Inorganic Chemical Technology
Prof. Nanda Kishore
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Lecture - 09
Industrial Gases - Carbon Dioxide

Welcome to the MOOC's course in Inorganic Chemical Technology, the title of today's lecture is Industrial Gases-Carbon Dioxide. Before, going into the details of a carbon dioxide such as its application in different forms, its production and economics etcetera. What we do we will be having a kind of recapitulation of what we have seen in previous lecture.

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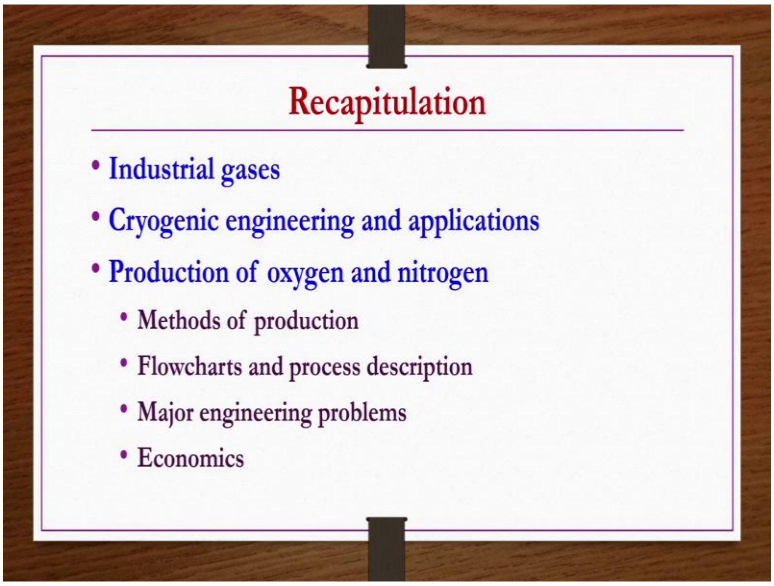

Recapitulation

- Industrial gases
- Cryogenic engineering and applications
- Production of oxygen and nitrogen
  - Methods of production
  - Flowcharts and process description
  - Major engineering problems
  - Economics

In the previous lecture we have seen a few basics of industrial gases what are these, why we are preparing or manufacturing industrially you know those details we have seen. We have also seen the requirement of cryogenics in the production of industrial gases or storage of industrial gases. So, what is the cryogenic? Some application of cryogenics etcetera those things also we have seen.

We have also seen production of oxygen and nitrogen by different methods, one is for the low purity tonnage oxygen another one is for a high purity oxygen production alright. We have also seen for these processes the flow charts and then process descriptions etcetera. And then we have seen what are the major engineering problems in production of oxygen and nitrogen; finally, a few economics of these industrial gases that is what we have seen in the previous lecture.

Now, in the today's lecture we are going to discuss about a another industrial gas that is carbon dioxide, its properties in different forms, its applications. And then production method or recovery methods etcetera of the carbon dioxide, that is what we are going to see in today's lecture.

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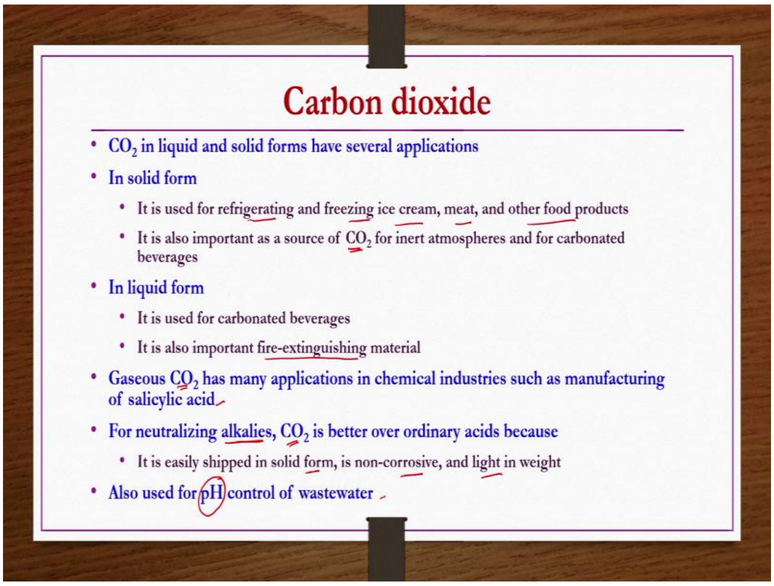

Carbon dioxide

- CO_2 in liquid and solid forms have several applications
- In solid form
  - It is used for refrigerating and freezing ice cream, meat, and other food products
  - It is also important as a source of CO_2 for inert atmospheres and for carbonated beverages
- In liquid form
  - It is used for carbonated beverages
  - It is also important fire-extinguishing material
- Gaseous CO_2 has many applications in chemical industries such as manufacturing of salicylic acid
- For neutralizing alkalies, CO_2 is better over ordinary acids because
  - It is easily shipped in solid form, is non-corrosive, and light in weight
- Also used for pH control of wastewater

We know that carbon dioxide in liquid and solid forms have several applications. Let us say in solid form it is used for refrigerating, freezing, ice cream, meat and other food products for this purpose it is often used. Then it is also important as a source of CO 2 for inert atmospheres and carbonated beverages etcetera. Not only in solid form, in the liquid form also it is having several applications.

Some of them include it is used for carbonated beverages and then it is also important fire extinguishing material as well. Then gaseous CO 2 also having a few applications in chemical industries such as, manufacturing of salicylic acid etcetera. Often whenever it is required to neutralize alkalis often you as often weak acids are used, but; however, CO 2 can also used for the neutralizing of alkalis and then it has been found that CO 2 is a better option over ordinary acids as well.

Because, it is shipped in solid form, it is non corrosive and light in weight ok, it is also used for pH control in waste water treatment. Because, earlier there were some objection for pH control of waste water using CO 2, but nowadays almost all industries they use CO 2 for pH control of their industrial waste water. Now, if you compare the properties of solid CO 2 that is a dry ice carbon dioxide versus water ice, then what you can find? You can find that it is having several advantages, these properties are tabulated here.

