Cryogenic Engineering
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Lecture No. # 19
Gas Separation

So, welcome to the nineteenth lecture of the NPTEL series on cryogenic engineering. Just to take a glance at what we learnt in the last lecture, this topic is what we are talking about is basically Gas separation.

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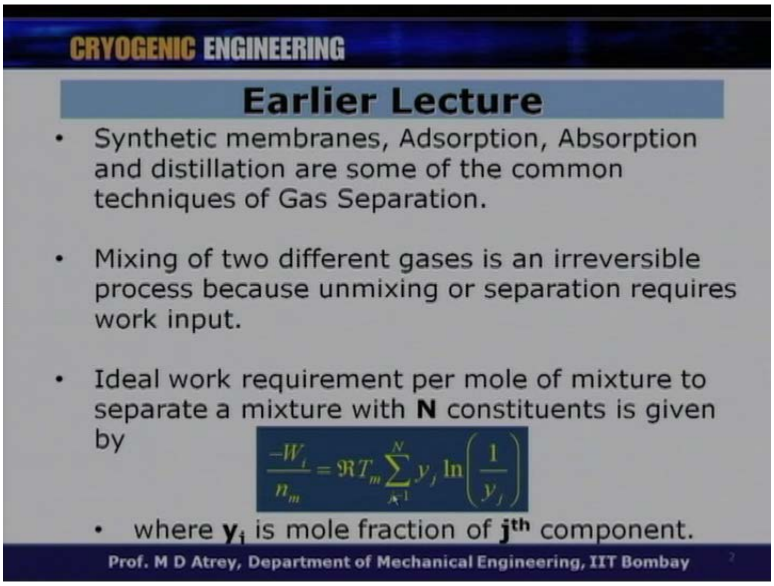

And during the last lecture, we found that synthetic membranes, adsorption, absorption and distillation are some of the common techniques of Gas separation. We touch briefly to understand how do they function? What is the basic fundamental understanding regarding use of such processes for Gas separation? We also found that mixing of two different gases is an irreversible process, because unmixing or separation requires one work input this is a common knowledge. We also calculated the ideal work requirement per mole of mixture to separate a mixture with N constituents and that is given by minus W i upon n m that is work of separation of Gas per mole of mixture is equal to R T m sigma j is equal to 1 to N y j log 1 upon y j, where y j is nothing but the mole fraction of the jth component.

So, one can have two components, three components, four components and accordingly, this sigma terms will be y 1 log 1 upon y 1plus y 2 log 1 upon y 2 plus y 3 log 1 upon y 3 etcetera and the summation of that will give this sigma term. And this is the work of separation of this n constituents may be two or three or four per mole of mixture. With this background let us find out what we are going to study in this lecture.

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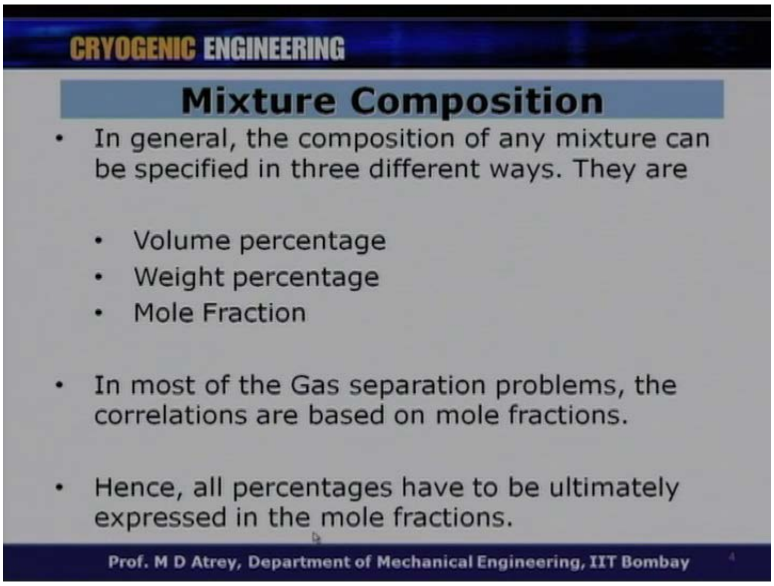

Continuing with Gas separation, let us keep studying ideal Gas separation system and what we will have here today is more tutorial based study. So, when we do some tutorials, we will understand the fundamentals of using this (( )), how to use those (( )) and what the different variables and how we conduct parametric study using the tutorial. So, what is the effect of temperature? What is the effect of different mole fractions of gases? What happens we have got only two components or three components of gases? Let us try to study those parameters with the help of this tutorials.

Let us go with a three Gas mixture also because the moment we go for higher Gas components the study can become more and more complicated to understand and therefore, we will have one more tutorial having three Gas mixtures. In general the composition of any mixture can be specified in three different ways, they are volume percentage, weight percentage and mole fraction. This is again a common knowledge I just want to touch upon this fundamentals because this is what we will be using in the tutorials etcetera.

And this is very important and fundamental to all the calculations which we will be doing. So, a composition of any mixture can be a given in volume percentage or volume composition could be given that volume of Gas A volume of Gas B volume of Gas C, in a mixture of A B C. Or we can have composition based on weights; that means, how much mass of how many grams of Gas A Gas B or Gas C will be given or it could be a mole fraction; that means, 80 percent or 20 percent molar fractions of Gas A or Gas B or Gas C is given.

So, these are the possible ways in which a composition of a mixture could be given and accordingly you will have to do first important calculations and then convert or use mixture rules. In most of the Gas separation problems the correlations are based on mole fractions. So, if the fraction is given in mole fraction, absolutely alright. However, if they are given in weight percentage or weight composition or volume percentage, we will have to first convert this composition from volume weight to mole fraction and then utilize the mixture rules and thing like that.

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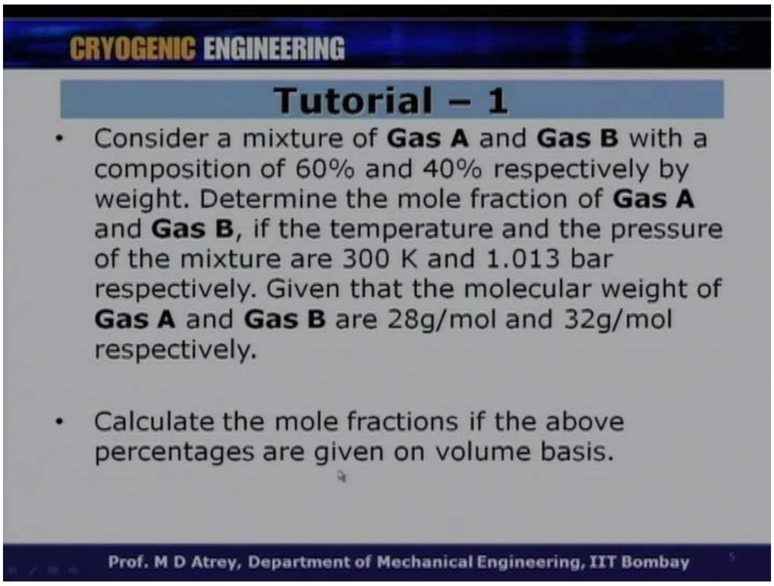

So, first we will like to understand what this mole fractions all about. Hence, all percentage have to be ultimately expressed in mole fractions. So, let us take a help of this tutorial one, wherein we understand how we convert the weight fraction into mole fraction or volume fraction into weight fraction etcetera. So, let us see the problem, consider a mixture of Gas A and Gas B with a composition of 60 percent and 40 percent respectively by weight. So, first problem is basically, referring the composition by weight in a ratio of 60 to 40 percent for Gas A and Gas B respectively. Determine the mole fraction of Gas A and Gas B, if the temperature and the pressure of the mixtures are 300 Kelvin and 1.013 bar respectively. Given that the molecular weight of Gas A and Gas B are 28grams per mole and 32 gram per mole respectively. So, the molecular weights are given over here.

The second part of the problem says, calculate the mole fractions if the above percentage that is 60 40 percentage are given in volume basis. So, first problem is basically, the composition which is given in a weight composition and the second one is given on a volumetric basis. So, ultimately we would like to convert these fractions into molar fractions of Gas A and Gas B respectively. So, what do we do?

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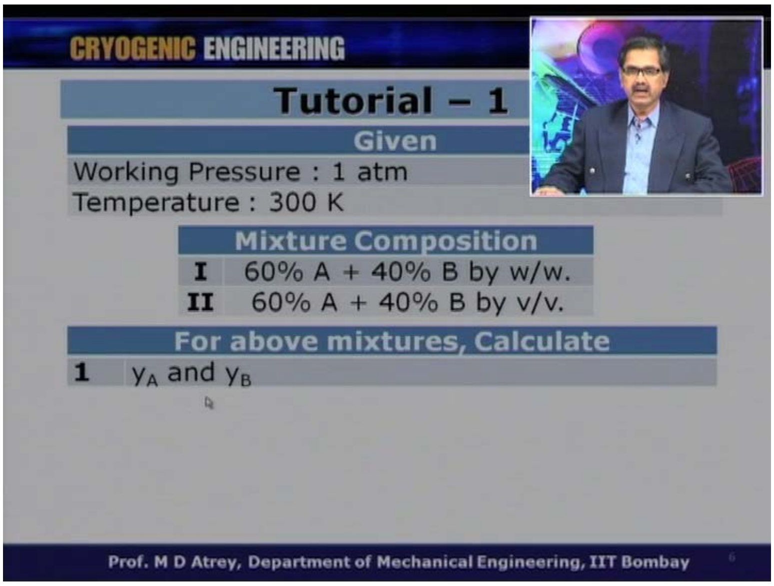

So, working pressure is one atmosphere, temperature is 300 Kelvin, the mixture compositions in the case one, 60 percent A and 40 percent B by weight, weight of A and B per weight of mixture or 60 percent A plus 40 percent B by volumetric basis. For above mixtures, calculate Y a and Y b, what are Y a and Y b? That the mole fractions of A and B that you got the problem statement is.

