Air Pollution Control
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Lecture 47
Practice Examples on Gaseous Emission Control Devices

Hello friends. Last time we discussed about practice examples related to particulate matter control devices. So, today we will discuss upon several examples which are related to gaseous emission control devices.

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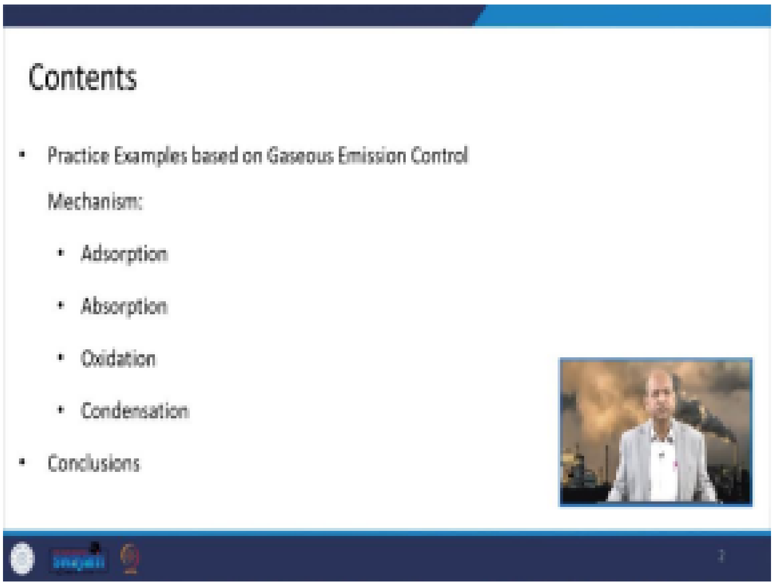

So, basically we will include the mechanism which governs the control devices or on the mechanism on which it is based those devices like adsorption, absorption, oxidation or condensation. These are basic physico-chemical principles on which gaseous emissions are controlled. So, those devices are based on these particular principles.

So, we will look into one by one and before that I would like to highlight some data which can be used here because we have taken several examples from FPS system.

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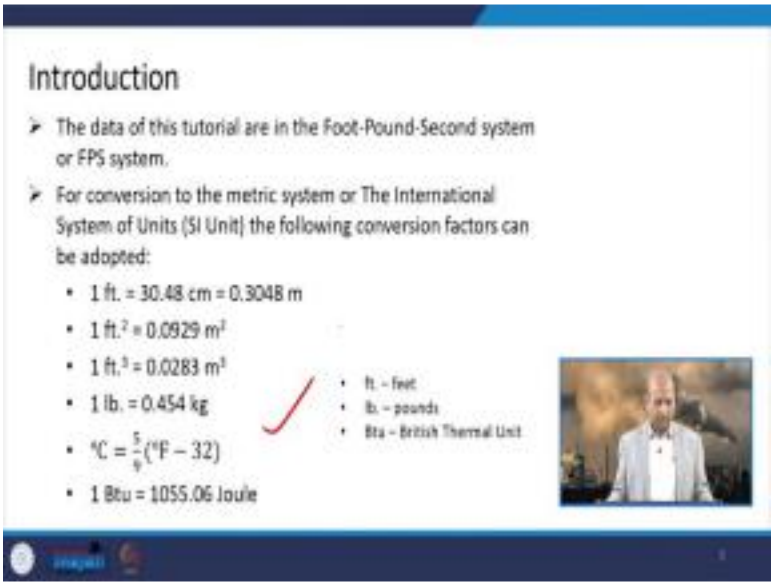

So, basically if you want to convert them into like this SI units, International Systems units or metric system then these are the basic conversion factors which can be readily used.

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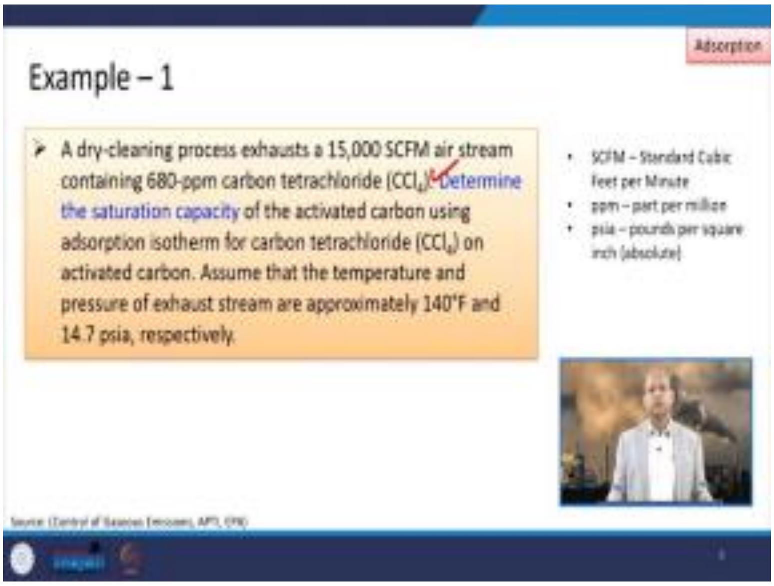

Well, so for example, we go for a dry-cleaning process exhaust means exhaust emissions are there and that air stream is having like a standard cubic feet per minute exhaust emission of 15,000 SCFM that is Standard Cubic Feet per Minute air stream exhaust and that contains around 680 PPM this carbon tetrachloride, CCl_4 carbon tetrachloride.

