# Environmental Air Pollution

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## Lecture No. 17
## Emission from Fugitive Sources and Sulfuric Acid Production

What we really need to do is the interpretation – it is a very very important part.

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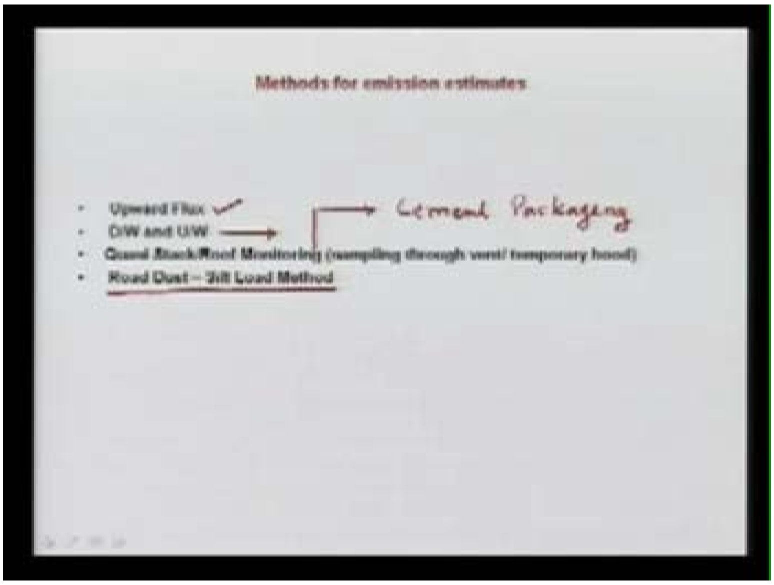

Methods for emission estimates

- Upward Flux ✓
- D/W and U/W →
- Quasi Stack/Roof Monitoring (sampling through vent/ temporary hood)
- Road Dust – Silt Load Method

→ Cement Packaging

Then, we see the methods to estimate fugitive emissions. These methods are called upward flux method – we will explain how this is used, we also use the method called you see here D/W and U/W – this is essentially referring to downwind–upwind method and we will see that also. There could be another method called quasi stack or roof monitoring. Suppose you have a large room, there are ventilators on top of the room and that is where you are having the fugitive emission. To give a typical example of quasi or roof monitoring, you can do sampling through vents and temporary hoods (you can call it temporary hoods). To give you a little example, maybe you can recall or correlate cement packaging – a little closed room, there can be little openings on the top, you can take your sampler on these openings because the emission will occur from those openings and then you can do the quasi stack or roof monitoring. This is the standard method for road emissions because you might have observed that the industrial roads are quite dusty and as the trucks carrying the raw material and end products move on the road in the industry, they cause significant emission. These are the methods to estimate the emissions from the road dust.

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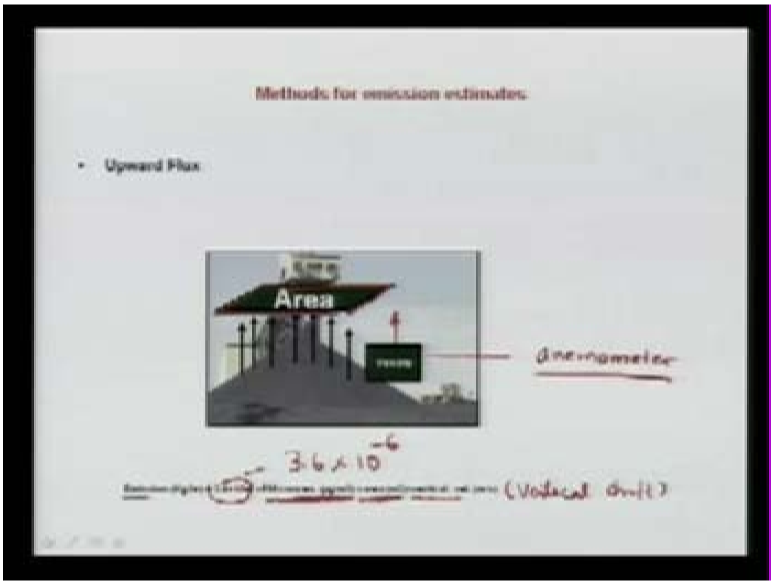

Methods for emission estimates

- Upward Flux

As I said, I will explain you the upward flux method. The method is very simple actually. You have to take the area into consideration, the area you see here. I can draw this – this is the area. Then, somehow on top of this if you can measure the upward velocity through a small handheld anemometer (you can measure the velocity using an anemometer) and all the other stuff, you can find out what is the velocity of the air – that is the vertical drift. Then, you simply multiply the area with the velocity of the up-drift and then you can find out the emissions that are occurring. A little example here. You have to measure the particulate concentration here, you see here PM concentration – the units may be microgram per meter cube.

Then, you need to know the area that is under consideration [03:33] by the area and then finally, you also multiply by the velocity – the upward velocity or the vertical drift. The velocity here is not horizontal wind speed – it is the vertical drift, if I can use the term vertical drift here. Then, there are the unit conversions that are required here. You should read this as 3.6 into 10 to the power of —6 actually. This is really 3.6 into 10 to the power of —6 [04:10] unit conversion and then you can get the emission rate in kg per hours – simple method. Now, let us talk about the other method. Whenever you are discharging the pollutant from the top or you can find the area where the pollution is likely to rise, you can use this particular method – this is a frequently used method.

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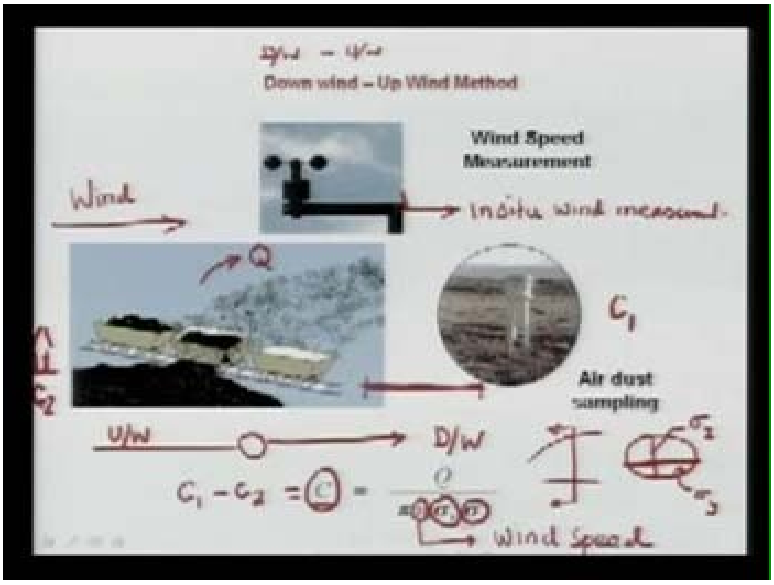

Down wind – Up Wind Method

Wind Speed Measurement

Air dust sampling

We also use the downwind–upwind method. What I have described in my earlier slide was downwind–upwind; maybe I used it this way – downwind and upwind method. What you see here is that emissions are occurring – they are not quite vertical but they are horizontal emissions. Suppose the wind is blowing like this and you are doing the measurements of the dust, this side is your downwind and this side is your upwind.

What you see is the emission is impacting this side and so you can measure the concentration here. Let us call this concentration as $C_1$. You can also measure the concentration on the upwind side. You can put a device here to measure the upwind concentration, let us call this as $C_2$. What you would see here is that the $C_1$ will be higher or is likely to be higher or should be higher actually. This $C_1$ is apart from the background this is the background and the impact caused because of the source. Here is the total impact – background plus this thing.

If I can define C as the concentration, it is the difference between $C_1$ and $C_2$. My $C_1$ and $C_2$ are measured and the difference in the concentration I will see that as the impact or the contribution caused by the source under consideration, which is a fugitive source. You can see here this C and this C is related to the emission. Q is the emission from here and I can say here Q is the emission rate – mass per unit time. C is the measure, u is nothing but wind speed and you measure that on the field. Here, this is the wind speed measurement in situ – it is important that you do in situ wind measurement (it is important that you do in situ) and so the wind speed is known.

Then, sigma$_y$ and sigma$_z$ are the dispersion parameters that you can get from the literature as the function of distance. Depending on the distance that you have measured, sigma$_y$ and sigma$_z$ are the dispersion parameters. I can show you here that you have emissions that look like this and if I take the section and look through the emissions here, I will see that the plume will look like this. The dispersion on this side, the measurement of the dispersion on this side we call as sigma$_y$ and this we call as sigma$_z$.

These things will become more clear when you learn more about the dispersion modeling, but dispersion modeling is a simple thing you can apply – sigma$_y$ and sigma$_z$ you can get from the literature and what is really unknown is the Q. Now, this exercise is to find out the emission Q caused because of the transport or disposal – I will not call it disposal but handling the raw material, the emission is Q. Let us circle the things we know.

We know C because we have measured that on the field, pi is known, sigma$_y$ is known, the u is known, the sigma$_y$ is from the literature, sigma$_z$ is from the literature and what is really left unknown is the Q. One can assume [09:16]. It is a simple technique but useful technique to find out the total emission that is caused because of the handling of the raw material or the tippling. This is called wagon tippler [09:29] when the coal dust is being tippled and there are emissions, one can very easily find these emissions.

