Fluidization Engineering
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Lecture – 12
Calculation of gas pumping power consumption in fluidized bed

Welcome to massive open online course on fluidization engineering. Today's lecture is on calculation of gas pumping power consumption in fluidized bed.

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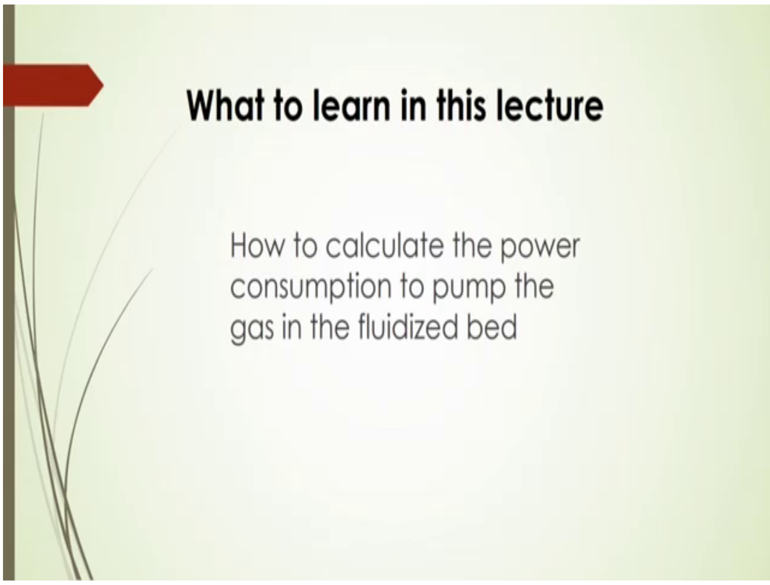

And, what to learn in this lecture? That we learn here how to calculate the power consumption to pump the gas in fluidized bed. The gas is distributed through the distributor in the fluidized bed. So, to pass this gas to the distributor of course sufficient power is required and then, this power how to calculate against the resistance of the fluidized bed on this gas consumption.

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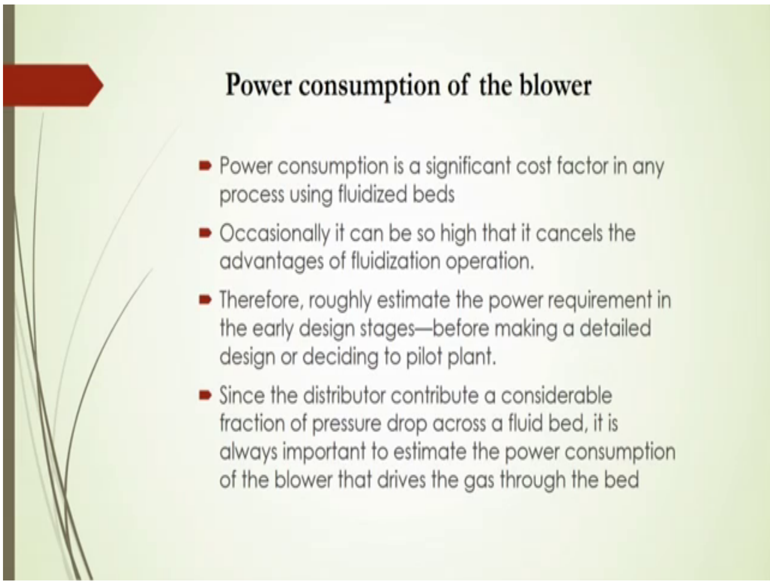

So, let us see how to calculate what should be the actual fiamble of this power consumption of the blower you will see that power consumption is a significant cost factor in any process using fluidized beds. Occasionally you will see it can be so high that it cancels the advantages of fluidization operation.

Therefore, roughly estimation of the power which is required for the distribution of gas through the distributor in the early design stages before making a detailed design of the design of the fluidized bed or deciding to the pilot plant operation of course, this will be required.

Now since the distributor constitute a considerable function of pressure drop across a fluidized bed it is always important to be noted that the power consumption of the blower that drives the gas through the bed. So, the power consumption mainly contributed by this by this by this distributor through which this gas is consumed gas is distributed inside the bed.

Of course, other different parts of the of the fluidization design that contribute to the power consumption of the fluidization operation in that case the power consumption through the fluidized bed for the distribution gas is the main contributory part. So, we will here know how to calculate this power consumption of the compressor or blower by which the gas is compressed to distributor through which gas is distributed.

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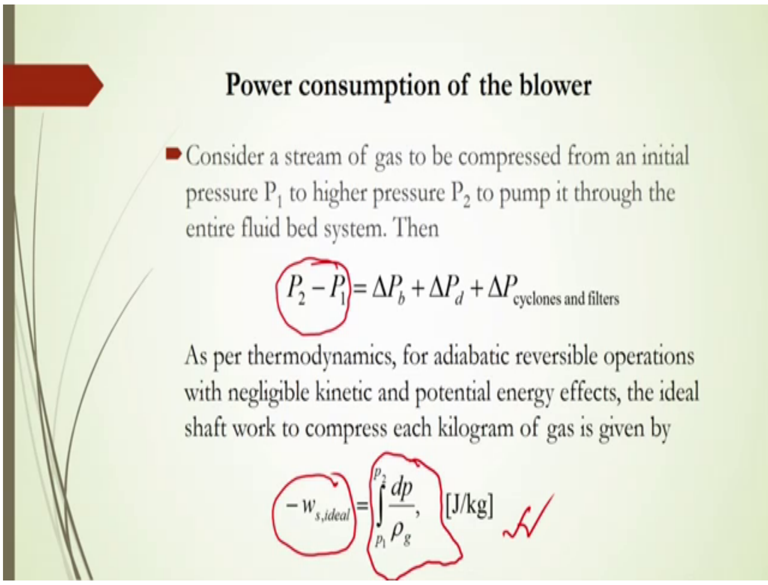