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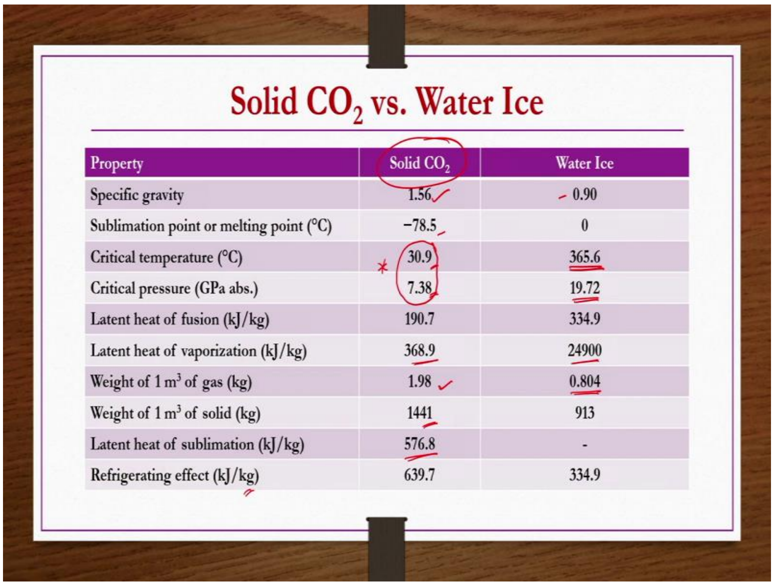

Solid CO_2 vs. Water Ice

Property	Solid CO_2	Water Ice
Specific gravity	1.56	0.90
Sublimation point or melting point (°C)	−78.5	0
Critical temperature (°C)	30.9	365.6
Critical pressure (GPa abs.)	7.38	19.72
Latent heat of fusion (kJ/kg)	190.7	334.9
Latent heat of vaporization (kJ/kg)	368.9	24900
Weight of 1 m^3 of gas (kg)	1.98	0.804
Weight of 1 m^3 of solid (kg)	1441	913
Latent heat of sublimation (kJ/kg)	576.8	-
Refrigerating effect (kJ/kg)	639.7	334.9

Let us say specific gravity if you take, it is its specific gravity that is specific gravity of solid CO 2 is much higher compared to the water ice. Sublimation point or melting point for solid CO 2 is minus 78.5 degree centigrade; whereas, it is 0 for water ice. Critical temperature is 30.9 degree centigrade's only for solid CO 2; whereas, it is very high for water ice that is 365.6 degree centigrade.

Similarly, critical pressure also it is very high for water ice that is 19.72 giga pascal's; whereas, it is very low for a solid CO 2 that is 7.38. Because, there are several super critical applications are there for this CO 2, those applications of super critical CO 2 are because of this lower critical temperature and critical pressure of CO 2 ok.

Latent heat of fusion is only 190.7 kilo joules per kg; whereas, it is almost double 300 334.9 kilo joule per kg for water ice. Similarly, latent heat of vaporization also very very low for solid CO 2 compared to water ice, that is for solid CO 2 it is 368.9 kilo joule per kg only; whereas for it is 24900 for water ice such huge difference.

Similarly, weight of 1 meter cube of gas in kg’s if you take it is it weights larger weight that is 1.98 kg’s you can feed 1 meter cube vessel. That means, indirectly in one meter cube vessel, you can feed 1.9 kg of a gases you can feed 1.98 kg’s of solid CO 2; whereas, water ice you can feed only 0.804 kg’s of water ice ok.

Similarly, if you take weight of 1 meter cube of solid in kg’s, then solid CO 2 is 1441 kg’s, because its specific gravity is higher; whereas, it is only 913 for water ice. Latent heat of sublimation is not there for water ice, but for solid it is 576.8 kilo joule per kg. Whereas, refrigerating effect because we know these material are especially solid CO 2 is used for the refrigeration purpose or storage of ice cream, meat etcetera for these purposes.

So, if you see the refrigerating effect per kg 639.7 kilo joules is possible by solid CO 2; whereas, only half of it or even less is possible for water ice that is 334.9 kilo joules per kg only. So, from these properties also what we can understand solid CO 2 dry ice is having superior properties compared to water ice; now, manufacture of pure CO 2 right.

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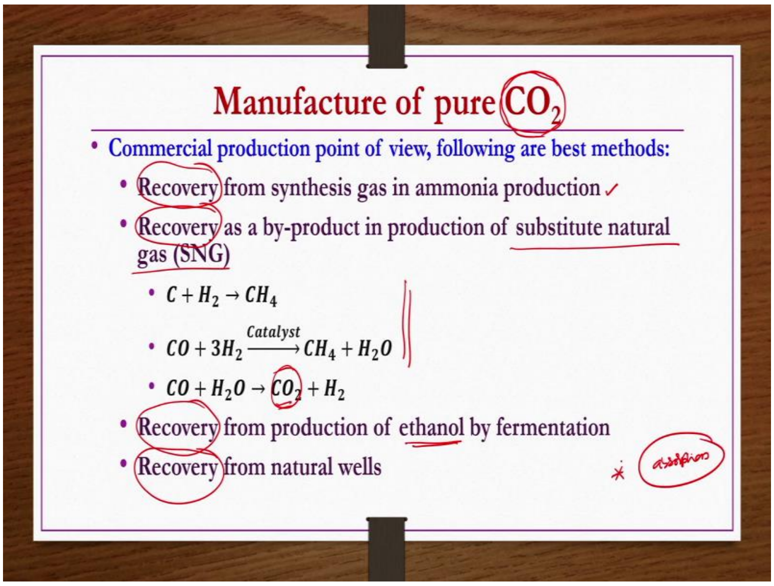

Manufacture of pure CO_2

- Commercial production point of view, following are best methods:
  - Recovery from synthesis gas in ammonia production ✓
  - Recovery as a by-product in production of substitute natural gas (SNG)
    - $C + H_2 \rightarrow CH_4$
    - $CO + 3H_2 \xrightarrow{Catalyst} CH_4 + H_2O$
    - $CO + H_2O \rightarrow CO_2 + H_2$
  - Recovery from production of ethanol by fermentation
  - Recovery from natural wells

* absorption

Commercial production point of view following are the best methods. So, before going to the best methods what we should understand that CO 2 in industries rather it is produced separately, it is recovered from different industries. Because, we know that in ammonia synthesis plants and then you know syn gas production plants, in fermentation plants for the production of ethanol etcetera all these processes we get a CO 2 also as a byproduct right.

Our flow gas also contains the CO 2; so, that CO 2 recovery is often done rather production of CO 2 separately ok; so, we see what are these recovery methods. So, recovery from synthesis gas in ammonia production, recovery as byproduct in production of substitute natural gas, substitute natural gas that is let us say if you have C plus H 2 you can get C H 4.

And then if you have CO CO plus 3 H 2 in the presence of catalyst you can get CH 4 which is known as methanation reactor. So, then the CH 4 production by these methods you know in industries is known as the synthetic natural gas, but the term synthetic and synthetic and natural are contradicting. So, the people started calling such kind of natural gas production; such kind of natural gas as substitute, substitute natural gas rather as synthetic natural gas right.