So, we need to determine the saturation capacity of the activated carbon which will be used in this adsorption system. So, these adsorption isotherms for carbon tetrachloride on activated carbon which we use, so we have to determine what is the saturation capacity and we have to assume that the temperature and pressure of exhaust stream are approximately around 140 degrees Fahrenheit and 14.7 this psia (pounds per square inch in absolute terms). So, these are the values which are given.

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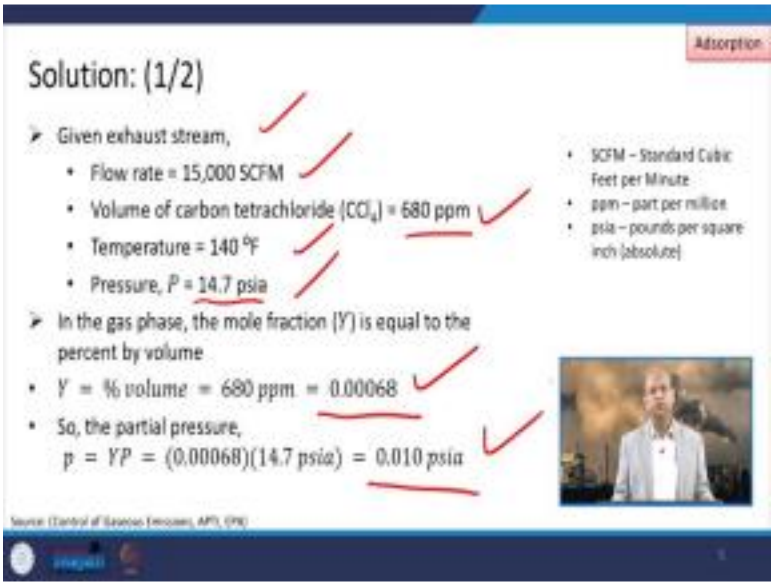

So, basically you can see the given values are of the exhaust system, exhaust stream system. Flow rate is around 15,000 SCFM that is a standard cubic feet per minute, volume of the carbon tetrachloride is 680 PPM, temperature and pressure is given. So, we need to convert first of all the mole fraction that is because 680 PPM is given. So, basically you can call it 0.0068 fraction in fraction volume it is in percentage or in PPM we have to convert.

So, in percentage volume 680 PPM will be known as 0.0068. So, this is the fraction basically. Then we can see this partial pressure. So, partial pressure we convert this 14.7 pounds per square inch which can be multiplied by this fraction that is 0.0068. So, we get this partial pressure of CCl_4 that is the carbon tetrachloride and that is around 0.010 pounds per square inch in absolute terms.

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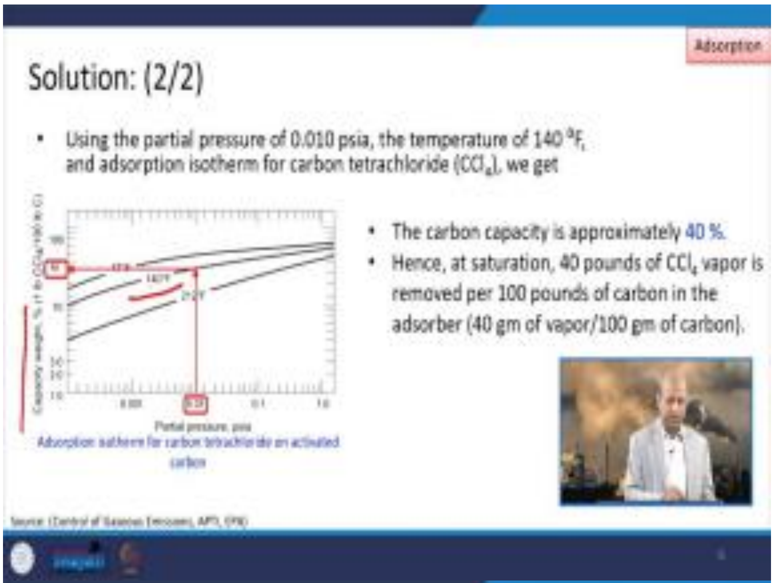