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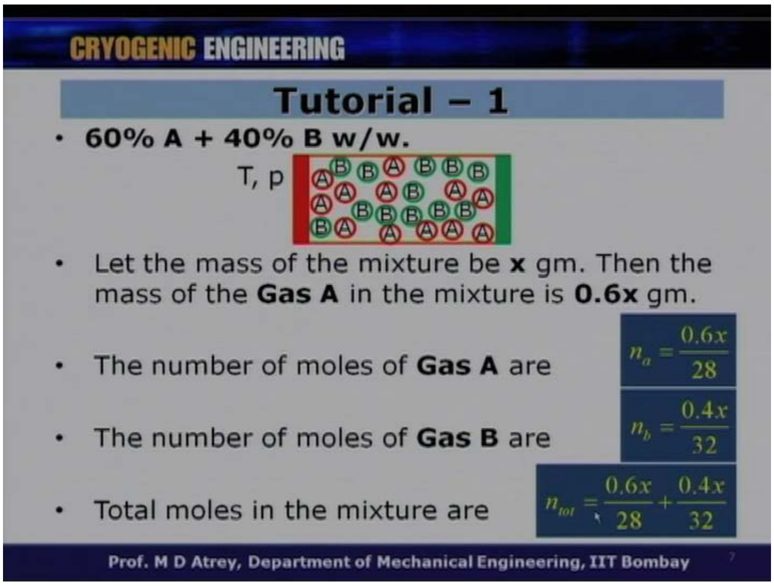

So, first let us take down 60 percent A and 40 percent B by on weight basis. So, let us say this is a mixture where A and B are in a ratio of 60 to 40 by weight. Let the mass of the mixture be x grams, alright, then the mass of Gas A in the mixture is 0.6 x grams, is clear. The total mixture gram is x, therefore, 0.6 x constitute the mass of Gas A.

The number of moles in Gas A therefore, will be the total mass of Gas A divided by molecular weight. So, N A is equal to 0.6 x upon 28, 28 nothing but the molecular weight in grams of Gas A. Similarly, the number of moles of Gas B will be N B is equal to 0.4 x upon 32. 0.4 x is nothing but 40 percent by weight of the mixture. So, 0.4 x upon 32 will be the molar fraction or number of moles of Gas B. So, the total moles in the mixture are N A plus N B, which equal to n total is equal to 0.6 x upon 28plus 0.4 x upon 32, clear, this n total.

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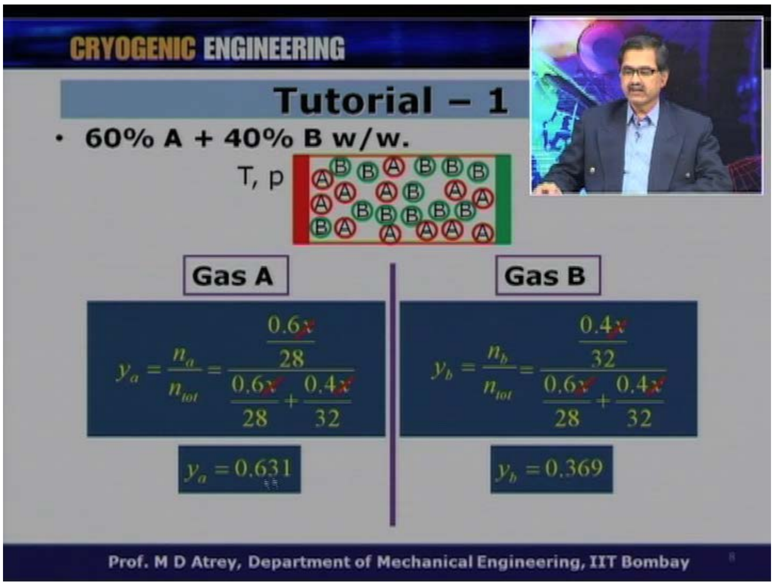

So, if I want to find the molar fraction of Gas A now, what is the definition of molar fraction? Y a is equal to N A upon n total, that number of moles a in a mixture divided by total number of moles. And if we write N A in terms of what we have written earlier, we have got 0.6 x upon 28 which is nothing but N A divided by n total, which is what 0.6 x plus 28 plus 0.4 x upon 32. If we take out x from all this things what we get Y a is equal to 0.631; that means, the molar fraction of a is 63.1 percent; however, the weight percentage is 60 percent here. Alright; that means, the molar fraction is different than that given by the on the weight basis. If we come to Gas B now, we have got a Y b is equal to N B upon n total and write the value of N B on the numerator now here and the total number of moles in the denominator, again the answer will be now Y b is equal to 0.369, that is 36.9 percent is the molar fraction of Y b.

So, the 60 percent by weight and 40 percent by weight B, get reduced to 0.631 molar of Y a and 0.369 molar fraction of Y b and this is what we will be using further for the calculations of work of separation. So, Y a and Y b are competed from a weight percentage, from the weight composition.

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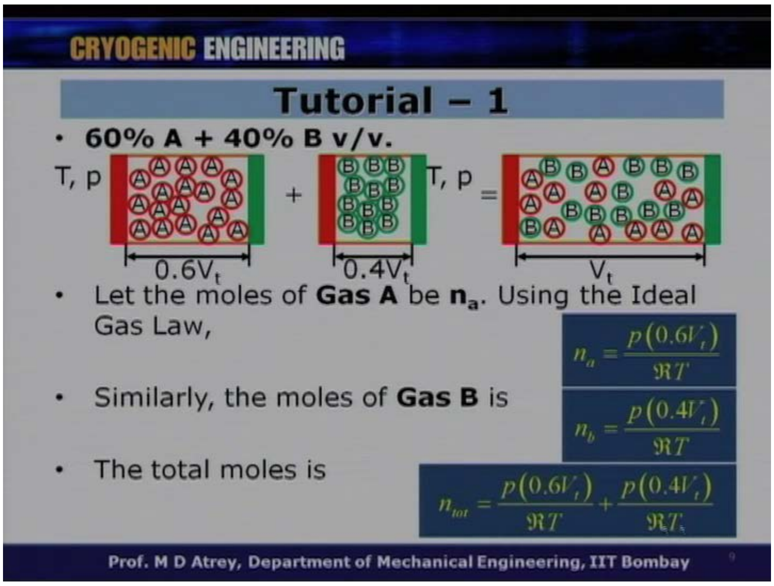

Now, let us see, the second case when the volumetric composition is given for a and b. So, we have got a 60 percent A and 40 percent B by volume basis. So, let us say this is 60 percent A basically. Which is it is going to compete, it is going to k, it is going to take 0.6 times total volume. The amount of volume it is occupied by a is going to be 0.6 times b total the V Total is the volume occupied when the two gases come together.

So, plus we have got a second Gas which is Gas B and it occupies 0.4 times V T; that means, 40 percent of total volume which is 0.4 V t and when they combine together what you get is a V T. So, what we know here is a Gas A occupies 0.6 V T Gas B occupies 0.4 V T, where V T is a total volume when the gases are mixed together. So, what do you calculate, let us calculate number of moles of Gas A, number of moles of Gas B and total number of moles will be number of moles of Gas A plus number of mole of Gas B.

So, let the moles of Gas A be N A and using ideal Gas flow what we know is an N A is equal to p v upon R T. So, N A into p N A is equal to p into 0.6 V T upon R T. Similarly, the moles of Gas B will be N B which is equal to p into 0.4 V T upon R T. So, we have got an N A and N B number of moles of a and number of moles of b calculated based on the respective volumes occupied. So, total number of moles will be n total which is equal to N A plus N B and if we put those values, this is what the expression comes for n total.

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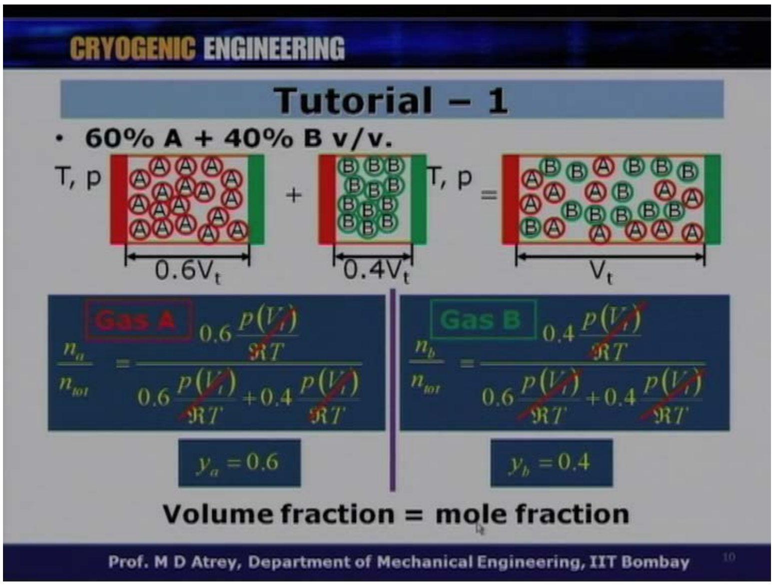

Going further now let us calculate the molar fraction of Gas A which is given by N A upon n total, right, this is clear to us. So, N A upon n total is equal whatever N A we have calculated just now divided by n total. So, if I go on I can just cancel p V T upon R T from all these three entities giving me y is equal to 0.6. That means, 0.6 was nothing but the volumetric composition of Gas A and molar composition of also is coming to be 0.6.

Similarly, if I do (( )) Gas B, again I calculate the molar fraction of Gas B which is the N B upon n total, I put respective values of N V and n total, again I do cancel the common term and I get Y b is equal to 0.4. So, the molar fraction is 0.6 for a sand 0.4 for b which is same as what it is given in a volumetric composition of a mixture of Gas A and B, which means that the molar fraction remains essentially remains the same as polymeric composition. But the molar fraction are not same when the composition is given on weight basis, this is essentially what we understand from this tutorial one.

So, what we say is volume fraction is equal to mole fraction. So, ultimately now, we have understood how to calculate the molar fractions whenever the composition is given based on weight or based on volume. If it is directly given in terms of molar fraction, fine one can immediately start calculate the work of separation of this Gas mixture, but if it is not then we will have to convert them first to the molar fraction as done in this particular tutorial.

