solid/ kg of gas so considering all these parameters we can calculate how much fractional entrainment is occurring or if we know the fractional entrainment that let us say 0.001.005 like that if we defined fractional entrainment accordingly we can calculate how much TDH is provided how much transport disengagement height is provide.

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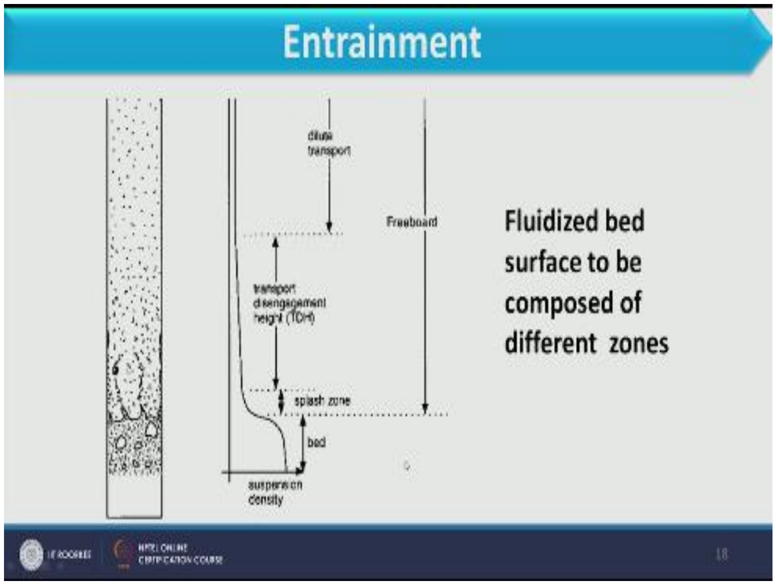

Now if you see this figure what happens here we have different section when we start from the distributor plate this is the height of the bed after this spash zone is there where particles moves up and then they fall down and after this we have transport disengagement height and then dilute transport so all these height all these sections are falling in free board section of the column so here we are discussing different zones of the fluidized bed.

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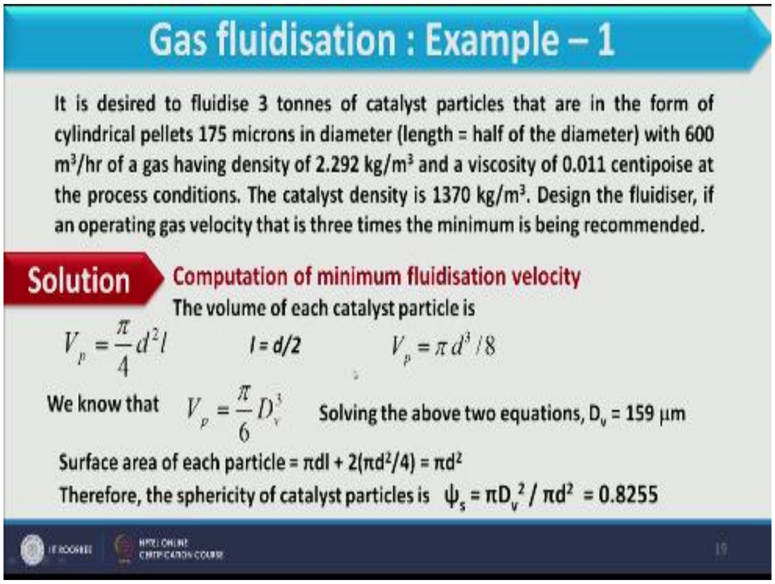

Now as far as gas fluidization is concert here we will discuss one example to illustrate the design of fluidizer and this example goes as it is desired to fluidize 3 tons of catalysts particles that are in the form of cylindrical pellets so here the shape of the particles is cylindrical not the spherical so pellets is having 175 microns diameter and what is the height is just half of the diameter and it is fluidized with the gas which is having volumetric flow as 600 $m^{3/}$ h density of gas is 2.292 kg . m^3 and viscosity is 0.11 centerpieces now catalyst density is 1317 kg/ m^3 we have to design a fluidizer if and operating gas velocity is 3 times than that of minimum gas velocity.