So, in the production of a substitute natural gas it is also possible that CO 2 forming through water gas shift reaction like shown here right; so, this CO 2 can also be recovered ok. Then recovery from production of ethanol by fermentation like, ethanol production by fermentation wherever we have whether it is by molasses or whatever method.

So, then CO 2 is also in general a produced if it is by fermentation if the ethanol production is by fermentation; so, that CO 2 can also be recovered, then recovery from natural wells. So, now what one thing that we should understand that all these methods are a kind of recovery, recovery of CO 2 while producing one or other chemicals industrially important chemicals that is what we see. So, also until now we have seen production of fuel gases and production of few industrial important gases only we have seen.

But by now already we understand that whenever we wanted to recover or remove CO 2 what we do? We use absorption, absorbing this particular gas by using some kind of solution; so, that is one of the important things. So, all these processes any process that you adopt to produce CO 2 or purify or capture CO 2 you will be doing absorption right, how do you do absorption?

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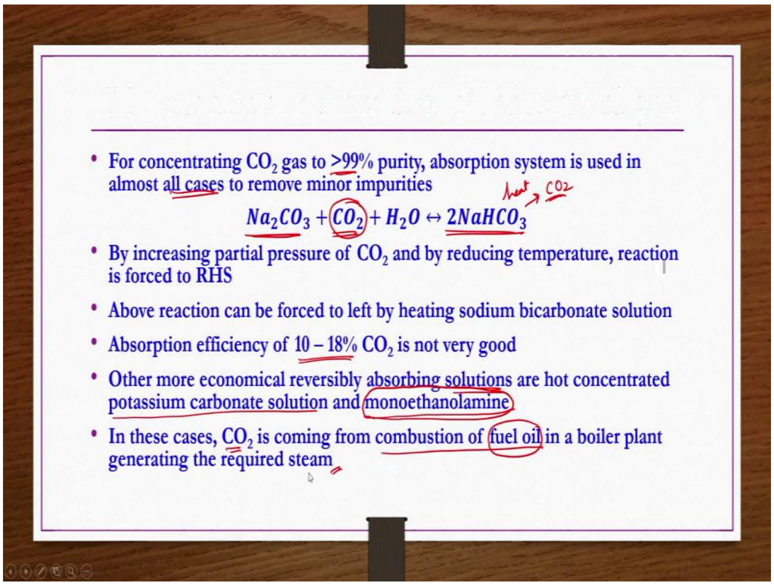

- For concentrating CO_2 gas to >99% purity, absorption system is used in almost all cases to remove minor impurities

$$Na_2CO_3 + CO_2 + H_2O \leftrightarrow 2NaHCO_3 \xrightarrow{heat} CO_2$$

- By increasing partial pressure of CO_2 and by reducing temperature, reaction is forced to RHS
- Above reaction can be forced to left by heating sodium bicarbonate solution
- Absorption efficiency of 10 – 18% CO_2 is not very good
- Other more economical reversibly absorbing solutions are hot concentrated potassium carbonate solution and monoethanolamine
- In these cases, CO_2 is coming from combustion of fuel oil in a boiler plant generating the required steam

You know you take some kind of solution and then try to absorb CO 2 in that particular solution, such details we are going to see now. Let us say for concentrating CO 2 gas to more than 99 percent, absorption system is used in almost all cases to remove minor impurities. Almost all cases in the sense, whatever that we have seen in the previous slides there may be other industries also ok.

So, how we do? We take a solution let us say Na 2 CO 3 solution sodium carbonate solution you are taking and then you try to absorb CO 2 in that one then spent liquid whatever that you get that would be sodium bicarbonate right. So, now, here let us say if you wanted to take out CO 2 from this one, simply you heat it.

You heat the solution this one; so, you get back your CO 2 in a pure form and then Na 2 CO 3 you can recover right. So, that is reversible reaction if you wanted to take if you want to carry separately after absorption. After absorption whatever solution this is there that you take in a different unit operation and then you heat it.

Then you can get the gases, out of that gases it will be having CO 2 along with some moisture or steam alright. So, but that is after absorption right, but initially you have to absorb CO 2 in Na 2 CO 3, for that you know forward reaction has to be taken has to take place.

So, forward reaction can take place if you increase the partial pressure of CO 2. How you can increase the partial pressure of CO 2 of the incoming gas which is being absorbed in Na 2 CO 3? If it is possible you can do it, otherwise what you can do you can increase the pressure of the system pressure of the absorbing system if you increase. So, partial pressure of CO 2 will; obviously, increase if its concentration is fixed.

So, that way you can make the reaction forward in a you can make reaction forward direction or you can decrease the temperature in the system; so, that the reaction moves towards the forward direction. If you wanted to get the reaction backward direction, you can simply heat the product 2 Na H CO 3; so, that to get back your CO 2 and Na O 2 and Na 2 CO 3 solution.

So, that Na 2 CO 3 that is sodium carbonate solution you can reuse for the absorption of more CO 2 ok alright. However, whenever you use such kind of solution, absorption has found to be very less up to 10 to 18 percent of CO 2 absorption only which is very less. So, then it is not efficient or economically it is not good one. So, then people have tried different solvents and then found that more economical reversibly absorbing solution or hot concentrated potassium carbonate solution and mono ethanolamine.

Mono ethanolamine solution wherever we use for the absorption of CO 2, then we call it as Gorbital process that we have seen previously and then today also we are going to see in one of the flow charts right. So, in these cases CO 2 is coming from combustion of fuel oil in a boiler plant generating the required steam. That is in a boiler plant somebody is producing the steam as per the requirement, when they are producing the steam they are what they are doing?

They are combusting the fuel oil or they may be combusting the coke alright. So, in that process you know CO 2 is are generated along with the steam, steam is their main product CO 2 is a byproduct that can be recovered, how it is that is what we are going to see now.