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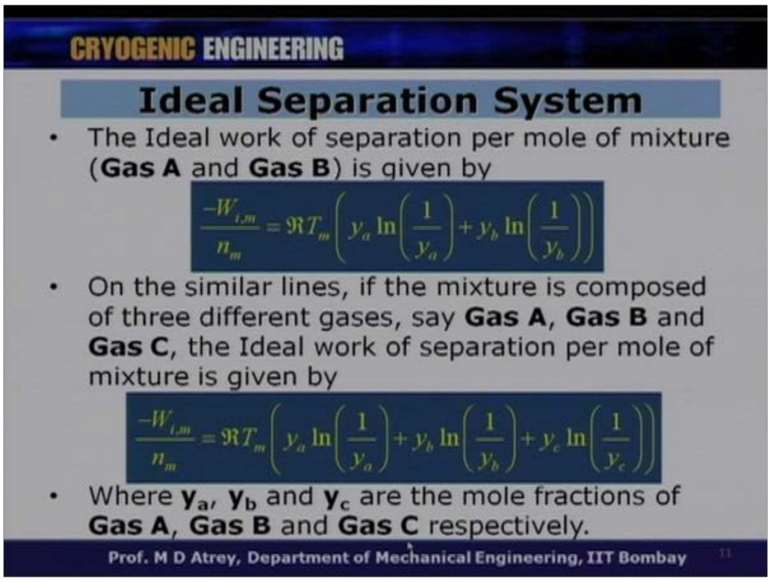

Now, let us come to the calculation of work of separation, let us see the ideal separation system. The ideal work of separation per mole of mixture, let us say, in a mixture of Gas A and Gas B is given by this formulae this is what we had derived last time. W i m upon n m is equal to R T m into Y a log 1 upon Y a plus Y b log 1 upon Y b where Y a and Y b are nothing but molar fractions of Gas A and Gas B respectively. On the similar line if the mixture is composed of three different gases Gas A Gas B and Gas c the ideal work of separation per mole of Gas is given by this formulae where Y a Y b Y c are the mole fractions of a b and c respectively this clear.

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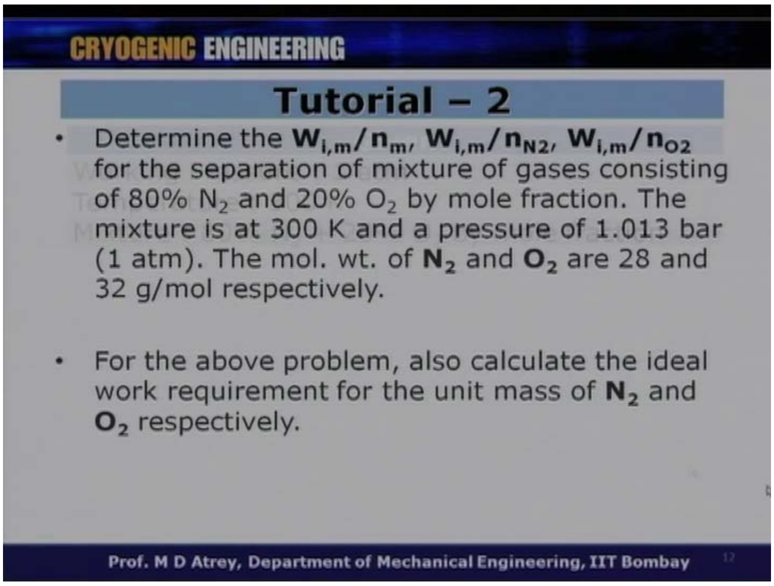

Now, let us see the tutorial where we understand all these respective values. Where we calculate the work of separation and we will understand the different nomenclature using work of separation. So, the tutorial two is aiming towards understanding this the ideal work of separation of mixture. The problem statement let us read determine the W i m by n m that is work of separation of mixture per mole of mixture, W i m by N 2 W i m by N O 2, the mixture is given as a mixture of N 2 and O 2 nitrogen and oxygen for the separation of mixture of gases consisting of 80 percent nitrogen and 20 percent oxygen by mole fractions; that means, Y a and Y b are have already been given.

The mixture is at 300 k and a pressure of 1.013 bar one atmosphere, the molecular weights of nitrogen and oxygen are 28 and 32 grams per mole respectively. For the above statement or above problem also calculate the ideal work requirement for the unit mass of nitrogen and oxygen respectively. So, the work of separation and here we want to calculate per unit mass of Gas Also this was per unit mole of nitrogen and oxygen the problem statement also calls that calculate the work requirement per unit mass of nitrogen and oxygen respectively.

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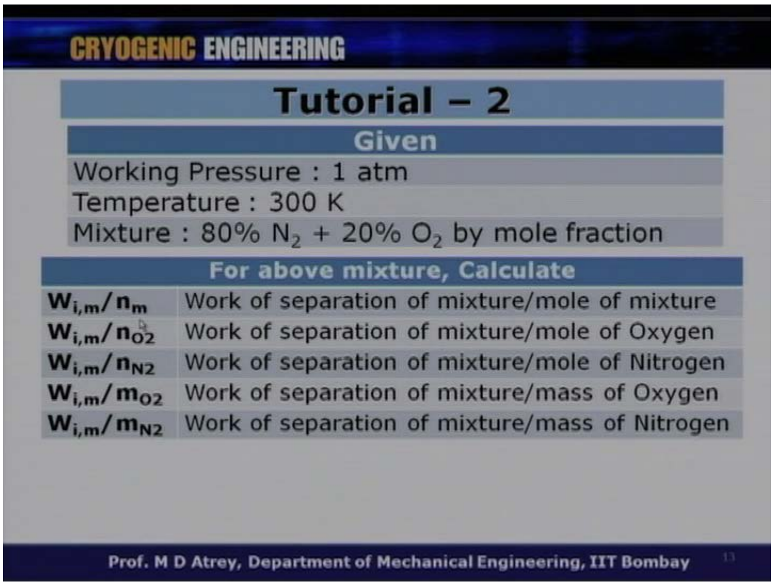

So, what are the data given which is the working pressure 1 atmosphere, temperature 300 Kelvin, mixture 80 percent, nitrogen and 20 percent, oxygen by a mole fraction. So, Y a is 0.8 Y b is 0.2. Now, the nomenclature that we are going to follow from this lecture onwards is to understand this and these are the terms which normally be used. So, what is W i m by n m that is work of separation of mixture per mole of mixture? So, when I say W i m this work of separation of mixture, when I say n m that is a mole of mixture. So, this is nothing but work of separation of mixture per mole of mixture. Now, this can also be interpreted in terms of mole of oxygen or mole of nitrogen which constituents one of the parts of the mixture or one of the gases of the mixture. So, I can ask for W i m by N O 2 which is work of separation of mixture per unit mole of oxygen.

Work of separation of mixture per unit mole of nitrogen, when n get replaced by m we can say it is per gram of oxygen or per gram of nitrogen. So, the mass comes into picture. So, W i m by N O 2 is nothing but work of separation of mixture plus mass of oxygen work of separation of mixture plus per mass of nitrogen. So, there are different terms over here per mole of mixture, per mole of oxygen, per mole of nitrogen or per gram of nitrogen, per mass of oxygen, per mass of nitrogen. So, depending upon problem statement one has to calculate all this things and one has to present the results.

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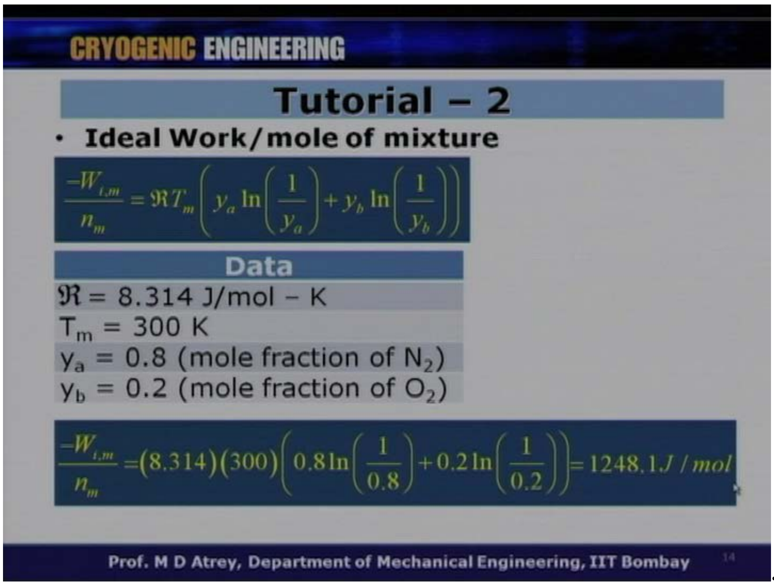

All right, so, ideal work per mole of mixture which is W i m upon n m and this is standard formulae. So, basically now, put the values. So, we know r is universal Gas constant 8.314 t m is equal to 300 Kelvin Y a is 0.8, Y b is 0.2. Putting these value W i m upon n m is equal to this formulae 0.8 log 1 by 0.8, 0.2l go 1by .2 into R T m and this is giving you1248.1 joule per mole.

This is work of separation of mixture per mole of mixture. Now, I would like to write the same work in terms of mole of nitrogen. So, now, I will be using ideal work per mole of nitrogen, how do I calculate that? So, for that I will use a formulae, how can I write that W i m upon N 2 which is what is required, work of mixture work of separation of mixture per mole of nitrogen can also be written as work of separation of mixture per mole of mixture into moles of mixture divided by moles of . The moles of mixture, n m and n m will get cancelled and ultimately what you get is a work of separation of mixture per mole of nitrogen.

Alright, so, this is what we get from this and you have what is n m upon N 2, it is nothing but mole fraction of nitrogen if I put n m down N 2 divided by n m is nothing but y N 2 n m upon N 2 is nothing but 1 upon y N 2 . So, if I replace that I will get W i m upon N 2 is equal to work of separation of mixture per mole of mixture divided by y N 2. So, if I know y N 2 I can calculate the work of separation of mixture per mole of nitrogen by these formulae.

So, what is W i m upon n m? which you have just calculated which is 128.1 y N 2 is 0.8 that is mole fraction of nitrogen in a mixture. So, W i m upon N 2 which is work of separation per mole of nitrogen is 1248.1 divided by 0.8, if I put this I get1560.1 joules per mole of nitrogen this is my work of separation per mole of nitrogen. Now, I can do the same thing per mole of oxygen also. So, my next calculations are ideal work requirement per mole of oxygen. Going by the same study, now, my work of mixture per mole of oxygen will be W i m upon n m divided by molar fraction of oxygen which is 0.2 so, this is 6240.5 joules per mole of oxygen. And similarly, now I can calculate ideal work per mass of nitrogen, I just converts the moles of nitrogen into the mass. So, W i m upon m N 2 is equal to W i m upon N 2 into n N 2 upon m N 2.