Very quickly, what you have is the source here, you do the measurements in the downwind, you do the measurements in the upwind, wind is blowing like this, measure some meteorological parameters in situ – that is what we have seen here, and C$_1$ minus C$_2$ is the impact of the emissions from this source. That is related to the total emission rate from the source divided by pi u sigma$_y$ sigma$_z$, u is the wind speed you are measuring, sigma$_y$ and sigma$_z$ are the dispersion of the pollutant plume in y and z direction, which are function of the distance – do not forget that, you can find out what will be the Q and then Q can be estimated. Let us go further and see how one can estimate the road dust.

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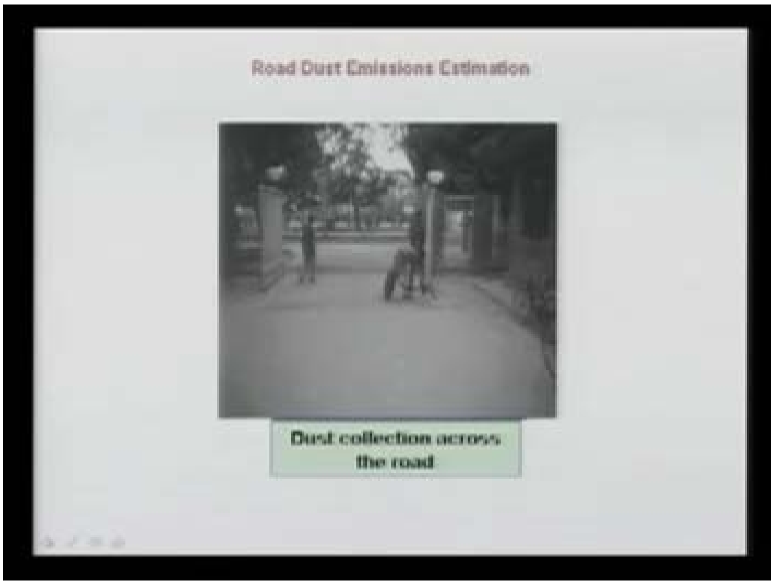
Road Dust Emissions Estimation

Dust collection across the road

The picture you see here shows how one can estimate the emission that will be caused because of the movement of the vehicles on the road. This can measure sources both in the urban area as well as in the industrial area because a lot of trucks are moving.

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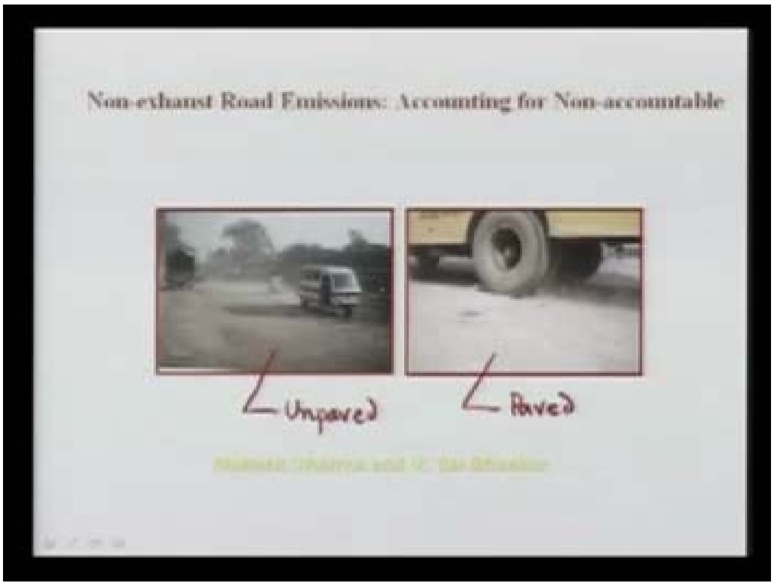
Non-exhaust Road Emissions: Accounting for Non-accountable

[illegible]

You see here we want to find out the non-exhaust road emissions. This situation we typically we find a lot in our Indian conditions. You see here that there is a little tempo that is going on the unpaved road or partially paved road and this is the paved road but heavy traffic is there. As a result, we want to estimate the emissions from this.

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Fugitive Road Dust Emissions

[illegible]

- CARB (2002)

The fugitive road dust emissions are important as you can see here.

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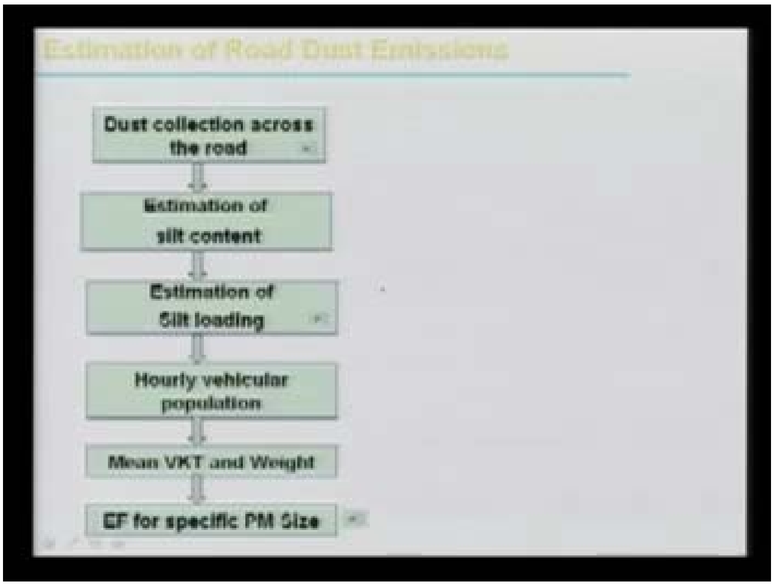

Estimation of Road Dust Emissions

Dust collection across the road

Estimation of silt content

Estimation of Silt loading

Hourly vehicular population

Mean VKT and Weight

EF for specific PM Size

How is this done? First of all, what you do is that you do the dust collection across the road. How is the dust collection done?

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In the picture shown, what you see here is that this is the road, you take some strip of the road and what you are really interested in is cleaning this road. Then, you see here this is the vacuum cleaner and there is a little bag here – not so little and in the bag, the dust that you have sucked through is collected because there is a filter here – there is a bag and there is a filter here. Then what you can do is you collect the dust on a particular area – do not forget that we are referring to a particular, specific area as you see the checkered thing here, that is what people are doing in every picture; I think this picture is from Bangkok, I am not sure, but you see a clean road and a dirty road and what you need to do is collect the dust particles from here.

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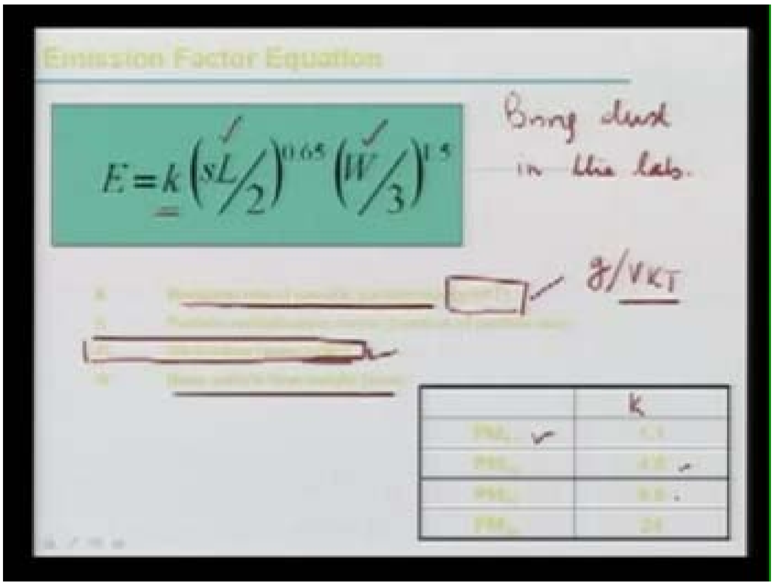

Emission Factor Equation

$$E = \underline{k}\left(\overset{\checkmark}{sL}/2\right)^{0.65}\left(\overset{\checkmark}{W}/3\right)^{1.5}$$

Bring dust in the lab.

g/VKT

| | k |
|---|---|
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | 24 |

Then, you need to bring the collected dust to the lab and do some measurements there. What you need to find out is the silt load. Before we start explaining some more terminology, you need to know the silt load – you sieve the dust that you have collected. The best way is once you have brought the dust, put down a newspaper and empty your bag onto the newspaper, take some part of the dust, weigh the entire dust and then find out the silt content in the dust you have collected. This is done through sieving.

You can pass through a particular sieve, I think it is [13:52] that you pass the sieve and then you see how much was the content of silt that was there. Then units. Do not forget we have done the measurement on a certain area. You see here the units grams are per meter square. The units are grams per meter square. The silt load is known to you and W is the mean vehicle fleet weight. You have seen how many trucks are going, how many scooters are going and how many cars are going. You can find out the mean fleet weight that is passing from the area that is under consideration. So this is again known.

You see here k. k is the factor that decides…. You do not see k here. This is the value of k here. k decides what emission you want to find out for. If you want to find out for $PM_{2.5}$, k is 1.1. If you want to find out for $PM_{10}$, the factor is 4.5. If you want to find for really large particles, then the factor is 24. Be very careful with the units that we have here. E is the emission rate of specific particle size. Why specific particle size? It is because k is dependent on specific particle size. Whatever be the value of k that you want to use…. You want to find out how are the fine particles, that is $PM_{2.5}$, then use the value of k as 1.1.