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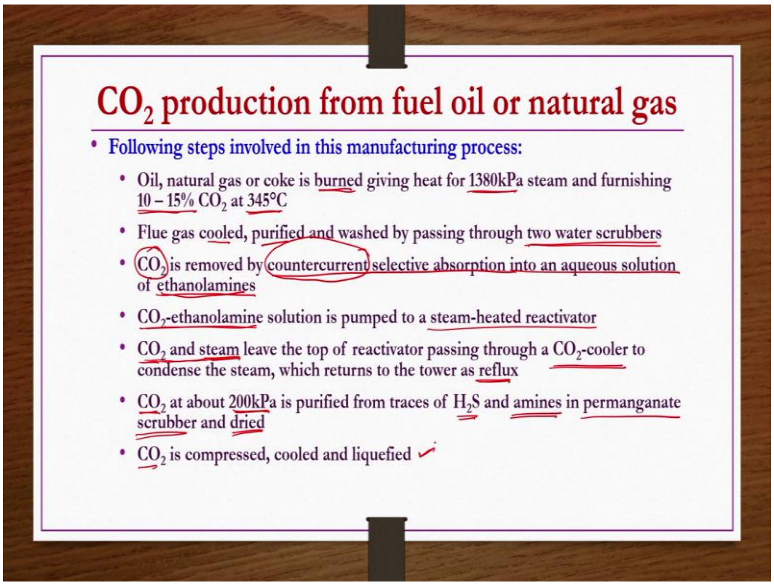

CO_2 production from fuel oil or natural gas

- Following steps involved in this manufacturing process:
  - Oil, natural gas or coke is burned giving heat for 1380kPa steam and furnishing 10 – 15% CO_2 at 345°C
  - Flue gas cooled, purified and washed by passing through two water scrubbers
  - CO_2 is removed by countercurrent selective absorption into an aqueous solution of ethanolamines
  - CO_2-ethanolamine solution is pumped to a steam-heated reactivator
  - CO_2 and steam leave the top of reactivator passing through a CO_2-cooler to condense the steam, which returns to the tower as reflux
  - CO_2 at about 200kPa is purified from traces of H_2S and amines in permanganate scrubber and dried
  - CO_2 is compressed, cooled and liquefied

CO 2 production from fuel oil or natural gas; first we see the steps involved in this process. then the same thing we are going to discuss in a flow chart as well, in a flow chart as well we are going to discuss the same thing. Following steps involved in this manufacturing process; oil or natural gas or coke whichever is your feed material to get the steam that is burnt in a water tube boiler ok.

For producing steam which is at 1380 kilo pascal and then it is giving flue gases that flue gases containing 10 to 15 percent of CO 2 and that is at 345 degree centigrade. So; obviously, the flue gas is at higher temperature what you have to do? You have to cool it, you have to cool it and then purify; so, that to get the; so, that to separate pure CO 2 as much as pure as possible.

Flue gas that cooled, purified, and washed by passing through two water scrubbers ok. So, since here the source of steam production is burning of oil, natural gas or coal; so, whenever you burn them there would be several hydrocarbons also in general. Some of them are water soluble, some of them are not water soluble alright. Then CO 2 is removed by counter current selective absorption into an aqueous solution of ethanolamines.

So, this whatever the flue gas is after cooling you know after washing with you know by using two water scrubbers right. It is again dried and then it is passed through a absorption column in which ethanolamine solution and then CO 2 are interacting in a counter current direction. So, that CO 2 would be get dissolved into the ethanolamines or absorbed by the ethanolamines and then it will forming CO 2 ethanolammine solutions ok.

And then whatever the flue gases which are not having CO 2 or CO 2 free flue gases would be taken away from the top of the absorption column ok. Whatever the CO 2 ethanolamine solution is there that is pumped to a steam heated reactivator, steam heated reactivator in the sense reactor or reactivator is there that is being heated by the steam to that one this solution is sent.

What is the point of it? When you heat this CO 2 ethanolamine solution in a reactivator you will get CO 2 and steam. From the top of the as in a kind of gaseous form you will get or any kind of gases form or in a kind of vapors form you will get CO 2 and steam they will be leaving the reactivator from the top. Whereas, the whatever the ethanolamine solution is there that will be collected from the bottom and then recirculated back to the absorption column alright.

So, whatever the steam and then CO 2 leaving the from the top of the reactivator that will be passing through a CO 2 cooler. Why are we passing it through CO 2 cooler? To condensate whatever the steam, because we want only CO 2 not the CO 2 plus steam. So, in order to condense there, condensate the steam this mixture is passed through a CO 2 cooler.

And then that steam once it is condensed that is sent back to the tower as a reflux ok. Now, after this step remaining CO 2 is would be at about 200 kilo pascal’s of the pressure and it is purified from traces of H 2 S and amines if at all they are present. How they do? It will be done by permanganate scrubber and then it is tried subsequently ok, this CO 2 is compressed cooled and liquefied further.

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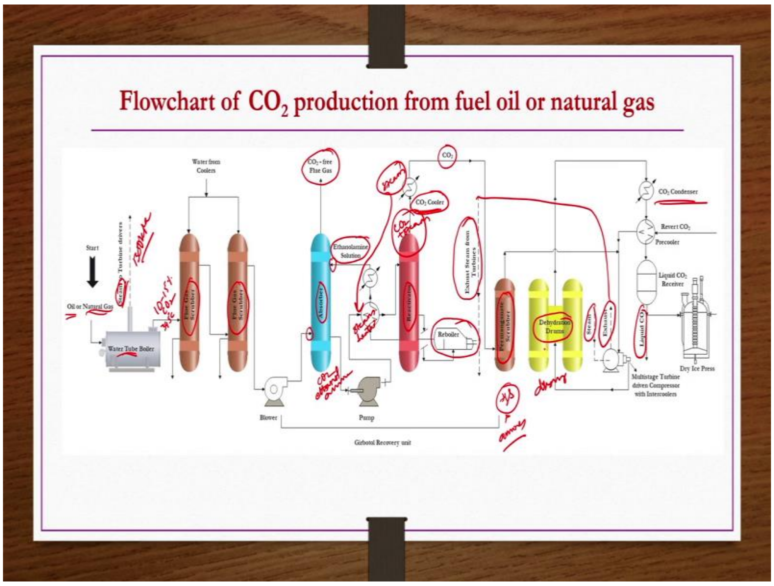

Flowchart of CO_2 production from fuel oil or natural gas

So, the same thing we are going to see in a flow sheet here, flow chart of CO 2 production from fuel oil or natural gas. So, the flow sheet whatever the steps that we have discussed in the previous slide are shown here again. So, steam is required to produce, the steam you are getting by burning oil or natural gas or coke in water tube boilers. So, you will get a steam which is at 1380 kilo pascal’s of pressure.

And then whatever the flue gases are there, they will be collected from here. These flue gases would be having 10 to 15 percents of; 10 to 15 percent of CO 2. These flue gases are very hot, because they are coming from the water tube boilers; so, they would be at something like 345 degree centigrade.

So, then what we do? We cool them and then try to remove any water soluble hydrocarbons etcetera if at all present in this one, because the feed is oil or natural gas. So, then when it is being burnt; so, then not only the steam and then CO 2, but other hydrocarbons may also possible. If at all there; so, they can be washed by water by using the flue gas scrubbers to flue gas scrubbers ok.