Now, power consumption of the blower let us see here how to calculate. In this case you will see that a stream of gas which will be compressed from an initial pressure to higher pressure if you consider that initial pressure is P 1 and the higher pressure is P 2 the then gas is to be compressed from this lower pressure of P 1 to the higher pressure P 2 to pump this gas through the entire fluid bed in the fluidized bed.

Then what should be the difference of this pressure that can be equal to P 2 minus P 1. P 2 minus P 1 here this equation. So, this is P 2 minus P 1 that is called the pressure difference; that means, the pressure of higher to lower what should be the difference that will be equals to the what should be the pressure difference of the bed and what should be the pressure difference or pressure drop in the distributor and is there any other pressure drop contributed by other means like cyclones or filters in the fluidized bed.

So, summation of this bed pressure distributor pressure and the pressure drop of different mechanical means for the contribution of this total pressure difference we have to then calculate the summation of this 3 or if any other pressure contribution to equivalence for the pressure from lower pressure to the higher pressure.

So, as per thermodynamics then for adiabatic reversible operations with negligible kinetic and potential energy effects you can calculate this ideal shaft works to compress each kilogram of gas from this lower pressure to the higher pressure to pump it the pump is gas through the entire fluidized bed system fluid bed system is given by this will be your notation about this shaft work.

This will be of course; it will be ideal shaft work which will be the integration of this pressure per unit mass of the gas from this initial pressure to this higher pressure P 2. So, here of course, this pressure will be negligible with compare to this kinetic and potential energy effects will be negligible compare to this shaft work here. So, based on this will be able to calculate what should be the what should be the work done by this compressor for compressing this gas from pressure P 1 to P 2.

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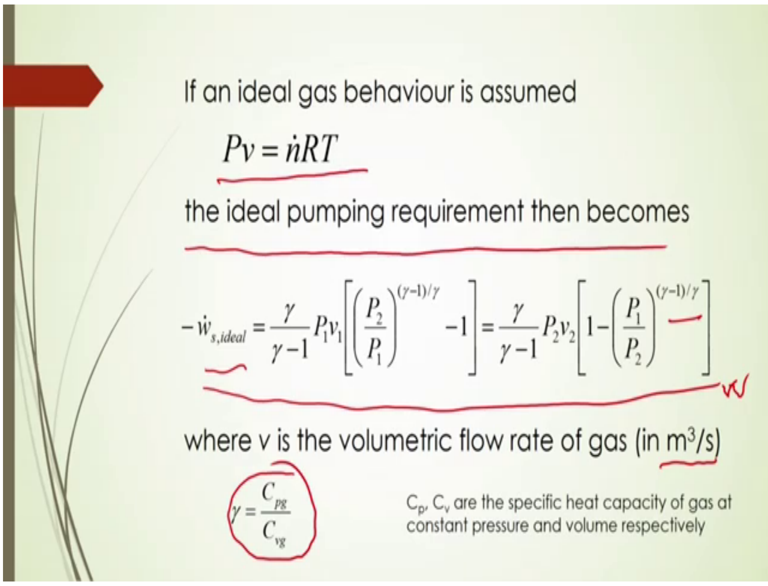

Now, if we consider that there is a ideal gas which is being compressed from this lower pressure to the higher pressure and if it is considered that ideal gas behavior is there then you can say this equation will be followed at that P v is equal to n R T.

So, the ideal pumping requirement then becomes after substitution of this P value here in this equation and then what should be the d P and finally, we can get this equation of this shaft work ideal shaft work as this is a function of this at that gamma and what is that v and the pressures.

So, this v is nothing but the volume per unit mass of the gases is. So, here so W s ideal that is called shaft work rate shaft work and ideal condition it will be gamma minus 1 into P 1 v 1 into P 2 by P 1 to the power gamma minus 1 by gamma minus 1 or you can say this will be is equal to gamma by gamma minus 1 into P 2 into v 2 into 1 minus P 1 by P 2 to the power gamma minus 1 by gamma.

So, in this case v is the volumetric flow rate of gas in meter cube per second. So, here in this case gamma, gamma is nothing, but the ratio of ratio of heat capacity of gas at constant pressure and constant volume. So, this gamma is defined as this which is denoted by this expression this gamma is equal to C P g by C v g.

So, from this equation you can ideally calculate what should be the shaft work done whenever pumping of this gas through this distributor and distributed into the bed from this lower pressure to the higher pressure.