Eventually, what you can do is that you can estimate E and the units will be gram per vehicle kilometer travelled. Let us be very clear about this – the measurement units are gram per vehicle kilometer travelled. This is an empirical formula and so you have to be very careful with the units. You have to have the specific unit as defined here. You cannot change your units on your own. You of course know the distance travelled by the various vehicles and you can find out the total emission in terms of grams of dust specific to particle size.

Again, these techniques can be used and they are all there in the literature. In fact, you can search through and you can find out as to how this can be done.

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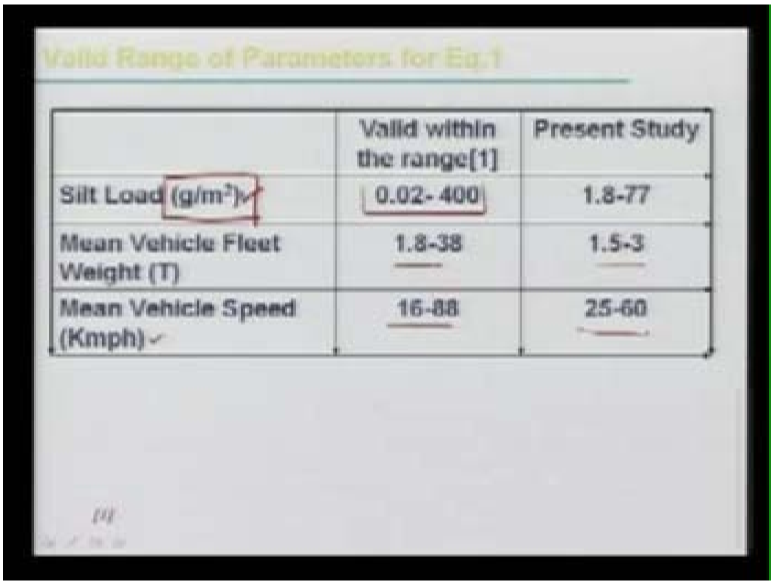

Valid Range of Parameters for Eq.1

| | Valid within the range[1] | Present Study |
|---|---|---|
| Silt Load $(g/m^2)$ | 0.02- 400 | 1.8-77 |
| Mean Vehicle Fleet Weight (T) | 1.8-38 | 1.5-3 |
| Mean Vehicle Speed (Kmph) | 16-88 | 25-60 |

[1]

What is the range for the equation 1 to be valid? We just discussed that – silt load should be in this range. What will be the units for the silt load? Grams per meter square. We must be very clear about this. Units are fixed, we have no liberty and we have no freedom to change the units here. The study [16:35] that was done… In the area where the study was done, we found that the silt load ranged between 1.8 and 77. That was well within the…. What you see here is that the mean vehicle fleet weight can be somewhere between 1.8 and 38 tons; in this study, it was like this. The mean vehicle speed is in kilometers per hour. It should be between 16 and 88; in this study, it was 25 to 60.

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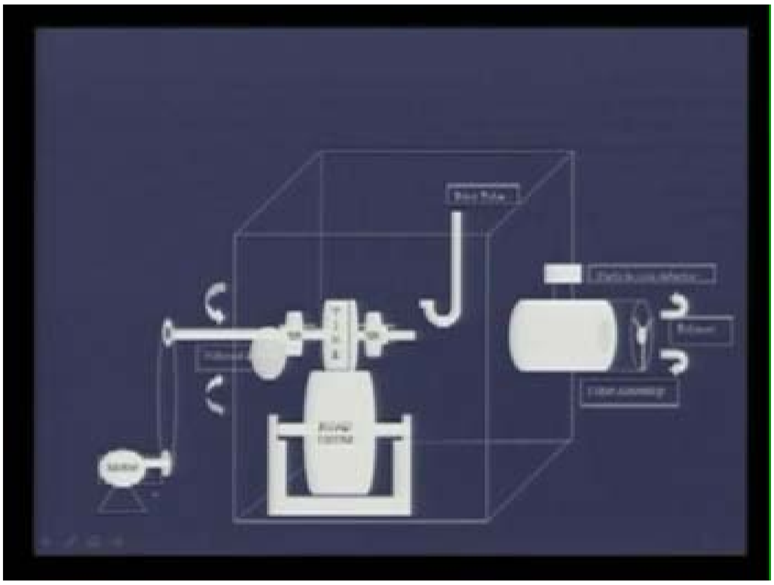

We could use this equation and we could really estimate the emissions but sometimes, we also need to do some research in terms of really doing the relationship between the road and the tire. This is particularly not applicable for equation 1, then we have to run this kind of test. What you see here is that there is a road [17:30], there is a tire, a weight that is put on this and there is a Pitot tube to see the velocity inside. You do the measurements inside this and you would say what will be the emissions that you can measure here depending on the weight and the kind of vehicles that you have that is determined by the weight.

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This study was done and you see here the road drum. Then, the tire was put on this and the emissions that occurred…. This is the road actually – I say bitumen road. Just take this as bitumen road. Experiments are done to see how much will be the emissions from here.

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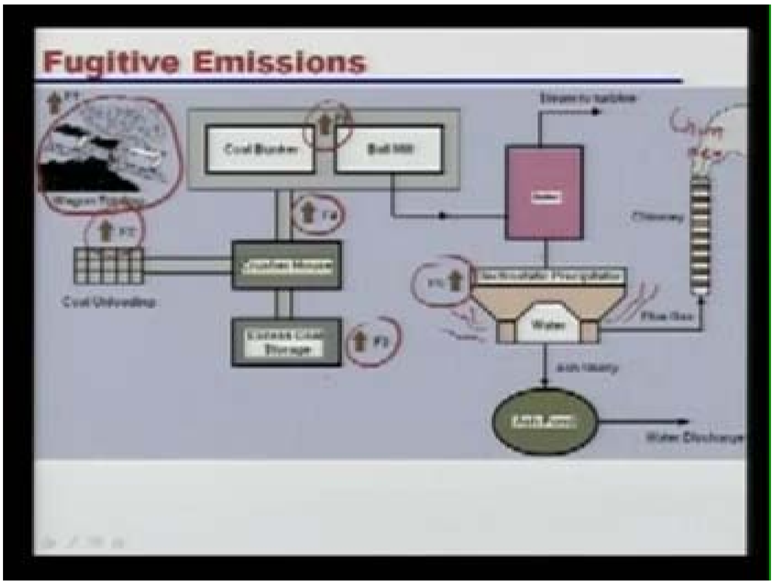

Fugitive Emissions

Let us quickly summarize especially for the PowerPoint what are the emissions that can occur – the emissions are largely of the fugitive nature. We have seen what happens through the chimney but let us quickly look at fugitive emissions. Let us go to the screen and see what are the emissions. As a result, we are trying to summarize. In the wagon tipplers, the coal is brought down and there is a lot of dust emission. That is what is called F1. That is the wagon tippler.

Here is a little mesh. They will crush the coal – very primary crushing. Then, this is coal unloading and storage. There is another emission that is taking place. Then you can also see that the excess coal is stored separately and that is another emission here. Then, here is the conveyor belt. From the conveyor belt, there will always be emissions, leakages – those are there. Things are stored in the coal bunker and taken to the ball mill. With the ball mill operations, a lot of dust is emitted and so that is another source. Finally, it goes to the boiler, which we have seen. Here the control which is the particulate control… As it is being transferred here to the water, there will be leakages. You call that source as F6.

You see here that apart from the regular source or the source from the chimney, stack is here. You see that apart from the chimney (which you observe very closely), the emissions that are fugitive in nature are occurring all over the plant. we put a lot of efforts, energy and money to control emissions from the chimney. We should do that but at the same time, we should not forget that there are other sources. We should be sensitive not only to the emissions that are occurring from the chimney but we should also be sensitive to emissions that are fugitive in nature, which are from the handling of the raw material, handling of waste product, handling of the product and transporting them, transferring them, storing them and so on. In fact, those emissions can become very large.

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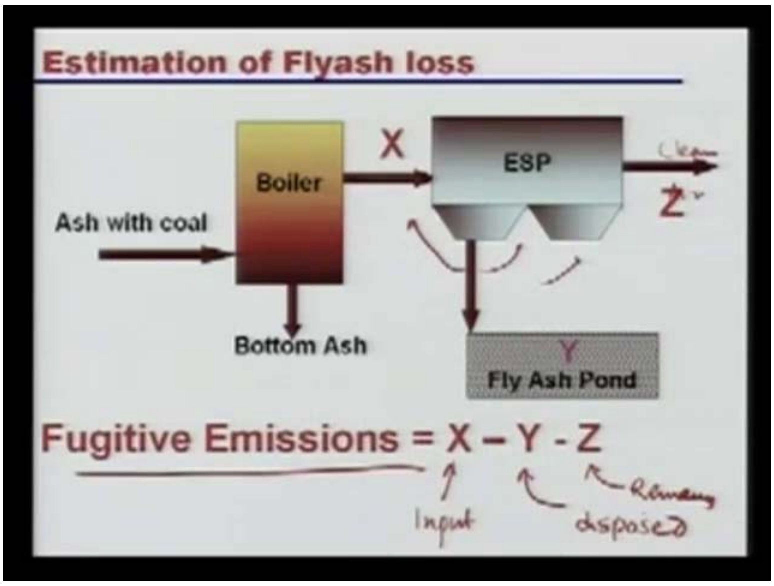

**Estimation of Flyash loss**

**Fugitive Emissions = X – Y - Z**

What is being shown here is the estimation of fly ash losses. You see here we are removing the particles from the ESP (electrostatic precipitator). So this will be clean air and the particles from the ESP go to the fly ash pond. But as they go to the fly ash pond, there are emissions that occur – I have shown this on the last slide also. Fugitive emissions can be…. X was the total thing that was going on, Y has gone to the ash pond, Z is going to the chimney but the remaining portion…. X was the total in, X is the input, Z is remaining, Y is disposed and whatever is the difference between the input and disposed will be the emission that is occurring from the bottom of the ESP. ESP is the again a device to control the particulate matter. This is how one can estimate the fugitive emissions. Let me tell you that you can do fugitive emissions not only for the power plants but you can also say what are the emissions likely to occur from let us say a desert, because that is also a source of pollution.