What is mass of nitrogen per mole of nitrogen is it molecular weight, what is m N 2 upon N 2 nothing but molecular weight N 2 upon m N 2 is nothing but one upon molecular weight m N 2 is a mass of nitrogen per mole here. So, I can put the molecular weight putting the values over here in this formulae I will get W i m upon m N 2 is equal to 1560.1 upon 28. So, 55.71 joule per gram of nitrogen is the ideal work of separation per mass of nitrogen. And same thing I can do for mass of oxygen by just putting the molecular weight of oxygen as 32 in this and you get 195.01 joule per gram of oxygen.

So, tabulating the results I get work of separation per mole of mixture which is 1248, work of separation per mole of nitrogen which is 1560 and work of separation per mole of oxygen 6240.5. If I go further going from moles of nitrogen to mass of nitrogen I can get W i m upon m N 2 that is work of separation per mass of nitrogen as these work of separation per mass of oxygen which is this. And always you can find that W i m upon n m is going to be less than any other component, this particular value is going to be less because n m is always more than N 2 or N O 2. n m which comes in the denominator is always going to be more than N 2 and N O 2 or N 2 and N O 2 is always going to be less than N and that is why these two values will always be more than W i m by n m by simple algebra basically.

Now, if I go for the parametric study I want to understand what is the effect of molar, what is the effect of temperature etcetera. I can understand by carrying out different parameter studies.

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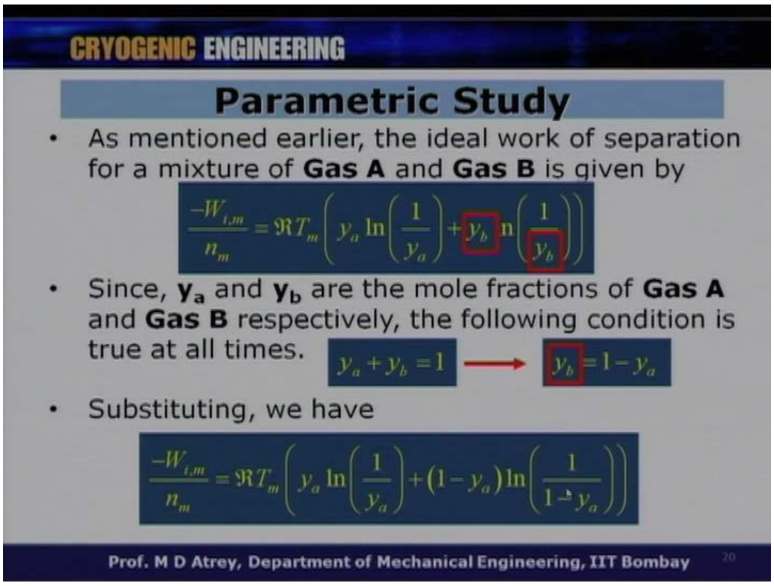

So, as mentioned earlier, the ideal work of separation for a Gas mixture Gas A and Gas B is given by this formulae which we know about. Since, Y a and Y b are the mole fraction of Gas A and Gas B respectively, the following condition is always true at all the times. Y a plus Y b is equal to 1 and therefore, Y b can be always be 1 minus Y as if I put this two values and this is possible when I am talking about two Gas mixtures Gas A and Gas

B, substituting these values what you get is this, Y a log 1 by Y a plus one minus Y a log one minus Y a need not be written Y b every time.

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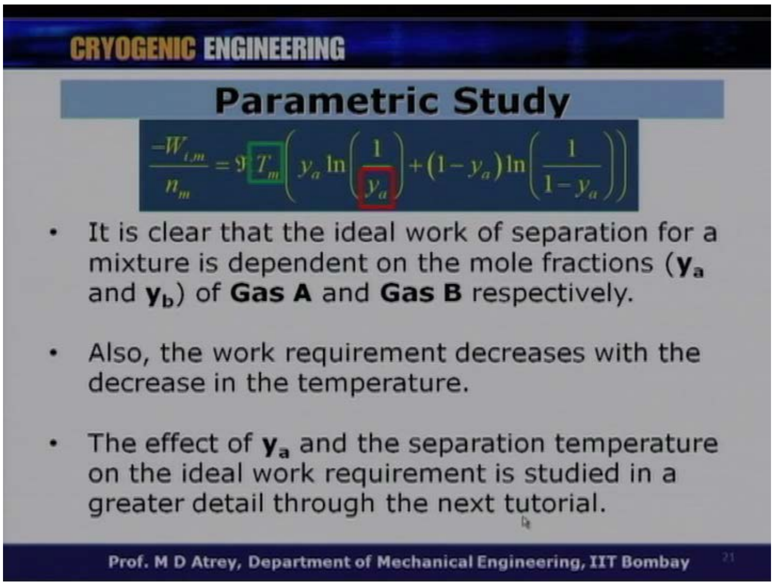

So, I can understand from this figure that it is clear that the ideal work of separation for a mixture is depends on mole fraction that is Y a and Y b on Gas A and Gas B respectively, also the work requirement decreases with the decrease in temperature you can see the t m value over here. So, depending on what is my quantity of Y a and Y b, the ideal work of separation will be vary. Also depending on the temperature is what the temperature of separation is the W i m by n m value will vary.

The effect of Y a and separation temperature on the ideal work requirement is studied in a greater detail in the next two tutorials. Let us study, what is the effect of Y a and Y b and also what is the effect of t m on the work of separation. So, for which we have taken a separate tutorial again to understand this dependency of this parameters and let us study how Y a and Y b and temperature of separation change the work of separation for different gases.

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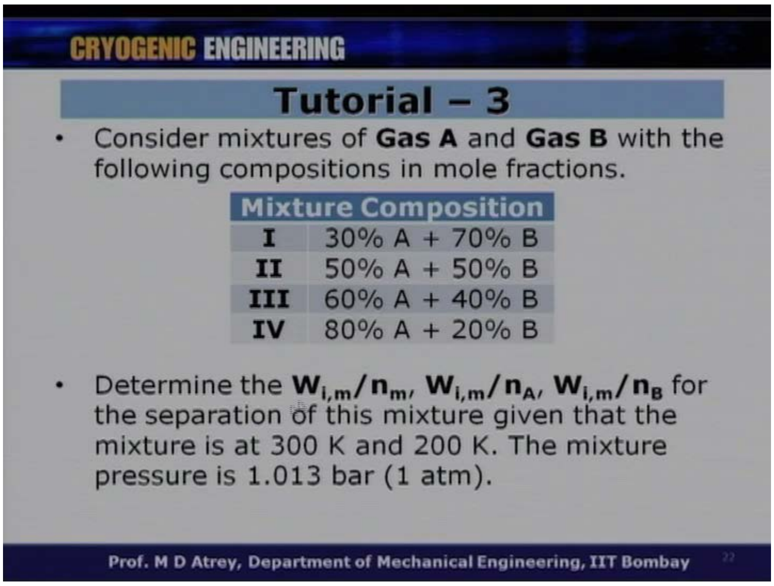

So, the tutorial three (( )) this and the problem statements are consider mixture of Gas A and Gas B with following compositions in mole fractions. So, you got a different compositions, composition one two three and four with 30 percent A 70 percent B 50 percent A. So, we go on increase the value of a from 30 to 80 and we go on decreasing corresponding the values of mixture composition (( )) 70 50 40 and 20 making it 100 percent all the time.

So, determine W i m by n m which is work of separation of mixture per mole of mixture W i m by N A we know what it is now W i m by N B for the separation of this mixture given that the mixture is at 300 Kelvin and 200 Kelvin. So, I want to have two cases one is the mixture separation is at 300 Kelvin or mixture separation as 200 Kelvin the mixture pressure is 1.013 bar. So, working pressure is 1 atmosphere, temperature 300 Kelvin and 200 Kelvin.

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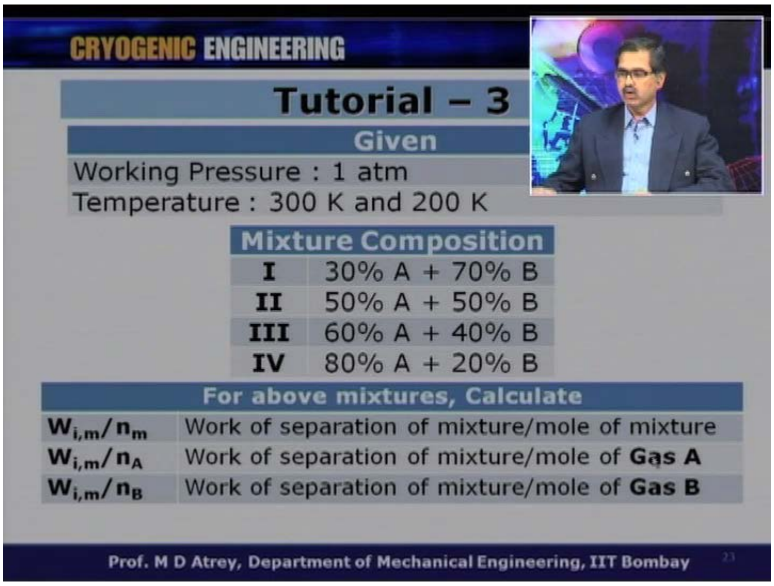

The mixture compositions are case one, case two, case three, case four and for above mixtures calculate W i m by n m which is work of separation of mixture per mole of mixture W i m by N A work of separation of mixture per mole of Gas A W i m by N B.