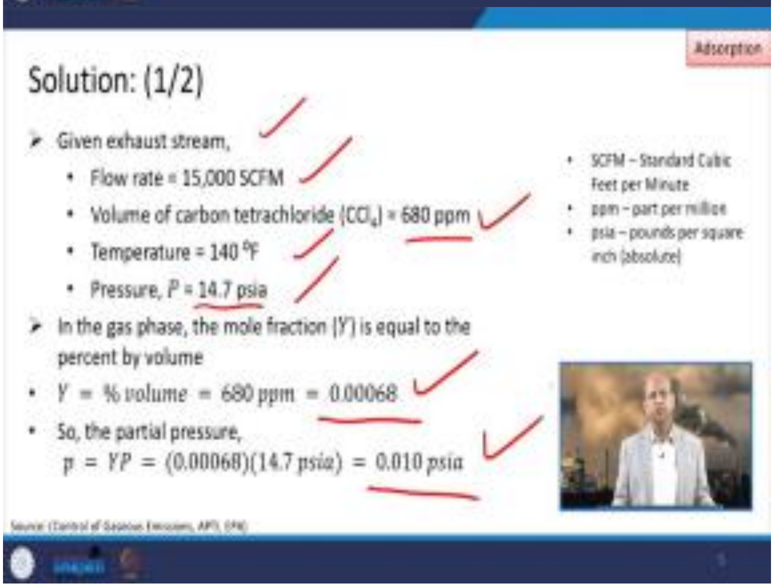

Then, we have this plot which can give us the value of percentage, this capacity weight in percentage per 1000 pound of the carbon. So, we go for this value which we have determined 0.01. So, 0.01 we go for 140 degree Fahrenheit this particular plot and go on the left side and we get this value is around 40 percent and that is per 1000 pounds of the carbon. So basically, we can say that 40 gram of the vapor per 100 gram of the carbon is the saturation value up to that only it will be removed.

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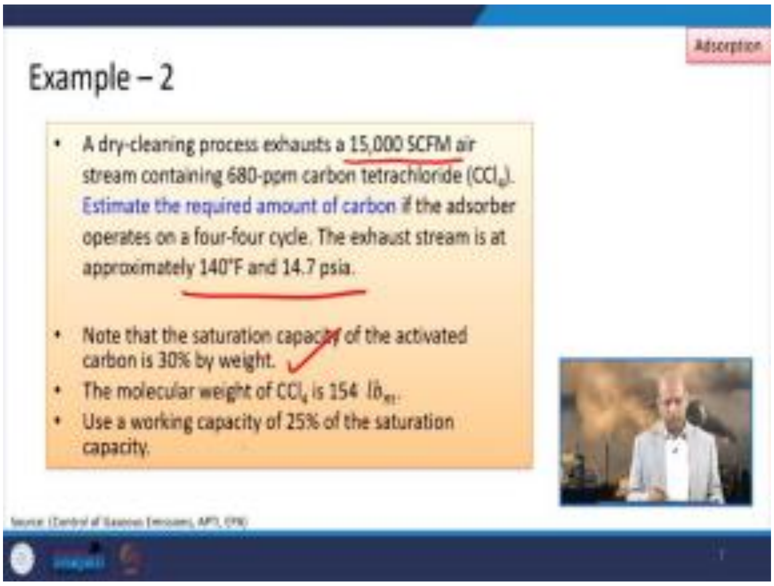

The next example is related to dry-cleaning process, the same example basically which we have seen. So, here values are same 15,000 SCFM that is standard cubic feet per minute of the stream flow and 680 ppm of carbon tetrachloride is there. We need to estimate the required amount of carbon which will adsorb in 4 by 4 cycle.

And this exhaust stream is again operating with the same temperature pressure. Here, we have to note that the saturation capacity of the activated carbon is 30 percent by weight this is given. Then molecular weight of CCl_4 is 154 this pound mole you can say like gram mole we represent in SI system or metric system similarly, this is pound mole.

Then we need to use working capacity of 25 percent of the saturation chemistry. So, we need to use these values to estimate the total requirement of the carbon which will adsorb this total carbon tetrachloride.

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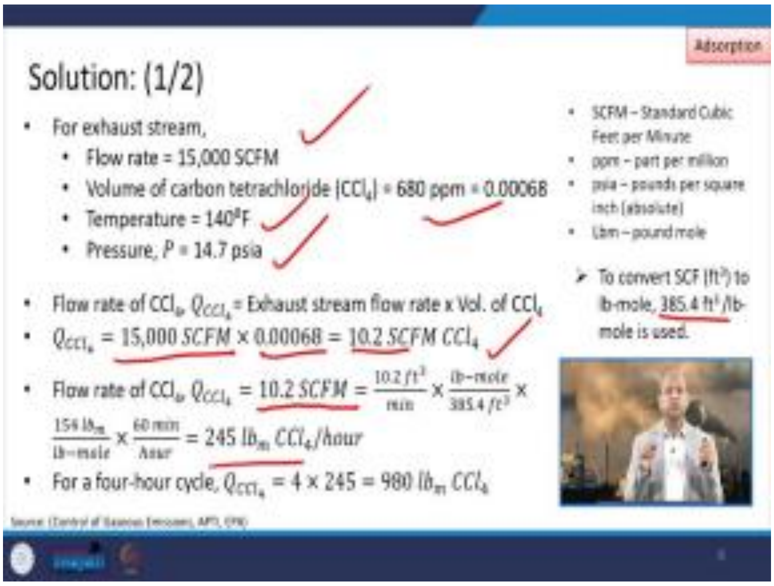

So, again those are the values which are given fraction 680 ppm we can be present into 0.0068 then temperature is given pressure is given. Now, we need to calculate flow rate of this carbon tetrachloride. So, flow rate means you have to multiply this flow this SCFM into the fraction which we have done 10.2 SCGFM of the CCl_4 that is the standard cubic feet per minute. Now, we can convert it into this like pound mole per hour.

So, what we need to do? We need to multiply this value of 10.2 SCFM with this pound mole in how much cubic feet pound mole is aerated. So, your value is given. To convert SCF that is the cubic feet to pound mole we have to use this particular factor basically because this cubic feet is per pound mole it is used. So, we have to multiply that and then we can convert minute into hour.