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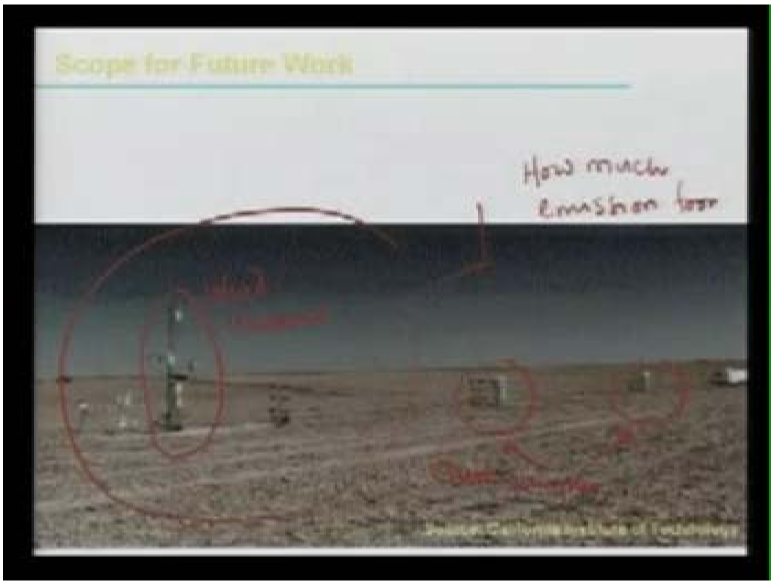

Scope for Future Work

Source: California Institute of Technology

The setup you see here is a study done by the California institute of technology. What they have done is that they have put many samplers here. You can see the sampler here, you can see the sampler here, you can see the wind measurements, let us say wind measurement and here is the dust sampler. Then on this side also, you can measure the dust and you apply the models or different kind of models and you can find out what is the contribution from the entire region, how much would be the emissions from the desert. You can do the estimation to find out how much is the emission from the desert or any process for that matter that is more like fugitive emission rather than emission through the chimney. What we have learnt so far is that we can actually find out the emissions from fugitive sources.

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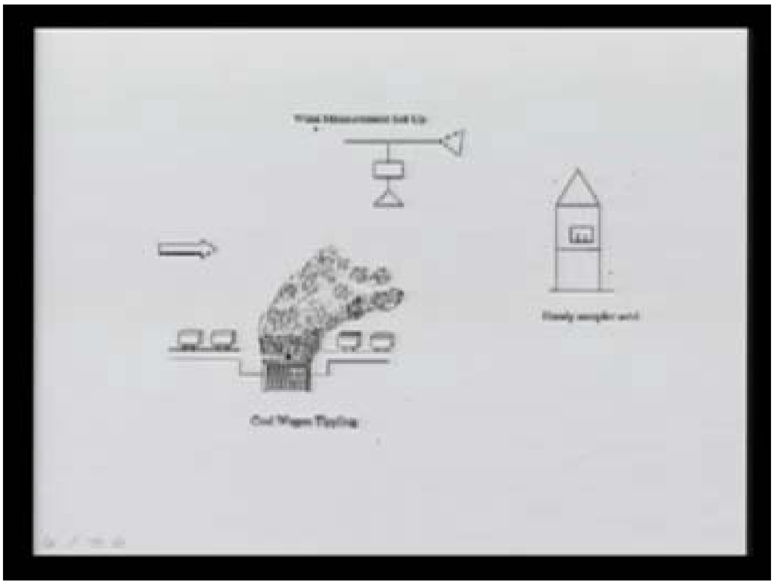

There is one more example you see here. This was a little measurement that was done.…

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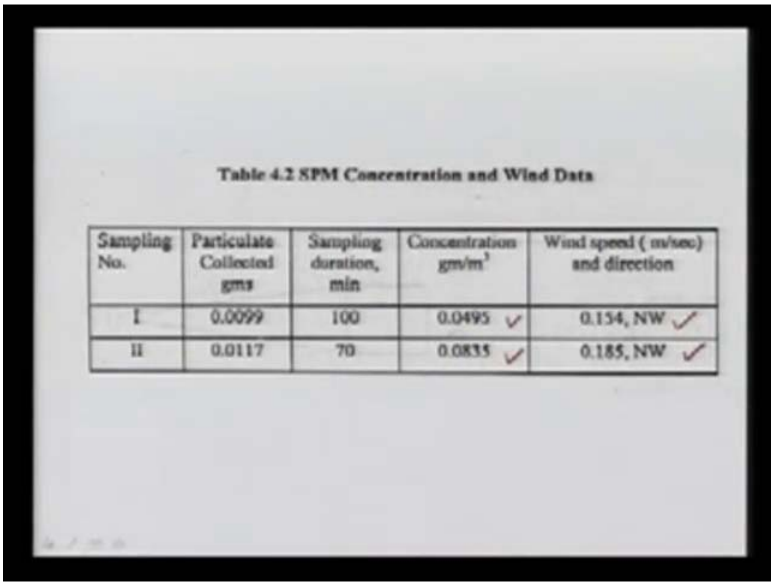

**Table 4.2 SPM Concentration and Wind Data**

| Sampling No. | Particulate Collected gms | Sampling duration, min | Concentration $gm/m^3$ | Wind speed ( m/sec) and direction |
|---|---|---|---|---|
| I | 0.0099 | 100 | 0.0495 ✓ | 0.154, NW ✓ |
| II | 0.0117 | 70 | 0.0835 ✓ | 0.185, NW ✓ |

As I said, wind speed and wind directions need to be measured. The concentrations are measured at the various sampling locations.

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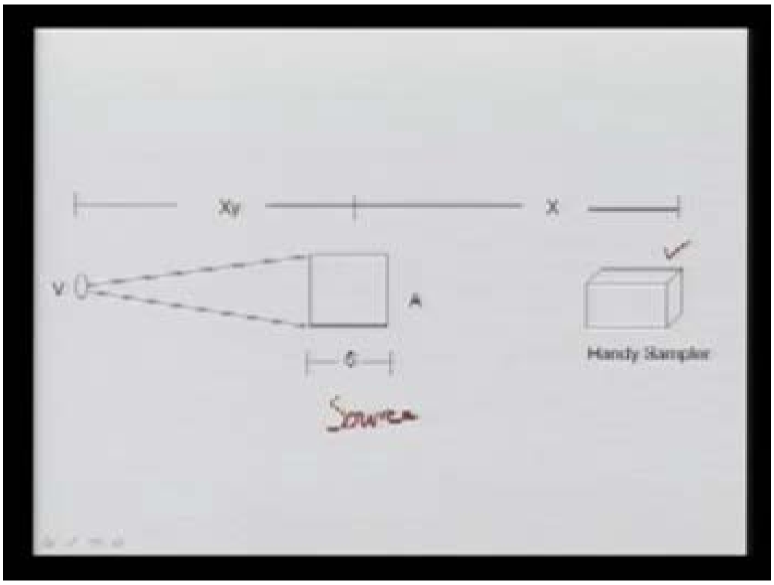

Again, this is a sampler here and this is the source. It is a repetition of what I have been saying.

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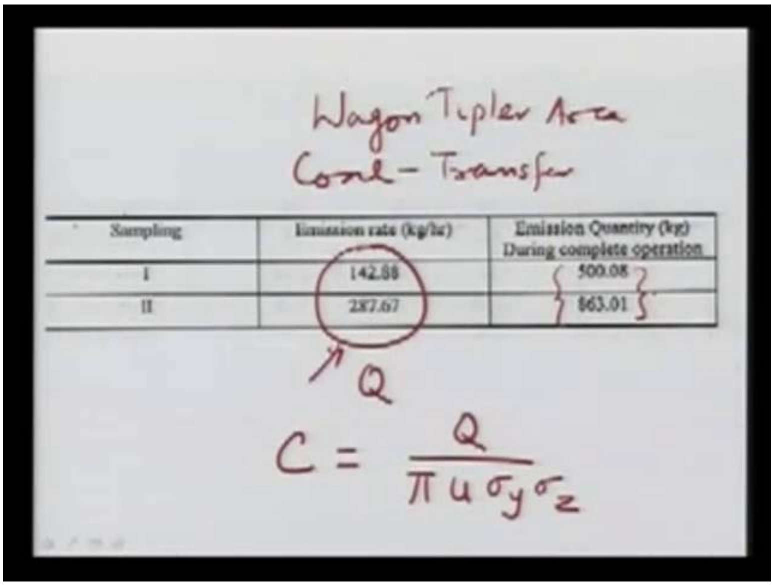
Wagon Tipler Area
Coal - Transfer

| Sampling | Emission rate (kg/hr) | Emission Quantity (kg) During complete operation |
|---|---|---|
| I | 142.88 | 500.08 |
| II | 287.67 | 863.01 |

Q

$$C = \frac{Q}{\pi u \sigma_y \sigma_z}$$

You can finally find out Q. You remember we are trying to find out Q. How are we trying to find out C? C was known to us from the measurements. This was equal to Q by pi u sigma$_y$ sigma$_z$. This is a real number that was done actually on one of the power plants. You can see the emission from the wagon tippler area. Let me say that to make it clear. Coal transfer. You have not only learnt the technique but you have also seen that it can really be applied on the field and measurements can be done. Depending on the number of hours of the operation….. Suppose the wagons are being transported and the whole operation went on for let us say 8 hours, then you can find out what will be the total emission that is occurring from the unloading operation. Let us also remember that these not only cause the air pollution but this is sheer wastage of the product as well and sheer wastage of the raw material because coal is the raw material in the process.