So for this condition we have to design the fluidizer so let us start the solution of this problem what we have to calculate is here we have to design the fluidizer column or fluidized bed and as far as design is concerned we have to calculate diameter as well as height.

Now how diameter will affected by velocity of gas and total volumetric flow of gas we know so when we calculate the velocity of gas we can calculate cross sectional area and then we can calculate the diameter and you see for this problem it is recommended that the operational gas velocity is 3 times more than the minimum fluidizing velocity so first of all we have to calculate minimum fluidizing velocity, so let us start this as you know that particles is not spherical we have to concerned the shape of the particles so volume of each catalyst particle is VP that should be Π /4 d^{-} l where l is d/2 because it is half of the diameter so considering this we can calculate particle volume as Π / $d^{3/}$ 8.

Now here as shape is not regular or it is not spherical we have to calculate volumetric diameter of particles and that we can find by equating the volume of sphere with that of the particles so volume of sphere should be Π / 6 dv^3 so when this VP is equated to the particles volume we can calculate dv value and it comes as 159 micro meter now we have to calculate surface area of each particle and that should be Π dl because it is cylindrical pallet so Π dl + 2 Π d^2 / 4 that is in cylindrical pellet .

So above surface we have to consider as the surface area of circle and that should be 2, so here we have Π d^2 as total surface area of particles so here we will calculate the sphericity of catalyst particles which can be defined as the surface area of sphere having equal volume then that of the particles divide by surface area of particles so sphericity here we can calculate as Π dv^2 that is a surface area of a sphere which is having equal volume then that of the particle divide by surface area of particle. So here we can divide this two it is sphericity comes as 0.8255.

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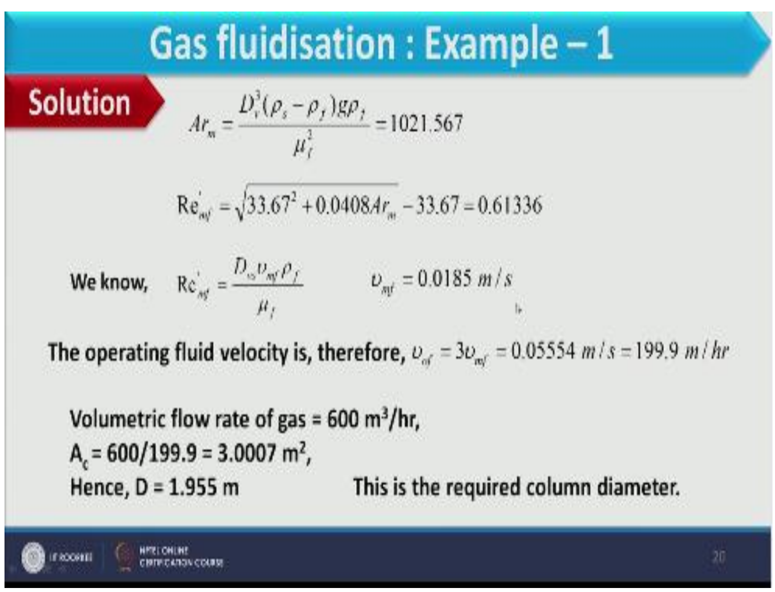

Now as we have to calculate minimum fluidization velocity we have to calculate Re number at minimum fluidizing condition and Galileo number because we have the relationship of Re number at minimum fluidizing condition and Galileo number so here you see this number we have that is Archimedes number and this Archimedes number and Galileo number these both number are equal.

Therefore we can use Archimedes number also and Galileo number also expression of both number would be same so Archimedes number here we will use where instead of diameter we will use volumetric diameter of particles considering all parameters over here we can have Archimedes number as 1021.567 and this expression we have used for Re number and how we can obtain this we have obtain if you remember second lecture of this week where we have discussed minimum fluidizing velocity of different shapes.

There we have derived this expression so in this expression while putting the value of Archimedes number we can calculate Re number at minimum fluidizing condition which comes as 0.61336 considering this Re number we can calculate minimum fluidization velocity and it comes as 0.0185 m/ s and where we know that operating velocity in fluidizer is 3 times more than the minimum fluidizing velocity.