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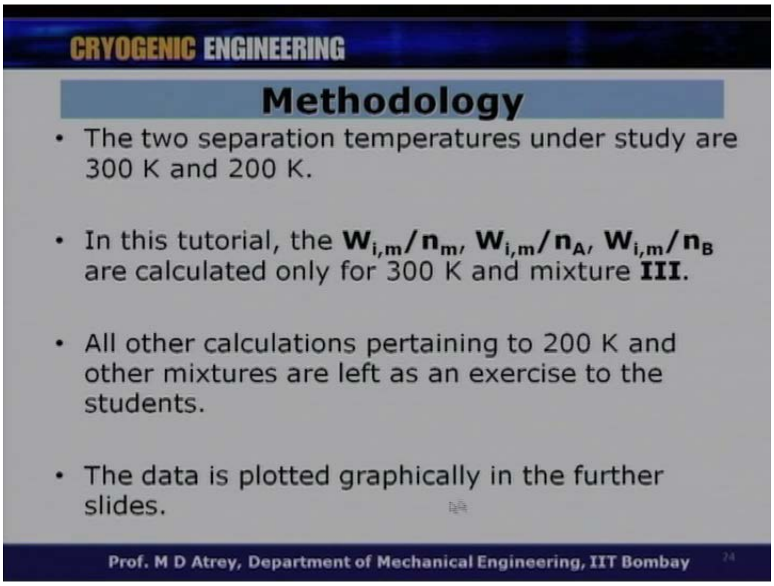

Which is work of separation of mixture per mole of Gas B. The two separation temperatures under study are 300 Kelvin and 200 Kelvin. In this tutorial, the W i m by n m W i m by N A W i m by N B are calculated only at 300 Kelvin and for mixture three. Only that means, all the calculations are shown only for case three and at 300 Kelvin while all other calculations pertaining to 200 Kelvin and other mixtures are left as an exercise to the students.

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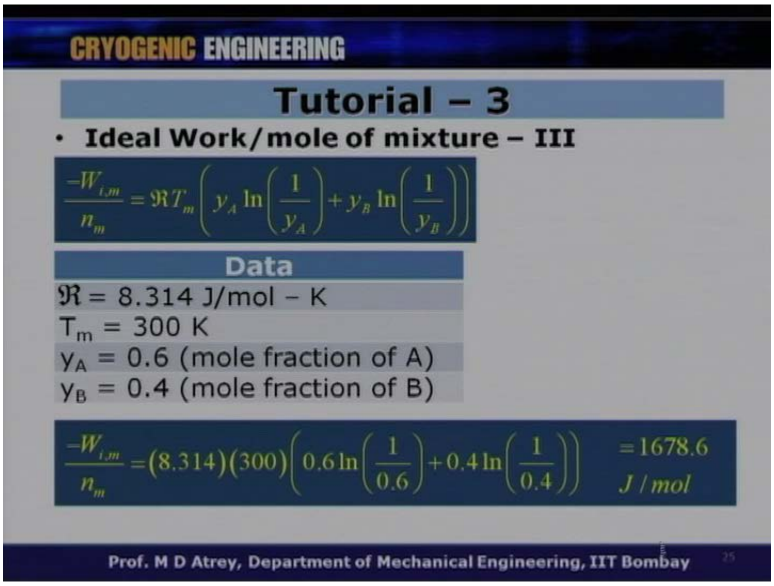

The data is plotted graphically, in further slides. So, let us first calculate ideal work requirement per mole of mixture for case three. So, this our formulae which is very well known. Now, the data is given and for case three, Y a is 0.6 that is 60 percent of a and 40 percent of b 0.6 and 5.4. So, calculate W i m by n m, put this 0.6 1 by 0.6 0.4 log 1 by 0.4 the answer is 1678.6 joule per mole of mixture. So, work of separation is this quantity for 60 40 cases.

Ideal work per mole of which is W i m upon N A is equal to W i m by n m into 1 by Y a just divide by the mole fraction. So, what we get is 1678.6 divided by 0.6 and we get 2797.6 joule per mole of a. similar, thing I will do to calculate ideal work per mole of b now. Just divide it by the mole fraction of b and we will get the answer for this which is 4196.5 joules per mole of b.

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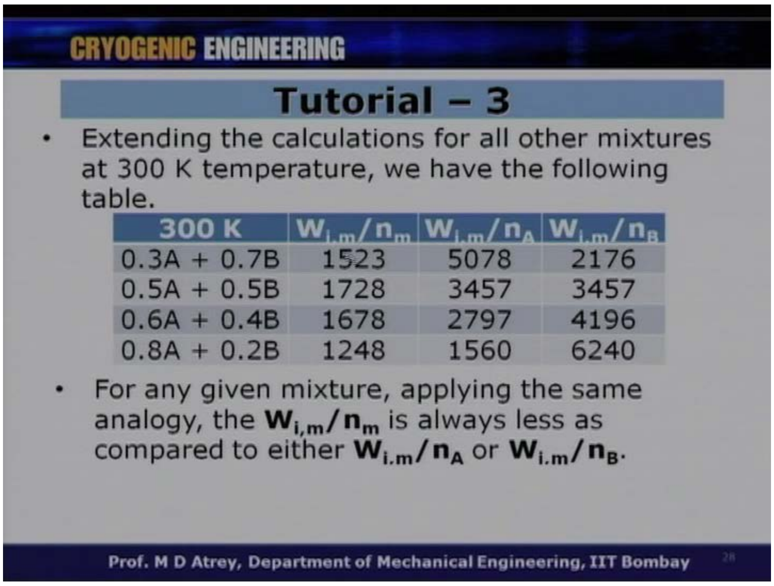

So, while calculated work of separation per mole of mixture work of separation per mole of Gas A and work of separation per mole of Gas B. For a mixture which had 60 percent a and 40 percent b on a molar fraction basis. Extending the calculation for all other mixtures at 300 Kelvin we have got the following table so, this calculation was shown in detail. Now, let us do it for all the mixtures case one, case two, case three, case four and this is my table.

So, first is we are doing all this studied at 300 kelvin and first case is 3.30 percent a and seventy percent b, where W i m by n m work of separation of mixture per mole of mixture is 1523, W i m by N A is 5078, W i m by N B is 2176. And if I go for increasing the value of a correspondingly decreasing the value of b you can see that the work of separation of mixture has increased first and then starts decreasing. So, 15,100 17,100 then 16,100 and 12,100 and odd kind of work you can see over here. And as the component increases what you can see that the work of separation per mole of Gas A is decreasing.

Because the molar composition for a is increasing and similar thing as the molar composition of b is decreasing, we can see that W i m by N B is increasing. In this case, we can study and understand this in better details when we go for graphical understanding. For any given mixture, applying the same analogy as W i m by n m is always less as compared to W i m by N A or W i m by N B. So, one can see that 15 23 is less than 5078 and less than 2162.

Because n m is equal to N A plus N B. So, n m value in the denominator is always is going to be more as compared to N A and N B and that why work of separation per mole of mixture is always going to be less than work of separation per mole of Gas A or per mole of Gas B this is what we saw earlier also. Similarly, the calculations for all other mixtures at 200 Kelvin temperatures the results are as tabulated below.

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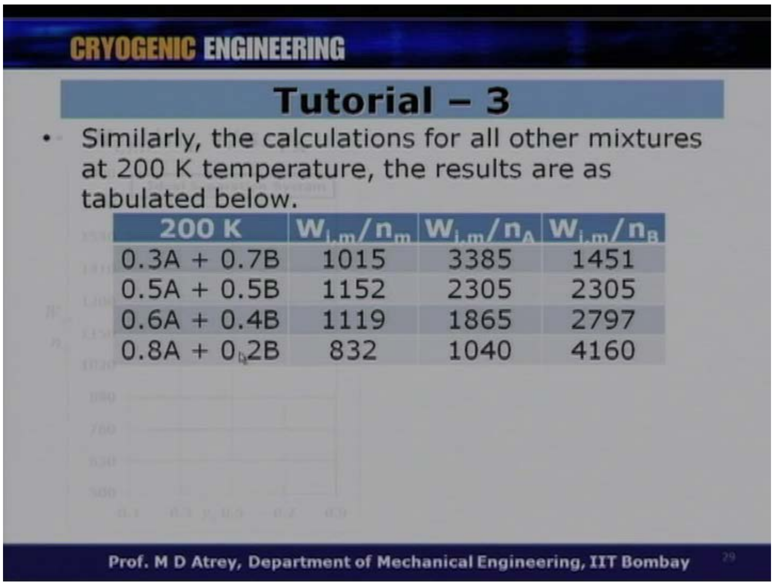

So, we had done calculations at 300 Kelvin which is separation temperature as well as we have carried out all the studies at 200 Kelvin also. So, this is the table now, gives for 200 Kelvin W i m upon n m W i m upon N A W i m upon N B and these are the mixture studies case one case two case three case four and again you can find similar trend as the value of separation per mole of mixture goes first increasing and then start decreasing down. You can see similar trend as what you saw earlier for work of separation per mole of Gas A which is decreasing as the composition of a increases in a mixture.

Similarly, you can find the work of separation per mole of Gas B starts is increases as the molar percentage of b decreases in a given mixture. Now, if I want to study the same thing in a graphical form it just to have a better understanding, I have plotted here work of separation of mixture per mole of mixture versus Y a that is molar fraction of Gas A.

So, Gas A molar fraction is increasing in the right side and on this pattern on this y axis what you see is work of separation per mole of mixture.

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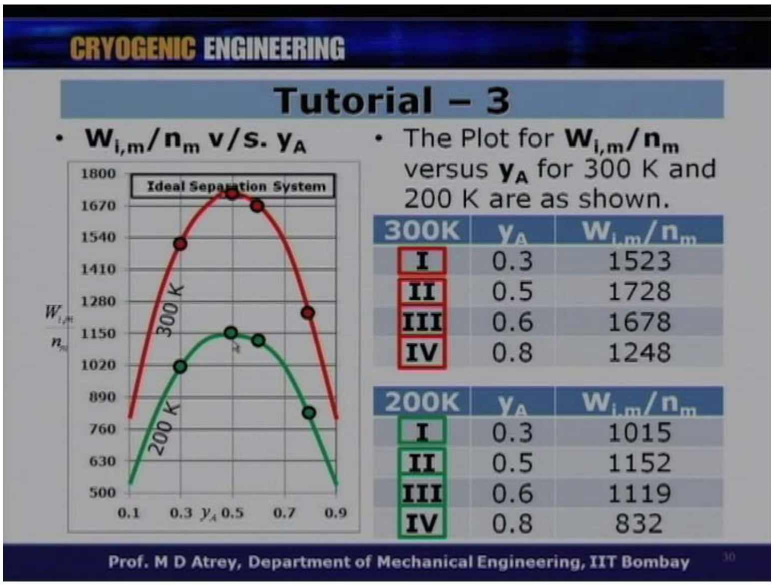

The plot of W i m upon n m versus Y a for 300 Kelvin and 200 Kelvin are shown. What are these cases case one case two case three case four and let us see all this four points. So, we 0.1523 other things and if we join this is a 300 Kelvin curve; that means, you can see that the work of separation of this mixture per mole of mixture touches maxima somewhere over here and comes down. And if I do the same thing for 200 Kelvin and point case one, case two, case three, case four points and connect them together I get a similar trend what you can see from here that this curve is at a lower level as compared to 300 Kelvin.

