Environmental Air Pollution

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Types and forms of Air Pollutants

Lecture 4

We have a serious air pollution problem and people ask: what can we do about it? Some suggestions come; some very funny suggestions actually come. In New Delhi, people write to the authorities that certain areas are very highly polluted and certain areas are clean. There is a small area called Anandh Parvath. On one side of the Anandh Parvath, you see, there were highly polluting industries; on the other side it was clean. They said to in order to clean that area, one side of Anandh Parvadh was like a little hill, what if we put huge fans and what we can do is this: the entire ventilation and cleaning of the air and the clean air can push the dirty air and then the whole place can be clean. These are general people, you know, they can they can come up with some idea.

In fact, the fundamental thing is to not drop any idea just on the face of it. This is a basic philosophy of the life. Do the calculation, do the analysis, think about it, comprehensively analyse that and then reject it. Even if something that on the face of it you know - how this can happen? Even if you know, it is just a matter of trying it and then rejecting it, rather than just rejecting on the face of it.

Of course, I will give you some examples. You know like if this is done, if that can be done because the ideas started because in the water treatment site, on the waste product treatment site, I do not know if you know about a concept called CETPs - Common Effluent Treatment Plants - where there were a cluster of industries, they decide to collect all the waste, either pumping the waste or through the gravity bring it at the central place and then treat it. Those are called CETPs. The concept was something very similar, that some kind of CETP - can it work out? For example: there are two power plants very close to Delhi; one suggestion was, the ducts coming out with dust, can they be joined and put through one system? Of course the distance between two power plants was about 4 kilometres or so. You all know, that in water something can be done; we can make use of the gravity, but in air we cannot make use of the gravity. We have to pump and of course leaving beside the ducting part and the pipes that you put, the cost of pumping is really huge. We will get on to something else. We have some slides here.

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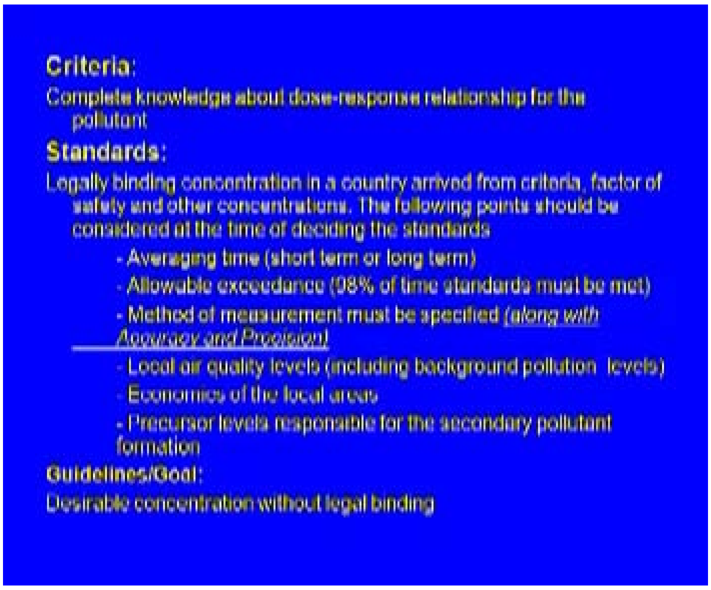

Criteria:

Complete knowledge about dose-response relationship for the pollutant

Standards:

Legally binding concentration in a country arrived from criteria, factor of safety and other concentrations. The following points should be considered at the time of deciding the standards

- Averaging time (short term or long term)
- Allowable exceedance (98% of time standards must be met)
- Method of measurement must be specified *(along with Accuracy and Precision)*
- Local air quality levels (including background pollution levels)
- Economics of the local areas
- Precursor levels responsible for the secondary pollutant formation

Guidelines/Goal:

Desirable concentration without legal binding

We will slightly revise a few things that we did last time and then get into something more. If you recall, we had tried to explain to you - what a criteria is and what a standard is. Criteria are the knowledge, very important, based on that knowledge standards are fixed and a standard should have certain strings attached with those. Otherwise, the standard is not complete because of the legal terms; if you do not want to put a legal sense to a number, then you put the guidelines and goals which is a desirable concentration. That is what we did last time. If you recall, I also gave you and I will be sending you these slides (please remind me if do not send them) on how the Indian standards look like.

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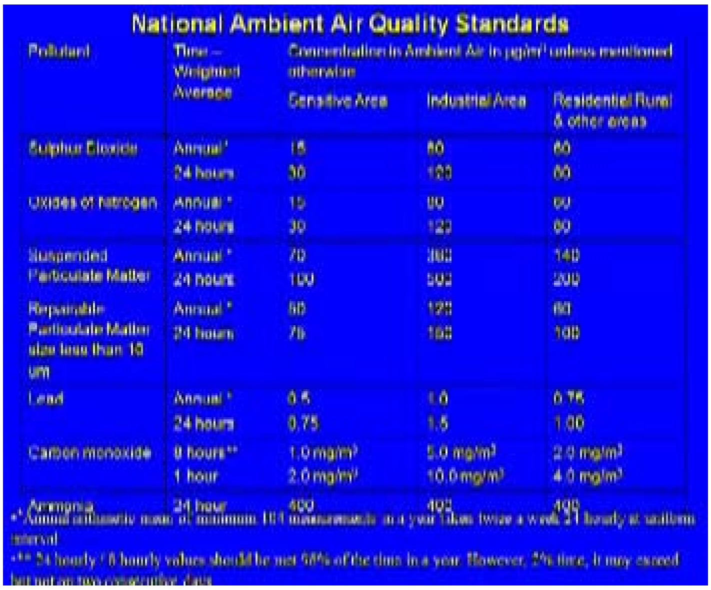

National Ambient Air Quality Standards

Pollutant	Time – Weighted Average	Concentration in Ambient Air in μg/m³ unless mentioned otherwise		
		Sensitive Area	Industrial Area	Residential Rural & other areas
Sulphur Dioxide	Annual * 24 hours	15 30	80 120	60 80
Oxides of Nitrogen	Annual * 24 hours	15 30	80 120	60 80
Suspended Particulate Matter	Annual * 24 hours	70 100	360 500	140 200
Respirable Particulate Matter size less than 10 um	Annual * 24 hours	50 75	120 150	60 100
Lead	Annual * 24 hours	0.5 0.75	1.0 1.5	0.75 1.00
Carbon monoxide	8 hours** 1 hour	1.0 mg/m³ 2.0 mg/m³	5.0 mg/m³ 10.0 mg/m³	2.0 mg/m³ 4.0 mg/m³
Ammonia	24 hour	400	400	400

* Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval

** 24 hourly / 8 hourly values should be met 98% of the time in a year. However, 2% time, it may exceed but not on two consecutive days

You see what all we discussed: averaging time, very fundamental thing; then, you also have the places where the standard should be met; then, how many measurements would constitute an annual measurement. You would also be surprised - for example, we may call this slide 24 hours, but sometimes the local conditions are so, particularly in India, the power supply is so poor that you will never get uninterrupted power supply for 24 hours, especially in a city like Kanpur. It was revised again, not documented, but if we get a measurement of 16 hours even that is okay; that could be considered as a 24 hour measurement. What you see here is everything: how many times it can exceed and things like that. So, that we have done last time.