So we can calculate operating velocity of the gas and it comes as 3 x 0.0185 so 0.05554 or 199.9 m / hr volumetric flow of gas that we know 600 m^3 / hr and here we can calculate cross sectional area of the column which is nothing but volumetric flow of gas divided by operating fluid velocity and it comes as 3.0007 m^2 and when we calculate diameter it comes as 1.955 m so this is a required column diameter for fluidizer now fluid will velocity we have considered as 0.05554 and this velocity should never be exec the terminal steeling velocity particle because then only entrainment is possible.

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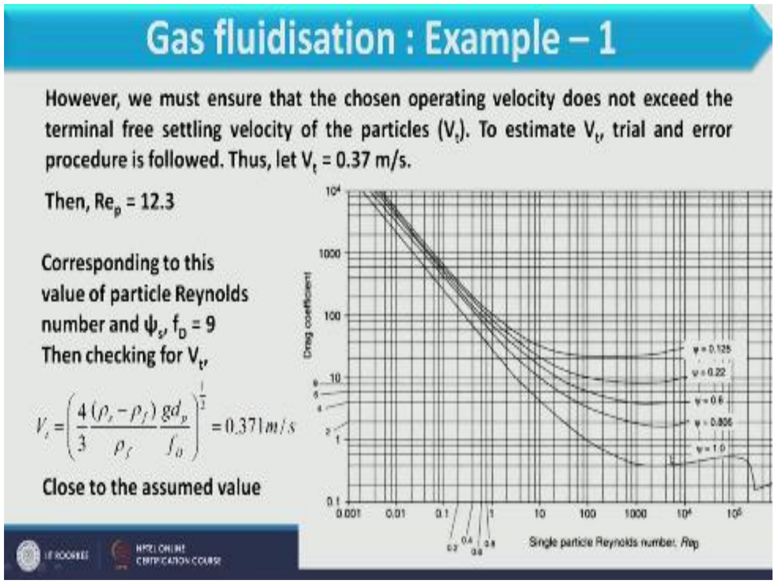

So we must ensure that the chosen operating velocity should not exceed terminal setting velocity of the particles that is V_t so we have to calculate V_t / trial and error first of all let us assume the value of Vt as 0.37 m/s and Re number we can calculate considering this velocity it comes as 12.3 now if you see this curve here the curve is drawn between drag coefficient and single particles Re number and the particles Re number over here is 12 .3 and here we have different sphericity curve this sphericity in present case is 0.82.

So it will lie somewhere here and it s 12 so we can see value from here so value of drag coefficient should be around 9 so corresponding to Re number 12.3 we can calculate fd value as 9 we can see fd value as 9 from this curve and when we go for terminal steeling velocity expression in terms of fd this is the expression and we but all parameters over here and terminal settling velocity should be 0.371 m / s and actual gas velocity is 0.555 so that is very less in comparison to this. So the deign so the condition is satisfied.

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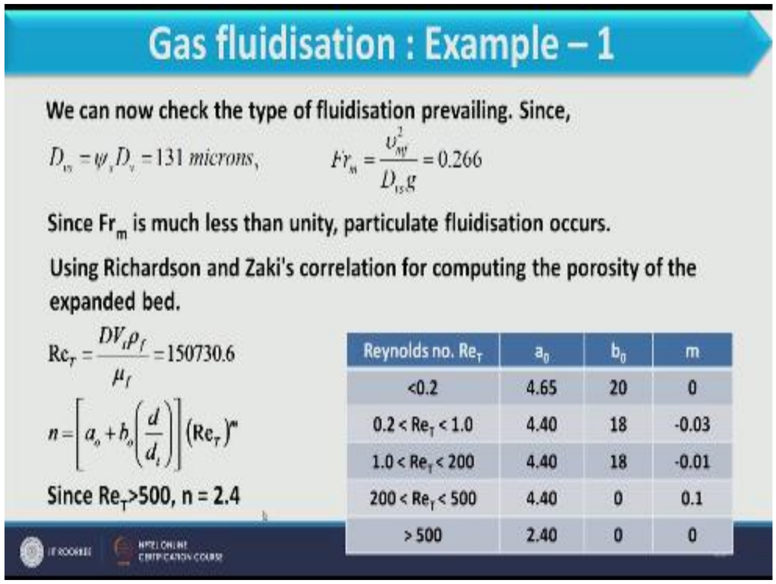

We can now check the type of fluidization prevailing so check the type of fluidization we met to calculate Fr number and in Formula number we diameter of particle and as diameter here is and as particles here is not a spherical we have to calculate volume surface diameter and that should be sphericity into volumetric diameter if you remember second lecture there we have defined the diameter of particle of irregular shape as sphericity into diameter of particles we are considering.