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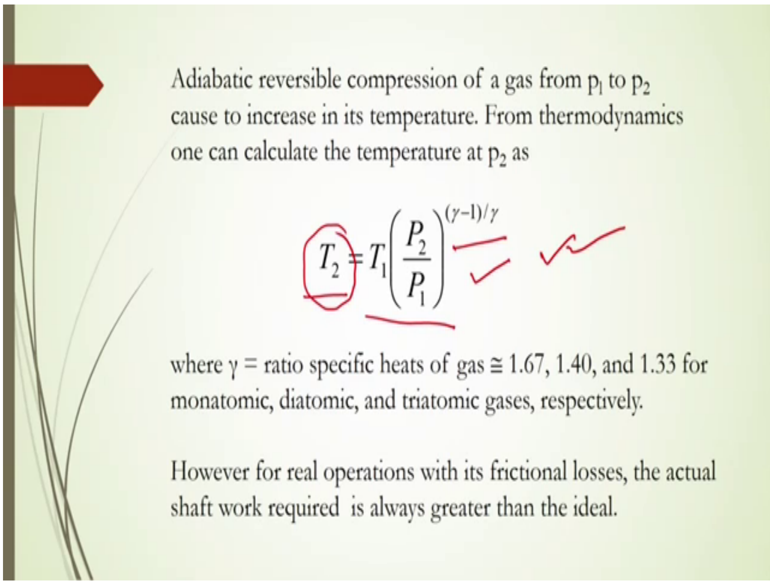

Now, adiabatic reversible compression of the gas from this lower pressure P 1 to the higher pressure that may cause an increase in temperature because of this pressure difference. Now from thermodynamics points of view of course, you one can calculate the temperature at P 2 as what should be the P 2 T 2 as this P 2 that means, if we compress this gas from this lower pressure to higher pressure at that higher pressure what should be the temperature change.

And then that change of temperature at then that final temperature at this P 2 will be is equal to T 2 that can be impulse to T 1 into P 2 by P 1 to the power gamma minus 1 by gamma. So, from this equation you will be able to calculate what should be the temperature at this at this pressure of P 2 this gamma is the ratio of specific heats of gas is equal to 1.67 for monatomic gases and 1.40 for diatomic gas.

And if it is triatomic gas, then you have to consider this gamma value as 1.33. However, for real operation of course, you will see that there will be a frictional losses and then frictional losses will be converted to this heat energy. Now this actual shaft work required always will greater than the ideal case. So, of course, this actual and practical condition you will see the actual shaft work will be required to compress this gas is greater than this ideal shaft work.

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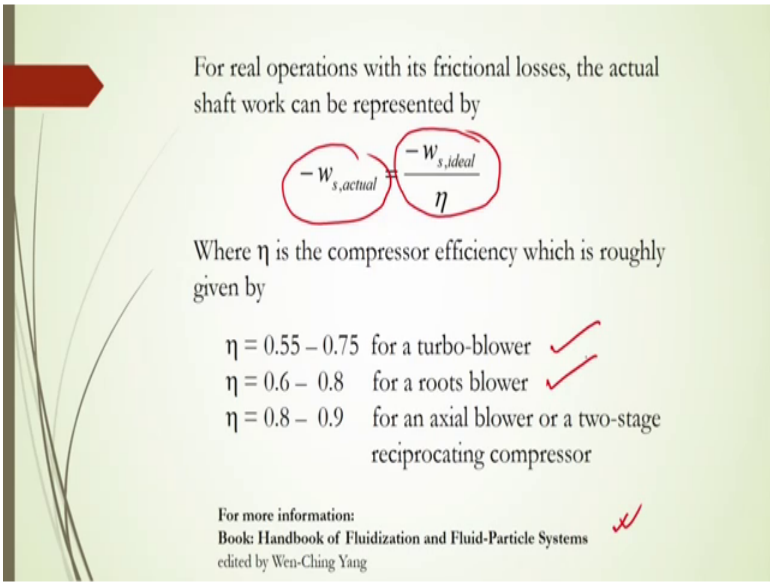

Now, for real operation then or practical operations then it is frictional losses we can say the actual shaft work can be represented by this W s actual that will be is equal to W s ideal divided by eta; eta is the efficiency of the compressor which is roughly given by this eta will be is equal to 0.55 to 0.75; that means, efficiency 55 percent to 75 percent for turbo-blower and it will be 60 percent to 80 percent if it is rooters blower.

And this efficiency will be 80 percent to 90 percent if an axial blower or a two stage reciprocating compressor is used to compress the gas from this lower pressure to the higher pressure through this distributor inside the fluidized bed. Now you can get more information of course, from this books of handbook of fluidization and fluid particle system that is edited by Yang. So, you can get more information on this.

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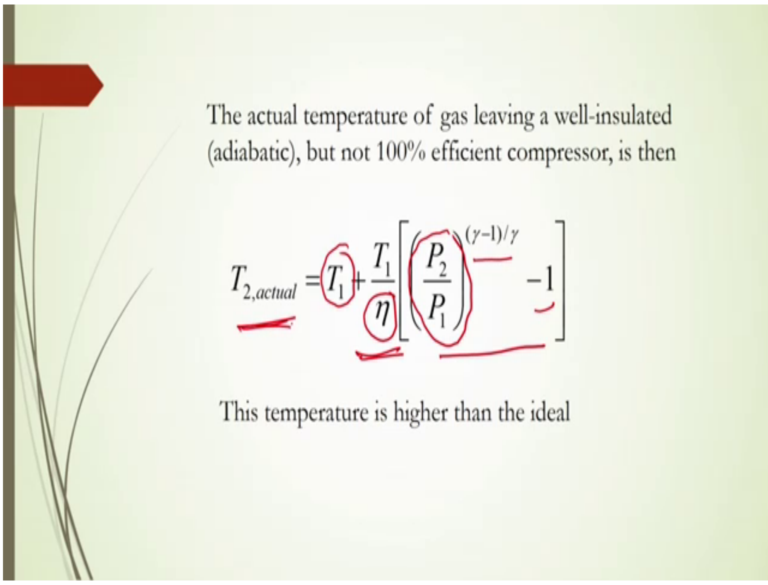