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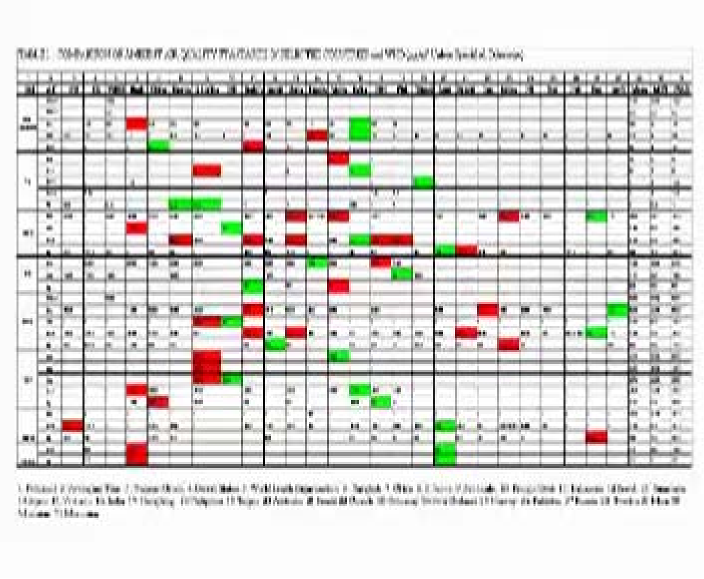

This picture, I am sure is not very clear to you, but I will send it out to you. What has been done here is - all the standards which are generally used in Asian countries, European Union and probably USEPA are there and then this slide really compares these standards proposed by various countries. Here what you see here is - 1, 2, 3, 4, 5, 6, 7, 8, and 9; for example, let us say number 10; 10, let us say, is Bangladesh. What you can see here is the various standards for carbon monoxide and various countries have different averaging time, as you can see here. The red and blue, and red and green - the green are the things which adhere to a very stringent standard and red is a relaxed standard. I am showing you this picture to show that the standards can vary from country to country and depending on many local conditions standards are fixed. It is just to give a little feel.

I do not know where India would be; let me show you, I think 16. You go here to 16, you see here, most of time we are green here. It means that somehow we have fixed standard which are far most stringent than many other countries. We have to be careful in fixing the standard; we do not want to fix a standard which you will never achieve. But the revisions are going on and more thoughts are going into this one, but it is a nice picture to compare as to how other countries are doing. I also wish to define this because you will see all the standards that you have seen and the methodology that is prescribed along the standard also specifies accuracy and precision.

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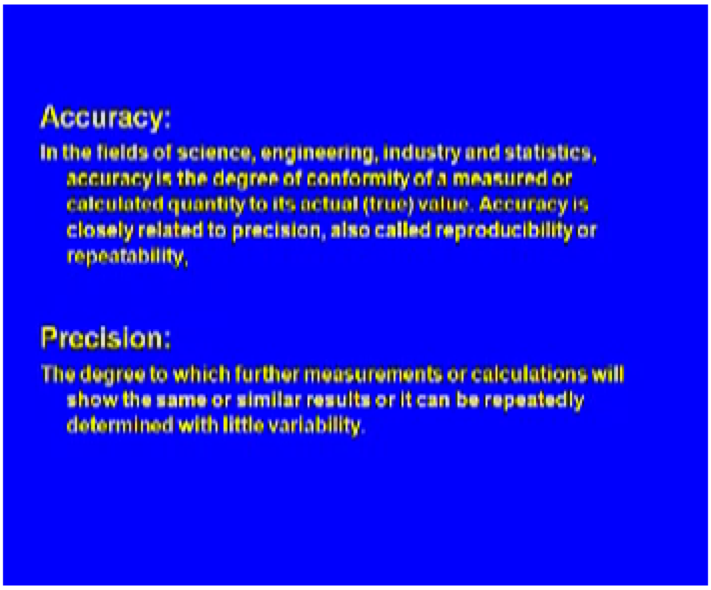

Accuracy:

In the fields of science, engineering, industry and statistics, accuracy is the degree of conformity of a measured or calculated quantity to its actual (true) value. Accuracy is closely related to precision, also called reproducibility or repeatability.

Precision:

The degree to which further measurements or calculations will show the same or similar results or it can be repeatedly determined with little variability.

This the standard definition of the accuracy and precision as you see here. The best way to explain the precision and definition is through some picture.

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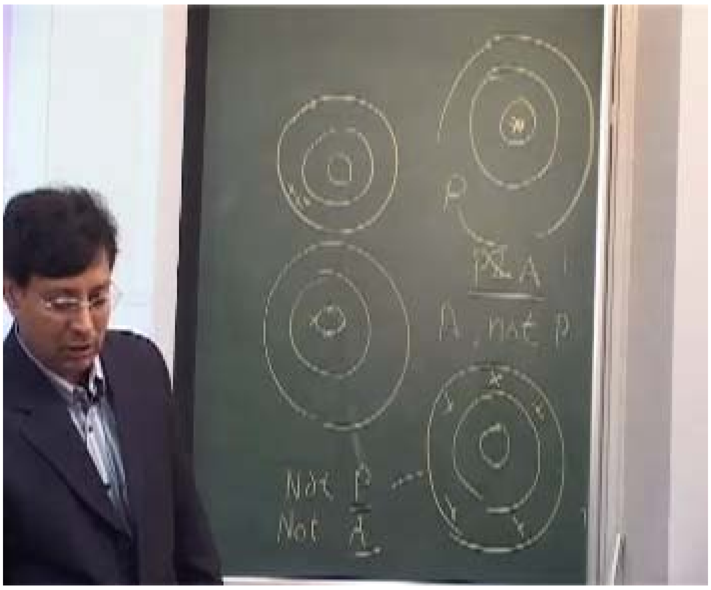

You know the game of darts. Suppose the person is hitting the arrows or the darts and he is able to hit here, here, here (Refer Slide Time: 08:12 min). What would you call this? Is it accurate, precision, or accurate but not precise, or whatever the possible combination there is. What would you call it? Precise. What if the situation is like this (Refer Slide Time: 08:33 min). What would you call it? Accurate and precise; would you like to call it that? I think it is accurate, but not quite precise. See the variability; one time it is hitting here, one time here, one time here and one time here. We can say it is accurate because it is very close to this one. Accurate, but not precise. If I have the picture, which is neither accurate nor precise and I might have another picture not precise (P for Precise) and not accurate; then we might have another picture here and everything you write here - this is precise and accurate.

Sometimes we know the accurate [value]; well sometimes we do not know what is accurate; because, if I ask you to do the measurement, let us say for sulphur dioxide, you can never know if it is very accurate, but sometimes you will see that the methods are described because some of the methods those are developed, they are developed for the known concentration. What they will do next is - they will try to stimulate the conditions and then they will do the measurement and say exactly what amount of sulphur dioxide has been put; and then they will say this method is so precise and so accurate. You can hope the things will be accurate here but the methods are generally defined in terms of its precision. Accuracy - sometimes you are not quite sure if things are quite accurate. This is something very similar to what I have said; so this just a repetition of this, but you will have those in slides, so that you can refer to it again and again if needed.

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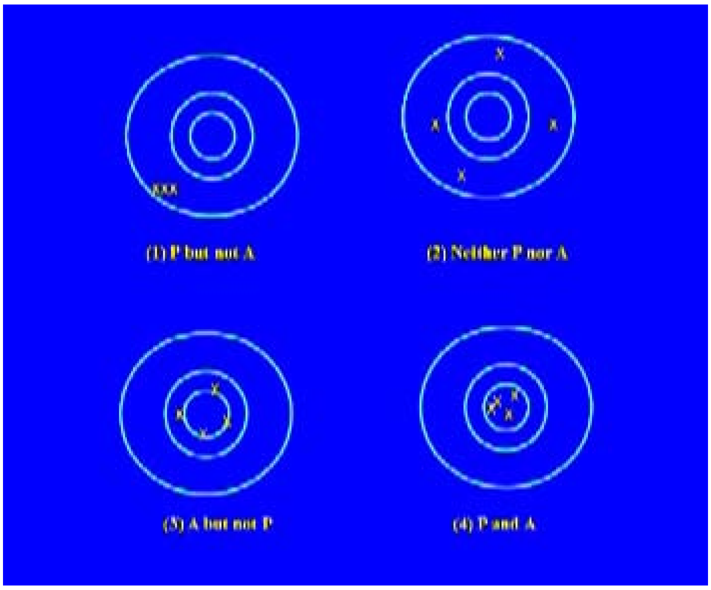

This is almost a better picture than what I have drawn here. It is a bigger picture; so it is kind of accurate because you are very close to the target, but it is not precise. Here, for example, everything is right in the in the circle; so what you see here is precise, as well as accurate. So, you should have this concept.