So ultimately, we can say that this is the pound mole of the carbon tetrachloride per hour in this particular flow rate. So, a 4-4 cycle, four-hour cycle four hour cycle, basically you need to multiply this value with 4 hour because that was the per hour value. So, 4 hour means 980 pound mole of carbon tetrachloride will be absorbed or removed.

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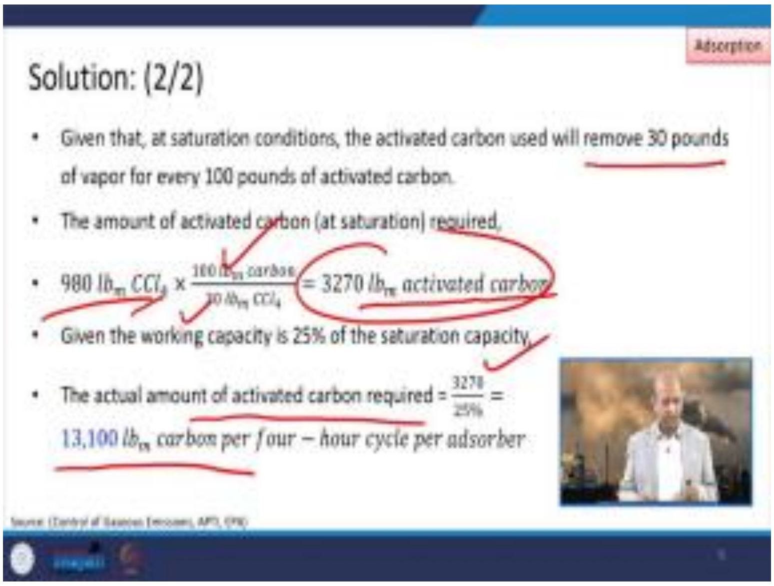

Now, what we need to see the saturation conditions. The activated carbon which is using this particular mechanism and removing around 30 pounds of the vapor for every 100 pounds of the activated carbon that is the 30 percent. So, with that value, you can use the 30 and 100 value and convert this 980 pound mole into total pound mole activated carbon.

This was the value of carbon tetrachloride. So, for removing that particular value, we need this much of amount of the activated carbon. So, given the working cycle of 25 percent of the saturation capacity, only 25 percent it is working. So, you divide by 0.25 then we get total amount of the activated carbon. We divide by 0.25. So, we get this much amount of this carbon per hour, 4-hour cycle of the adsorber basically.

The actual amount of activated carbon required = $\frac{3270}{25\%} = 13{,}100\ lb_m\ carbon\ per\ four - hour\ cycle\ per\ adsorber$

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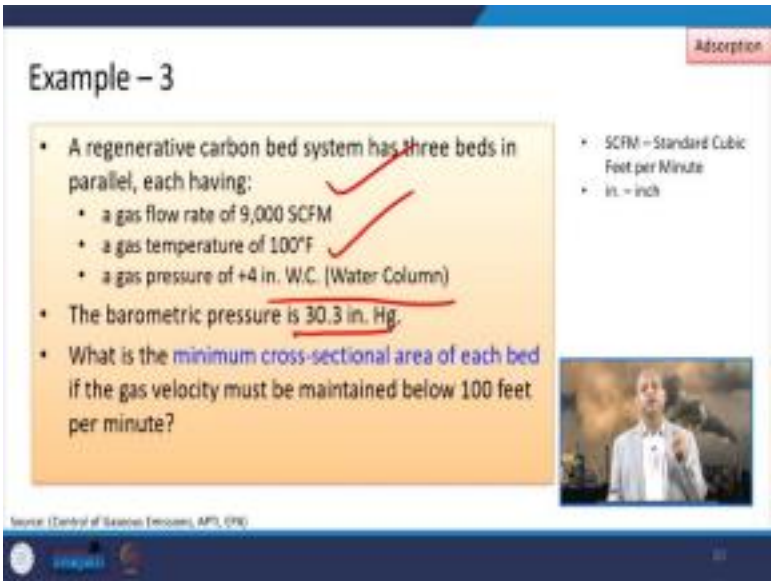

Next, we have to see this regenerative carbon bed system which has three beds in parallel basically and it is removing the gas flow rate of this 9000 SCFM, temperature is given, gas pressure is given in terms of water column. Now, please always pay attention to the units. It is very important when we are calculating something then we have to give proper attention to the units. If we do not use proper units, then calculations will be erroneous and our design of the instrument will be totally wrong.

And we will not achieve those objectives or goals we want to achieve for removal of the air pollutants. So, barometric pressure is around 30.3 inch of the mercury. So, what is the minimum cross-sectional area of the each bed if the gas velocity must be maintained below 100 feet per minute? So, those values are given and we have to estimate this minimum cross sectional area.
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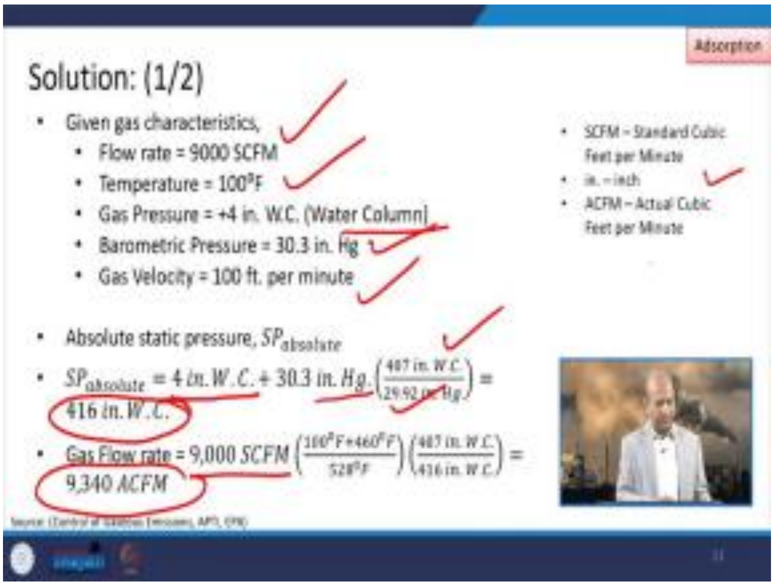