So, then after the cooling what would be done? So, the gases whatever are coming from the second scrubber they will be sent to an absorber sent to an absorber to which ethanolamine solution is fed from the top and then gases are fed from the bottom. So, that in a counter current way they will interact they will interact. So, in this absorption column what will happen, CO 2 would be absorbed by ethanolamine solution.

And then whatever CO 2 free flue gases are there they will be collected from the top. Depending on the compression of the flow gas subsequent processes should be done that is not required to discuss here ok. And then whatever the CO 2 ethanolamine solution is there that is pumped through a steam heated chamber to re-activator to re-activator ok.

So, why? Because, here the when you heat it what happen the CO 2 whatever is there that will be collected from the top. So, not only CO 2, there would also be some steam would be there from the top; so, CO 2 plus steam would be there. So, what we do? This mixture of gases or vapors we pass through a CO 2 cooler; so, that steam would be condensed here and then pure CO 2 would be sent to the subsequent purification step.

Whatever the steam that will be recovering as a condensate here, while this flue gas is passing through the CO 2 cooler; so, that steam is fed back to this steam heater again ok. That is the advantage here. And then CO 2 if it is containing any traces of H 2 S etcetera or amines, because for removing the other gases flue gases this flue gas mixture is passed through absorption column where ethanolamine solution is there.

So, CO 2 ethanolamines are forming; so, when you send them to re-activator CO 2 along with this steam are being released. So, in this process because we are heating not only this CO 2 and then steam, but also some amines may also be there in the there in these vapors in these vapors right; so, those things has to be removed right.

If your in your source that is in natural gas or oil whatever you are taking that feed material, if there is a some if there is a sulphur, then there is also possibility of H 2 S. So, then removal of that H 2 S and amines would be done by using this permanganate scrubbers alright. That whatever the final flue gases which is very rich in CO 2, if at all it is having some traces of H 2 S, and then amines then only this step is required ok.

So, when you removing these things; obviously, well we are doing this process what is happening? These gases you know are you know CO 2 is wet; so, dehydration is required. So, dehydration has been done in the drums for the drying of the gas purpose ok. So, now, these dried gases are sent to the CO 2 condenser and then liquefied CO 2 receiver and then collect as liquid CO 2 ok.

So, now, here whatever the gases they are coming from the permanganate scrubber after removing the traces of H 2 S and amines, they would be fed through multistage turbine driven compressor with intercoolers. So, here we are giving some steam for this compressor ok, it is required; so, then whatever the exhaust steam is there that can also be reused for this re-boiler water re-boiler here alright.

So, exhaust stream exhaust steam from turbines whatever is there this one that would be used for re-boiler here again ok. Now, let us say if your product is liquid CO 2; so, then you can collect as liquid CO 2 after the this CO 2 condenser and then liquid CO 2 receiver etcetera.

But; however, if you wanted to produce solids then that will be sent to the air compressor where dry ice you know solids have been collected and then different sizes or shapes as per the requirement different size ice cubes are prepared ok. Whatever the CO 2 in gases form or liquid form instead that will be revert back to this CO 2 for this dehydration steps and then that continues here ok.

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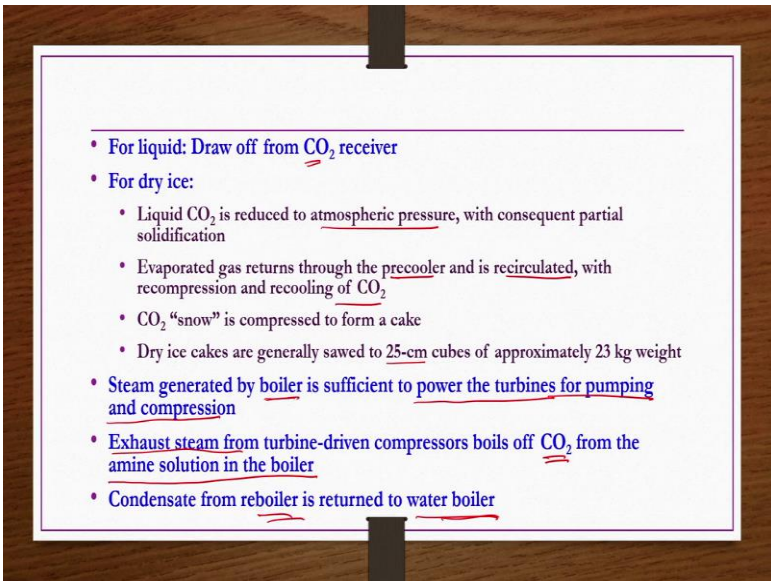

- For liquid: Draw off from CO_2 receiver
- For dry ice:
  - Liquid CO_2 is reduced to atmospheric pressure, with consequent partial solidification
  - Evaporated gas returns through the precooler and is recirculated, with recompression and recooling of CO_2
  - CO_2 “snow” is compressed to form a cake
  - Dry ice cakes are generally sawed to 25-cm cubes of approximately 23 kg weight
- Steam generated by boiler is sufficient to power the turbines for pumping and compression
- Exhaust steam from turbine-driven compressors boils off CO_2 from the amine solution in the boiler
- Condensate from reboiler is returned to water boiler

So, if the liquid is your main product then a draw from CO 2 receiver in liquid form However, if you want dry ice; so, then what you can do liquid CO 2 is reduced to atmospheric pressure with consequent partial, solidification, evaporated gas returns through the pre-cooler and is re-circulated with the recompression and re-cooling of CO 2.

CO 2 S now is compressed to form a cake, dry ice cakes are generally sawed to 25 centimeter cubes of approximately 23 kg weight, but; however, it depends on the application to application. Steam generated by boiler is sufficient to power the turbines for pumping and compression. Whereas, the exhaust steam from the turbine driven compressors boils off CO 2 from the amine solution in the boiler that is before the re-activator.

Then whatever the condensate from the re-boiler is there that is returned to the water boiler as well. So, what you understand from here; so, the steam generated extra exhausted steam etcetera not only them, but also condensate is also be applicable or applied or utilized in the same process same plant.