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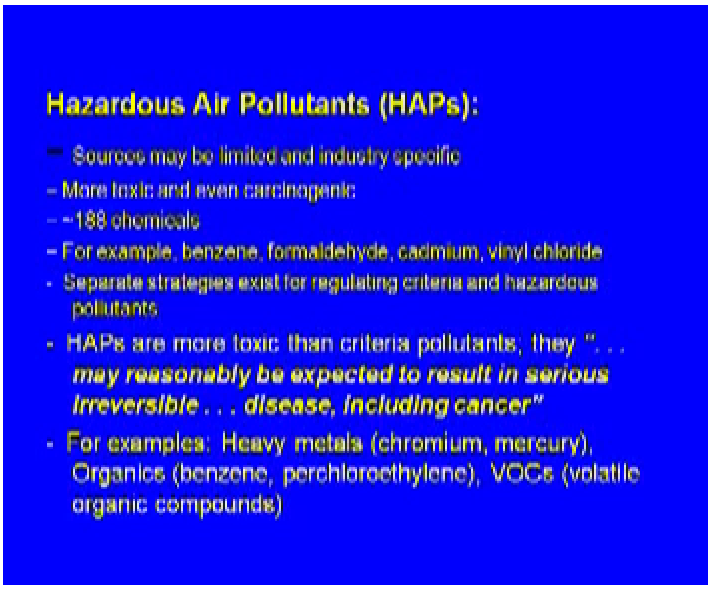

Hazardous Air Pollutants (HAPs):

- Sources may be limited and industry specific
- More toxic and even carcinogenic
- ~188 chemicals
- For example, benzene, formaldehyde, cadmium, vinyl chloride
- Separate strategies exist for regulating criteria and hazardous pollutants
- HAPs are more toxic than criteria pollutants; they ". . . ***may reasonably be expected to result in serious irreversible . . . disease, including cancer"***
- For examples: Heavy metals (chromium, mercury), Organics (benzene, perchloroethylene), VOCs (volatile organic compounds)

There is another new thing which is coming up in air pollution and we are still kind of talking about the introduction to air pollution. I got into the physics and chemistry of air pollution; so another thing we come to is hazardous air pollutants or HAPs. Everyone wants to talk about HAPs. The other pollutants that we were talking earlier and tried to give the standards, what were the names that we gave to those pollutants? Criteria pollutants. You remember the six criteria pollutants which we wrote down. Let us revise those because everyone would like to refer those six criteria pollutants: particulate matters, sulphur dioxide, NO_X, ozone, lead and carbon monoxide. Apart from PM, which will stand for particulate matter, there are standards; the other part is also considered as the criteria pollutant, which are the subset of the total particulate if you recall, I will try to define as PM_{10} and $PM_{2.5}$.

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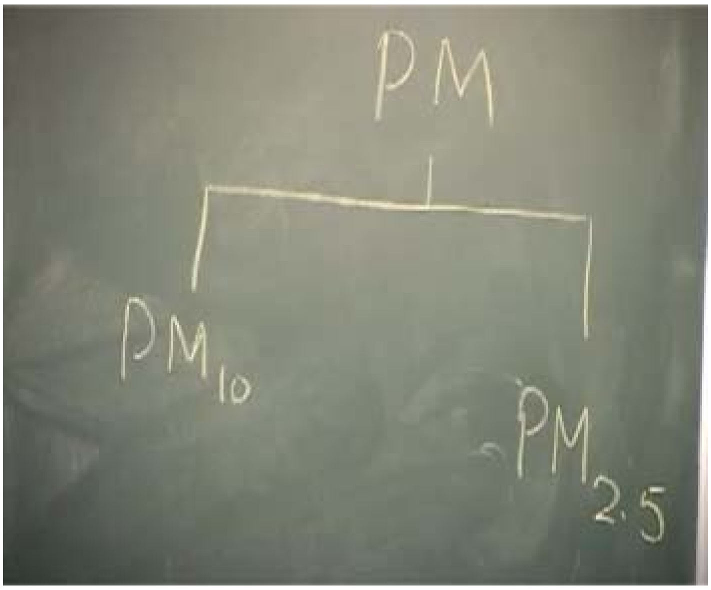

Perhaps we will explain more about PM_{10} and about $PM_{2.5}$ in the next classes. This is the particulate matter that has bifurcation. These will be the particles which are of the size less than or equal to 10 micron and there will be less than or equal to 2.5 micron.

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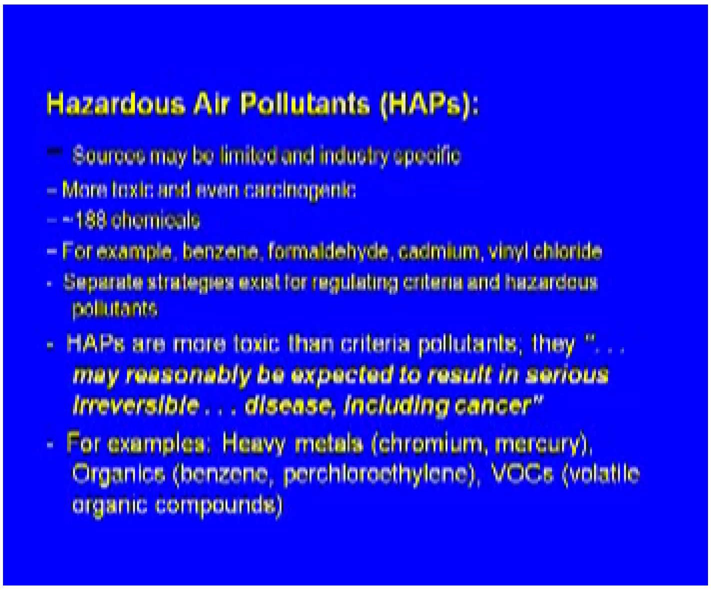

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We were talking about the HAPs and what you see is that the HAPs are the sources of hazardous pollutants. USCPA have identified 188 chemicals as hazardous air pollutants and most of the countries have accepted those pollutants as the HAPs. For example, what the HAPs may include are benzene, formaldehyde, cadmium and many more things. If you go to

USCPA site - www.epa.gov - you can access all 188 HAPs in there and of course we are not writing all those here. The problem with the HAPs are that they are commonly found in the atmosphere and some of them are found in a particular environment depending on what kind of industries are found in the surrounding area. For example, if you go to the refinery, we in India have the second largest refinery, which is that? It is the Reliance refinery in Jamnagar. It is a very large refinery. If you go into that area, you may find some of pollutants which otherwise will not be found even in an urban environment. So that HAPs has become quickly a matter of concern in that particular area. We should at least know what these HAPs are and HAPs are more toxic than the criteria air pollutant. They may reasonably be expected to result in serious irreversible diseases including cancer.

We talk about the public health all the time and even the heavier metals come into that one, many of the VOCs will come into that category, many of the pesticides that come into that category.

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The problem is with the compounds which are HAPs, if you look at the kind of dose response that we have been discussing ever since, there is a response here and here is the dose. It does not show any kind of threshold; so, you might find something like this and then you do not find any threshold; this picture is particularly true for HAPs.