So again, first of all, put all the values which are given in the problem, problem statement. So, the given gas characteristics are flow rate is this much then temperature is given gas pressure is given in terms of water column, barometric pressure 30.3 inch mercury gas velocity is also given. Now we estimate this absolute static pressure, SP absolute.

So, you can convert this 4 inch of this water column plus 30.3 inch of the mercury convert into water column again, 29.92 of the mercury 407 inch of the water column. So, we get the value of 416 inch of the water column. Gas flow rate 9000 SCFM given, temperature is given. So, you can convert and you get this value of ACFM (actual cubic feet per minute). And that is the value of 9,340 of the actual cubic feet per minute. This is the value.

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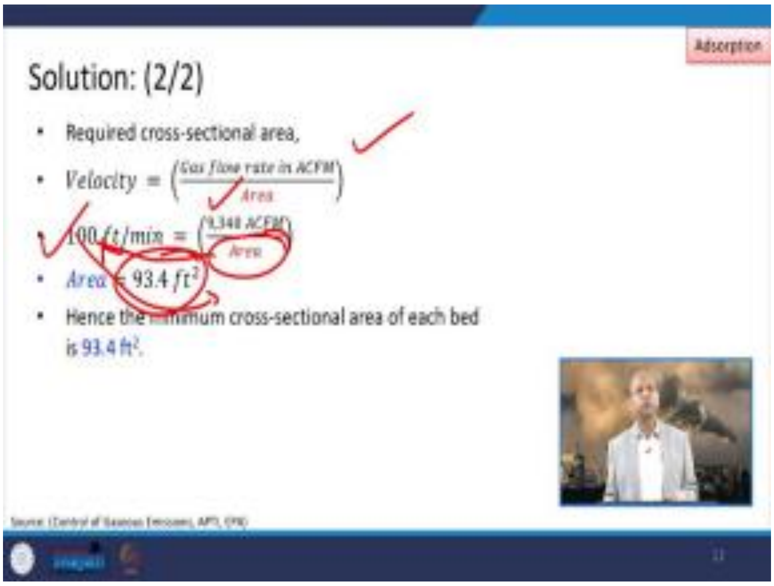

Now, this value basically velocity how to represent velocity? Flow rate divided by the area and area we need to calculate basically. So, velocity is given 100 feet per minute, this is given basically, gas flow rate you have just calculated 9340 SCFM. So, put these values and area is the unknown. So, we take area here 100 here and ultimately we get this value 93.4 square foot. So, this is the minimum cross-sectional area of the each bed which will be required to adsorb that amount of particular gaseous pollutant.

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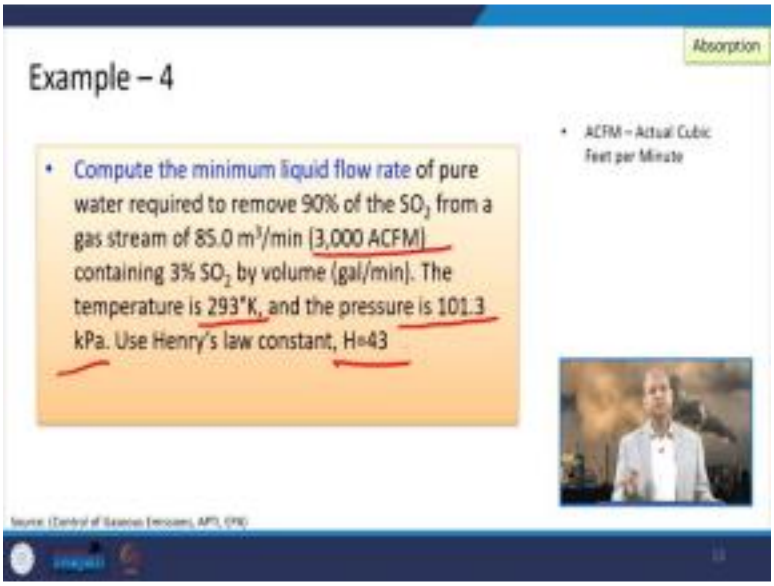

Next is related to absorption. So, we need to compute the minimum liquid flow rate of pure water required to remove 90 percent of the sulfur dioxide from a gas stream of 85 cubic meter per minute or 3000 ACFM in FPS unit containing 3 percent of the SO_2 by volume that is gallon per minute and the temperature is given 293 degree Kelvin and pressure is given 101.3 kilo Pascal. Henry's law coefficient or constant is given as 43.