So here we have to recalculate the diameter and it comes as 131 micron once we calculate the Formula number considering minimum fluidizing velocity it comes as 0.266 so which is less than 1 particulate fluidization is prevailing in this case now using Richardson and Zaki's correlation we have to compute the void age of the expanded bed so to calculate the void age we need n index and that index is related torn number by this expression where this Re number t is the Re number at terminal steeling velocity.

So that we can calculate because we terminal steeling velocity so it comes as 150730.6 now to calculate n index we need a_0 b_0 and m which we can see from this table so if you see this Re numbers value, so if you see Re number value it is falling in this section where it s greater than

500 so a0 should be 2.4 b0 0 and m0 considering all these value over here n we can obtained as 2.4.

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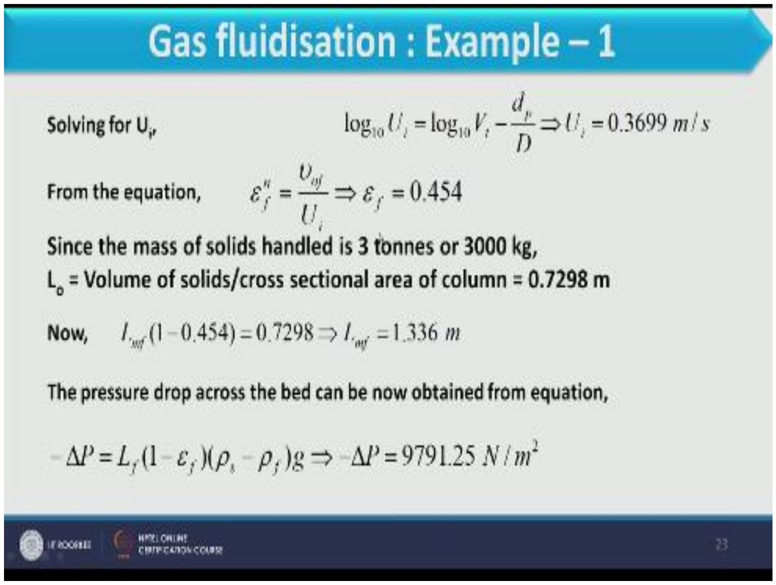

So once we know the n factor we can calculate porosity by this where U_{of} is the actual operating velocity of the bed actual operating velocity of the gas that we have already calculated and this Ui we can calculate by this expression that we have also discussed so here using this expression we can calculate Ui as 0.3699m/ s considering these value void age of the bed is found as 0.454, now we have to calculate height of the bed how we can calculate since the mass of the solids handled is 3 tons or 3000 kg.

So here we have defined as parameter L_0 and this = to volume of solids divide by cross sectional area of the column so here basically L_0 is the height of the column when void age is 0 so volume of the solid and cross sectional area of the column that we know volume of the solid is this 3000 kg / it is density so that should be the volume of solid cross sectional area we know so that L_0 value comes as 0.7298 further while balancing the solid we can get this expression L_{mf} 1-0.454 because we can get this expression L_{mf} 1- 0.454 = L_0 that is 0.7298.

Now if considered this particular expression here L_{mf} is the total height of the bed when this much porosity is this much void age is applicable ,so total solid is available in height of L_{mf} and that solid is = 2.7298 so while balancing the solid we can calculate height of bed as 1.336 m further we have to calculate pressure drop in the column if you remember that we have derived in first lecture of this week so this expression I guess you remember so while putting values in this expression we can calculate pressure drop which comes out as 0.979 kg N/ m^2.