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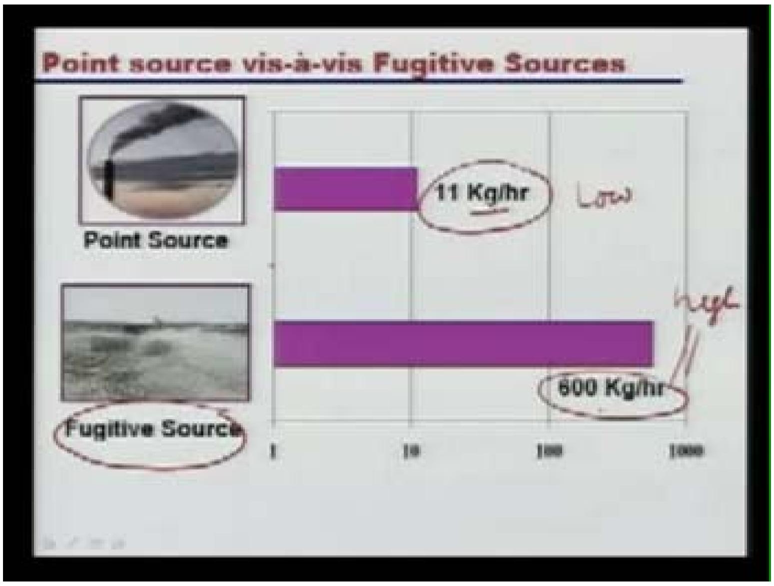

Point source vis-à-vis Fugitive Sources

The interpretation was a very important part. A person always gets a little feeling as to which is important when you start showing things in a relative sense. Sometimes, people do not understand absolute numbers. This is an example for a study that was done. You see here the regular source from the chimney. These are very highly controlled. A lot of money is spent – ESPs, bag filters and so on. No one was there to take care of the fugitive sources. You see here the fugitive source was very high. This is low. You see here that we spend a lot of money but we have to at least be serious. The major problem is here, we have controlled this. Fine, very good, but we also need to control this.

This is why we would like to end this lecture by saying that the fugitive emissions are important, they need to be controlled, serious cognizance needs to be taken, we need to quantify them and see if they are important. If they are important, we need to control them. We do not need to control only thing things which are going out from the chimney but we need to control emissions that are fugitive or the non-point emissions because they can be very large sometimes and they also impact immediately because they are all at the breathing level.

We will talk about the air pollution from the sulfuric acid product. This is an important chemical industry. Sulfuric acid is used in many processes – it is a raw material for many processes. Therefore, all over the country, we find that sulfuric acid plants are there in all states. You will find sulfuric acid plants in the best of industrial areas. So we will go through the process of sulfuric acid. We will see what are the sources, what are the operational parameters that govern the emissions from sulfuric acid plants. Now what we will do is we will talk about the air pollution emissions from sulfuric acid plants. Sulfuric acid is a very important chemical industry.

In fact, sulfuric acid is used in many processes that produce different chemicals. Sulfuric acid production is not a very complicated industry. We will find that the sulfuric acid industry is distributed all over the country. Almost all our states have a sulfuric acid plant. In fact, there are many plants in industrial areas. You will find a sulfuric acid plant even in some of the metallurgical processes like copper smelting and zinc smelting. Sulfuric acid is produced as a raw material from sulfur but it can also be produced from metallurgical industries.

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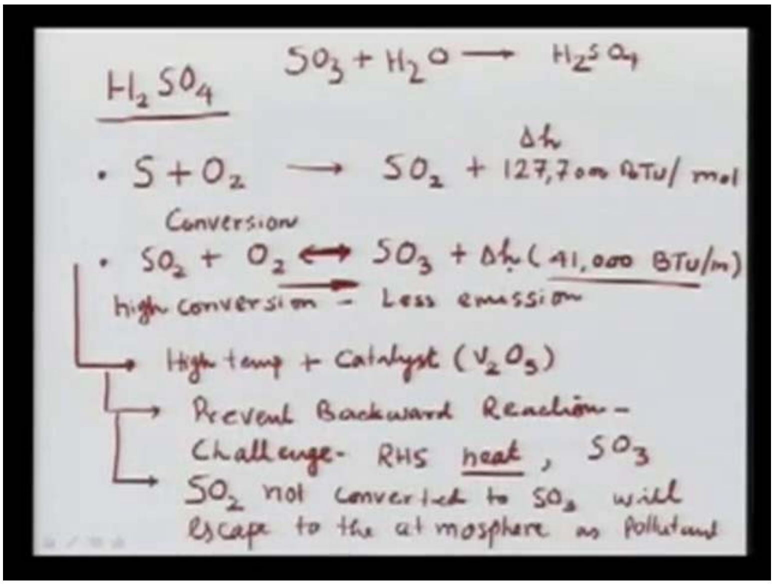


$H_2SO_4$ $SO_3 + H_2O \longrightarrow H_2SO_4$

- $S + O_2 \longrightarrow SO_2 + \overset{\Delta h}{127{,}700}$ BTU/mol

Conversion

- $SO_2 + O_2 \longleftrightarrow SO_3 + \Delta h$ (41,000 BTU/m)

high conversion – Less emission

→ High temp + Catalyst ($V_2O_5$)

→ Prevent Backward Reaction –

Challenge- RHS heat, $SO_3$

→ $SO_2$ not converted to $SO_3$ will escape to the atmosphere as Pollutant

What we will do now is that we will talk about the air pollution aspects of a sulfuric acid plant. Let us write $H_2SO_4$. The quick process…. Of course, we will go into the details of the process because in this industry, the emissions are almost fully dependent on how the plant is operated. The basic principle of $H_2SO_4$ production is that the sulfur is burnt to produce sulfur dioxide and you are getting $SO_2$ plus you get a lot of heat and the amount of heat is 1,277,000 BTU per mol.

This is a significant amount of energy that you get from here. This is the heat and let us call this as delta h. The next step is that this $SO_2$ that we produce must be converted into $SO_3$ and this also produces heat. Again, let us call that as delta h. It is a little less – the amount is around 41,000 BTU per mol. The interesting part or the heart of the entire sulfuric acid production is this equation. Why we call it the important equation is because this equation is reversible. $SO_2$ can go on to form $SO_3$ and $SO_3$ can also break down back to sulfur dioxide. This step is what you call as the conversion step. So let us write this as the conversion step.

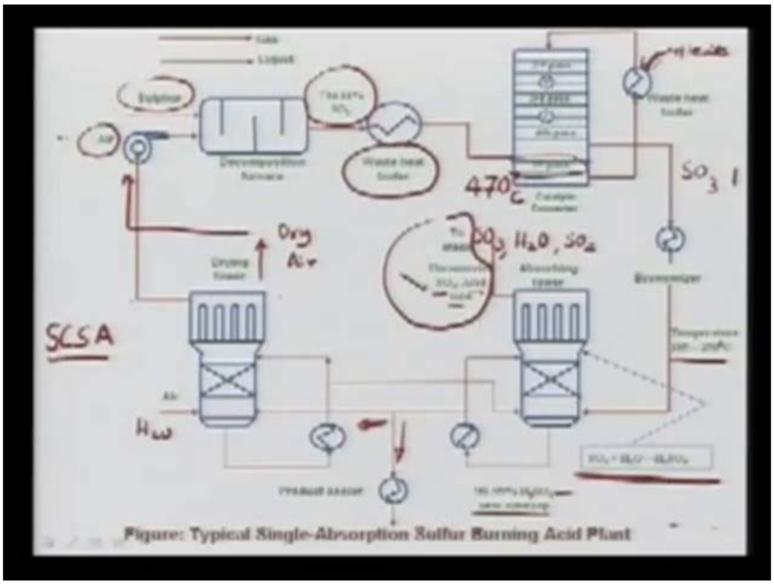
The simple rule is high conversion, less emissions. If I can say it in different words, if you are successful to make this reaction go forward, that is where the success lies from the air pollution point of view as well as from the production point of view. But the problem is that in order for this reaction to go forward, in order for this to operate, in order to convert $SO_2$ into $SO_3$, we need high temperature (higher the temperature, the better the situation) and then, we also need a catalyst to make this reaction go forward. This catalyst is generally or normally vanadium pentoxide.