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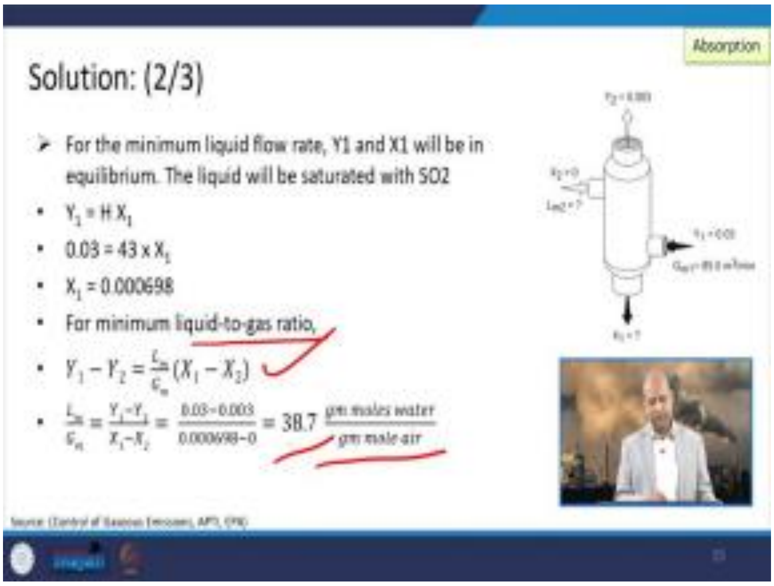

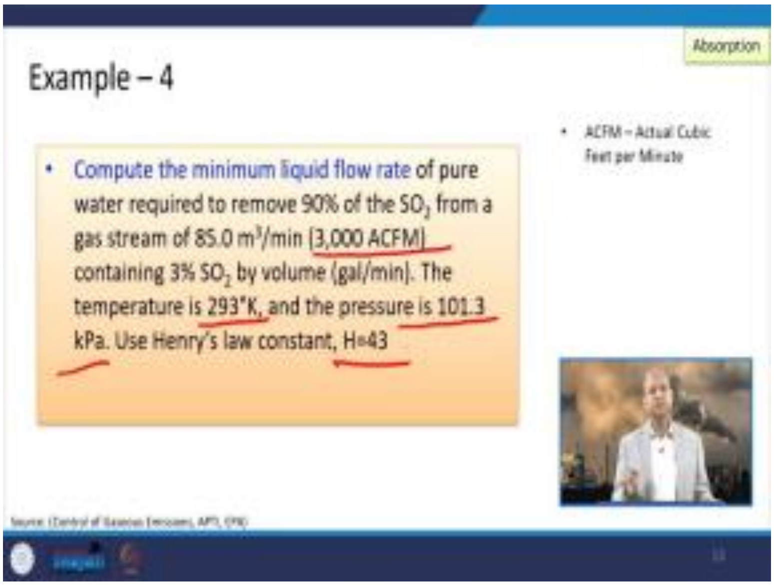

So, we need to use these values. These are the flow chart and you can use those values it will give easy visualization. So, the given values flow rate is given SO_2 concentration by volume is given. Now, in gas phase 0.03 percentage 0.03 fraction basically 90 percent of SO_2 is to be removed remember it and 10 percent so basically remaining SO_2 concentration 10 percent in the inlet 0.003 is the fraction.

These values we have to use and 43 value varieties coming from? You can see 43 is the constant value and these coefficient you have to use. So, you can use those values and get these minimum liquid gas to ratio (Y_1 - Y_2) equals this moles water and per gram moles of the air. So, these equations are used very simple relationships which you can put those values and get the value of around 38.7 gram mole water per gram mole of the air basically.

(Refer Slide Time: 12:17)

Then given the flow rate how much? 85 cubic meter per minute. So, at 0 degrees Celsius this 101.3 kilo Pascal pressure is given. So, there are these kinds of cubic meter per gram mole those ideal gas values. Then at 20 degrees Celsius you can convert those values that is 0.024 cubic meter per gram mole. Now, we have to use this again relationship so 38.7 we just calculated 85 cubic meter per minute that is 3540 gram mole per air per minute that value is there.

So, we multiply both and we get this value into gram mole water per minute that is this 137000 gram mole water per minute. So, then you can convert it into cubic meter per minute by this particular relationship. So, that way you can this is the value basically we wanted to calculate we wanted to calculate minimum liquid flow rate. So, this much is the minimum liquid flow rate which is needed to achieve that particular targeted value.

(Refer Slide Time: 13:23)

Next is related to calculation of amount of calcium hydroxide or lime which is needed to neutralize the HCl absorbed from a gaseous stream having 50 ppm HCl and a flow rate of 10,000 SCFM, standard cubic feet per minute. Assume this HCl removal efficiency as 98 percent. So, these are the given values.

(Refer Slide Time: 13:48)

You can use this particular equation which 2 HCl plus Ca OH hydroxide calcium hydroxide plus 2Ca plus 2Cl minus and plus 2 H2O. So, basically you can see one mole of lime or calcium hydroxide is removing two moles of HCl. So, that we need to remember. So, the HCl concentration 50 ppm that is 50 into 10^6.

$$2HCl + Ca(OH)2 \rightarrow 2Ca+ \; + 2\,Cl- \; + 2H2O$$

This pound mole of the HCl flow rate is given, 98 percent is the removal efficiency. So, use these values and multiply and you get values of the HCl in terms of mole, this pound mole of the HCl per minute. So, these values can be put in this particular very simple arithmetic and relationships are there.