And then actual temperature of the gas leaving a well insulated adiabatic, but not 100 percent efficient compressor is then calculated by this T 2 actual will be is equal to T 1 plus T 1 by eta into P 2 by P 1 to the power gamma minus 1 gamma minus 1. So, what should be the actual temperature at it is higher temperature if you are considering that there will be a fictional losses during the operation of the compression from this lower pressure to the higher pressure.

Now in this case you will see this T 2 of course, you will see the function of this T 1 of course, the and also in pressure at higher pressure if suppose pressure is this higher then this it will be of course is greater than 1 and this temperature greater than T 1, that is why the temperature is higher than the ideal case here. So, this eta will give you the efficient of the compressor from which you can calculate what will be the actual temperature.

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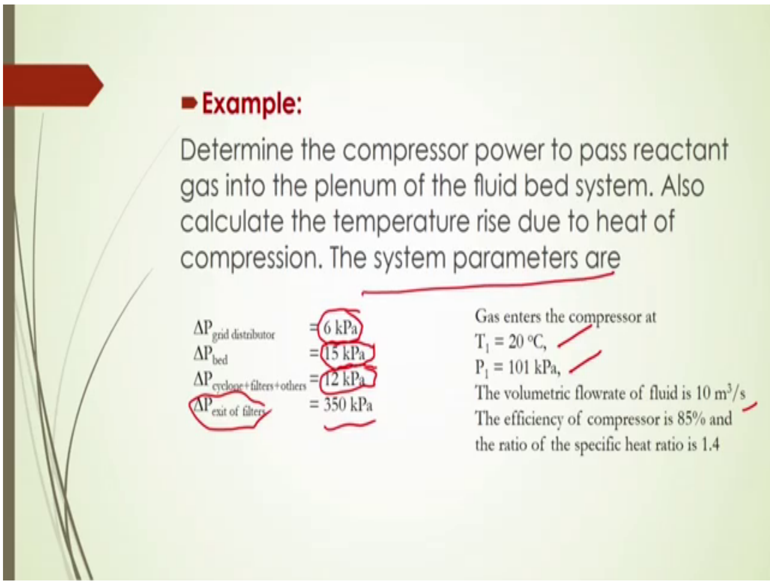

Now, let us see one example that how to calculate this pressure compressor power to calculate to calculate the power of gas distribution into the plenum of the fluidized bed system by this compressor by compressor or any blower, also calculate how to calculate the temperature rise due to the heat of compression here.

Now let us see that system parameters are given as here if suppose grid distributor pressure is here this 6 kilopascal; that means, here some distributor like grid type distributor is used to distribute the gas into the fluidized bed and bed pressure is fifteen kilopascal whereas, this cyclone filters and others pressure drop is given as 12 kPa and the exit of filters it is given as this 350 kPa and gas enters the compressor at T 1 is equal to 20 degree centigrade and initial pressure at 101 kPa, and the volumetric flow rate of the fluid is 10 meter cube per second the efficiency of the compressor is considered as 85 percent and the ratio of the specific heat ratio is 1.4. So, with these conditions how to calculate the compressor power to pass this reactant gas into the plane amount of fluidized bed system let us see.

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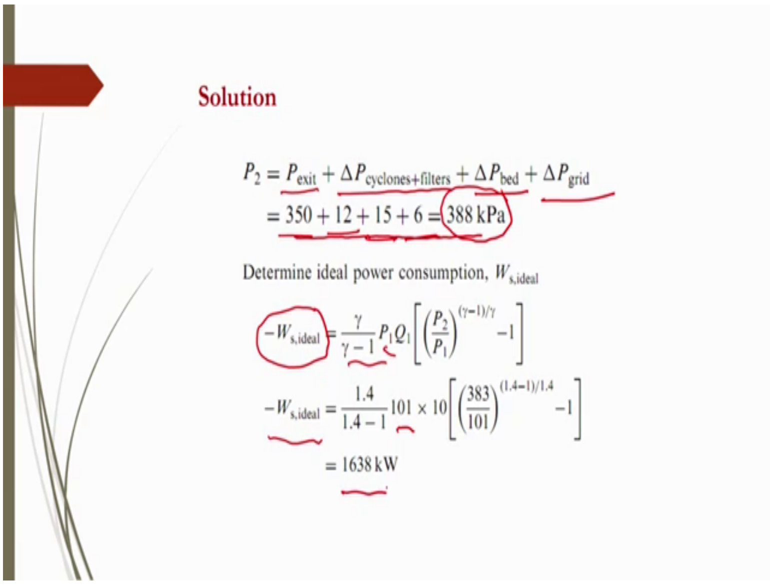

Here this solution what is this you have to calculate first what should be the what should be the pressure that is final pressure P 2 then final pressure P 2 will be is equal to what should be the P exit pressure. What should be the pressure contribution by the cyclones and filters what should be the bed pressure drop and what should be the distributor pressure drop which is as used as grid here.