As you see, the problem is that we need temperature on this side, the left-hand side here but then we are getting a lot of temperature here. We should either consume the $SO_3$ quickly or if we are having a very high amount of heat, the reaction tends to go backwards. We can say that the issues here are we must somehow prevent backward reaction. It is not simple actually – it is a challenge. Why? It is because on the right-hand side, the heat is not removed. On the right-hand side, you have a lot of heat. Which heat am I referring to? I am referring to this heat (Refer Slide Time: 32:59). If this heat is not removed, there is a possibility that the equation can go backwards and if I am not removing the $SO_3$, then also there is a possibility that the reaction can go backward. Once it goes backward, the portion of the $SO_2$ that is not converted into $SO_3$ has no other way but to escape out as pollutants. So let us write that also –$SO_2$ not controlled or not converted to $SO_3$ will escape to the atmosphere as pollutant. The next step is once you have the $SO_3$, you simply dissolve the $SO_3$ and make it react with water to produce sulfuric acid. If I can quickly remove this thing now…. Let us write it here.

Now, we have got $SO_3$. This $SO_3$ is reacted with water. It is a very quick and instant reaction and we can then produce $H_2SO_4$. One more thing before we move to the next slide is this: do not forget that this needs to be balanced. This is 1 by 2. What we have understood is the conversion of sulfur to sulfur dioxide and sulfur dioxide to sulfur trioxide and the heat must be quickly removed. Otherwise, there is a fear of the possibility of $SO_3$ decomposing back to sulfur dioxide and if it does happen, $SO_2$ will be emitted as emission.

Ideally, we want the reaction of sulfur dioxide to oxygen to continue to go in the forward direction. We will see how this is done in the actual plant. I repeat that the $SO_2$ that is not converted into $SO_3$ will escape, there will be pollution and we want to prevent that. Let us go into the actual process flow sheet. W we are going to the actual treatment plant. Let us take a visit of the treatment plant, a sulfuric acid plant and see how this works.

(Refer Slide Time: 35:34)



What you see here is sulfur and air. It is burnt. This is the sulfur and the air is burnt in the boiler in the combustion process and it produces sulfur dioxide. The percentage of sulfur dioxide is an important term here. It is about 7 to 11 percent of the gases that come out from the furnace. The immediate point is that the heat is very high and we want to reduce the temperature. What we do is waste heat recovery because we want to bring down the strain to the temperature to a level that is more optimum for the conversion of $SO_2$ into $SO_3$ because the heart of the operation is conversion of $SO_2$ to $SO_3$. We take it further for the conversion from $SO_2$ to $SO_3$ but before that, we bring down the temperature by the waste heat boiler or heat recovery.

You will see that we almost bring down the temperature to around 470 degree Celsius. Then we are passing through the converter. You see here this is a converter tower but the conversion is done in various phases. You can see the first phase, second phase, third phase and fourth phase. What is the idea of doing this in phases? The phases are very important because we have to make sure that the reaction is going on continuously in the forward direction. So we must continue to recover the heat. Else what will happen? If the heat is more, the reaction will go more towards the backward side, $SO_3$ will go back to $SO_2$ and we will not get $SO_3$.

Let us go now back to the flow sheet. You see here the first pass. $SO_2$ is passed into the first pass. First pass means it is immediately converted into $SO_3$. Once the conversion is done before it can go back to sulfur dioxide (you remember that it can go back to sulfur dioxide), we quickly recover the heat. Once the heat is recovered (from the right-hand side of the equation, if you recall), the $SO_3$ that is converted will not go back to $SO_2$ but there will still remain some $SO_2$. We will again recover the remaining $SO_2$ into various passes.

You pass it here in the second phase and in the second phase, the remaining $SO_2$ will convert into $SO_3$, it will again produce heat and that heat must be recovered. This sign that you see here is what we are referring to as heat recovery. We pass through the second stage of the conversion and again, more heat is developed because $SO_2$ gets converted into $SO_3$ and the heat is recaptured. Then, you go to the third step and again, the heat is recaptured. In the process, we are trying to convert $SO_2$ into $SO_3$ at various stages and in every stage when the heat is generated, we recaptured recapture the heat.

You see here that most of the $SO_2$ is converted into $SO_3$ over here. The temperatures could still be high and so we pass it through the columnizer and bring down the temperature to around 185 to 250 degree Celsius. Now is the time to pass this $SO_3$ to the absorbing tower and produce the sulfuric acid. How it happens is that you are passing the stream that is rich in $SO_3$ to make sulfuric acid. This is the reaction that you want to happen in here. How is this done?

You are not directly using the water but you are using sulfuric acid – about 98 to 99 percent sulfuric acid. What is so special about 98 percent/99 percent is that we are recycling this acid and we are using this acid to make the acid more and more concentrated. The point here is that this condition (98 to 99 percent $H_2SO_4$) is the near-isotrope situation. What is the isotrope situation? Isotrope situation is a situation when the partial pressure in the liquid for the various dissolved species is minimum. There are many things going here. You see the $SO_3$ is going, water is there (some water moisture can come) and there could be $SO_2$.

The partial pressure of these species is minimum. We will see what can possibly happen if this is not minimum. This is continuously recycled and whatever is not absorbed in the tower and what is not converted into sulfuric acid goes out as the emission. Those emissions are unconverted $SO_2$ as you can see here and some little acid mist can also go out into the atmosphere. Let me complete this picture. What else is happening here? As you are using this sulfuric acid, it is getting concentrated because dissolving more and more $SO_3$ and reacting and forming the sulfuric acid.

Once you are getting this required strength of the sulfuric acid, this is taken out. This can be taken out and one stream can go as the product. You see here this is the product and some portion of this is taken to the air-drying tower. We are using air in the process, but where is this air coming from? Air is coming after drying in the drying tower. We use the sulfuric acid for drying the…. This is the stream that is going. You recycle this sulfuric acid and keep on drying the air that you have. Here, you may have some moisture but what is going out is dry air. It is very important the dry air in the process. This is dry air.

This is the stream for dry air. Now, what you need to observe here is that conversion is important. We do the conversion – various steps to $SO_3$. $SO_3$ comes out and the strength of sulfuric acid is recycled, the sulfuric acid gains more strength, part of it goes as a product and part of this can go to the drying tower used to dry the air because this air may have moisture. If we had not removed the moisture, this moisture will also be present here. Once moisture is present, this moisture can escape from here and it can quickly react with $H_2O$ and form acid mist. That acid mist will also go out from the absorbing tower. As a result, you will not only get $SO_2$ that is unconverted but you will also get acid mist. So the problem here is quite complicated in the sense that we must operate every bit of the process properly and the attempt should be made as far as possible to ensure that there is no moisture is present in here. Otherwise, moisture will also escape and form acid mist.

Now the issue here is can you improve the process? This process that we have seen is…. Let us go to back. This process is called SCSA. What is SCSA? Single conversion single absorption because at a single time, we converted the sulfur dioxide into sulfur trioxide and there is single absorption here. That is called SCSA. Now you pay a little attention here. If the conversion is poor, if I could not convert $SO_2$ into $SO_3$, this is going to show up in the stack. You can read this here: to stack unconverted $SO_2$ and acid mist. If I have any further opportunity to convert this $SO_2$ into $SO_3$, I would think I have done a good job because I want to essentially control $SO_2$ and the best way to control $SO_2$ in the sulfuric acid plant is to convert this into $SO_3$. Let us see how we can convert this into $SO_3$. For this, a new method has been developed. Well, it is not new anymore but this is called the DCDA process.

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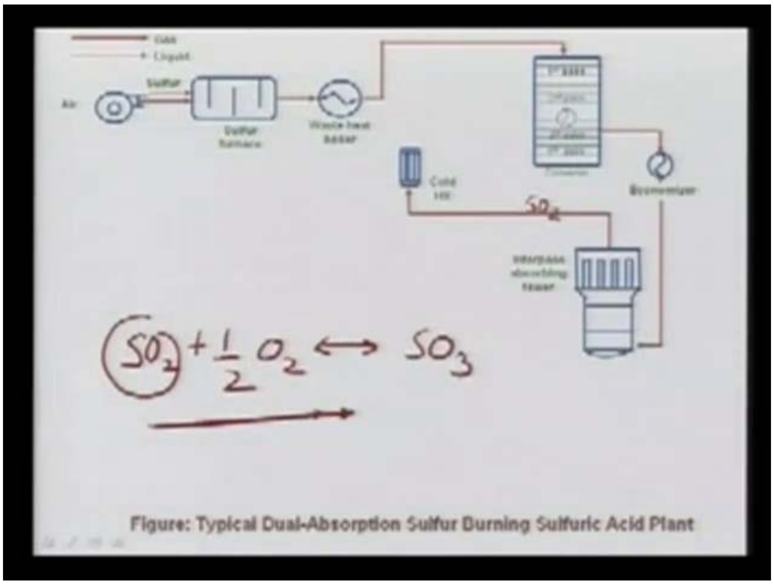

Figure: Typical Dual-Absorption Sulfur Burning Sulfuric Acid Plant

So far, we knew the process that you see on your screen. We have understood the first part and we have understood this part also (Refer Slide Time: 45:50). Now the question is the last time when I was doing SCSA, the emissions from the absorbing tower were put into the atmosphere but we are no more putting this into the atmosphere but we are converting the $SO_2$ that was left back into $SO_3$. This is the $SO_2$ that remained unconverted. In my earlier process, this was going to the atmosphere but what I am trying to do this time is to take this $SO_2$ and convert it again into $SO_3$ so that I am converting more and more of $SO_2$ into $SO_3$

and if I am able to convert more and more of $SO_2$ into $SO_3$, it means I am ensuring that $SO_2$ emissions are smaller and smaller. In other words, I can say the emission of sulfur dioxide that will occur from the sulfuric acid plant is essentially a function of non-conversion of $SO_2$ into $SO_3$.