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Then you get this value of just got 0.00123 pound mole of the HCl per minute. So, they are the same value. Now, how much calcium hydroxide is required? So, we know basically this pound mole per minute you can convert it into the pound the 74 this value, particular calcium hydroxide and you got this 0.0455 pound per minute that is the 2.73 pound per hour because you can multiply it by the 60. As the amount of calcium hydroxide lime needed to neutralize the HCl absorbed as 2.73 pound per hour. This is the molecular weight in terms of this.

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Now, next example is related to thermal oxidizer. So, we have seen adsorption and absorption related mechanism devices we need to design based on those principles. Now, oxidation processes there. So, a thermal oxidizer, a thermal oxidizer is there which controls emissions from a paint baking oven and the cylindrical unit is there which has a diameter of 5 feet or you can say radius is 2.5 feet and a length is 12 feet.

So, we need to remember when we calculate the volume of this particular cylinder with all combustion air supplied by an auxiliary source and the exhaust from the oven is 8000 SCFM, (standard cubic feet per minute) and the oxidizer uses 300 SCFM of natural gas and operates at a temperature of 1400 degree Fahrenheit.

What is the residence time in the combustion chamber to remove that particular pollutant? Assume the fuel is 100 percent methane and there the burner is being operated at 125 percent of the stoichiometric requirement. So, those values we will be using in this particular problem.

(Refer Slide Time: 16:30)

So, we have this combustion reaction methane it oxidized by oxygen and converted into CO_2 and $2H_2O$. This water so stoichiometric oxygen requirement is 2 moles of oxygen for each mole of the methane. We have to remember that. You use this particular values which are given 300 SCFM and this 385.4 cubic feet per pound mole is used for conversion into SCF that we have already earlier also used.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

So, convert that into pound mole of the methane per minute, these values and because we know 3 moles of oxygen required. So, twice of this particular pound mole of the methane will be required as oxygen and you can convert that value into this pound mole of the oxygen per minute because this value is to be used as per CH_4 and those molecules.

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Next is the total oxygen requirement because 125 percent is the stoichiometric requirement it does not go like purely 100 percent, you need more. So, 1.25 times of the stoichiometric requirements you multiply by 1.25 you get this value 1.95 pound mole of the oxygen per minute. Now, how much nitrogen will be there in the air?

The relationship around 21 percent of the oxygen and 79 percent of the nitrogen is there. So, you use this particular relationship and you get how much nitrogen this is 7.37 pound mole of the nitrogen per minute will be there.

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Next is like this flue gas flow rate. So, flue gas flow rate is basically the exhaust gas which is heated plus product of the combustion plus nitrogen and excess of the oxygen which we have calculated. So, exhaust gas is given 8000 SCFM, products of the combustion are CO_2 plus H_2O after this oxidation. So, CO_2 you can calculate by this particular relationship, the relationship H_2O.

So, the total of the CO_2 and H_2O is around 2.34, around 1.56 plus that 0.77 or 2.78 you can say. So, 2.37 pound mole per minute of the total exhaust is there of the CO_2 and water vapor you can say. So, 2.34 you can convert into this SCFM again by multiplying this particular factor, so 902 SCFM is the value.

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Now, next is the oxygen consumed, how much oxygen is consumed as per stoichiometric requirement? We have calculated already around 1.56 you can see here 1.56. Then amount of oxygen remaining so total minus consumed so 1.95 minus 1.56 so around 0.39 is access Nitrogen excess total $N_2 + O_2$ remaining.

So, total is around 7.76. So, 7.76 will be the excess that can be converted by multiplying by 385.4 SCF that factor, so SCFM that is 2990 standard cubic feet per minute. So, the total flue gas flow rate is the 8000 which is given plus 902 which we have calculated just now here and then this excess one 2990, so total is 11,900 SCFM.

(Refer Slide Time: 20:11)

Now, step five is conversion of the flue gas flow rate to the actual conditions ACFM actual conditions. So, this 11,900 SCFM you can convert into ACFM. So, you can have these temperature values, so you can convert into like 41,900 ACFM. Now next is calculation of the volume of the combustion chamber.

So, we remember the radius 2.5 feet was the diameter so 2.5 feet is the radius so 2.5 square pi r square is the area and into length . So, this is the volume length is 12 feet it is given so 235.5 cubic feet is the volume of that chamber. So, residence time very easy now, the chamber volume the volumetric flow rate.

So, divide this volume of the chamber by volumetric flow rate you will get the residence time. So, this value is divided by this flow rate that is the actual one and you get around 0.00562 minute. You can convert it into milliseconds around 337 millisecond very quickly this process happens. So, that is very efficient you can say. So, 337 milliseconds is the residential time in that particular combustion chamber and you get the results.

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Next is like now condensation. So, we have seen adsorption, absorption and oxidation. Now, the processes condensation. So, in condensation what is the maximum toluene removal efficiency? This is one problem. Possible in a refrigeration type condenser operating at 100 degree Fahrenheit if the inlet concentration is around 10,000 ppm and the given outlet partial pressure error at this temperature 100 Fahrenheit is almost 0.015 millimetre of mercury.

