

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

**NPTEL**

**NPTEL ONLINE CERTIFICATION COURSE**

**Unit operations of Particulate Matter**

**Lec- 20**

**Transportation of solids (Part-03)**

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Welcome to the fifth lecture of week four of the course unit operations of particulate matter, in this lecture we will discuss non mechanical conveyors. Now as for as non mechanical conveyors are concerned these are two type first is hydraulic conveyor and second is pneumatic conveyor, and we also called this as hydraulic transport on pneumatic transport, so now these non mechanical conveyors that is hydraulic as well as pneumatic transport these are used for longer distances and why these are used for longer distances for this, we should see some facts.

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**Non - Mechanical Conveyors**

**Hydraulic and Pneumatic Transport**

In a country like India where the coal fields are highly localized, it has been observed that the cost of transportation of coal over long distances (600 – 1000 km) by railways often exceeds the cost of the transported coal itself. In this situation a continuous mode of transport such as slurry transportation is desirable.

Solid can be conveniently conveyed through pipe lines in the form of a slurry or suspension in a fluid.

If the carrier is water → Hydraulic transport

If the carrier is air → Pneumatic transport

Hydraulic transport through underground pipelines can be employed for transport over long distances.

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In a country like India where the coal fields are heavily localized what is the meaning of this that when we have to take the coal from one place to another place because coal are found in some specific states only like Jharkhand, Orissa extra. So in this, so these states or these locations are quite specific and from here we have to take the coal to other spaces, we have to take coal to other places, so it has been observed that the cost of transportation of coal over long distances that is around 600 to 1000 kilometer or more than that by railways often exceeds the cost of transported coal itself.

So here we are taking one example of coal and when we are transferring this by railways after some distances it will not be that much economical so in that case we use some other means and these are hydraulic as well as pneumatic transport. In this situation a continuous mode of transport such as slurry transportation is desirable, so what happens in hydraulic as well as pneumatic transport.

The solid is transferred through a media that is in the form of slurry or when it is suspended in the fluid. If the carrier is water, if the fluid is water we call it hydraulic transport and if it is air we call it pneumatic transport. Hydraulic transport through underground pipeline can be employed for transport over long distances, so you see here hydraulic transport can be made underground also so that is one of the reason that it can, that is one of the reason why the hydraulic transport is so popular.

Because it can be transported through any route or underground also so space requirement will not be that much high in this case.

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| Hydraulic and Pneumatic Transport  |                    |   |                              |
|--|--------------------|---|------------------------------|
| <b>Advantages</b>  |                    |   |                              |
| <ul style="list-style-type: none"><li>➤ Continuous operation</li><li>➤ Practically immune to adverse weather conditions</li><li>➤ Less manpower requirement</li><li>➤ Possibility of following a relatively shorter route.</li></ul> | Mode of transport  | Specific transportation capacity, kg/kW | Power consumption, W/(kg.km) |
|  | Automobiles        | 65 – 200                                | 0.149                        |
|  | Railways           | 270 – 800                               | 0.037                        |
|  | Waterways          | 2700 – 6700                             | 0.011                        |
|  | Airways            | 1.5 – 4.0                               | 0.746                        |
|  | Pipeline transport | 5400 – 40000                            | 0.011                        |

Now let us see few advantages of this, advantages of hydraulic as well as pneumatic transport and these are continuous operation, operation continuous for longer time. Practically immune to adverse weather condition, now what happens when it is transported in the form of slurry it is transported inside the pipes, so either that pipe is available over the earth or inside the earth it is not affected by the weather because slurry is transported inside the pipes.