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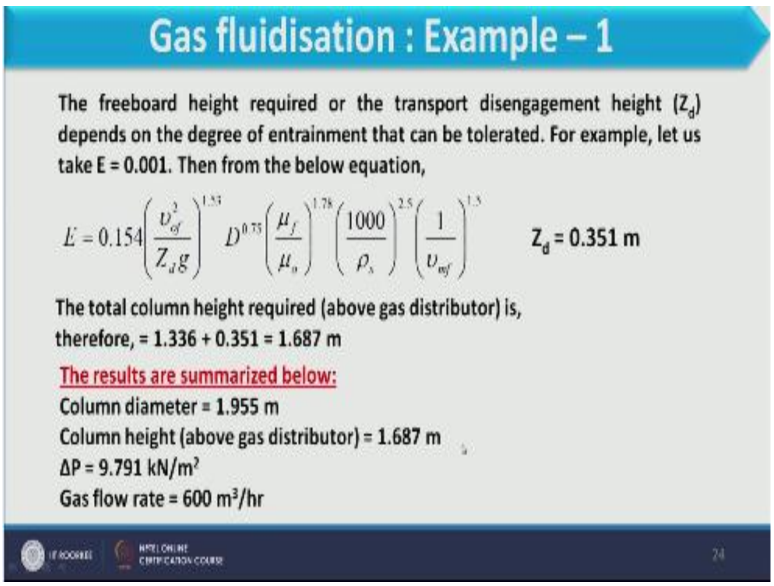

Now how we have to calculate the height we need to calculate free board height because height of the bed we already know so free board height or transportation disengagement height we need to calculate and for this propose we have assumed that entrainment should be very less and that should be 0.001 and while putting values in this expression this expression is used to calculate the height of transport disengagement section.

So while putting entrainment as 0.001 and other factors we can calculate Z_d as 0.351 so height of the column we can calculate above distributer as 1.336 that is bed height + height of transport disengagement zone so it comes out as 1.687 m so results are summarized here column diameter

1.955 column height 1.687 pressure drop is this much and gas flow rate gas volumetric flow rate $600m^3/ hr$

So you can observe from here that column diameter is height than this because to calculate we need other factors we height of other zone and coming of these we can calculate total height of the column and here another factor is this like when we increase the gas velocity so in that case more height is possible so all this factor we have to consider to calculate height of the column, so in this way we can design the fluidizer as for as design is concern we have to design we have to calculate diameter height and pressure drop.

Now lastly we should discuss the application of fluidized bed in industry here we have two type of application first is physical and second is chemical.

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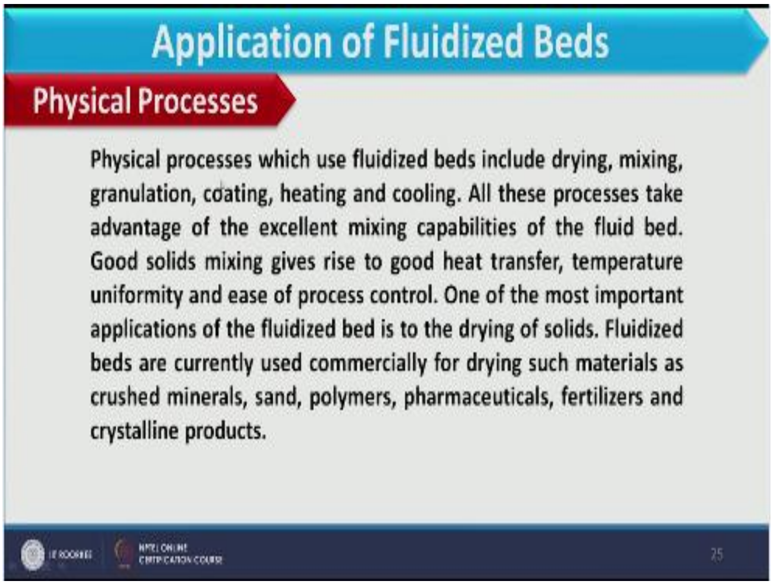

So for physical processes which use fluidized bed include drying mixing granulation coating heating and cooling all these process take advantage of the excellent mixing capabilities of fluidized bed as we have discussed that it has a it mix the particles of different densities as well as size good solid mixing gives rise to good heat transfer temperature uniformity and ease of process control. One of the most important application fluidized bed is to dry the solids as we have seen that it is used to dry the rise wheat etc.