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The conversion of those systems. So, need not to worry you can use those. So, inlet concentration is 10,000 ppm, given the outlet pressure at 100 degrees Fahrenheit is given this much. Now assuming the outlet gas stream is in equilibrium with the toluene condensate. So, the outlet partial pressure determines the outlet concentration and the conversion of outlet concentration to ppm can be done easily.

So, the outlet concentration by this you can convert this 10 to the power 6 ppm and these you have values you can convert that that is around 19.7 ppm. Now, removal efficiency in minus out inlet outlet divided by in and multiplied by 100. So, 10,000 is inlet outlet how much this we have calculated 19.7/10,000 multiplied by 100. So, around 99.8 percent is the removal efficiency, wonderful efficiency basically.

(Refer Slide Time: 23:09)

Next is determination of the following for a condensing system to remove VOCs, volatile organic compounds from an air emission stream. So, determine we need to determine the partial pressure of the HAP that is hazardous air pollutants in the condenser effluent. Assuming the pressure in the condenser is constant and at atmospheric level. Determine the condensation temperature from the given plot.

So, plot is given these are the values maximum flow rate is given temperature is given what is the hazardous air pollutant which we are dealing with it is also given this is tiling, then this concentration is also given 13,000 ppmv by volume corresponding to saturation conditions. Moisture content is negligible we can just neglect it. Pressure is given 760 mm, removal efficiency is 90 percent.

(Refer Slide Time: 24:10)

So, we have those values basically. So, partial pressure you can calculate easily and you get this value around 13,000 ppmv already given.

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So, use those values and calculate partial pressure around 1 mm of the mercury. So, that would be the partial pressure.

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And using that particular partial pressure you can get the value of the temperature. So, that is basically from this graph and it is around 20 degree Fahrenheit because 0.00208 is this is logarithmic graph. So, basic value is 20 degree Fahrenheit.

(Refer Slide Time: 24:45)

Next is determination of different design parameters like the moles of the HAP in the inlet emission stream then moles of the HAP in the outlet emission stream HAP outlet. This is emission stream moles of the HAP condensed and in heat of the vaporisation HAP, hazardous air pollutants heat of the vaporization this enthalpy change associated with the condensate condensed HAP that is also be determined.

Then enthalpy change associated with the non-condensable vapours that is air that we have to calculate. Then condenser heat load that is the load we need to calculate and the values which are given are these one this flow rate is there, temperature is there, name of the hazardous air pollutant is also given all these values are given as the earlier one.

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So, this given data is there then simple relationships again you can just calculate those values multiply with those keep in mind the proper units. So, these values are given, you just multiply by the respective coefficients and the conversion factors and you get the values.

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Similarly, like here you got this value and similarly, this moles of the HAP outlet you can calculate. So, all those simple calculations are there.

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So, I can just quickly go and then heat of the vaporization is there can this can be taken from the chemical engineers handbook because these design parameters are there which will be used for designing of the instrument. So, as an engineer you have to be very much convergent of these design parameters you got this value from this engineers, chemical engineers hand book.

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Then enthalpy you can calculate with these relationships which are simple calculations, plus minus addition subtraction those similarly, the enthalpy change associated with the non-condensable vapours also can be calculated in the similar fashion.

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And the condenser heat load again same those emission factors and those values are there and heat and this energy per minute of the values are there. So, you can multiply and add those values and you can get that total value.

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Similarly, in this example, next example is to determine those parameters like logarithmic mean temperature difference, condenser heat exchanger surface area, then coolant flow rate, refrigeration capacity, then quantity of the recovered product we need to go for recovery. So, these are the given values and we have to use and determine these coefficient.

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So, again use these given values and convert them into the desired parameters.

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And you can calculate whatever like condenser heat exchanger you can calculate by these kind of simple empirical equations.

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Coolant flow rate also you can calculate by this particular relationship ultimately 14,700 pound per hour the coolant calculation is there.

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Refrigeration capacity so this much value we know because this H_{load} is there, so that you can use and this capacity divided by 12,000 and this 20 tons is the estimated value then quantity of recovered product so you can use other those values and ultimately you can get this 373 pound per hour.

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So, in conclusion, basically we can say that all these principles which we have seen like adsorption, absorption or oxidation and condensation, these simple principles are there and of thermodynamic kind of relationships are there which we have to use and we need to calculate whatever desired parameters are there so that our instruments can be designed properly and they can function on the desired efficiency.
Like in the given examples, we can see that the absorption of the saturation capacity of the activity and carbon was around 40 percent by weight. Removal efficiency of the gaseous pollutant in the absorption we could see around 98 percent it was there. Residence time was very less 338 kind of milliseconds which is very rare. So, it can show that it is very efficient mechanism and the condensation removal efficiency greater than around 99.8 percent could be achieved.

So, these are the examples practice examples, when you go at ledger properly in a focused manner, you read the statement problem statement very calmly and then go step by step so that you can calculate those parameters and that way you will be like design engineer for designing the equipments or processes or mechanism which are required to remove the gaseous air pollutants.

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So, this is all for today and these are the references wherefrom we have taken these practice examples for you. So, I advise you please practice these examples whenever you get time. So, you will learn and you will appreciate how these design parameters are really helpful for removal of gaseous air pollutants. So, thank you for your kind attention. This is all for today. See you in the next lecture. Thanks.