Now in this case P exit pressure is given 350 whereas, P cyclones and filters it is given 12 k P a, and the bed pressure it is given as 15 kPa whereas, this grid pressure drop is 6 k P a. So, now in this case this they have total exit total pressure that is a final pressure will be the summation of this 1, 2, 3, 4 pressure contribution and it is coming 388 kilopascal.

Now next part that you have to determine then what should be the ideal power consumption which is required to distribute the gas through this grid distributor, now as per this formula of this shaft work at ideal condition that is gamma by gamma minus 1 into P 1 into Q 1 into P 2 by P 1 to the power gamma minus 1 by gamma minus 1.

So, in this case gamma is given as 1.4. So, 1.4 by 1.4 minus 1 into P 1 is given as 101 kilopascal and then Q 1 is given 10 meter Q per second and after the substitution of this P 2 as 383 and P 1 as 101 to the power this gamma value if you substitute and finally, if you calculate it you will get this ideal shaft work as 1638 kilo watt.

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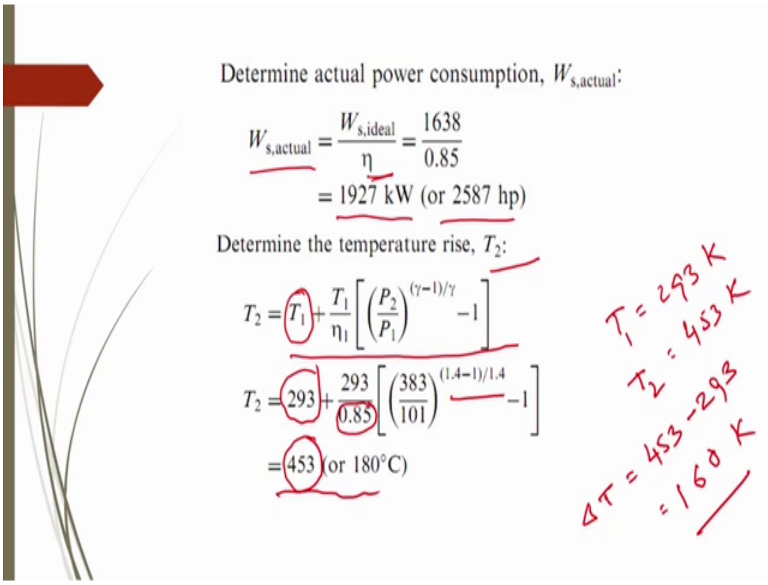

Then what should be then the actual power consumption if the if the compressor or blower efficiency is 85 percent then shaft work actual shaft work will be is equal to W s ideal by eta it has deficiency of the compressor then it will be 1683 divided by 0.85 then it is final is coming 1927 kilo watt or you expressed as 2587 horse power.

Now what should be the then temperature rise the T 2 because of this compression of gas from this P 1 P 1 that is 101 kilopascal to this P 2 that is 388 kilopascal then, you will get this T 2 from this equation here. So, this T 2 will be is equal to T 1 plus T 1 by eta 1 into P 2 by P 1 to the power gamma minus 1 by gamma minus 1.

So, from this you substitute this T 1 value T 1 is given here that initial temperature is 293 and this 293 divided by 0.85 that is efficiency of the compressor and then P 2 is 383 and P 1 is 101 and substitute this gamma value finally, you will get it is coming 453 or 180 degree centigrade.

So, in this way you can calculate what should be the temperature rise during this compressor of this gas from this lower pressure to the higher pressure. So, we are getting here T 2 as 453 whereas, T 1 is whereas T 1 whereas T 1 is given you 293 K and T 2 now we are getting as 453 K. So, temperature increase delta T increased 453 minus 293 that will be is equal to that will be is equal to that is here you can say here 160 K by this increase of by this compression of this gas from lower pressure of that is 101 kilopascal to 383 kilopascal.

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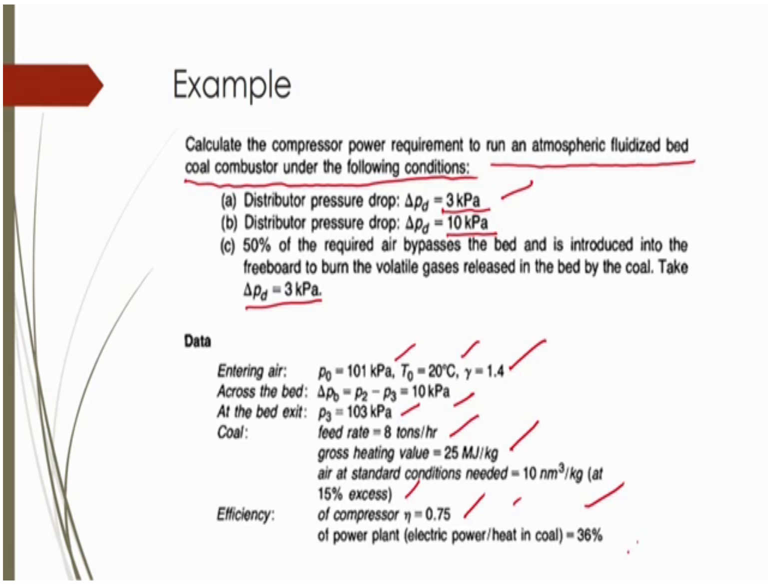

Now, let us see another example if we use the if we use the distributor in such way that it is the pressure drop is some value and if we if we distribute the gas in two locations or it will bypass this gas in such way different condition then what should be the power consumption.