Unfortunately, you will not find all 188 HAPs in the environment; it again depends on the specific area. It is difficult to control and talk about all of these chemicals, so what people have done or what the scientists have done is that they have found out some 33 HAPs which are commonly found in the urban environment, where most of the people reside.

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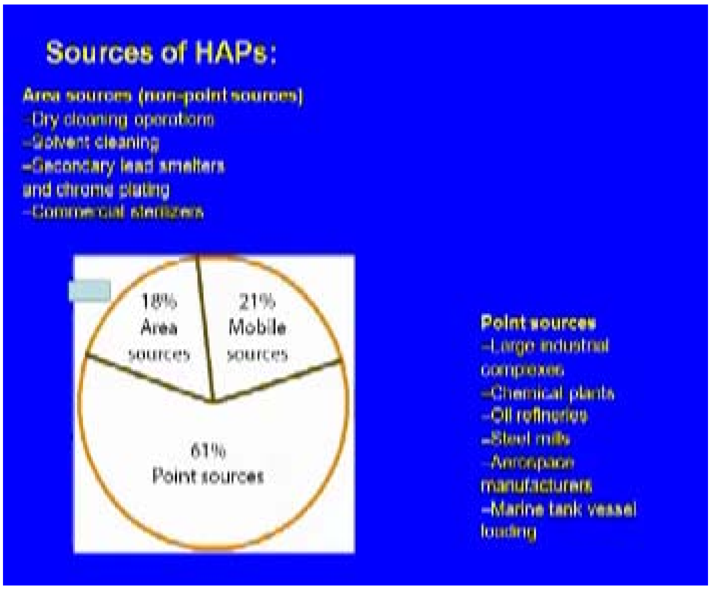

Sources of HAPs:

Area sources (non-point sources)
-Dry cleaning operations
-Solvent cleaning
-Secondary lead smelters and chrome plating
-Commercial sterilizers

Point sources
-Large industrial complexes
-Chemical plants
-Oil refineries
-Steel mills
-Aerospace manufacturers
-Marine tank vessel loading

The sources of HAPs you can see. In fact you will be surprised that you would not know but dry cleaning is one of the very open operation that happens, is a very serious environmental problem, but we have to live with the dry cleaning in urban environment.

Solvent cleaning, secondary lead smelters – do you know the difference between primary and secondary lead smelters? The primary lead smelters are those integrated large smelter plants where the ore is processed to produce a lead; that is a primary lead smelter. If the lead is already being used and you then want to extract or recover the lead from somewhere, for example, you know all the batteries will have lots of lead. In fact, the majority of lead goes into the batteries; these batteries, after they have lived their life, they are taken back and the lead is recovered from there. This is called the secondary processing of the lead. This happens a lot and a lot happens in Kanpur particularly because of the power situation. We have the many industries here which do the lead smelting; the lead smelting done here is the secondary lead smelting.

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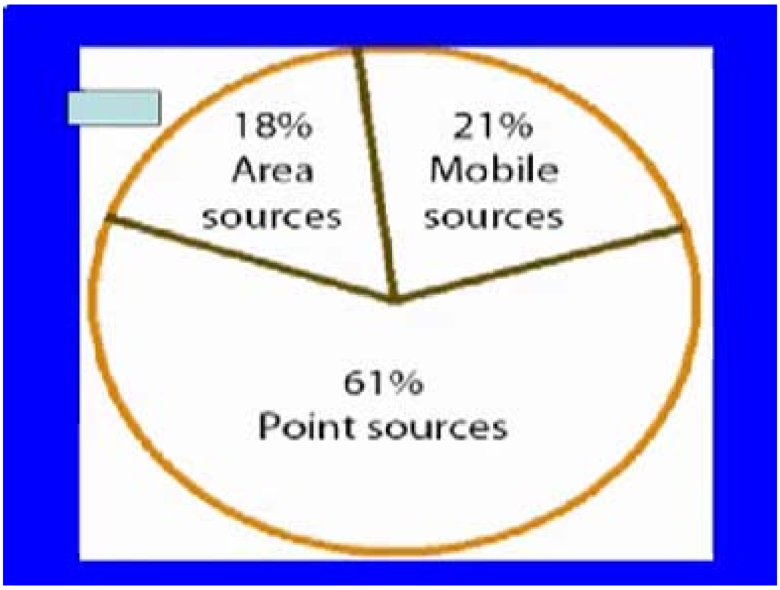

We can also see that apart from the chrome plating, which is known as commercial sterilizers, many of the sources are mobile sources and some are from the automobile; some of this may come from a particular area; point sources may come from the chimney. Point sources include the large industrial complexes, especially the refineries, chemical plants, steel mills, aerospace manufactures, marine tank vessels loading, and things like that. These are the major sources.

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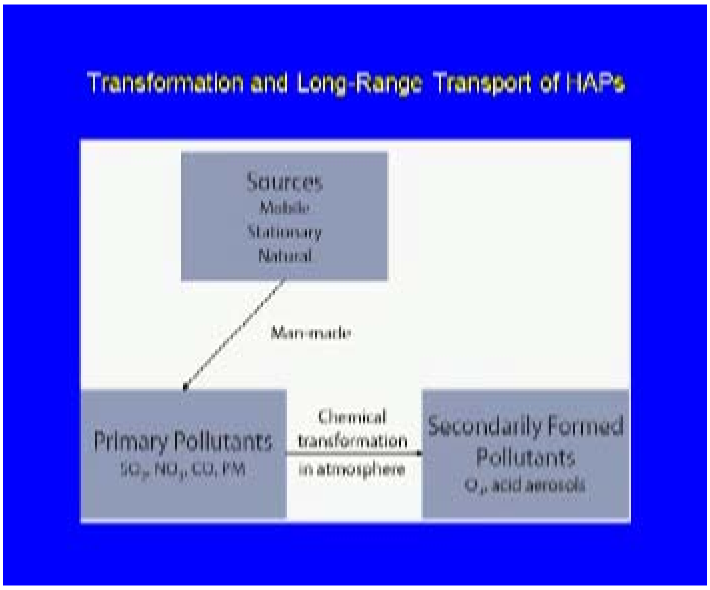

Transformation and Long-Range Transport of HAPs

Sources
Mobile
Stationary
Natural

Man-made

Primary Pollutants
SO_x, NO_x, CO, PM

Chemical
transformation
in atmosphere

Secondarily Formed
Pollutants
O_3, acid aerosols

They can also be transported, source from the mobile and stationary, say man made. The thing which you need to see, we will be spending sometime in this lecture, are the common pollutants. They could be chemically transformed. We should also think whether hydro carbons formed here can be transformed into other pollutants in the atmosphere. In this primary pollutant, how they are formed into secondary pollutants and they are transported; some of the hydrocarbons which are HAPs could drive, give rise to the secondary pollutants, which are never emitted from the source. We will talk about that in a moment, but let us first finish the discussions on HAP. I am giving you an example of 20 odd HAPs here.