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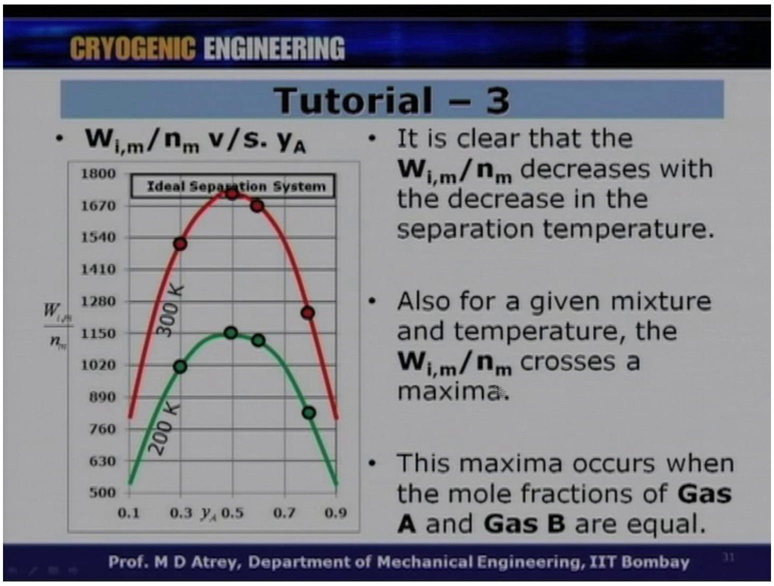

Meaning which directly that the work of separation requirement is less for 200 Kelvin than at 300 Kelvin and this is what our first conclusion should be. It is clear that work of separation per mole of mixture decreases with the decrease in separation temperature and this is clear from the formula itself. Now, what is to be understood is also for a given mixture and temperature the W i m upon n m crosses a maxima, which is what you can see, the maximum here, the maximum here.

And what is most important to understand is this maxima occurs when the mole fractions of Gas A and Gas B are equal. That means, the maximum happening at 0.5, when Y a is equal to 0.5 correspondingly Y b also is equal to 0.5 so, Y a is equal to Y b is equal to 0.5 and the work of separation is maximum when Y a is equal to Y b is equal to 0.5. So, the maximum occurs when the mole fractions of Gas A and Gas B are equal and this is mathematically correct. If you see the formula you can see that Y a is equal to Y b this W i m upon n m will be maximum.

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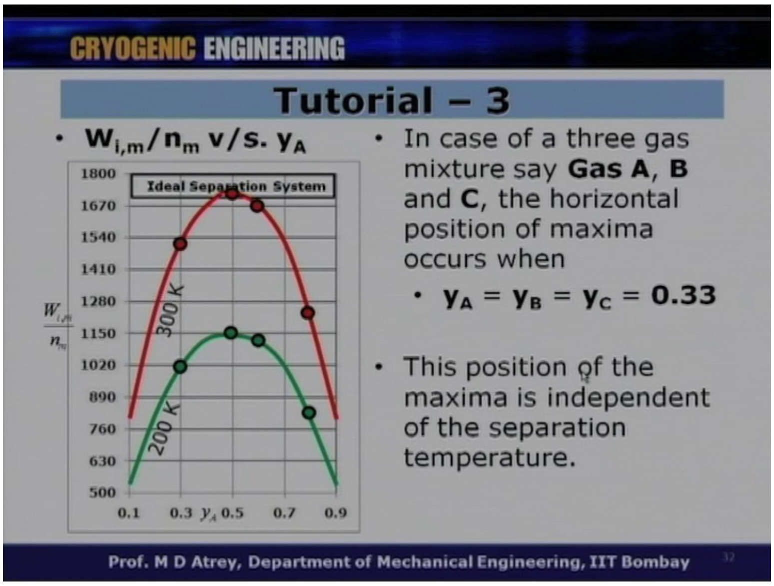

In case of three Gas mixture, suppose, instead of going for Gas A and Gas B, if I go for Gas A and Gas B and Gas C, the horizontal position of maxima occurs when Y a is equal to Y b is equal to Y c is equal to 0.33. So, I will get maximum now, when all the three gases are present as 33.33 percent actually, their equal percentage basically. So, this position of the maximum is independent of separation temperature as you can see maxima occurring at 300 Kelvin and at 200 Kelvin are at the same location.

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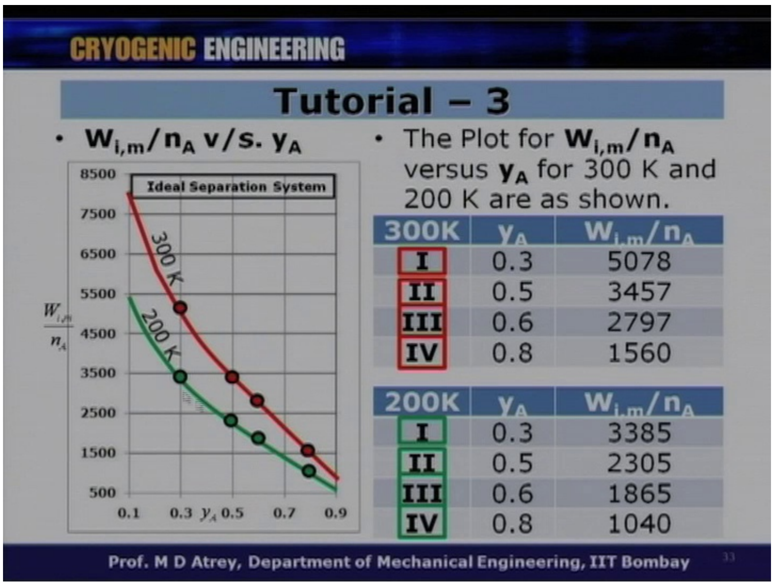

300K	y_A	$W_{i,m}/n_A$
I	0.3	5078
II	0.5	3457
III	0.6	2797
IV	0.8	1560

200K	y_A	$W_{i,m}/n_A$
I	0.3	3385
II	0.5	2305
III	0.6	1865
IV	0.8	1040

So, basically the position of maxima is independent of what is the temperature of separation is. And it completely depends on when Y a is equal to Y b is equal to Y c three Gas mixture. Now, if I want to plot, this is what we plotted first of work of separation per mole of mixture. Now, instead of that I am now competing work of separation of Gas per mole of a Gas A against y a. So, W i m upon N A on y axis and Y a or molar fraction of Gas A on the x axis. The plot of W i m upon n m versus Y a for 300 Kelvin and 200 Kelvin are as shown here.

So, what are my cases? Case one, case two, case three, case four and if I join them what you can see that as the value of Y a increases the work of separation of the mixture per mole of Gas A decreases and this is for 300 Kelvin. If I do it 200 Kelvin, I find the work of separation has decreased per mole of Gas B Gas A at 200 Kelvin. So, the confusions that can be drawn here are similar to what we saw earlier. It is clear that W i m upon N A that is work of separation per mole of decreases with the decrease in separation temperature.

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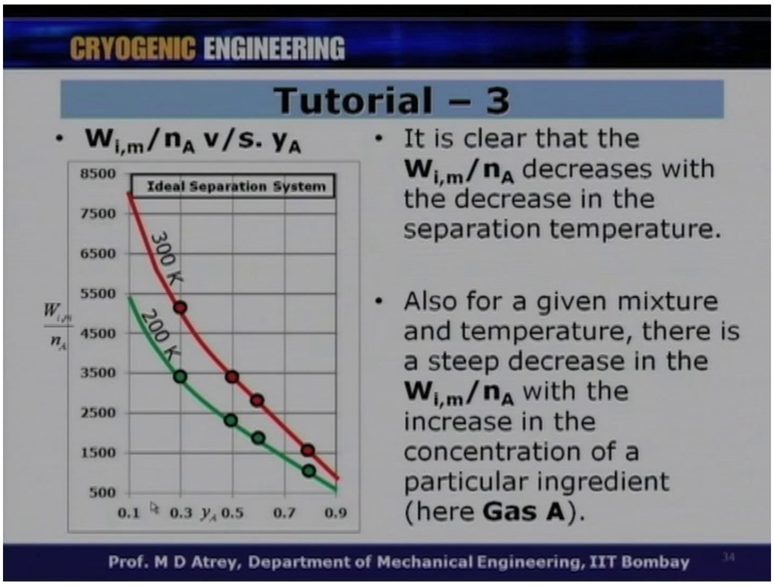

Also for a given mixture and temperature there is a steep decrease in W i m upon N A with the increase in the concentration of the particular ingredient that is as you go on increasing the Y a value or as you go on increasing the concentration of Gas A in a mixture W i m upon N A is going to be decreasing. Because naturally, and if you see mathematically the numerator the denominator goes on increasing and therefore, W i m upon N A will start decreasing as you go with the increase in the value of y a.

Similar thing will happen even if the temperature is lowered from 300 Kelvin to 200 Kelvin alright. So, what we saw from all this tutorial is what happens to the work of separation. First of all we understood what are these different nomenclature W i m upon n m W i m upon N A W i m upon m a work of separation of mixture per mole of Gas, work of separation per mole of a, work of separation per mass of a these are three different quantities.