Is there any benefit of this bypassing of gas to distribute the gas into the fluidized bed whether it will be beneficial or not? Let us see some one example whether this bypassing of gas is useful or not or is there any reduction of power consumption or not. Let us see this things with this example. Now calculate the compressor power requirement to run an atmospheric fluidized bed coal combustor under the following condition.

Condition one is that distributor pressure will be 3 kPa another condition distributor pressure will be 10 kPa and third condition that if it is the condition like that 50 percent of the required air that will be bypass bypassed to the bed and is introduced into the freeboard of the fluidized bed to run it and also because of this you will see some volatile gases will be burned in the fluidized bed and released in the bed by the coal. Now at this condition you have to take distributor pressure as this initial condition whatever it is the 3 3 kPa.

Now you have to consider that that gas is entered initial at 101 kilopascal and initial temperature is 20 degree centigrade and the gamma value that is ratio of specific heat capacity it is constant pressure constant volume as 1.4 and across the bed the bed pressure it will be is equal to 10 kPa and at the bed exit that 103 kPa it will considered.

Now coal is supplied into the bed at a rate of 8 tons per hour and a gross heating value is 25 mega joule per k g air at saturated conditions needed at 10 normal meter cube per k g at 15 percent excess and efficiency of the compressor is given 75 percent of power plant it is 36 percent.

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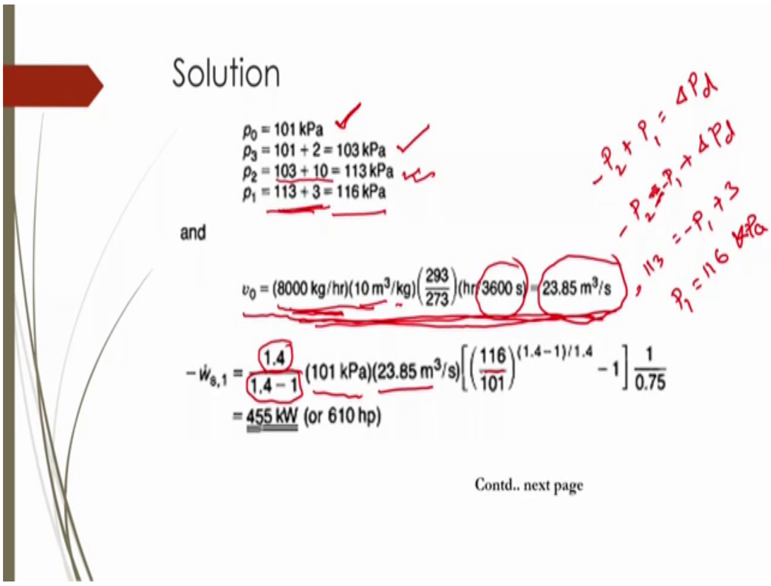

Let us see the solution here it is given that initial pressure is 101 kilopascal.

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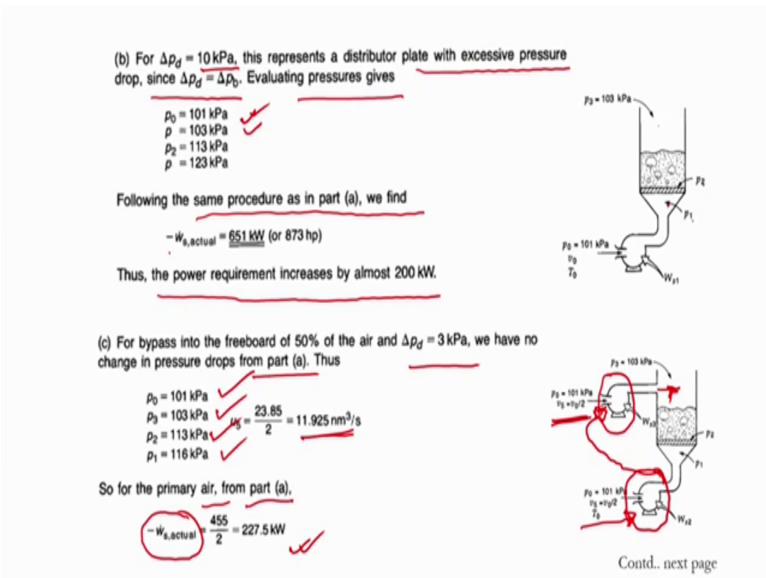

And this P 3 on the bed it is given this P 3 here in this figure you will see P 3 here at this condition this 103 and P 1 it is not there, but shaft work you have to calculate and P 0 is 101 kilopascal. What is the v 0 what is the T 0 is not given.

Let us see here what should be the v 0 that is volumetric flow rate of the gas here it is seen that that it is given that 800 k g or 8 ton per hour 8 ton per hour feed rate is the coal feed rate is 8 tons per hour and air at saturated condition needed this 10 normal meter cube per k g of coal.

So, in this case air is required 10 meter cube per k g of coal, but whereas, this k g is supplied as 8 tons that is 8000 k g per hour and then if you multiply it by 10 then you will get this how what would be the volume of gas per hour to be supplied and then at this condition of this that is here at this T 0 condition that is at the initial condition.