Here I am taking this opportunity and I am taking back whatever was the remaining sulfur dioxide and trying to convert this. Remember that our reaction was $SO_2$ plus half $O_2$ and we get $SO_3$. In order for this reaction to go forward, if I am rich in sulfur dioxide, my reaction will tend to go forward. Here, I will again see my $SO_3$ is gone here. I am again back to rich in $SO_2$. If I am rich in $SO_2$, I can again move it forward and I can produce more of $SO_3$. That gives me the opportunity to again remaining $SO_2$, which is richer now because remember that $SO_3$ is taken up in the absorbing tower in the form of sulfuric acid. The remaining $SO_2$ …. This stream that is coming out is again rich in sulfur dioxide.

If it is rich in sulfur dioxide, I can make the reaction happen back in the forward direction and produce more $SO_3$. If I am producing more $SO_3$, it means I am decreasing the emission of $SO_2$.

(Refer Slide Time: 48:05)

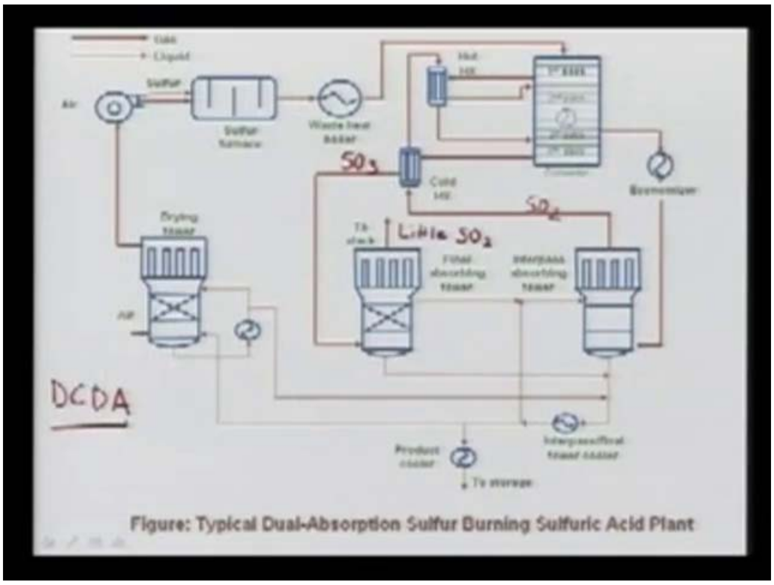

Figure: Typical Dual-Absorption Sulfur Burning Sulfuric Acid Plant

If that is clear, now let us try to convert this $SO_2$ here. The temperature here is a little low. So we bring it here and give this stream a little heat. What we are trying to do is we are taking a little heat from here and heating up this $SO_2$ here and then… or rather using this tower, which is not quite heating up but you will heat it up in the upper portion. Then you can see here that you will take the little stream out from there, make it hot and pass it for conversion. Now, you can see here this line that is going back to the converter.

The remaining $SO_2$ that was there will be converted into $SO_3$ and that would come out here. Then once it comes out here, we have to cool it. In order for this to be able to be absorbed again – the $SO_3$ into the absorbing tower, we need to bring down the temperature. Here, what you do is bring it down and you make it cold. This was the heating part (Refer Slide Time: 49:15), this was the converting part and again cooling, because now we want to take this out. What I am getting here Again is $SO_3$. I converted this $SO_2$ that had become in excess back into $SO_3$. What it needed was to heat it up, then convert it and then cool it because only the cool gases can go to the absorbing tower and bring it to the next absorbing tower.

In the next absorbing tower, what I show is that the $SO_3$ is now converted into the final absorbing tower. You will see here to stack is very high or I will use the word very little. Little $SO_2$, a good job done because I could convert the remaining $SO_2$ back to $SO_3$ and use that $SO_3$ in absorbing and making the sulfuric acid. So I enhanced the value in the system by converting more and more of $SO_2$ to $SO_3$ and once $SO_3$ is $SO_2$ is converted to $SO_3$, the emissions will reduce significantly. Let us complete the picture here.

That is similar to what we had done last time. What we are really doing is converting the $SO_2$ two times to $SO_3$. First conversion route and then whatever remaining is converted again and absorbed again. Then the little portion that has remained is sent back and so this process is called DCDA – double conversion double absorption, but the focus for us has been on how to reduce $SO_2$ emissions. Let us see what we have really achieved in terms of pollution control because the objective is to see the pollution control here.

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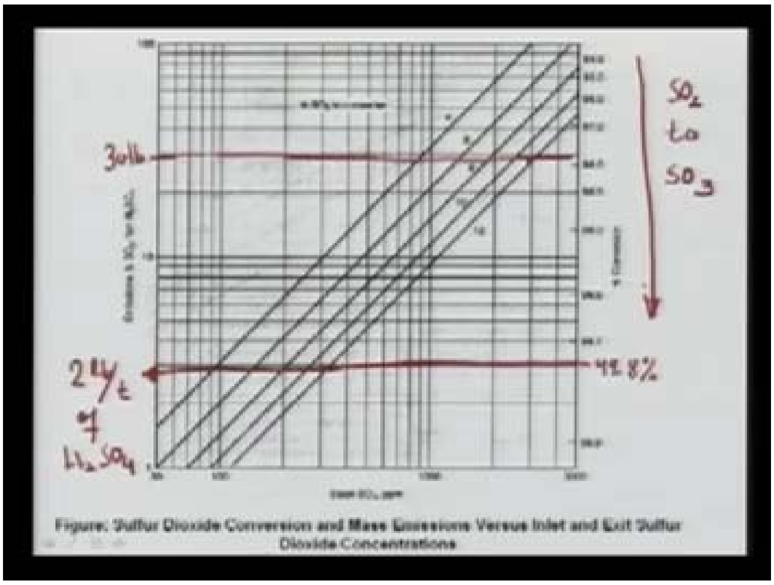

Figure: Sulfur Dioxide Conversion and Mass Emissions Versus Inlet and Exit Sulfur Dioxide Concentrations

This scale shows the conversion. We see here conversion more and more conversion is occurring in this direction. Conversion of what? Conversion of $SO_2$ to $SO_3$. You see here if I was operating at some percentage of $SO_2$ and if I am able to increase the conversion let us say that was… You can read that here as 98 percent conversion and suppose I could convert it to 99.8 percent, suppose this value is let us say 99.8 percent, when I did the double conversion, first conversion I was here (Refer Slide Time: 52:06) and second conversion I was here. If you see here after double conversion, the corresponding emission will be something like 2 pound per ton of $H_2SO_4$.

If I was operating only at the single conversion, let us say the emission would be something like maybe [52:38] 20 or 30 kg, 30 lb and this is 99.8. You can see the advantage of going into double conversion double absorption. This conversion is better and so all the time, we want to improve the conversion. If the conversion is improved, your emission will reduce significantly and that is how you operate the sulfuric acid plant.

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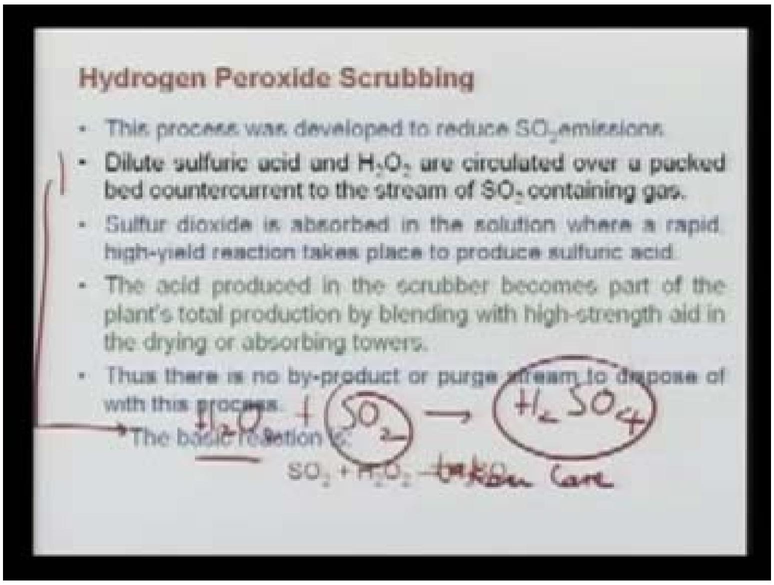

Hydrogen Peroxide Scrubbing

- This process was developed to reduce $SO_2$ emissions.
- Dilute sulfuric acid and $H_2O_2$ are circulated over a packed bed countercurrent to the stream of $SO_2$ containing gas.
- Sulfur dioxide is absorbed in the solution where a rapid high-yield reaction takes place to produce sulfuric acid.
- The acid produced in the scrubber becomes part of the plant's total production by blending with high-strength aid in the drying or absorbing towers.
- Thus there is no by-product or purge stream to dispose of with this process.
  - The basic reaction is:

$SO_2 + H_2O_2$

$H_2O_2 + SO_2 \rightarrow H_2SO_4$

taken care

There is also a technology to treat the sulfur dioxide that is emitted out from the absorbing tower because it might still have some sulfuric acid; sulfuric acid mist of course is there but apart from that, you can also have $SO_2$. So people have developed a technology but the fundamental remains that if we can convert the $SO_2$ into $SO_3$, the problem of $SO_2$ emission from the sulfuric acid plant is more or less handled. But if you still want a very very clean stack and you do not want any $SO_2$ emission to go out, you can use this technology.