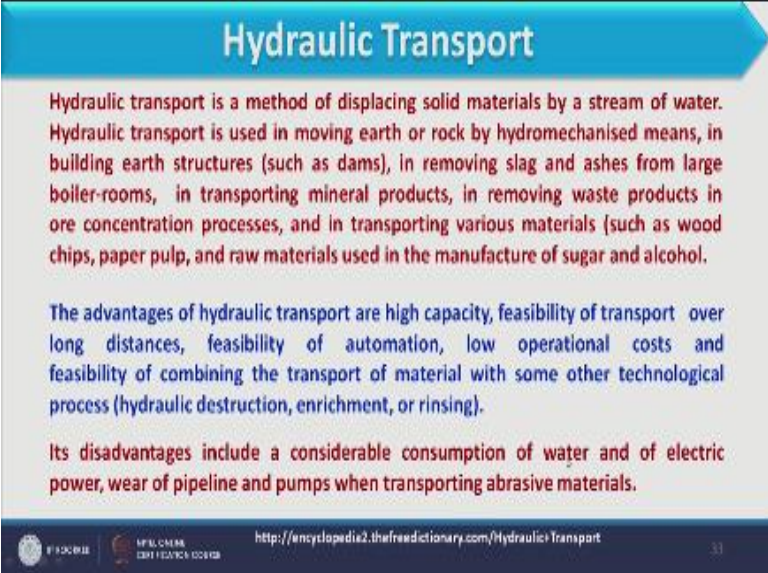
So that is one major advantage, it has less manpower requirement. Possibility of following a relatively shorter route, because it can be placed underground also so route requirement will be, so route requirement can be reduced or we can go for shortest route in this case. Otherwise when we have to transport through rail or road we have to go with this specific route only. Now here I am having one table which speaks about mode of transport they are different modes of transport.

And specific transportation capacity that is material, weight of the material that is kg/kW that is kg/kW means how much material can be transported per unit consumption of power and power consumption is W/kg.km. When we go for automobile specific transportation capacity moves from 65 to 200 and power consumption 0.149 and similarly you can see other factors whereas

when we are considering through airways it is a specific transportation capacities very less and power consumption is significantly high so that is not use for general purpose.

Whereas when we consider for pipeline transportation its capacity varies from 5400 to 40000 kg/kW so that is very huge specific transportation capacity and power consumption is very less even it is almost equal to water waves but carrying capacity in pipeline is significantly higher than the water waves, so in this way pipeline transportation is most economic.

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### Hydraulic Transport

Hydraulic transport is a method of displacing solid materials by a stream of water. Hydraulic transport is used in moving earth or rock by hydromechanised means, in building earth structures (such as dams), in removing slag and ashes from large boiler-rooms, in transporting mineral products, in removing waste products in ore concentration processes, and in transporting various materials (such as wood chips, paper pulp, and raw materials used in the manufacture of sugar and alcohol).

The advantages of hydraulic transport are high capacity, feasibility of transport over long distances, feasibility of automation, low operational costs and feasibility of combining the transport of material with some other technological process (hydraulic destruction, enrichment, or rinsing).

Its disadvantages include a considerable consumption of water and of electric power, wear of pipeline and pumps when transporting abrasive materials.

<http://encyclopedia2.thefreedictionary.com/Hydraulic+Transport>

Now let us start with hydraulic transport as we have discussed that in hydraulic transport the mode is water or carrier is water, so when we have to transfer the solid we have to make slurry in the water and then that slurry will be transported through pipe so that is, that happens in hydraulic transportation. Now here we will discuss some of the advantages and disadvantages of hydraulic transportation.

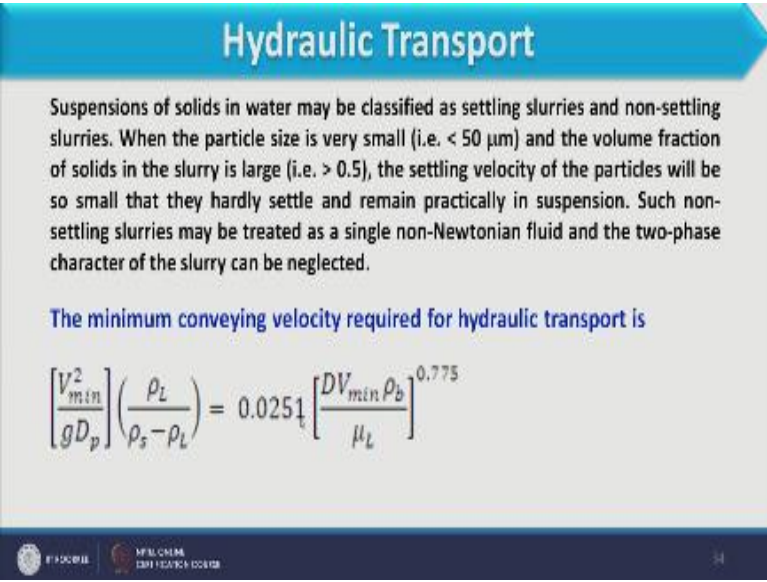
Advantages of hydraulic transport are high capacity, feasibility of transport over long distances, high capacities there feasibility of transport over long distances, feasibility of auto machine, low operational cost and feasibility of combining the transport of material with some other

technological process such as hydraulic destruction, enrichment or rising. So here we have different advantages of hydraulic transportation but along with this we have some disadvantages also such as.