In spouted bed fluidized bed fluidized beds are currently used commercially for drying such material as crushed minerals, sand polymers, pharmaceutical, fertilizers and crystalline products.

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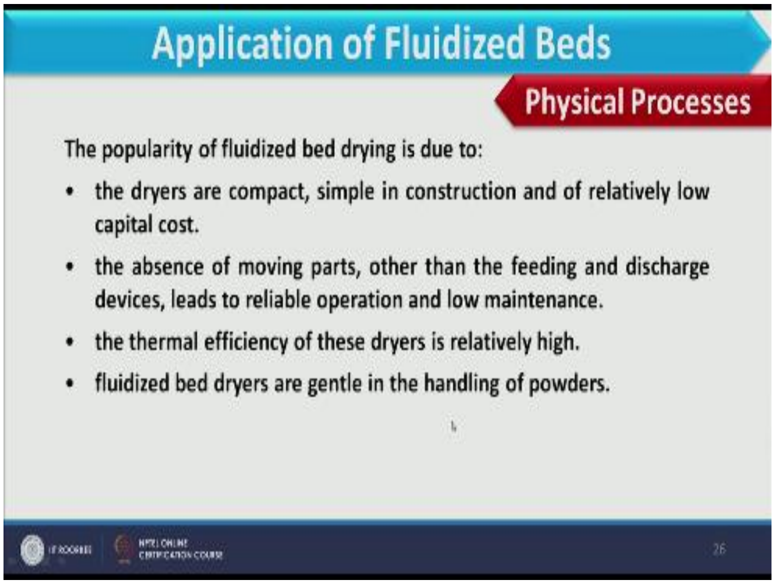

Now popularity of fluidized bed as dryer is due dryers are compact simple in construction and of relativity low capital cost the absence of moving parts other than the feeding and discharge devices leads to reliable operation and low maintains the thermal efficiency of these dryer is relativity high and fluidized bed dyers and fluidized bed dyers are gentle in handling of powders, so these are some factors based on that it is highly useful as dyer. Now we will discuss one example or physical process and here we are using fluidized bed as solid cooler.

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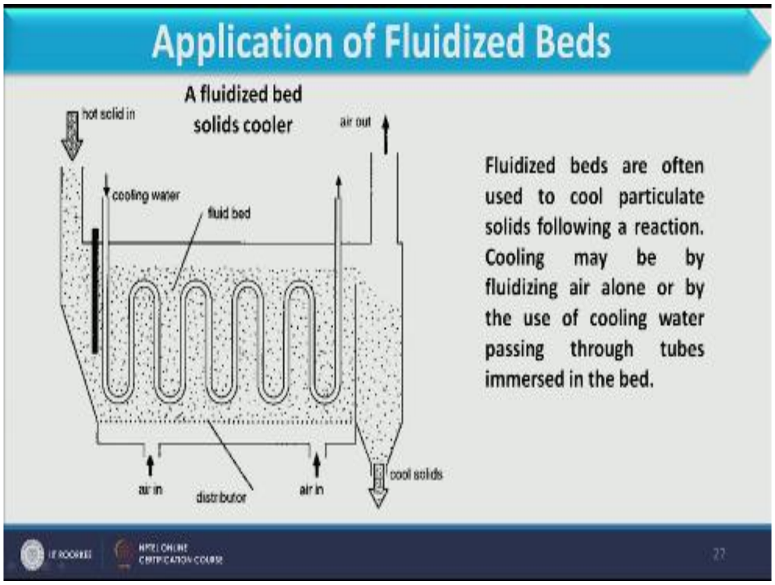

Now if you see this image what happens solid enters hot solid enters through this and it is fluidized when air is entering form the bottom so hot solid enters from here form this section and it is fluidized and complete bed is having coils in which cooling water flows so as this solid particles are in fluidized state the heat transfer will be enhanced and due to this the solid can be cool down so this is the fluidized bed solid cooler.