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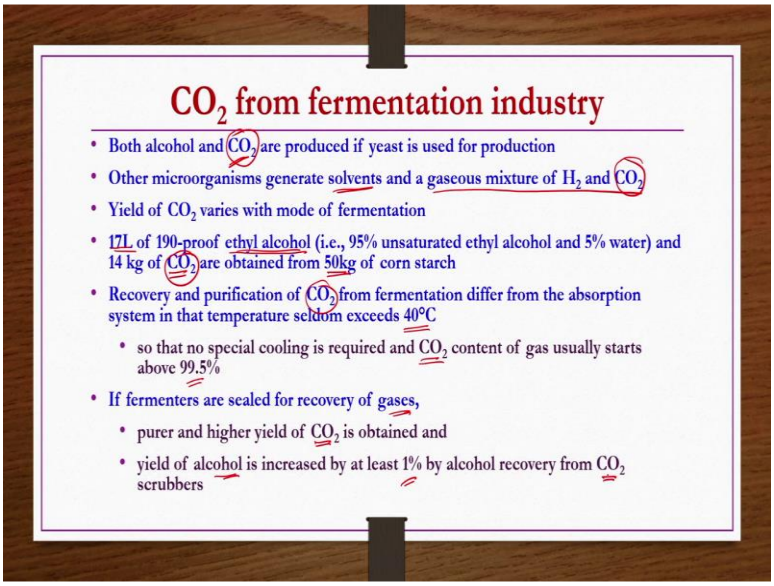

CO_2 from fermentation industry

- Both alcohol and CO_2 are produced if yeast is used for production
- Other microorganisms generate solvents and a gaseous mixture of H_2 and CO_2
- Yield of CO_2 varies with mode of fermentation
- 17L of 190-proof ethyl alcohol (i.e., 95% unsaturated ethyl alcohol and 5% water) and 14 kg of CO_2 are obtained from 50kg of corn starch
- Recovery and purification of CO_2 from fermentation differ from the absorption system in that temperature seldom exceeds 40°C
  - so that no special cooling is required and CO_2 content of gas usually starts above 99.5%
- If fermenters are sealed for recovery of gases,
  - purer and higher yield of CO_2 is obtained and
  - yield of alcohol is increased by at least 1% by alcohol recovery from CO_2 scrubbers

Now, what we see? CO 2 production from the fermentation industry. For the production of alcohol, if the yeast is used; so, then along with the alcohol you will also get CO 2 right. In some other fermentation where yeast is not used some microorganisms are also used; so, under such conditions also some solvents would be generated along with the gases mixture of H 2 and CO 2.

So, this CO 2 can be recovered; that means, from the fermentation industry whether it is ethanol production or any other fermentation industry there is a possibility of CO 2 and then that can be recovered ok. Now, yield of CO 2 varies with mode of fermentation; for example, 17 liters of 190 proof ethyl alcohol, 190 proof ethyl alcohol is nothing but 95 percent unsaturated ethyl alcohol and 5 percent water that is produced.

And 14 kg’s of CO 2 is produced from 50 kg of corn starch; let us say, from the corn starch by fermentation if you are producing ethyl alcohol then you will be getting 17 liters of 95 percent unsaturated ethyl alcohol and then 14 kg’s of CO 2. So, this 14 kg’s of CO 2 you can get and then this you are getting from 50 kg’s of cornstarch

Then you can see what is it is a roughly one third of the feed material on mass basis if you take one third of the feed material is being converted into the carbon dioxide. Such large amount of carbon dioxide is being produced; so, that can be recovered for the applications wherever CO 2 is required either in gases form, liquid form or solid form.

So, recovery and purification of CO 2 from fermentation differ from the absorption system. Whatever, the previous sections that we have seen by absorption, because in absorption you are having some conditions like you know 345 degree centigrades or even something like that 200 kilo pascal’s etcetera. But in fermentation the temperature never exceeds 40 degree centigrade in general; so, if the temperature does not increase 40 degree centigrades in general.

So, then; obviously, one important advantage is that you do not need any unit operation for cooling purpose. So, that is no special cooling is required and then CO 2 content of gas usually starts above 99.5 percents. If the fermenters are sealed for recovery of gases, then also yield of CO 2 increases also purity of CO 2 increases. So, but in addition to that one the yield of alcohol also increases by at least 1 percent, by alcohol recovery from CO 2 scrubbers.

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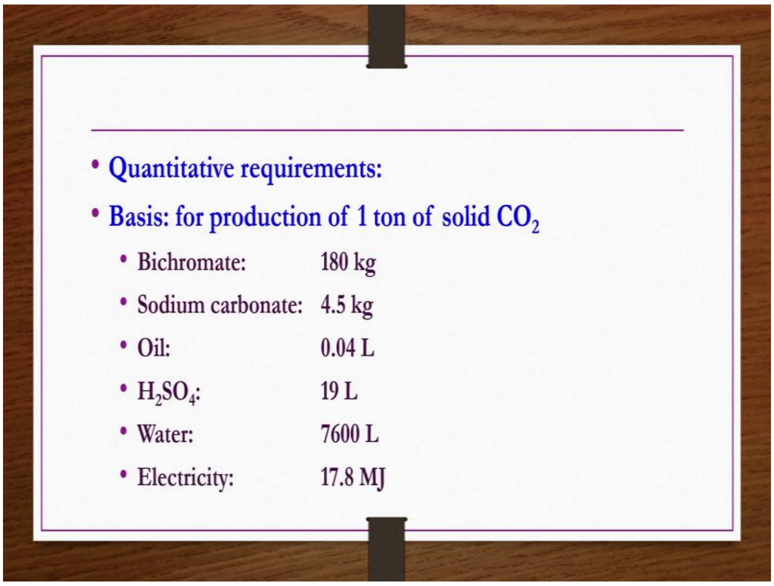

- Quantitative requirements:
- Basis: for production of 1 ton of solid CO_2

Bichromate:	180 kg
Sodium carbonate:	4.5 kg
Oil:	0.04 L
H_2SO_4:	19 L
Water:	7600 L
Electricity:	17.8 MJ

Now, let us say if you wanted to produce you know CO 2 from ethanol fermentation industry, then what are the raw materials and then what are the quantitative requirements etcetera we are going to see now ok. So, let us say if you wanted to produce one ton of solid CO 2, bichromate solution you need 180 kg's sodium, carbonate solution you need 4.5 kg's, oil usually glycerin is considered for this purpose that is 0.04 liters required.

And then concentrated sulfuric acid 19 liters required, water 7600 liters required; whereas, the electricity 17.8 mega joules ok.