Disadvantages include a considerable consumption of water, because it is entirely transferred as a slurry and that is prepared with the water so obviously water consumption is very high in this case, and of electric power consumption is very high because we have to use the pumps, wear of the pipeline and pumps when transporting abrasive materials, so when we have to transport the abrasive material we can have wear and tear in pumps and pipelines extra. So these are some disadvantages for more you can refer this link.

And when we are preparing the slurry or suspension we have to take care about few factors like how much should be the concentration, what should be the volume fraction extra.

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**Hydraulic Transport**

Suspensions of solids in water may be classified as settling slurries and non-settling slurries. When the particle size is very small (i.e. < 50  $\mu\text{m}$ ) and the volume fraction of solids in the slurry is large (i.e. > 0.5), the settling velocity of the particles will be so small that they hardly settle and remain practically in suspension. Such non-settling slurries may be treated as a single non-Newtonian fluid and the two-phase character of the slurry can be neglected.

The minimum conveying velocity required for hydraulic transport is

$$\left[ \frac{V_{min}^2}{gD_p} \right] \left( \frac{\rho_L}{\rho_s - \rho_L} \right) = 0.0251 \left[ \frac{DV_{min} \rho_b}{\mu_L} \right]^{0.775}$$

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So when the particle sizes very small if it is less than 50 micro meter and volume fraction of the solid in slurry is large that is greater than 0.5 the settling velocity of the particles will be so small that they can hardly settle and remain practically in suspension. So what happens when we have

to transport hydraulically the solid which we are, which we have to transport for this we prepare a suspension or slurry but whatever particles are available that should not be settle down.

And when they will not be settle down, when the terminal settling velocity of the particle is lesser than the velocity of slurry, so velocity of the suspension so when it will be greater than when velocities greater for suspension it will never allow particle to settle on the other hand particle will be suspended in the slurry. Now in hydraulic transport what happens when we have to transport the solid we prepare slurry with these solid where solids are mixed with the water and prepare the slurry.

Now what happens in this slurry whatever particles are available that particle should remain suspended and it should not be settle down because in that case there will be forming of solid at the lower section of the pipe and transportation will not happen, so such non-settling slurries may be treated as a single non-Newtonian fluid and the two phase character of the slurry can be neglected.

So when particle size is very small and volume fraction of solid in the slurries greater than 50 we can consider that slurry as single phase where particles are completely suspended in the slurry. Now the minimum conveying velocity required for hydraulic transport is imperially related like this  $V_{min}^2/gD_p$  here we have density fraction that is  $\rho_L/\rho_S-\rho$  in 2.0 251 into this factor, so here you see  $u$  minimum is basically the minimum conveying velocity which lies here also,  $D_p$  is the particle size and what is the limitation over this  $D_p$  value that we will discuss this is the density of liquid this is for solid and  $D$  is diameter of pipe in which transportation occur  $\rho_b$  is the density of bulk and  $\mu_L$  is the viscosity of l equate.




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## Hydraulic Transport

It is assumed that 85% (by weight) of particles have a size less than  $D_p$ .  $\rho_b$  is the bulk density of the slurry and can be estimated from as:

$$\rho_b = (1 - \varepsilon)\rho_s + \varepsilon\rho_L \quad \varepsilon = \text{volume fraction of liquid (water) in the slurry}$$

This equation is based on experiments performed using slurries containing particles of size less than 1 mm and pipe diameters in the range of 0.025 to 0.3 m.