So fluidized beds are often used to cool particulate solids following a reaction cooling may be by fluidized air along or by the use of cooling water passing through tubes immerged in bed as we have just discussed.

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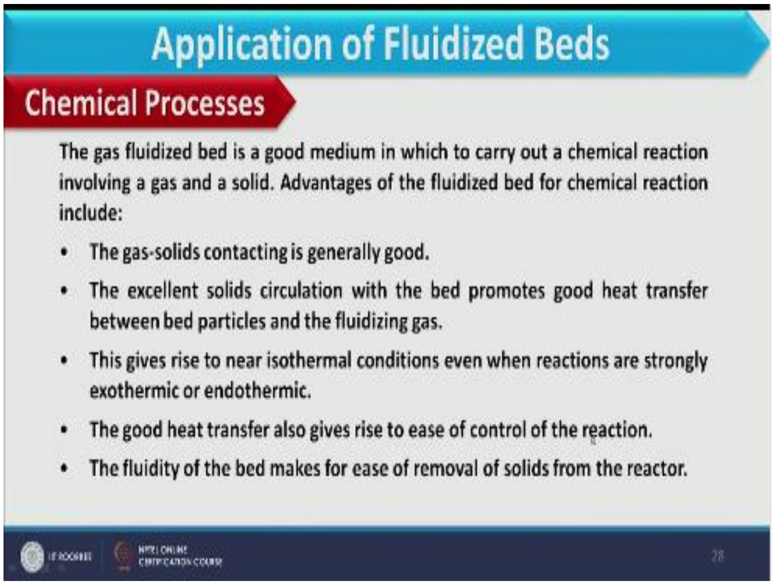

Now as for as chemical process application is concerned the advantages of fluidized bed for chemical reactions are the gas solid contacting is generally good because gas and solid both our in moving condition the excellent solid circulation with the bed promotes good hear transfer between bed particles and the fluidizing gas this gave rise to near isothermal condition even when reactions are Strongly exothermic or endothermic because here continues movement is there so the uniformity of temperature is maintain inside the bed.

Good heat transfer also gives rise to ease of control of the reaction and the fluidity of the bed makes of ease of removal of solids form reactor so when we are considering solid in the reactor as it is in moving condition that can exit the reactor very easily so that is also an advantage.

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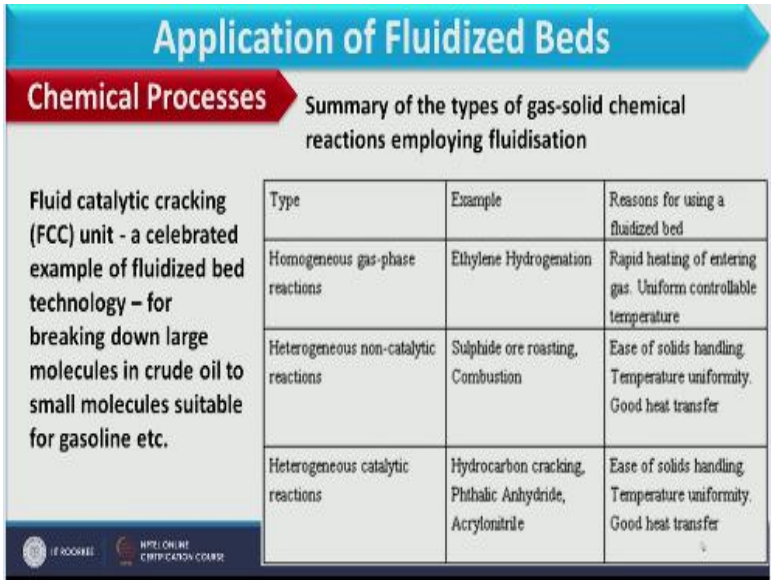

As for as chemical process is concerned the very famous example very common example is fluid catalytic cracking unit it is a celebrated example of fluidized bed technology for breaking down large molecule in crude oil to small molecules suitable for gasoline etc… so here you see in petroleum industry or in petroleum plant to break the crude into a smaller change of hydrocarbon we use FCC unit that is fluid catalytic unit and that is very common example, further her we have summary of gas solid chemical reactions which involve or which employee fluidization.