What should be the volume of the gas at this temperature of 20 degree centigrade then you will get this then it will this meter cube per hour and again if you divide by this 3600 second you will get ultimately meter cube per second it is coming 23.85 meter cube per second.

Now, this is your initial gas supplied at the initial condition to this fluidized bed. Now what should be the shaft work for this? Now if you substitute all the values in this equation of the shaft work in ideal condition then you will see that it will be your gamma by gamma minus 1 into this P 1 into this volume v 1 that is 23.85 meter cube per second into P 2 by P 1 P 2 here it is coming 116; 116 how it is calculated here P 2 is nothing, but here this P 103 plus 10 103 what 103 this is nothing but here what should be the P 3 and this.

Now according to this here see this will be your P 3 this is P 3 then what should be the P 2 and P 1; P 2 and P 1 P 2 is nothing a 103 plus 10, 10 is what this is the your distributor pressure 10, then P 2 plus then P 2 is equal to P 3 plus 10 that will be is equal to 113 and then P 1 is equal to 113 plus 3 that will be is equal to 116.

How it is coming 3 here see 3 is nothing, but equivalent distributor pressure as 3. So, distributor pressure as 3. So, P 1 P 1 plus 3 that will be P 1 will be is equal to then this P 1 this P 1 how it will be this P 1; P 1 how to calculate this P 1; P 1 is nothing, but this 113 that means, P 2 plus 3 P 2 plus 3.

Why because this P 2 minus P 1 P 2 minus P 1 that will be is equal to delta P d distributor pressure drop, then P 2 will be is equal to then P 2 is equal to P 1 plus delta P d. So, P 1 is given to you that P 1 is P 1 is given to you P 1 is nothing but P 1 what is the P 1 minus P 2 is equal to P 1 minus P 2 then it will be is equal to it will be P 1 P 1 minus P 2 is equal to delta P d and then here P 2 is given to you that is 113 plus 10 then it will be is equal to 113 this is 1 1 minus 113 minus 113 that will be is equal to that will be is equal to minus P 1 plus delta P d 3.

So, ultimate P 1 will be is equal to P 1 will be is equal to 116 kPa. So, in this way we know that what should be the P 0. What should be the P 3? P 3 is nothing, but what here in this case it is the atmospheric pressure atmospheric pressure P 3 that is 101 plus 2 here and this is 103 P 3 and then P 3 will be is equal to 101 plus 2 that will be is equal to 103 103 why it is coming like that this P 3 is given to you actually this P 3 is this nothing but P 0 plus P 0 P 0 minus P 2 minus P 2 here. So, this will be given as 103.

So, P 2 will be is equal to what 103 plus 10; 10 is what 10 is nothing, but the P d distributor pressure and P 1 is equal to this. So, finally, we are getting the pressure as 455 kilowatt.

Now, if we consider that v condition where delta P d is equal to 10 kPa the this represents a distributor plate with excessive pressure drop. Since delta P d is equal to delta P b here then evaluating pressures gives as P 0 is equal to 10 P 0 is equal to 101 and P is equal to 103 and here this P 3 and P 2 that would be is equal to 113 and P is equal to 123; 123 k P a.

And following the same procedure as in part a then we find this actual shaft work is equal to 651 kilowatt or 873 h hp. Thus the power requirement increases by almost 200 kilowatt if the distributor pressure is increased from this 3 kPa to the 10 kPa.

Now in the third condition for 5 bypass into the freeboard of 50 percent of the air and distributor pressure is 3 kPa then we have no change in pressure drops from part a. So, in that case P 0 is equal to 101 and P 3 is equal to 10 P 2 is equal to 113 and P 1 is equal to 116.

And then v s will be is equal to what? Since here very interesting that this whole amount of gas is not supplied from this compressor and whereas, this 50 percent of this gas is bypassed and it is it is first this compressor here in this freeboard region. So, what should be then v s for this compressor here it should be of course, half of this total amount of gas which is being compressed.

So, for the primary air from part a we can say that this actual shaft work will be is equal to half of that actual shaft work which is obtained as per that equation in initial condition that is this is in part a then that is 455 divided by 2 this will be is equal to 227.5 kilowatt.

So, by this equation you will be able to calculate what should be then what should be the what should be the power consumption if we if we by pass this only then 50 percent of this air will pass through this compressor remaining 50 percent; again it will be compressed through this compressor another compressor is this.

Now if we use this compressor to compress this 50 percent of air within this operating condition of initial pressure of 101 and this volumetric flow rate of this gas as half of this initial volumetric flow rate of the gas or air then what should be that?