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Now in this expression  $D_p$  value is the particle diameter and it is assume that 85% of particles have a size less than  $D_p$ , so how we decide the  $d_p$  value like  $D_p$  value is decided wherever 85% of the particle is  $\psi$  particle is of size less than  $D_p$ , so  $D_p$  can be calculated as when 85% of the particle lies then 85% of particle will have size lesser than  $D_p$ , so when 85% collection is obtained then we can say that then whatever would be the particle size that we can consider as  $D_p$ . And through one example with the illustrate in detail how the  $D_p$  should be calculated and here  $\rho_b$  is the bulk density of the slurry.

And that is  $1 - \varepsilon \rho_s + \varepsilon \rho_L$ , so  $\varepsilon$  is basically the volume fraction of liquid in the slurry, so this equation is based on experiments performed using slurries containing particles of size less than 1mm and pipe diameter should be in the range of 0.025 to 0.3m, so carrying out experiment in this condition we can have that empirical relationship now if you see this image this image shows a pipe line and if you see the environment this is completely cold condition, so here we have transportation of slurry in a hydraulic form.



More closely you can see here we have some slurry which is of black color may be this is coal and here we can observe more closely that in this way the particle prepare the slurry and hydraulically it is transported hydraulically it is transported like this so in adverse weather condition also material can be transported through hydraulic transportation.

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Hydraulic Transport : Example

Material A (specific gravity = 1.5) has the following size distribution. If the total material is to be transported hydraulically through a 0.3 m horizontal pipe to a distance of 15 km in the form of a homogeneous slurry containing 20% by weight of solids, estimate the minimum conveying velocity that is to be maintained.

| Particle size (mm) | Cumulative mass fraction |
|--------------------|--------------------------|
| 1.6                | 1                        |
| 1.4                | 0.96                     |
| 0.8                | 0.85                     |
| 0.6                | 0.72                     |
| 0.4                | 0.4                      |
| 0.3                | 0.15                     |

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Now here we have one example in this example material a of a specific gravity 1.5 has a following size distribution this is the following size this is the size distribution for the material if the total material is to be transported hydraulically through a 0.3m diameter horizontal pipe to a distance of 15km in the form of homogenous slurry containing 20 person by weight of solid estimate the minimum conveying velocity that is to be maintained, so here you see slurry is preparing the 20% solid mass with 20% solid particle size distribution is given to us.

And other parameter such as pipe diameter etc. Is given to us so let us start the computation of minimum conveying velocity in hydraulic transport.



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### Hydraulic Transport : Example

The minimum conveying velocity  $V_{min}$  :

$$\left[ \frac{V_{min}^2}{g D_p} \right] \left( \frac{\rho_L}{\rho_s - \rho_L} \right) = 0.0251 \left[ \frac{D V_{min} \rho_b}{\mu_L} \right]^{0.775}$$

Where  $\rho_L = 1000 \text{ kg/m}^3$   
 $\rho_s = 1500 \text{ kg/m}^3$   
 $D = 0.3 \text{ m}$   
 $\mu_L = 0.001 \text{ kg/m-s}$   
Since the suspension contains 20% by weight of solids

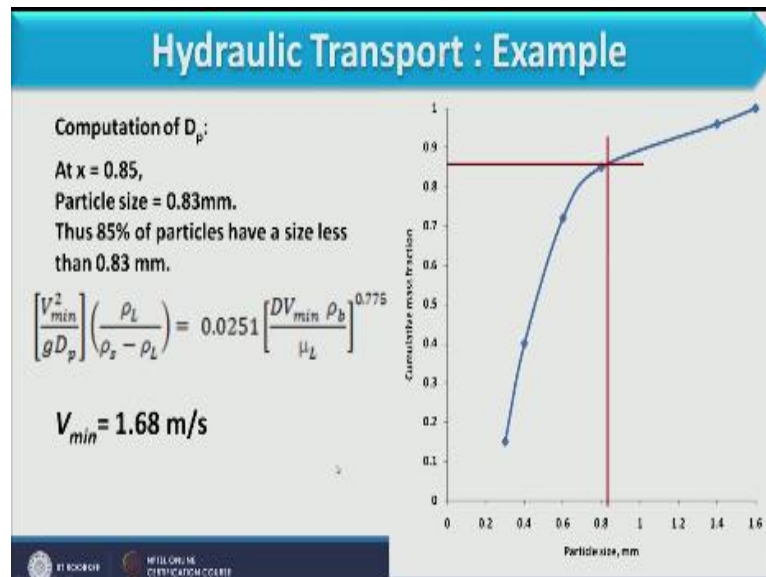
$$\rho_b = \frac{100}{\left( \frac{20}{1500} \right) + \left( \frac{80}{1000} \right)} = 1071.4 \text{ kg/m}^3$$