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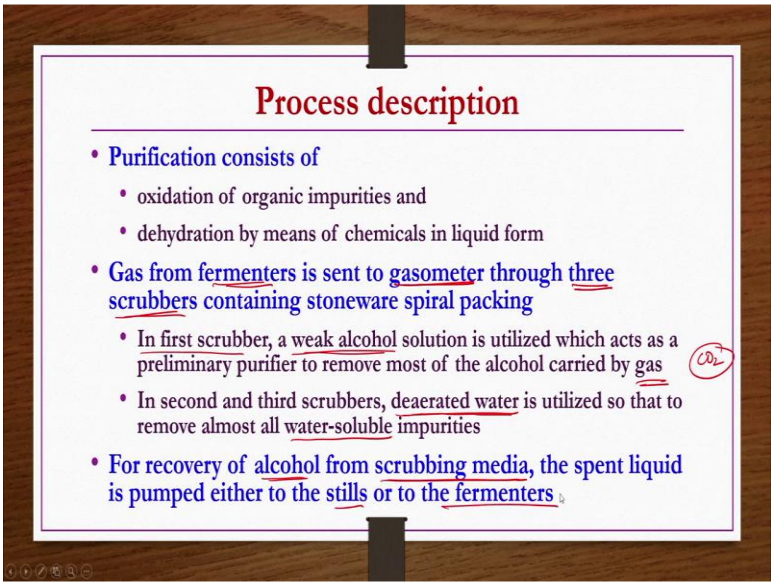

Process description

- Purification consists of
  - oxidation of organic impurities and
  - dehydration by means of chemicals in liquid form
- Gas from fermenters is sent to gasometer through three scrubbers containing stoneware spiral packing
  - In first scrubber, a weak alcohol solution is utilized which acts as a preliminary purifier to remove most of the alcohol carried by gas CO_2
  - In second and third scrubbers, deaerated water is utilized so that to remove almost all water-soluble impurities
- For recovery of alcohol from scrubbing media, the spent liquid is pumped either to the stills or to the fermenters

Now, here also first what we do we see process description then we go to the flow chart. So; obviously, that we understand that from the fermentation industry if you are producing CO 2, it is mostly purification it is mostly purification again. So, purification here in this process consists of two important steps; one is the oxidation of organic impurities if at all present.

Obviously, they will be present, because ethanol let us say in this process ethanol production from the starch we are doing. So, then so many organic impurities would be there; so, oxidation of such organic impurities is required. Then dehydration by means of chemicals in liquid form right; so, so many I mean like in the process like you know like fermentation usually contains you know lot of moisture kind of conditions at less than or equals to 40 degree centigrade.

So, then dehydration or the drying of the gases is required that is also done by the chemical means by using some kind of chemicals or sulfuric acid something like that ok. So, now, whatever the gas from the fermentation is there that would be sent to the gasometer right. Before sent to the gasometer, it will be sent through three scrubbing units they would be containing stoneware, spiral packing.

So, what is the purpose of these scrubbing units? First one is the or in the first scrubber what we have? We have a weak alcohol. So, what is the purpose of this one? Is to it will act as preliminary purifier to remove most of the alcohol carried by the gas whatever the gas that is there mostly CO 2 let us say. If at all it is carrying alcohol also if you wanted to remove that one you need to have this preliminary purifier in the form of a scrubbing with weak alcohol ok.

Then second and third scrubbers they are containing or you know in the second or in the second and third scrubbers we will be having deaerated water which is used for removing almost all water soluble impurities. In ethanol production most of the impurities whatever are there mostly they are water soluble. So, most of them are may be removed by scrubbing the feed in the water scrubber ok by using deaerated water.

For recovery of alcohol from scrubbing media, the spent liquid is pumped either to the steels or to the fermenters back ok.

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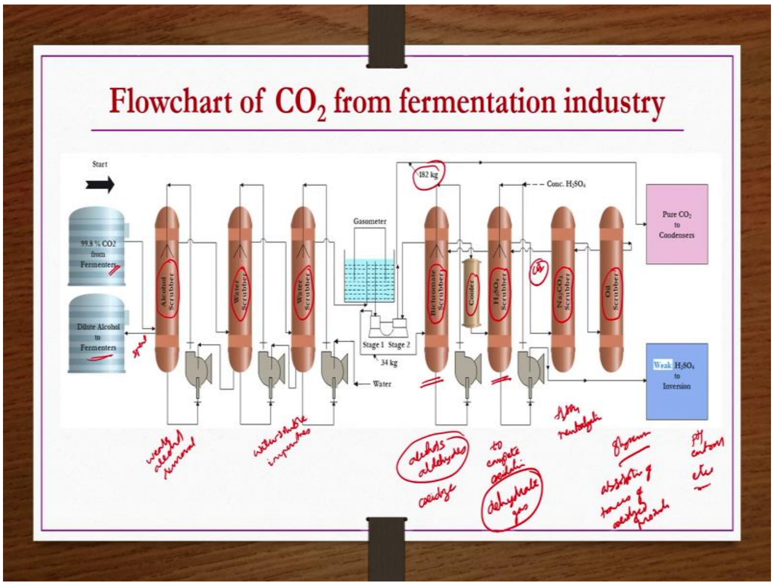

Flowchart of CO_2 from fermentation industry

Now, same thing we see in a flow sheet form now, whatever the CO 2 that you are getting from the fermenter industries along with the alcohol. So, you separate the alcohol whatever the gases that are there in the fermentation industries you take them in a alcohol scrubber. Using weak alcohols, you know if the gas if the CO 2 gas is containing any alcohols they can be removed by this weak alcohols in the alcohol scrubber units.

So, spent alcohols whatever are there they can send back to the you know fermentation, fermentation or fermentation units back ok. So, after removing the alcohol or once the gas you assume that or you found or your process conditions you maintain such a way that the gas is now free from the alcohol. Then what you do that you send to the second and third scrubber where we are using deaerated water to remove water soluble to remove water soluble impurities these two things.

Whereas here, you know weak alcohol the removal is taking place right. So, once the water soluble impurities and then weak alcohols have been removed from the gas that would be sent through a gasometer. And then from the gasometer what we do? We send it to the bichromate scrubber, bichromate scrubber will send it to the bichromate scrubber.

What is the point of sending here this bichromate scrubber? Because we know that CO 2 is coming from the fermentation industries. So, then that will be containing some alcohols, aldehydes etcetera whatever the purification you do some amount would definitely be there. So, what you do? You oxidize them, if you oxidize them you can get some more CO_2 etcetera.

So, that oxidization would be done here in the bichromate scrubbers. So, after this bichromate scrubber whatever the effluent gases are there they would be further sent back they would be cooled they would be cooled and then sent to sulfuric acid scrubber. The purpose of using sulfuric acid scrubber is to complete oxidation.

Let us say if at all some amount of or some traces of alcohols aldehydes etcetera are not being, oxidized completely in bichromate scrubber, then they will be completely oxidized in the H_2SO_4 scrubber ok. In addition to that one it will also dehydrate gas, the H_2S scrubber; so, H_2SO_4 is coming from the top and then gases are coming from the bottom.

In fact, all scrubbing units and the same thing happens the liquid or scrubbing medium is coming from the top and then gases. Gases mixture is coming from the bottom and the counter current way they interact and then absorption of a specified or targeted gases component takes place right.