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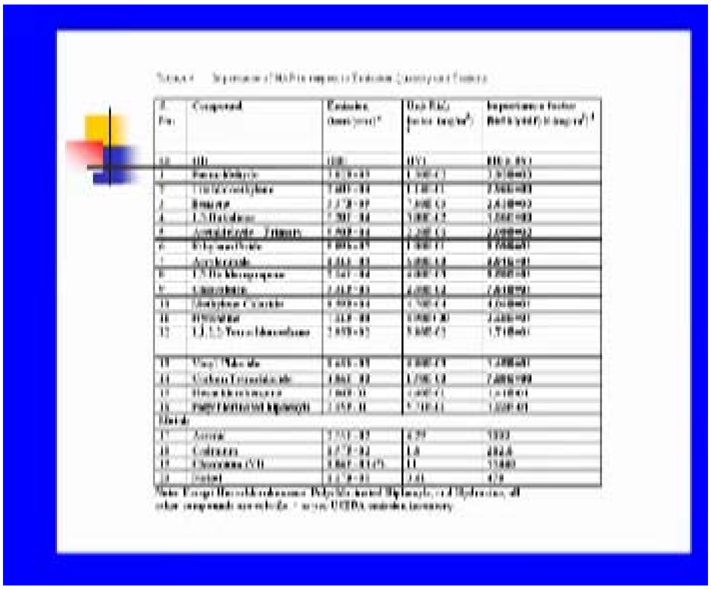

How do we to prioritise the HAPs? We cannot control every one of them. What we did here is that, you see the list of the HAPs, we put the entire list of HAPs, as you see here, but then you see here we looked at the emission quantities. It is not in India but it is from the US. But this part of the work, as you see here, was done here. So what we did is to find out and prioritise which we should control that, what we should target, as we cannot do everything. There is an emission quantity and hoping that the emission quantities... we do not know in India, but going by the normal urban life that is probably similar everywhere in a relative sense. The emission quantity will be in the relative sense similar. In the sense, this will be more and this will be less; that sort of thing (Refer Slide Time: 19:51 min). And then what was done, was that the unit risk factor is a sub-major of toxicity; again, you see here the measure of the toxicity here (Refer Slide Time: 20:03 min). If we multiply the quantity and the toxicity and that will it be? The more a quantity and suppose toxicity is also more, those products will be on largest. This means it is a serious problem. Whereas the pollutant may be that the quantity may be very high and toxicity is very low, in that, the impact will be low. That is how this factor was derived and if I am right, you can see this is already put into the decreasing order.

What you will find is that formaldehyde is very toxic both because it is toxic, as well as emitted in large quantities. This is a serious thing we should do. The benzene, one three (( )) .What we are proposing in India as well as in the US is that we cannot do much about these things, but let us take the formaldehyde as one of the pollutants controlled in India because this may cause a serious problem; both the quantities are high, the risk is high; so benzene becomes an important thing and that sort of things that you even handle the HAPs. The first type of the HAPs what the world is doing is not to provide a legal value to that, but we are trying our best to control that; because, you see even the measurement of these things will not be so easy. We require sophisticated instrumentation, sampling devices and things like that. What they are doing is at this source, the source inventory is done and then they check the leakages there; the emission quantity should be controlled by the factory.

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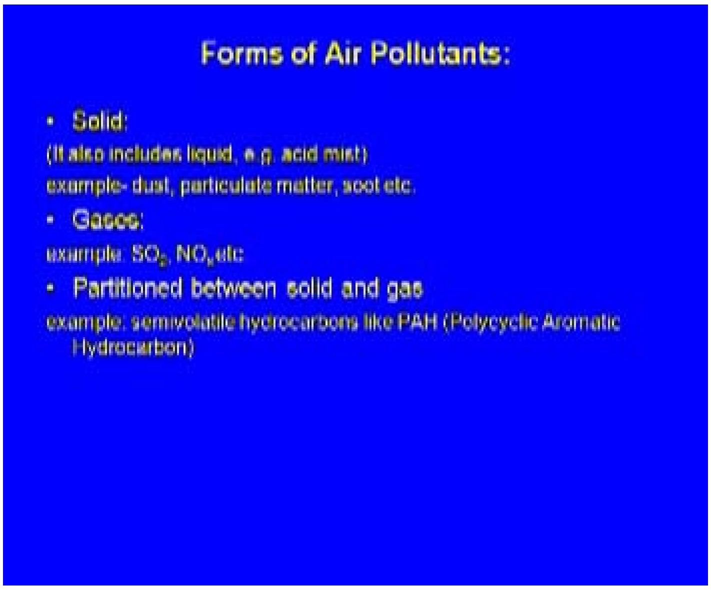

Forms of Air Pollutants:

- Solid:

(It also includes liquid, e.g. acid mist)

example- dust, particulate matter, soot etc.

- Gases:

example: SO_2, NO_x etc

- Partitioned between solid and gas

example: semivolatile hydrocarbons like PAH (Polycyclic Aromatic Hydrocarbon)

We are into something basic, but you should still know about this; we will now into the forms of the air pollutants. Normally the physical forms, as you would see, are: solid, liquid, gas. Here the solid, but in air pollution you see the liquid is missing. Do you see a liquid here? No it is not a liquid. Normally what we do is we consider even if some pollutants are in the liquid form, mist for that matter; for example, we may have the sulphuric acid mist in the atmosphere; we might have the nitric acid mist in the atmosphere, but we will still consider it as a solid. We do not take that separately, it includes acid mist even as a liquid. Normally, water is never considered a pollutant, so we see them as this. The gaseous pollutants, some of the pollutants are semi-volatile, and can partly be absorbed on to the solid and partly they can be in the vapour phase.

There are some compounds or some pollutants that can be, especially like the PHS, in the partition between solid and the gaseous phase. To give you a little feel - if I were volatile compound - everything is volatile or non volatile, but among these pollutants, for example, I have a heavy compound, which has a large molecular weight and the same category of compound is low molecular weight, which one will be in the gaseous phase or which one will be in the particulate phase or which one could be partition between gas and the solid. Low volatile, low molecular weight compounds will be completely in the volatile phase. Very heavy compounds will be completely in the solid phase and the compounds which are somewhere in between they can very well be partitioned between the solid and the gases.

The compound which are in the gaseous phase - how would you measure them and on which system? Will you want to measure them on gas chromatography or liquid chromatography? Gas chromatography; because, they can be very easily put into the vapour phase or the gaseous phase. Gas chromatography is based on the volatilisation of something. Something that cannot be volatised, we like to do it on HPLC or high performance liquid chromatography. It can be also done in GCMS. Depending on the compound that we are trying to do, we can also decide the instrumentation; of course, that you probably you will learn in some other course. Just notice that some of the compounds can [ ]. You may see that the temperatures are high, even if the molecular weight is slightly high, the compound may be in the vapour phase. In fact, if you want to do the complete sampling of the same compound, it may require collection on the solid phase as well as in the gaseous phase. Otherwise you will only be reporting only part of the concentration or part of the fraction you are only capturing, so this becomes little tricky. We are not talking about the sampling analysis of those but this. These are the little things you should be aware of. As you do more advanced courses on this one, you will learn more about this one.

There are no questions. Let us also talk about something very important. I told you about two things: primary pollutants and the secondary pollutants. Let us see what the definitions are.

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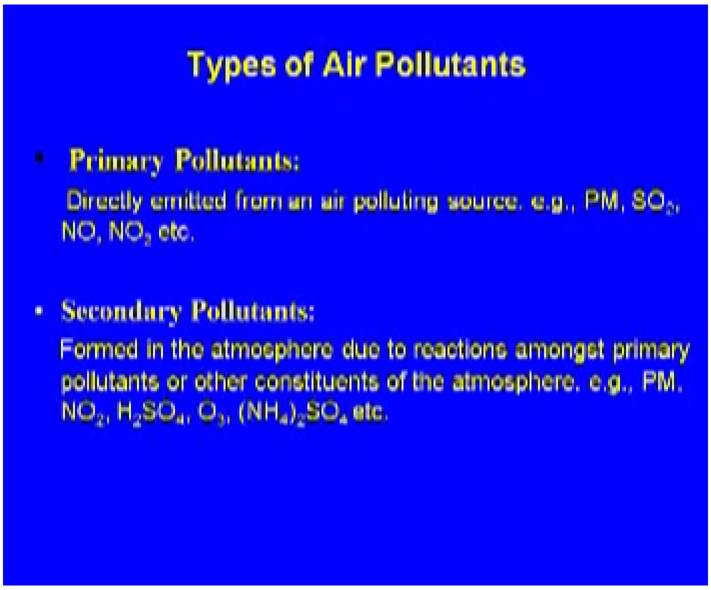

Types of Air Pollutants

- **Primary Pollutants:**
  Directly emitted from an air polluting source. e.g., PM, SO_2, NO, NO_2 etc.
- **Secondary Pollutants:**
  Formed in the atmosphere due to reactions amongst primary pollutants or other constituents of the atmosphere. e.g., PM, NO_2, H_2SO_4, O_3, $(NH_4)_2SO_4$ etc.