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This is the equation that just we have discussed  $V_{min}$  will have to calculate over here, so  $V_{min}$  lie in both side and where  $\rho_L$  is 1000 because water we have used as a carrier here  $\rho_L$  we have considered as density of water because water is used as a carrier solid density 1500 kg/ m<sup>3</sup> diameter of pipe is 0.3m  $\mu_L$  is that is viscosity of water, now suspension contains 20% by weight or solid so we can calculate bulk density like 20% if solid, so 80% should be water so  $100/20 / 1500 + 80 / 1000$  so 1071.4kg/m<sup>3</sup> is the bulk density of the slurry.

So pb we know already now we have calculated value of  $D_p$  other parameters we know except  $V_{min}$ .

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So as far computation of  $D_p$  is concerned what we have to do we already know the particle size distribution which is given to us and if you remember we are given particle size as well as cumulative mass fraction, when we plot this in this curve what happens particle size corresponding to 85% mass fraction we have to find. Because as far as definition of  $D_p$  is concerned that is corresponding to 85% mass fraction that is corresponding to 85% mass fraction, so when draw the line of line around 85% in this y axis because that is cumulative mass and when we draw the line vertically.

Towards x axis the particle size we can obtain is 0.83mm so here particles size is 0.83 and thus 85% of particle have size less than 0.83 because all these particle will having size less than 0.83 which comes below 85% cumulative mass fraction, so while putting all these value over here we can calculate minimum conveying velocity that is 1.68m/s. So in this way you can calculate the minimum conveying velocity in hydraulic transport, now we will discuss pneumatic transport in pneumatic transport.

You know the carrier is air, now here we will discuss some of the advantages and disadvantages of pneumatic transport.

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| Pneumatic Transport   |                                 |
|---|---------------------------------|
| Pneumatic conveying uses a gas to convey solid material.                |                                 |
| Advantages  | Disadvantages                   |
| No dust contamination   | Particles must be dry           |
| Flow direction can be varied  | Possibility of product breakage |
| Low maintenance costs   | Wear and tear on the pipes      |
| Can handle multiple products with one system                            |                                 |
| Virtually no limitation in capacity, product type, distance, or routing |                                 |

Advantages are no dust contamination flow direction can be varied because we can go for smallest or any route we can go through or we can take any term because that is pneumatically transported low maintenance cost it can handle multiple products with one system because pneumatically it has to transport so it will not a contaminated the inner level of the pipe so we can handle multiple production in the same, we can handle multiple products in the same system or same pipe line.

Virtually no limitation of capacity product type distance or routing these are the advantages along with this some disadvantages are also there like particle must be dry we cannot transport moist solid, so particle should be dry possibility of product breakage because when we particle are transported with the suspension of other particle, so they can strike with each other or they can strike with the wall of the pipe so breaking may occur were and tear on the pipe it happens these are some disadvantages or pneumatic transport.

Now when we consider pneumatic transport as we have discussed in hydraulic transport that slurry that particle should be suspended in the slurry, so in the similar line we consider in pneumatic transport also that particle should be uniformly distributed in the pipe like carrier is

air so particle which we are considering that should ne uniformly spread into the convare or into the pipe line, and then this happen with the low density.


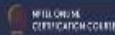
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### Pneumatic Transport

In pneumatic transport through horizontal pipes, the air velocity should be adjusted in such a way that the particles remain uniformly distributed in the fluid. With low-density solids or low solid to gas ratios and high gas velocities, the solids normally remain fully suspended. At low solid to gas ratios (less than 10.0 by weight) as usually employed in pneumatic conveyors,  $V_{min}$  can be estimated

$$V_{min} = 132.365 \left[ \frac{\rho_s}{\rho_s + 1000} \right] D_p^{0.4}$$

Where  $D_p$  is the diameter of the largest particle to be conveyed, m. This equation is based on experiments with particles less than 8 mm in size and specific gravity less than 2.65.