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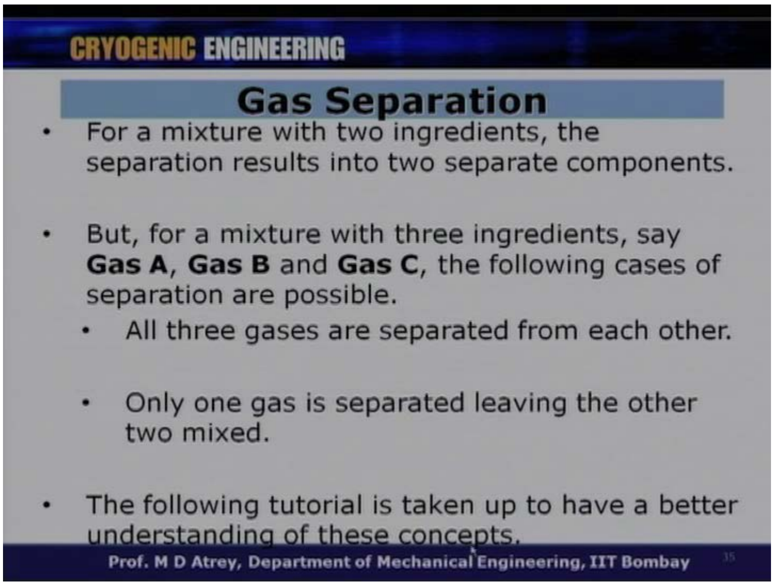

Also we understood that, that the work of separation passes through maxima work of separation depends on the separation temperature and we will go for a different study. Going ahead what we have learnt. Now, for a mixture with two ingredients, the separation results in two separate components, this was a simple case you had a Gas A and Gas B separated Gas A and Gas B, but, we can we have got a mixture wherein we can have three components Gas A Gas B and Gas C. So, but, for a mixture with three ingredients say Gas A Gas B and Gas C following case of separation are possible.

What of these cases all three gases are separated from each other; that means, after separation I get Gas A Gas B and Gas C the second case is only one Gas is separated leaving other two gases mixed. That means, I am not interested in any other gases, but Gas A. And therefore, for a mixture of a b and c, I would like to take only Gas A out and would not bother to separate b and c, let them remain combined. So, what I am going to separate out from a b c is only a and the other lot will be b plus c.

So, work of separation of Gas A Gas B and Gas C that means, work of (( )) of entire mixture is one case, which is what is given by first case. While, I could be interested only Gas A or Gas B or Gas C; that means, let us say I am interested in Gas C. So, my separation problem will be now, separate Gas c from A and B. So, work of separation of separating Gas C from A and B will be different than separating all three gases. Did you understand the difference; this is the difference between separating A B and C from each other or separating only one of the gases from mixture of other two gases.

And this is what I am interested in I want to calculate the amount of what is the work input required just taking out Gas A from a mixture of Gas A B C or I want to calculate the amount of work to be done in order to separate A B and C from each other; that means, I need a b and c all three different gases to be separated in that case. The following tutorial is taken up to have a better understanding of this concept. Because this concept is a very different now and let us understand it from using this tutorial and so that we can get some quantity to fill in also at the same time we can understand the qualitative approach also.

So, the tutorial four basically is solved to understand the mixture of three different gases and also conceptual understanding of separation of one of the components from this mixture of three gases or separating the entire three components from each there can be understood from this tutorial four. So, what is the problem statement reads? The problem statement is consider air has a mixture of 78 percent nitrogen 21 percent oxygen and 1 percent argon by mole fraction.

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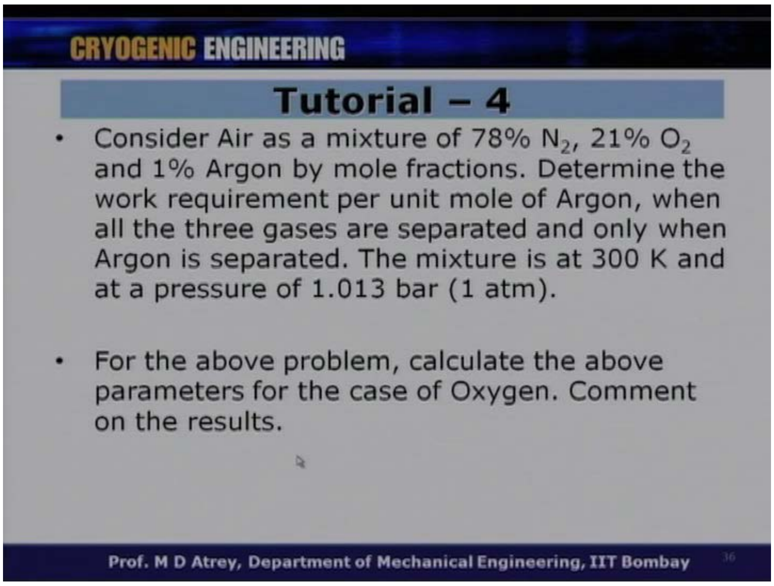

Determine the work requirement per unit mole of argon, when all the three gases are separated and only when argon is separated. That means, first case is what is work of separation per unit mole of argon and second thing is what is the work of separation when only argon is separated from this mixture of three gases. The mixture is at 300 Kelvin and at a pressure of 1.013 bar.

The second part of the problem also reads like this for the above problem calculates the above parameters for the case of oxygen. So, instead of argon I have oxygen, alright comment on the results. So, important is comment on the results and explain the results basically.

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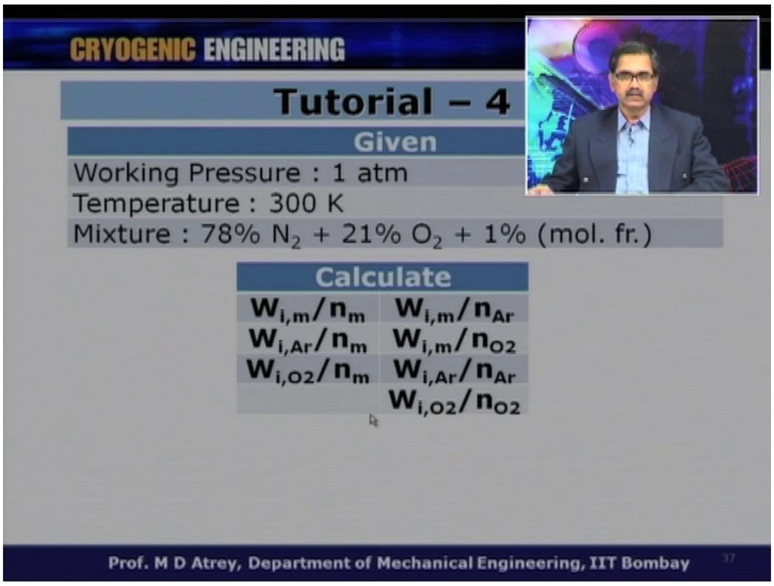

So, what are the parameters given? Working pressure is given, temperature is given, and the mixture composition on molar basis is also given. So, what are the molar basis? 78 percent nitrogen 21 percent oxygen 1 percent argon.

So, 0.78, 0.21and 0.01 that is what our molar fraction of the mixture, nitrogen, oxygen and argon is, what is to be calculated is all these parameters so, what are all these parameters; let us read one by one. So, W i m by n m is work of separation of mixture per mole of mixture, then we go to W i m upon n A r which is work of separation of mixture per mole of argon, then work of separation of argon per mole of mixture, work of separation of oxygen per mole of mixture, work of separation of mixture per mole of argon, work of separation of mixture per mole of oxygen, then work of separation of argon per mole of argon work of separation of oxygen per mole of oxygen, (( )) all of them are different quantities.

So, here in the first part of the first column the separation is done per mole of mixture alright. So, W i m upon n m work of separation per mole of mixture work of separation argon per mole of mixture, work of separation oxygen per mole of mixture, in the right side I need the values with respect to one of the gases which is argon and oxygen. So, here I say work of separation of mixture per mole of argon here I say work of separation of mixture per mole of oxygen. Now, here I want to convert this quantity instead of per mole of mixture I want per mole of argon work of separation of argon per mole of argon and work of separation of oxygen per mole of oxygen.

This concept should be absolutely clear, what is ask in a problem and how do we get those values basically this should be absolutely clear. So, please get used to this nomenclature and this is what a new nomenclature and this is a very important to understand this nomenclature. So, let us calculate first W i m by n m which is work of separation per mole of mixture and you got a formula here.

So, y R T m work of mixture consists of three gases argon, oxygen and nitrogen so, we got a b and c terms. So, we got a Y a r log 1 upon Y a r y o 2 log y upon y o 2 y N 2 log 1 upon y N. So, we got terms for Gas a Gas B and Gas C which is sigma term basically. So, putting those values, what was Y N 2 0.78, Y O 2 0.21, Y A R 0.01 put those values in equation we get, work of separation of mixture per mole of mixture is equal to 8.314 into 300 0.78 log 1 upon 78.21 log 1 upon 0.21 plus 0.01 log 1 upon 0.01 this is equal to1515.6 joules per mole of mixture.

So, work of separation per mole of mixture is given by this; that means, all the three components are separated and the work is represent per mole of mixture. Now, I want to represent the same thing as per mole of argon. So, work of separation of mixture per mole of argon is divide this by argon molar fraction of argon, as we have seen earlier 1415.6 divided by 0.01 and suddenly this value will be very high. Because the molar fraction of argon is very, very small 0.01 so, work of separation of mixture per mole of argon is going to be huge quantity, 141560 joule per mole of argon because the fraction the molar fraction of argon is very, very small quantity. And therefore, this division gives a very large number, a big number. Now, I want to calculate work of separation of mixture per mole of oxygen. So, what is the molar fraction of oxygen is 0.21.

So, I divide this by 0.21, now, I should have 0.01 in earlier case, I divide by 0.21 and now I get work of separation mixture per mole of oxygen as 6740.9 joule per mole of oxygen and this is my work of separation per mole of oxygen. And now I have got a work of separation argon per mole of mixture, this problem is different than what we have studied earlier, earlier we were separating only work of separation of mixture.

Now, here I want to calculate only work of separation of argon from the given mixture. The formula is going to be different in this case so, be careful. So, what my formula will be now, work of separation of argon per mole of mixture is equal to R T m. Now, my Gas A is argon and my Gas B is a mixture of other two gases because I am not bothered about oxygen plus nitrogen. I just want to take argon out from the mixture of argon plus oxygen plus nitrogen. So, my Gas A is going to be argon and my Gas B is going to be mixture of two gases Oxygen plus Nitrogen. So, formula is Y A R log 1 upon Y A R plus 2 plus N 2 log 1 upon molar fraction of oxygen plus nitrogen these is a small mixture by itself, because of a mixture of A plus B plus C, I just want to take out a that is it I am not interested in B and C. So, B and C will always remain in a mixture form here.