Primary pollutants are those pollutants that are directly emitted from an air polluting source. They are at the source: they are in the chimney, they are in the exhaust. These pollutants are called the primary pollutants. An example you can see here: particulate matter, sulphur dioxide, NO and NO_2 also. Once the pollutants are in the atmosphere, they can undergo chemical reaction within themselves or the primary pollutants plus the atmospheric constituents. They also react with the atmospheric constituents and do react very significantly to produce some new compound which was not present in the atmosphere. Such pollutants are called secondary pollutants.

The definitions of these pollutants are they are formed in the atmosphere due to reaction of the primary pollutants or other constituents of the atmosphere. The interesting part is the particulate matter can be emitted and can also be formed in the atmosphere. For example, NO_2; it can be emitted from the source and it can also be found in the NO_2. H_2SO_4 is largely formed in the atmosphere. Ozone is almost 100 percent formed in the atmosphere by some small sources. Ammonium sulphate could be formed in the atmosphere and this a little bit we shall see. We will look at this at the later stage, but it might be the good idea to know it.

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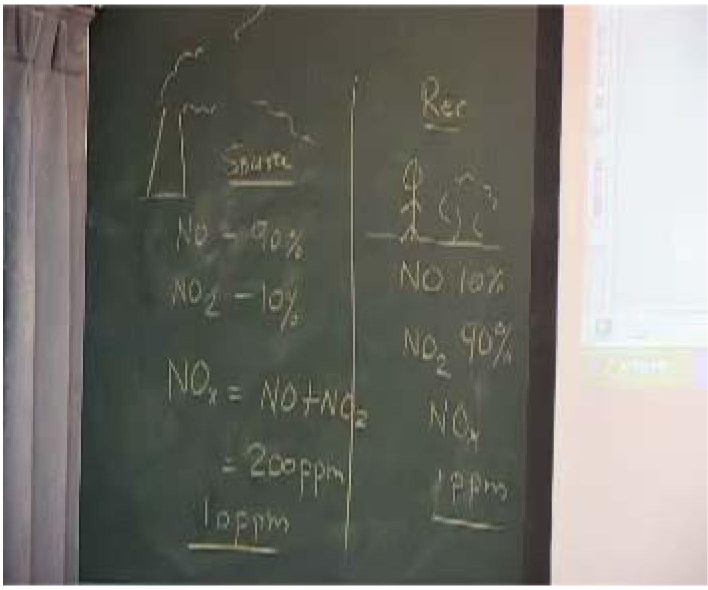

Suppose this is a chimney. We are specifically talking about NO and NO_2. This is dispersing and is coming to the receptor and reaching the receptor. By the time it travels you will still find NO and NO_2. The interesting part is, and the thing you should really know is that at the source what will be of larger quantity, NO and NO_2? You say the NO_2 and someone else say NO. Fair enough, as do not know about that, but you will be surprised that at the source about 90 percent or more in fact, we will do this calculation; we will go through the combustion process. I will show you why NO could be 90 percent or in fact 90 to 95 percent and this could be about 10 percent. As it travels the picture is reversed. This NO becomes nearly 10 percent approximately; we should not go in absolute numbers because you may find something different, these values had something and we are finding something else, then we might just get NO_2 about 90 percent. If you recall, I also had given you a term to explain NO_X. It equals NO plus NO_2.

Why we are discussing this is if I am defining NO_X here, what I am doing is predominantly, which one is I am really referring to? I am referring to NO. If I measure NO, here at the source, I can almost say this is NO_X because I know at this source inside the chimney the emissions will be largely NO. That will do some calculation with some formula just to show at some state and at the source, if I am calling, or the NO_X level is so much. The NO_X at source, let us say is 200 ppm, that is, per parts per million and here NO_X is let us say 1 ppm, which of course will be very low, but the meaning of NO_X here at the receptor and source is entirely different (Refer Slide Time: 30:59 min). This is because here the NO_X will be largely

NO_2 and here NO_X will largely be NO. This will show at some point but it might be a good idea to have some knowledge. Then you see here, you have almost insignificant NO_2, which I do not want to call a primary pollutant, because the quantity is so much; but here it has become a secondary pollutant. The primary pollutant was NO and kind of secondary pollutant is NO_2 and this is what is done. People are now saying that well something should be done because this could always be confusing unless we are into it; then people might just get confused with NO_X measurement at source and NO_X measurement at the receptor.

Another funny story goes that lots of people learnt quickly because this measurement of NO is little more difficult and NO_2 measurement is not so difficult. So people in the ambient air whether receptor or the breathing level were measuring for mostly NO_2 and happily calling it NO_X, which is a fair, reasonable assumption. Then, people also wanted to measure at the source. To measure at the source, they use this because they did not realize that this kind of situation may exist. This method is very easy to do and they did the sampling here; then they are only measuring NO_2 and still calling it as NO_X, thinking that well NO_2 is largely constitutes the NO_X. They found something like 30 ppm or even less actually, close about to 10 ppm and they said - look how low the emissions of NO_X are. This is really a true story.

Therefore, you see there should be a difference between some people who can just do the measurement and what is more important is an understanding of the process, having the knowledge of the process. If you had the knowledge you will quickly catch him; well come on, you are talking something about.... And always about the data or the numbers and I tell all my students to get a feel of it. You should not accept the numbers as such. Look at it with your knowledge and science, you should first analyse of the data by just scanning the data and that does a lot of things. For instance, say you look and find something wrong because at the source NO_X cannot be 10 ppm. We are drifting from what we should be doing but it does not matter. In fact, some standard for the NO_X was fixed, as you have the standard here. We also have the standard that could be allowed and some standard are fixed as 200 ppm because that was borrowed from somewhere else, but the method was not prescribed; so people use a method they knew and they always reported NO_X as 10 ppm. They always said, we are meeting the standard, we have no problem, our process is very clean. But the foolish thing they were doing was they were only measuring NO_2 because they used that method, which they were measuring the nitrogen dioxide there to refer as the NO_X.

Recently it is being talked about that we should measure both NO and NO_2 at the source. If you do not measure NO_2, fine, fair enough. At least measure the NO and quickly this number, as people are reporting or the industries reporting as 10 ppm will quickly change. This is just a little story but then we have to be very careful with the numbers and things like that. Reasonability of the numbers is so important and you can very easily do checks and balances, if you have the knowledge.

In the water parameters, the person will come with the knowledge, so you can easily find out if there is something wrong with the analysis or somebody is trying to cheat on the numbers. That is quite possible because you understand the physics and chemistry behind it and things like that.