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Solids or low solid to gas ratio and high gas velocity the solids normally remain fully suspended at low solid to gas ratio that is less than 10 by weight as usually employed in pneumatic transport minimum conveying velocity can be calculated by this expression where it is equal to  $132.365 \rho_s / 1000 D_p^{0.4}$  where  $D_p$  is the diameter of largest particle to be convared because when we are able to carry able to convey the largest particle obviously smaller particle will be carried or will be convared easily.

So this equation is based on the experiments with particle less than 8mm in size and specific gravity less than 2.65, so this is about minimum conveying velocity.

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## Pneumatic Transport

The total pressure drop in pneumatic transport through a horizontal pipe is:

$$(-\Delta P) = (-\Delta P)_{ag} + (-\Delta P)_{as} + (-\Delta P)_{fs} + (-\Delta P)_f$$

$(-\Delta P)_{ag}$  = pressure drop for acceleration of gas to the carrying velocity =  $(1/2)\rho_{dg}V_g^2$



$\rho_{dg}$  = dispersed gas density (mass of gas per unit volume of pipe),  $\text{kg/m}^3 = \epsilon\rho_g$

$V_g$  = actual velocity of gas,  $\text{m/s} = (V_g)_{app}$  = (superficial velocity of gas)

$(-\Delta P)_{as}$  = pressure drop for acceleration of solid particles =  $\rho_{ds}V_s^2$

$\rho_{ds}$  = dispersed solid density,  $\text{kg/m}^3 = (1 - \epsilon)\rho_s$

$V_s$  = actual velocity of solids,  $\text{m/s}$



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Now here we have total pressure drop in pneumatic transport through horizontal pipe these are different pressure drops and details of these pressure drops are showing in this slide and once we calculate value of total pressure drop we can calculate total power consumption utilized in pneumatic transport, now here we will discuss one example on pneumatic transport.

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### Pneumatic Transport : Example

Estimate the minimum velocity required to transport ore particles (specific gravity = 2) pneumatically at the rate of 30kg/min to the distance of 25 km from the following data:  
Diameter of pipe (G.I.) = 0.07 m  
Particle size distribution (mm)= -2.032+1.676, -1.676+1.6

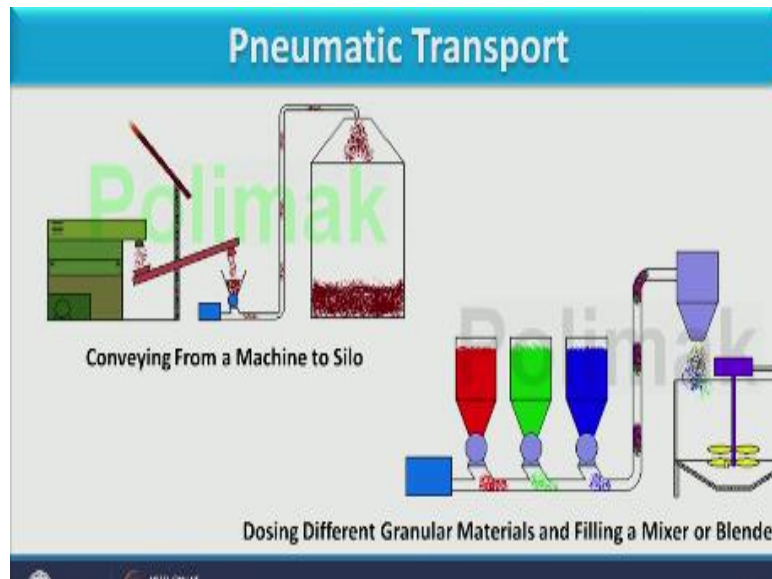
**Solution**
$$V_{\min} = 132.365 \left[ \frac{\rho_s}{\rho_s + 1000} \right] D_p^{0.4}$$

Largest particle size,  $D_p = 2.032\text{mm}$   
 $\rho_s = 2000 \text{ kg/m}^3$   
 $V_{\min} = 7.394 \text{ m/s}$

Now in this example what we have to do we have to estimate the minimum velocity required to transport ore particle with a specific gravity to pneumatically so we have to transport the ore particle pneumatically at the rate of 30kg per minute to the distance of 25 km from following data so diameter of pipe is given 0.07m and particle size distribution is given in mm has -2.032 + 1.676 and – 1.676 + 1.6, so in this range particles are available which we have to transport, now how we can calculate minimum conveying velocity.