So, what is my Y A R? Y A R is .01 and Y O 2 plus N 2 is 0.9 nitrogen plus oxygen 0.78 plus 0.21 which is 0.99. So, this is what Y O 2 plus N 2 will figure here. So, putting this respective values over there, work of separation of argon per mole of mixture is equal to 8.314 into 300 0.99 log 1 upon 0.99 which is this particular bracket plus 0.01 log 1 upon 0.01 which is refer in to the argon Gas and is equal to139.6 joule per mole of argon mole of mixture this is what my work of separation per mole of mixture is given as.

Now, I want to convert that and represent in terms of mole of argon only. So, my work of separation of argon per mole of argon is equal to; I know work of separation of argon per mole of mixture. So, I will just divide by per mole of fraction of argon basically. So, work of separation of argon per mole of argon is equal to139.6 divided by 0.01 which is 13960 joule per mole of argon. Now, this is clear we have done it several times now, so, the concept should be absolutely clear by now.

Now, as I expecting work of separation of oxygen per mole of mixture, so I again got a instead of argon now, I am separating out only oxygen and the other part will remain is now mixture of argon and nitrogen alright. So, I have got a Y O 2 log 1 uponY 2 I have got a Y an r plus N 2 log 1 upon Y an r plus x. So, what is the value of Y O 2 0.21 molar fraction of oxygen and YN 2 plus O 2 is 0.78 which is nitrogen plus argon.

So, putting those values over here I will get integer values 0.78 log one upon 0.78 0.21 log one upon 0.21 this is the oxygen part of it putting these values get 13100.8 joules per mole, which is work of separation of oxygen per mole of mixture. And now, I can convert the same to understand what is my work of separation of oxygen per mole of oxygen W i o 2 divided by n m is thirteen 1000.8 the molar fraction of oxygen is 0.21.

So, W i o 2 per mole of oxygen, work of separation of oxygen per mole of oxygen is equal to work of separation of oxygen per mole of mixture divided by two that is molar fraction of oxygen which is 1300.8 divided by 0.21 which is 6194.3 joules per mole of oxygen this is my W i o 2 per mole of oxygen.

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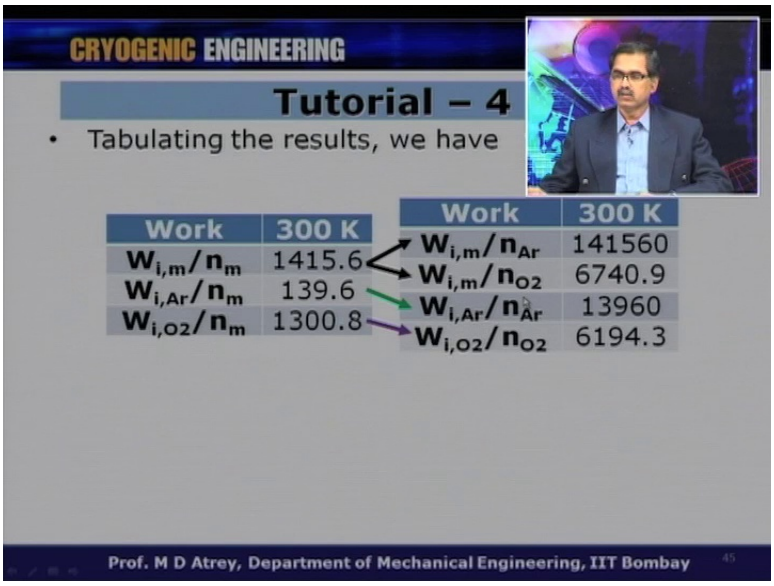

So, tabulating all the results together what we can get is a combined look work at 300 Kelvin work of separation at 300 Kelvin. So, work of separation per mole of mixture is 1415.6, work of separation of argon from this mixture per mole of mixture is very small 139.6. Argon being a small quantity then work of separation of oxygen per mole of mixture is 1300.8 this is oxygen is going to be separated from the mixture per mole of mixture.

Now, I can represent per mole of mixture as per mole of argon or per mole of oxygen so,this is just a representation of style. So, I can get now, work of separation of mixture per mole of argon. So, divide this by a molar fraction of argon which is this and because the molar fraction of argon is very small this quantity looks very big and work of separation of mixture per mole of oxygen is given by this.

Similarly, I can represent work of separation of argon per mole of mixture in terms of work of separation of argon per mole of argon also which is what is given by this. Also extending instead of having n m I can have N O 2 it work of separation of oxygen per mole of oxygen which is 6194.3. So, eventually one may ask you what is this value W i o

2 by N O 2 or it could be only W i o two by n m. So, what is important is what has been asked.

Basically, one can understand from work of separation of work of liquefaction per mass of Gas which is compressed, if you remember my earlier topic work of liquefaction per mole of Gas which is liquefied. Similarly, here work of separation per mole of mixture or per mole of oxygen or argon or nitrogen or whatever. So, this understands the problem statement and represents your work of separation per mole of mixture in terms of per mole of oxygen or argon or nitrogen for that matter.

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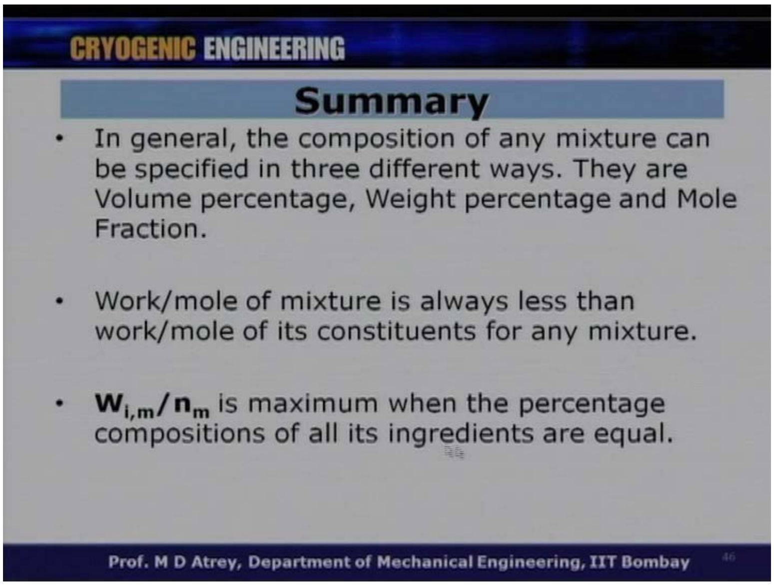

Coming to the summary, with all these understanding of work of separation of Gas A, Gas B and Gas C. We have understood various nomenclature represented to calculate the work of separation of Gas A or work of separation of Gas B or work of separation of the entire mixture and that could be terms as per molar basis on a mixture or per molar basis of oxygen or nitrogen or Gas A or Gas B or Gas C it could be anything alright. So, in summary, in general, the composition of any mixture can be specified in three different ways.

They are volumetric percentage weight percentage and mole fractions. So, as you understood what we ultimately want is mole fraction. So, suppose, the problem has not been given into mole fraction or the composition has not been given on a molar basis. We can have convert weight percentage, weight composition into molar composition while we know that the volume composition is nothing but the molar composition itself. So, in that case, we do not have to do any extra algebraic calculations.

Work per mole of mixture is always less than work per mole of its constituents for any mixture this was clear, because we know that n m is equal to N A plus N B where N A and B are constituents of mixture. So, work per mole of mixture is going to be always less than work per mole of Gas A or work per mole of Gas B because mole of Gas A and Gas B fraction is going to be less than one, less than moles of mixture basically.

So, W i m by n m is maximum when percentage compositions of all its ingredients are equal, which we found that from the graphical representation that when Gas A is equal to Gas B is equal to 0.5, we hit the maximum the work of separation in that case is maximum. Similarly, for each components when the Gas A is equal to Gas B is equal to Gas C is equal to 0.33 then it will hit the maximum the work of separation is going to be maximum in that case.

So, this is just to understand the same thing with the decrease in the percentage work per mole of component increases. So, as the percentage composition of that particular component decreases the work of separation the work per mole of that component; that means, work per mole of Gas A will increase if the Gas A is percentage is decreasing in that case. This is what we saw again graphically when we saw W i m by N A is a function of Y A alright.

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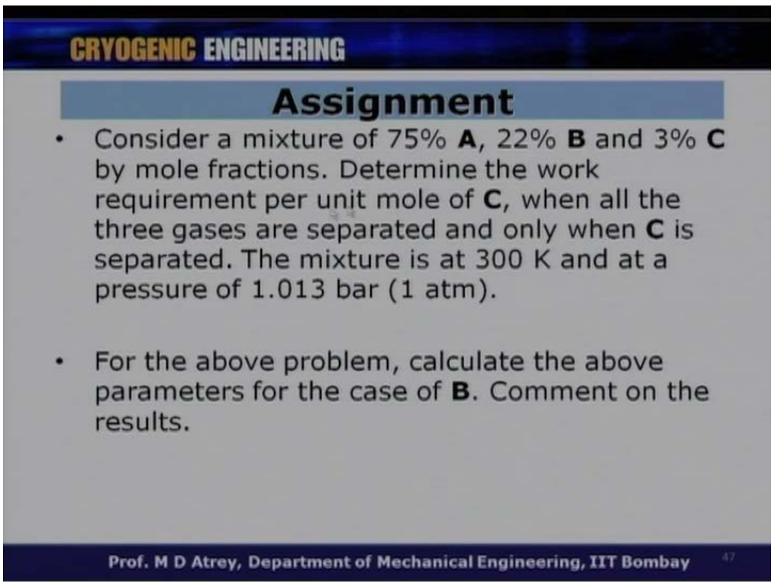

With this background, an assignment has been given for mixture of Gas A, Gas B and Gas C, percentage has been given mole fractions to calculate determine the work requirement per unit mole of c when all the three gases are separated and only when c is separated. So, it is a similar kind of problem what we have just solved, the mixture is this and the pressure is given. For the above problem, calculate the above parameters for the case of B and comment on results. So, this is a very important thing, please do carry out this calculations. The answers are given over here. So, please check your answers after this and see that they are correct. Thank you very much.