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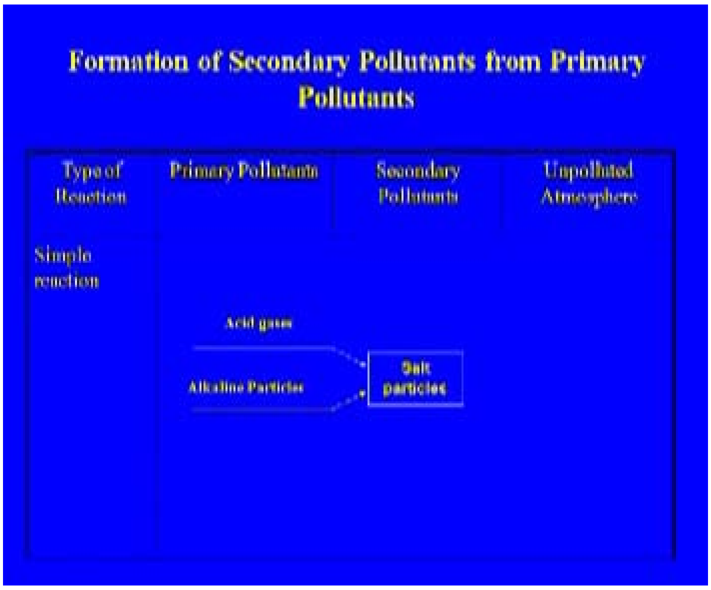

Formation of Secondary Pollutants from Primary Pollutants

Type of Reaction	Primary Pollutants	Secondary Pollutants	Unpolluted Atmosphere
Simple reaction	Acid gases Alkaline Particles	Salt particles	

Let us look at some more examples as to how the secondary pollutants are formed. Let me also tell you that some of the secondary pollutants, not some but most of the secondary pollutants, are deadlier than their parent compounds. When you talk about the control of secondary pollutants or the management of the secondary pollutant, you must manage the pre-cursor pollutant; because, you have no ways and because you cannot tackle the atmosphere; you cannot tackle the transport mediums in air. In the water medium you can probably tackle. You can probably hold on to the water and say before it is discharged we will do something to the water but you cannot hold on to the air volume. We cannot make sure that the secondary pollutants are not formed; you cannot control that. The only way you can control is through the primary pollutant. Most of the time the control of the primary pollutant is dictated by the potential it has for making the secondary pollutant because secondary pollutant might be or generally are more hazardous. In fact, I will give you an example: NO, has almost no health effects, whereas NO_2 has significant health effects. When I want to handle the NO_2, I would ask the industry to control NO. It would be foolish for me to say NO_2 is the problem, so let us control NO_2. So when I want to control NO_2, I will ask the industry to control NO not NO_2. These are the little things but very important and that is why we should understand the science and the knowledge we require.

You have here the simple reaction. You may have the acidic gases SO_2, NO_2 and things like that. Then you also have alkaline particles like the calcium carbon and ammonium chloride. What they would do is, they will react and then they can make the salt particles. It is like a huge reaction chamber in the atmosphere and you will see they are the particulate matter they will be formed. We will talk a great deal about this one, but at this time I am just introducing it so that you clearly understand the primary and secondary pollutants because they indeed have very serious bearing on to the control of the pollutants. How to manage the air quality?

Always remember our objective is to safe guard. So these particles could be formed and then you can see the dust level is going up, you see my chimney is very clean and that I am polluting nothing. Why do I still have so much haze in the atmosphere? Mostly the haze that comes out is from a similar kind of reaction. We are not talking about the complete picture. The complete picture in atmosphere is very complex and many times we understand something and many times we do not understand something. In fact, we do lots of reaction chambers studies and control studies and things like that.

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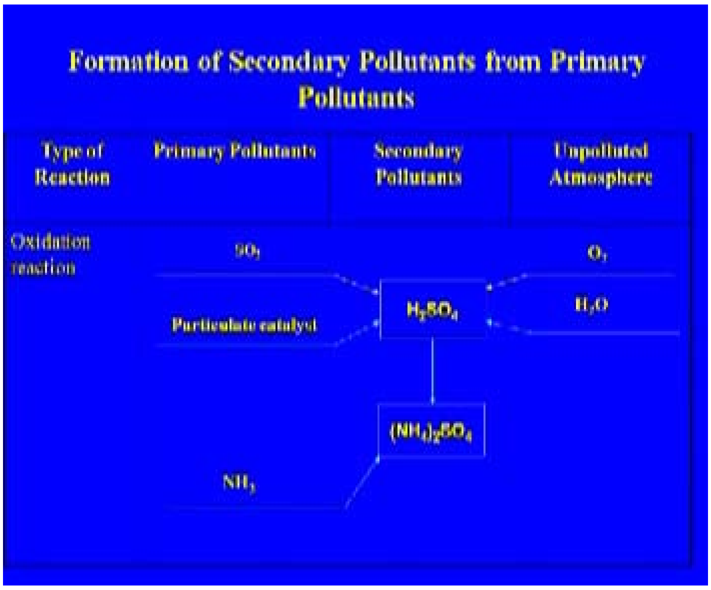

Formation of Secondary Pollutants from Primary Pollutants

Type of Reaction	Primary Pollutants	Secondary Pollutants	Unpolluted Atmosphere
Oxidation reaction	SO_2		O_2
	Particulate catalyst	H_2SO_4	H_2O
		$(NH_4)_2SO_4$	
	NH_3		

Some more examples; see here you have SO_2 and in the atmosphere, suppose you have some particulate catalyst, to give for example, suppose you have vanadium in the atmosphere vanadium or vanadium pentoxide - V_2O_5. This catalyst can quickly help convert SO_2 into SO_3. Once you have SO_3 and a little water and oxygen, and this catalyst vanadium pentoxide, quickly the whole thing will convert. First SO_2 will go into SO_3 and with the water; it will quickly produce the sulphuric acid. This could be a very fast reaction provided you have the catalyst; otherwise, there are other ways for this slow reaction. What is the source of the vanadium? Diesel and heavy oils contain vanadium in it so vanadium is emitted.

Look at the ammonia emissions which are there. Ammonia is present in the atmosphere and ammonia and H_2SO_4, provided you have humidity and other conditions, quickly form the ammonium sulphate and very fine particles of size less than one micron. You will see little haze in the atmosphere.

Look at where we have started and where we are reaching. When we are talking about the management, the control, we sometimes we need to... and you see we are understanding the chemistry part of it, then we measure all and then we might decide to well take a guess. Suppose, I want to somehow control the formation of the ammonium sulphate, I might do a little bit of you know optimisation, go through the process and go through the control technology. I might decide if I take out this catalyst from the atmosphere or if I handled the source of catalyst in the atmosphere, which is causing conversion of SO_2 to SO_3, I might not be even forming the little haze that you see in the atmosphere. It opens up many avenues if I can say, as to for the scientist, engineer to control and manage the air pollution. So that is what it is. I am just giving you some examples. These things are very complicated, not easy but we are still at the introduction level.

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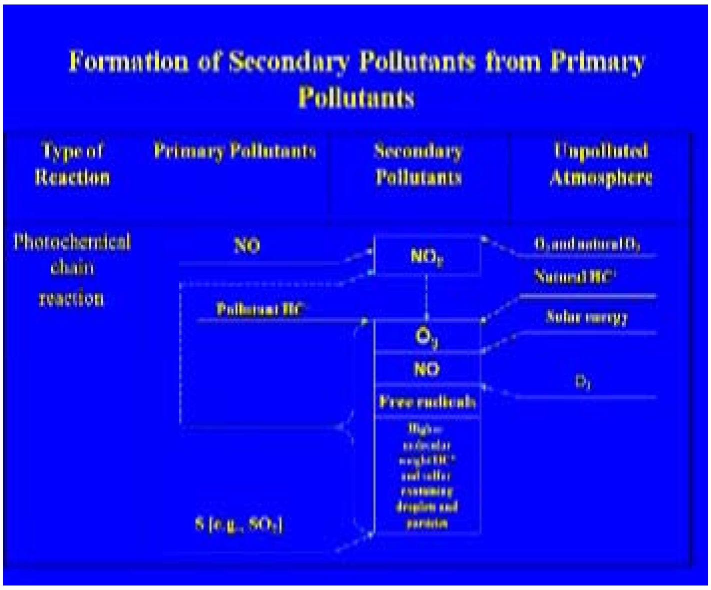

Formation of Secondary Pollutants from Primary Pollutants

You have seen see NO and if you have little ozone, NO goes into NO_2. In fact, we are emitting NO most of the times and we are getting the atmosphere as NO_2.You can also see some of the hydro carbons and the system of the gases NO, ozone and NO_2. See here, you have lots of periodicals in the atmosphere that are there and then they can form ozone, as I said the primary source of the ozone in the troposphere, it is almost not there in stratosphere. Most of the ozone is formed as a secondary pollutant and we are not emitting it from any source; no power plant and no car will emit ozone. But they will emit NO, they will emit hydro carbon. In solar energy there is always some hydrocarbons, and this again we will talk in detail, but that can yield or that can give out of the ozone as a form this one and ozone is a serious problem. This is a standard question. While ozone is a boon in this in the stratosphere, it is a curse in the troposphere.