This is the expression here only problem is with  $D_p$  if we find out the value of  $D_p$  we can calculate  $V_{\min}$  now if you remember what is  $D_p$ ,  $D_p$  is basically maximum diameter of particle that we have to transport so if you see the particles has distribution maximum should be 2.032 and minimum should be 1.6 so  $D_p$  should be the maximum size so here we can consider  $D_p$  as 2.032mm so here  $D_p$  we have note it down  $\rho_s$  we already know so  $V_{\min}$  can be calculated very easily, so that is 7.394m or second so in this way we can calculate minimum conveying velocity for pneumatic transport.

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Now in this slide I have shown some of the example where material is filled in silo through pneumatic transport, so you see here material is available which is convey from here to here through you can see this may be your screw conveyer we can say because feed is coming over here and discharge is a not at the end but before that so that is possible in a screw conveyer so material is coming over here and here we have the blower through this blow solid can be taken by this air and that is filled in this silo.

Pneumatically another animation we have when we are considering dosing different granular materials and filling a mixture or blender when we have to consider dose of different material and we have to prepare the mixture of this each dose will be collected and then it will be transported pneumatically and while transporting this mixing occur inside the pipe and therefore when we get the material and discharge and it already a mixture, so in this way we can use pneumatic transport here very interesting example.

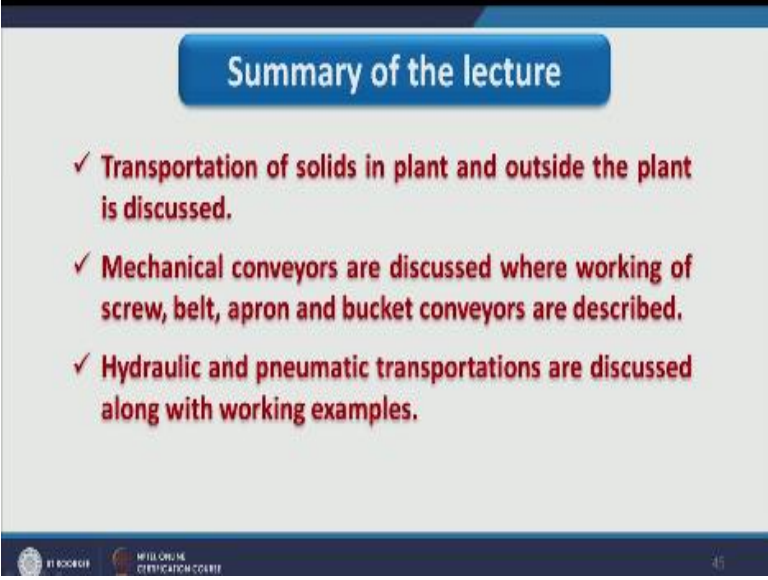


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Like if you see this is basically wheat and the we have to pack the wheat that can be pack through pneumatically because from here it takes the wheat and here we put some container where this wheat can be stored, so in this way is storing of wheat or packing of wheat can be done pneumatically, now here we have summary of the lecture now this summary of the lecture.

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**Summary of the lecture**

- ✓ Transportation of solids in plant and outside the plant is discussed.
- ✓ Mechanical conveyors are discussed where working of screw, belt, apron and bucket conveyors are described.
- ✓ Hydraulic and pneumatic transportations are discussed along with working examples.

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Now this summary of lecture 3, 4 and 5 which we have discussed for transportation of solid, so in this lecture transportation of solids in plant as well as outside the plant is discussed mechanical conveyors are discussed where working of a screw belt apron and conveyor are described and finally we have discussed hydraulic and pneumatic transportation along with working example.

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**References**

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And here you can have the books through which you can go through about transpiration of solid in detail few web lines are also used which are available in this lecture slide so that you can refer and here we are ending this course as it was the last lecture of last week so in this 4 week course we have discussed unit operations such as sedimentation, filtration fluidization, fluidization and transportation of solid I hope you are benefited with this course I wish you success in upcoming online examination thank you for joining new in this course thank you very much.

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