So, now here from here whatever you know CO_2 is there which is almost pure which is almost pure, but; however, some traces of H_2SO_4 may be there some traces of H_2SO_4 may be there. So, then neutralization is required, because some end to end H_2SO_4 may also be coming from the top of the H_2SO_4 scrubber along with the CO_2 gas. So, those entrained are traces of H_2SO_4 should be neutralized; so, that you can get a pure CO_2.

For that purpose what you do that CO_2 which is containing traces of H_2SO_4 acid mix etcetera. They will be scrubbed in another column where sodium carbonate solution will be using. This sodium carbonate solution will use; so, then that will be absorbing CO_2; so, then that you will be having you know you know you know $NaHCO_3$ sodium bicarbonate solution would be formed. That solution may be collected and then you know heated to get the CO_2 ok.

Whatever the traces of H_2SO_4 are there, they are removed in Na_2CO_3 scrubber. So, after that pure CO_2 whatever is there that is almost pure; so, that will be sent through oil, scrubber oil scrubber usually use glycerin as a medium, it will be to use absorption of traces of oxidized products. Because, prior to this step what we have?

We are having we are having bichromate scrubber step and then H 2 SO 4 scrubber steps, where you know oxidation of any you know amines aldehydes etcetera that are present along with the gas that is taking place oxidation of those components are taking place.

So; obviously, when oxidation of this aldehydes amines taking place; so, then there would be oxidation products also depending on the products different types of oils are used to absorb them often you know glycerin is used. So, through this one you know you can remove them also remove those solutions as well. So, whatever the CO 2 purified CO 2 is there that is sents back and then it continues for the second stage, this goes for the two stages; so, that more and more purification takes place ok.

So, whatever the pure after second stage? Whatever the pure CO 2 is there you get roughly 182 kg's and then that will be sent to condenser for condensation. Whereas, the weak H 2 SO 4 or spent H 2 SO 4 solution that we you get from the H 2 SO 4 scrubber that will be taken for a pH control purpose etcetera.

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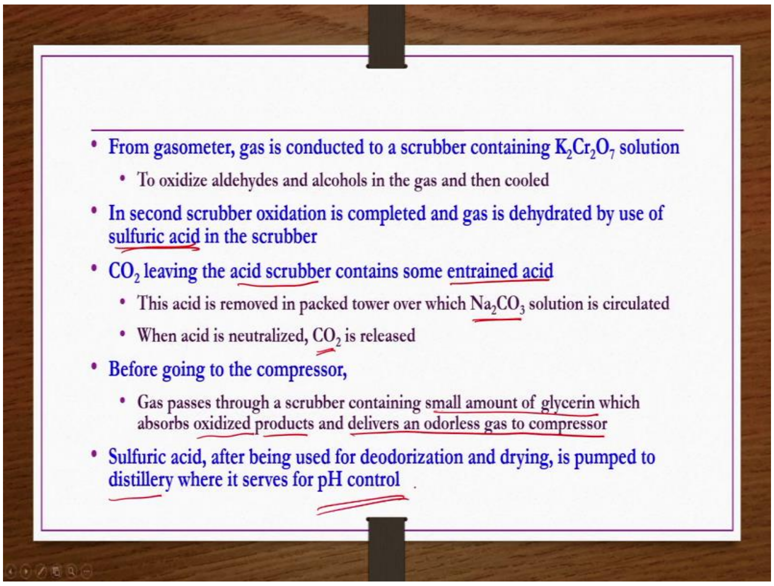

- From gasometer, gas is conducted to a scrubber containing $K_2Cr_2O_7$ solution
  - To oxidize aldehydes and alcohols in the gas and then cooled
- In second scrubber oxidation is completed and gas is dehydrated by use of sulfuric acid in the scrubber
- CO_2 leaving the acid scrubber contains some entrained acid
  - This acid is removed in packed tower over which Na_2CO_3 solution is circulated
  - When acid is neutralized, CO_2 is released
- Before going to the compressor,
  - Gas passes through a scrubber containing small amount of glycerin which absorbs oxidized products and delivers an odorless gas to compressor
- Sulfuric acid, after being used for deodorization and drying, is pumped to distillery where it serves for pH control

So, that is remaining steps are from the gasometer, gas is conducted to scrubber containing bichromate solution. The purpose of this scrubber to oxidize aldehydes and alcohols in the gas and then cooled. In the second scrubber oxidation is completed and gas is dehydrated by the use of sulfuric acid. In the sulfuric acid scrubber CO 2 leaving the acid scrubber contains some entrained acid also; so, neutralization is required.

So, this acid is removed in packed tower over which Na 2 CO 3 solution is circulated and when acid is neutralized CO 2 is released. Before going to the compressor, gas passes through a scrubber containing small amount of glycerin which absorbs oxidized products and delivers an odorless gas to compressor. Sulfuric acid after being used for deodorization and drying is pumped to the distillery where it serves for pH control purpose.

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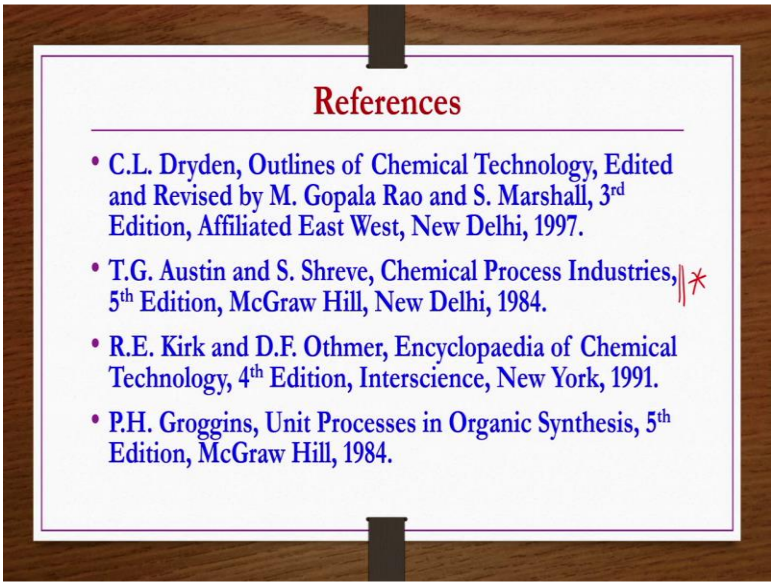

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Reference for today’s lecture are provided here, but; however, the notes that is presented in this today’s lecture is you know taken from this book Chemical Process Industries by Austin and Shreve.

Thank you.