So homogeneous gas phase reaction it is example is ethylene hydrogenation and reason is rapid heating of entering gas uniform controllable temperature second reaction types is hydrogenous non catalytic reaction example sulfide ore roasting and combustion reason ease of solids handling temperature uniformity good heat transfer and similarly we have hydrogenous catalytic reaction where examples are hydrocarbon cracking pathetic hydride and reason are gain ease of solid handing temperature uniformity good heat transfer.

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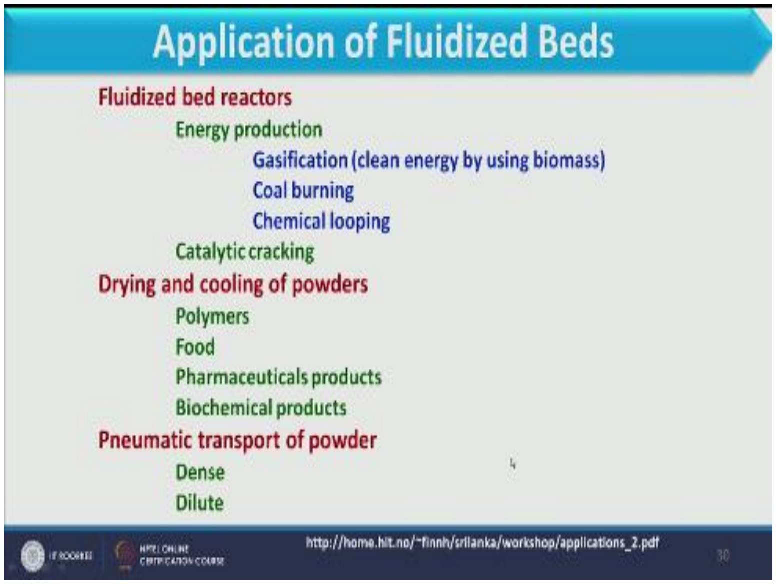

So here some we are summarizing the application fluidized bed reactor, energy production it is used in a energy production through gasification coal burning and chemical looping reactor also use as catalytic cracking as we have discussed in the last slide drying and cooling of power in this fluidized bed are used for polymers food pharmaceuticals product biochemical products pneumatic transports of powder fluidized bed are used for dense as well as dilute condition.

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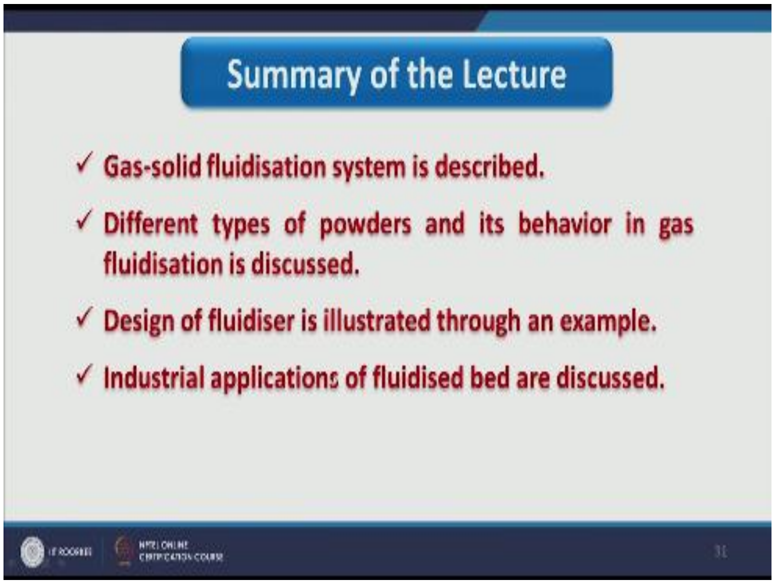

And here we have to summaries the lecture this summary is for lecture number 4 as well as 5 and here gas solid fluidization system is described different types of powders and it is behavior in gas fluidization is discussed design of fluidizer is illustrate through an example and industrial application of fluidized bed are discussed.

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And here we have the references and that is all for now thank you.

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