Some of the things we will talk about in a great detail.

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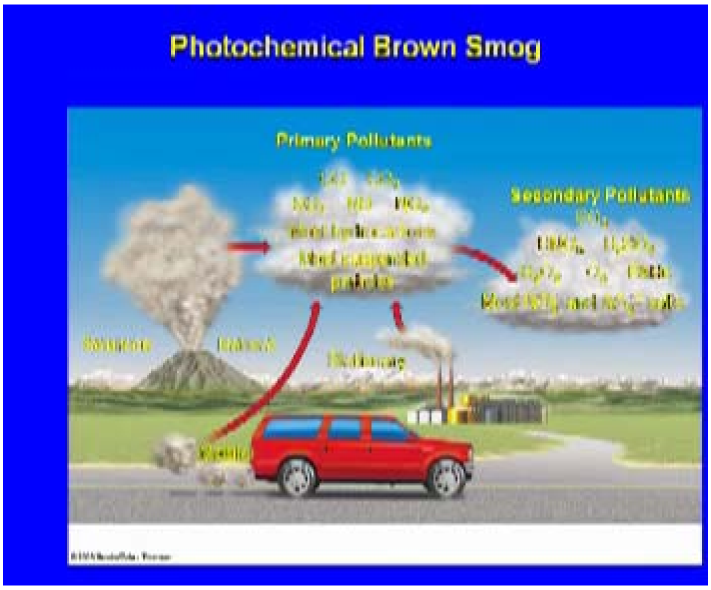
Photochemical Brown Smog

The picture here shows you all natural sources. These are the primary sources, as you see here. These are the primary sources that go into the atmosphere, undergoes lots of reactions and then what you form here is the secondary pollutant. You cannot see at the back probably sulphur trioxide, H_1 O_3, H_2SO_4, PHS, ozone, here, H_2 O_2 is formed, very significant amount; we formed the nitrate and sulphate salts and that gives rise to the particulate matter.

In fact, you will be surprised that in India, the major problem is the dust; you see the particles. If you travel to other countries, especially European countries or North America, you do not find so much dust. Then the question is that.... Then, of course, we have been trying to control very hard the emissions from the power plants, still we get the dust; it is because of the secondary reactions that are taking place. Here most of the reactions are largely triggered by the UV radiation and solar radiation. We have lots of sun shine and as a result our reactions, and our pictures, will be very different. We will have the hazy condition more frequently than this.

So we might probably have a greater challenge than many other countries when it comes to air pollution; because, all these are the functions of the temperature and the radiation that are coming; high temperature are very conducive for the reactions to take place. We have lots of energy because we have the tropics and then as a result we have more complications. We will talk in a great detail about this in this course, probably in a few classes.

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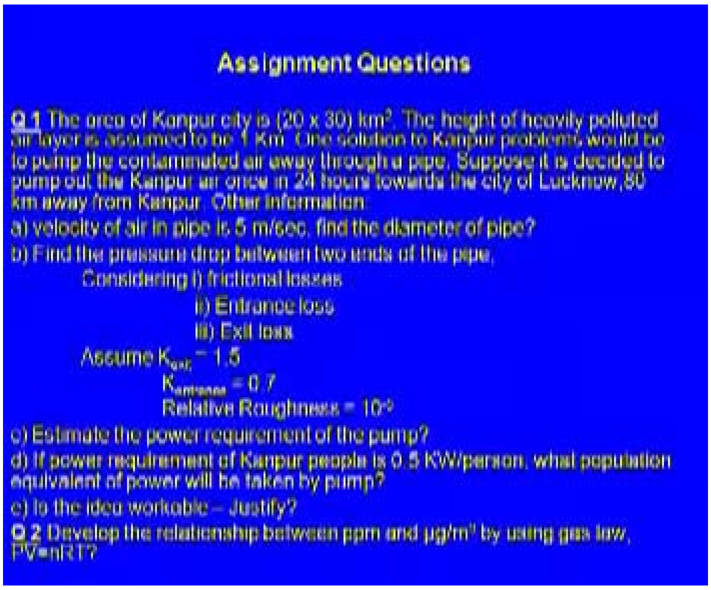

Assignment Questions

Q 1 The area of Kanpur city is (20 x 30) km^2. The height of heavily polluted air layer is assumed to be 1 Km. One solution to Kanpur problems would be to pump the contaminated air away through a pipe. Suppose it is decided to pump out the Kanpur air once in 24 hours towards the city of Lucknow, 80 km away from Kanpur. Other information

a) velocity of air in pipe is 5 m/sec, find the diameter of pipe?

b) Find the pressure drop between two ends of the pipe,

Considering i) frictional losses
ii) Entrance loss
iii) Exit loss

Assume K_{exit} = 1.5
$K_{entrance}$ = 0.7
Relative Roughness = 10^{-2}

c) Estimate the power requirement of the pump?

d) If power requirement of Kanpur people is 0.5 KW/person, what population equivalent of power will be taken by pump?

e) Is the idea workable – Justify?

Q 2 Develop the relationship between ppm and µg/m^3 by using gas law, PV=nRT?

Let us discuss question number 1, and then I will take this one out and discuss something like that. This is the question that I want you to do; do it honestly, but do not submit it. This is a simulated problem. The area of the Kanpur city - let us say 20 kilometres by 30 kilometres area. The height of heavily polluted air - we can think up to 1 kilometre has the pollutants. There is 1 kilometre. One solution to the Kanpur problem would be to pump out the Kanpur air once in 24 hours; we pump out from the upstream here because the air this side is better and as you move towards the city the pollution levels are high.

Suppose, it is decided to pump out the Kanpur air once in 24 hours towards the city of Lucknow, which is about 80 kilometres away from Kanpur. I am also hypothetically supposing that I am providing a pipe from Kanpur city to go all the way to Lucknow. We will drive it out from there. I have given you velocity of the air pipe as 5 meters per second. Find the diameter of the pipe. You will find the pressure drop because all the time we are handling and we are dealing is with the energy issues. A successful engineer is one who can reduce the energy users and you will be the top at the company.

Let us examine the issue. Let us see how far we can go. Consider the frictional losses; there will be losses at the entrance of the pipe; there will be losses at the exit of the pipe; K exit and K entrance - you recall from Bernoulli's principles - use this value, and what is the relative roughness? Where do you use the relative roughness? Friction; to find out the coefficient of friction. What charts do use for that? Modis chart. Look through this one, take the Modis chart and I want you to find out the pressure drop. The pressure drop is nothing but the energy. To estimate the pressure drop between the two ends of the pipe, estimate the power requirement of the pump that you will install to pump out the air. Then, if I say the power requirement of Kanpur people is .5 kilo watt per person, what population equivalent of the power will be taken by the pump.

Do all the calculations; check if the idea is workable. Obviously, we know this is not going to work as will need huge amount of power but still do the calculation. The second part we will do it in the next class. We will spend some time and talk about the units because what I have not done is, I am using very frequently ppm, and microgram per unit cube and so on. I will derive an simple expression, takes about 5 minutes, but in view of the class they have, we will stop with here and then we will continue it further tomorrow.