It is developed by the oxidation of sulfur dioxide with $H_2O_2$. What you can see here is that this was developed to reduce the $SO_2$ emissions. Dilute sulfuric acid and $H_2O_2$ are circulated over a packed bed in the direction countercurrent to the stream of $SO_2$ containing gas. With regard to what is really happening here, maybe I can write the equation here. $H_2O_2$ plus $SO_2$ will give $H_2SO_4$. $H_2O_2$ is a strong oxidizing agent and this $SO_2$ will be taken care of. Sulfur dioxide is absorbed in the solution where a rapid high-yield reaction takes place to produce sulfuric acid – that is what the reaction is. The acid produced in the scrubber becomes part of the plant's total production. So this is again part of the production (Refer Slide Time: 54:39) – let us not forget that sulfuric acid is a product and it is not that we want to throw out the sulfuric acid.

This technology has been developed, but I would rather say that the success of pollution control or let me say success in prevention of emission in the sulfuric acid plant is related to how smartly you can convert $SO_2$ into $SO_3$. The next thing is… I have shown you the basic reaction.

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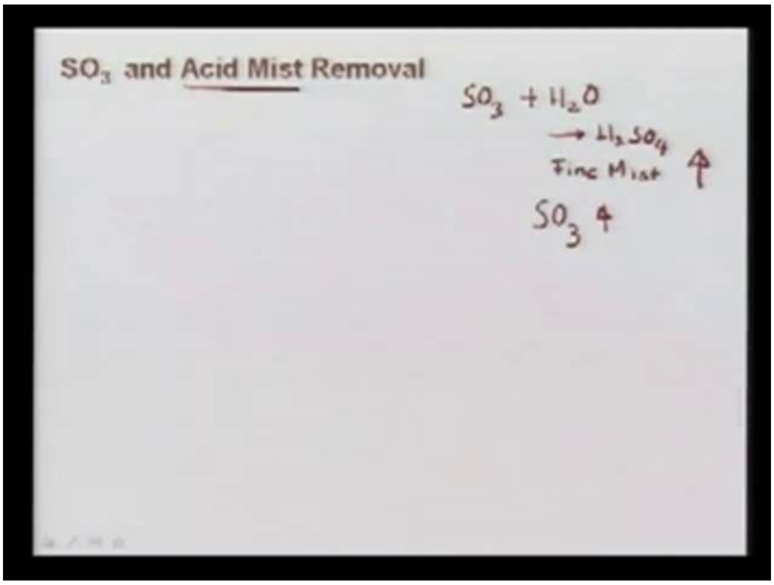

**$SO_3$ and Acid Mist Removal**

$SO_3 + H_2O$

$\rightarrow H_2SO_4$

Fine Mist $\uparrow$

$SO_3 \uparrow$

Apart from $SO_2$, some of the acid mist as you see here will be emitted. Why is acid mist emitted? It is for two reasons. Suppose the partial pressure of $SO_3$ becomes higher in the absorbing tower (I am talking about the partial pressure) and suppose you also have some moisture in the absorbing tower, it can produce $H_2SO_4$ but this will be like a fine mist. You cannot control that and you cannot stop that fine mist – that will be emitted into the atmosphere. Sometimes, the partial pressure of $SO_3$ becomes higher even if there is no moisture – $SO_3$ can go out as it is to the stack. How do we control the mist or the acid mist that has been formed?

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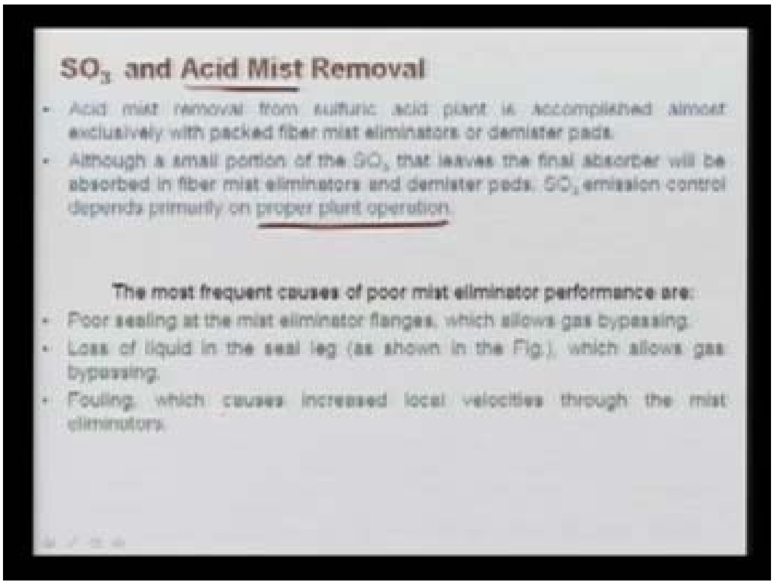

## $SO_3$ and Acid Mist Removal

- Acid mist removal from sulfuric acid plant is accomplished almost exclusively with packed fiber mist eliminators or demister pads.
- Although a small portion of the $SO_3$ that leaves the final absorber will be absorbed in fiber mist eliminators and demister pads, $SO_3$ emission control depends primarily on proper plant operation.

**The most frequent causes of poor mist eliminator performance are:**

- Poor sealing at the mist eliminator flanges, which allows gas bypassing.
- Loss of liquid in the seal leg (as shown in the Fig.), which allows gas bypassing.
- Fouling, which causes increased local velocities through the mist eliminators.

Here, we are talking about the removal of acid mist. Acid mist removal from sulfuric acid plant is accomplished almost exclusively with packed fiber mist eliminators or demister pads. What are these really? Although a small portion of the $SO_3$ that leaves the final absorber will be absorbed in fiber mist eliminators and demister pads, $SO_3$ emission control depends primarily on proper plant operation. We need to underline this (Refer Slide Time: 56:43). What is the technology to remove the mist? We will see this here. Poor sealing at the mist eliminator flanges can lead to this.

(Refer Slide Time: 57:00)

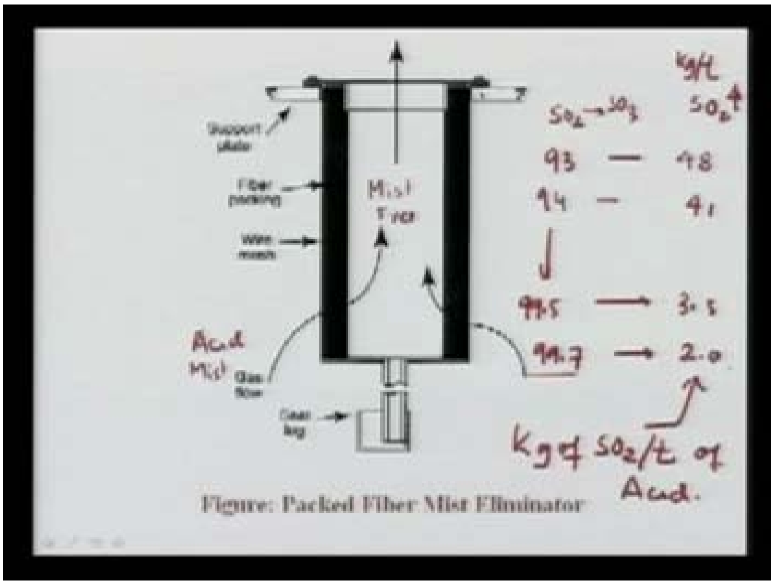

Figure: Packed Fiber Mist Eliminator

But I really want to show you is this process here. What you see here is.… This is the gas flow, this is the wire mesh and inside the wire mesh, this is the fiber packing and then you pass the gas, which is rich in acid mist. Then you have this fibrous pad here and then the mist passes through this. The mist is in the form of fine particles and it will be trapped all over the place and mist-free air will go out. These pads can be changed. In fact, I can explain to you something very simple. We see desert coolers. We have desert coolers in our houses. There is a pad here, water is falling on this, [57:59] is filled (some fiber material is filled), acid mist goes through this and gets stopped here. We can simply change this the way we sometimes change the desert cooler packages. The mist that is collected here is also retrieved.

Very quickly, it might be a good idea to give you a little feel about the $SO_2$ emissions and the conversions. Suppose the conversion is let us say $SO_2$ to $SO_3$ and here are the $SO_2$ emissions. Let me put a little arrow up there. If only 93 percent conversion is there, emission is around 48 and this quantity is in terms of kg of $SO_2$ per ton of acid. Suppose you are converting let us say 94, then the emission could be around 41 and if you keep on improving your efficiency and suppose you are producing 99.5, the emission of sulfur dioxide is reduced so much that it can become 3.5.

If you further improve the efficiency of conversion of $SO_2$ to $SO_3$ let us say to 99.7, this can even become around 2.0. Again, do not forget the unit that I am referring here is kg of $SO_2$ per ton of acid. Well in summary as I have been saying again and again, the conversion of $SO_2$ to $SO_3$ is the key process and if we can handle that, then the $SO_2$ emissions will significantly reduce. Again, I repeat: very high conversion, the emission is very very small. Similarly, the acid mist emission will again depend on how smartly you are operating your absorbing tower. This covers the emission aspects of sulfur dioxide, acid mist and $SO_3$ from the sulfuric acid plant. The acid mist that is formed can still be removed from the acid mist eliminators. I think we will stop here because this shows us the details of sulfuric acid plant.