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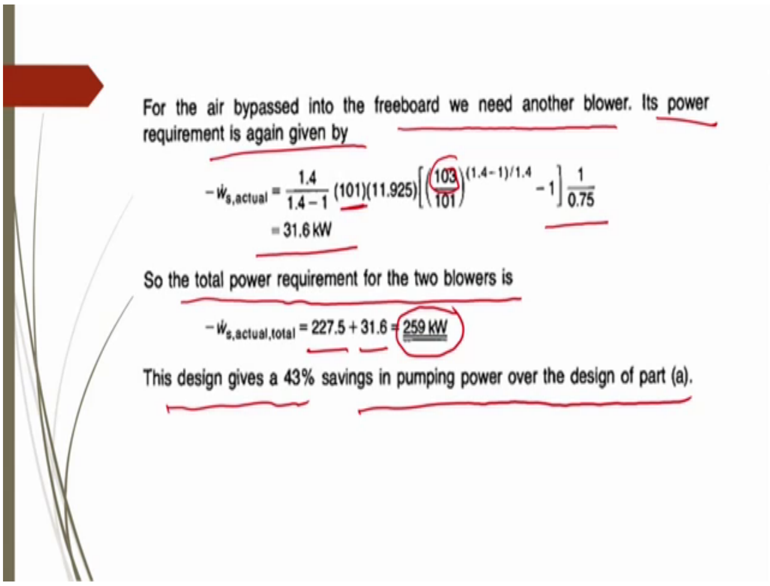

So, for the air bypassed into the freeboard we need another blower of course, or compressor it is blower requirement is again given by this again the same equation to be used to calculate the actual shaft work as this. So, it is coming here of course, this is function of pressure this is initial pressure, this is this pressure here it will be 103 because this at this region the atmospheric pressure is 103 kilopascal here.

So, based on this actual shaft work will be is equal to 31.6 kilowatt. So, that total power requirement for the two blowers will be the summation of this two work like this here initially it was 227. 5 and for the bypass gas it is 31.6. So, total 259 kilowatt.

So, this design gives at least see 43 percent almost 43 percent savings in pumping power over the design of part a. So, what we observe that if we bypass some amount of gas here we can get the benefit of the power consumption if we if we if we bypass then of course, the lowering the power consumption as per this example.

Of course, some other operating condition to be designed or to be kept in such way that this power consumption will be less compare to this. So, according to this problem we are getting at least 43 percent power saving by bypassing 50 percent of the gas through the another blower and supply to the freeboard of this fluidized bed operation.

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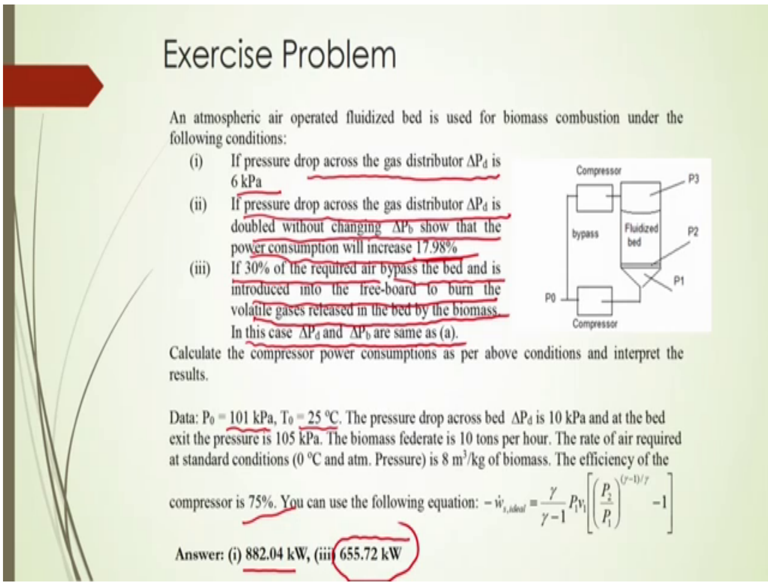

Now, if we do another exercise problem here you can get same way now if pressure drop across the gas distributor is 6 kPa. And what should be the then power consumption if pressure drop across the gas distributor doubled without changing delta P which show that power consumption will increase 17.98 percent.

If 30 percent of the required air bypass the bed and air introduced to the freeboard to burn the volatile gas is released in the bed by the biomass in this case delta P d and delta

P b are same as a. So, at this operating condition of this initial pressure of this and T 0 is this.

Then, what should be the power consumption? If the compressor power compressor efficiency is 75 percent and it is seen that at the same way for the calculation it is seen that the power consumption will be the initial case 882.04 whereas, this power saving will be 17.98 percent if the pressure drop across the gas distributor is doubled without changing bed pressure there and of course, if 30 percent of the gas if it is bypass the bed and introduced into the freeboard then we will see that the power consumption will be 655.72 here. So, almost 17.98 percent will be power saving here.

So, from this lecture what we what we observe that we can calculate the power consumption from the thermodynamic equation and what should be the actual shaft work and what should be the ideal shaft work to compress the gas from this lower pressure to the higher pressure and also we can see if the gas is bypassed and compressed to the distributor then we can of course, save some power during the operation.

And for this it is to be noted that of course, you have to consider other pressure drop is there any mechanical devices used to compress or any other operation if it is attached like any other heat energy or any other energy is required to the operation of the fluidized bed and what should be the total energy required for that that you have to calculate here in this case only we are considering that what should be the compressing power is required distribute the gas inside the bed, because this part is actually main contributory part for the fluidization operation.

So, this is very important to know and we have seen that several other parts also will be contributing this distributor pressure and which will make you the consumption estimation for this fluidization operation. In the next lecture we will try to discuss something about other type of distributor is spatial type of distributor like type of fluidized bed like a bubbling fluidized bed. What should be the other component of the bubbling fluidized bed and also what should be the bubble characteristics in the bubbling fluidized bed we will be discussed in the next lecture.

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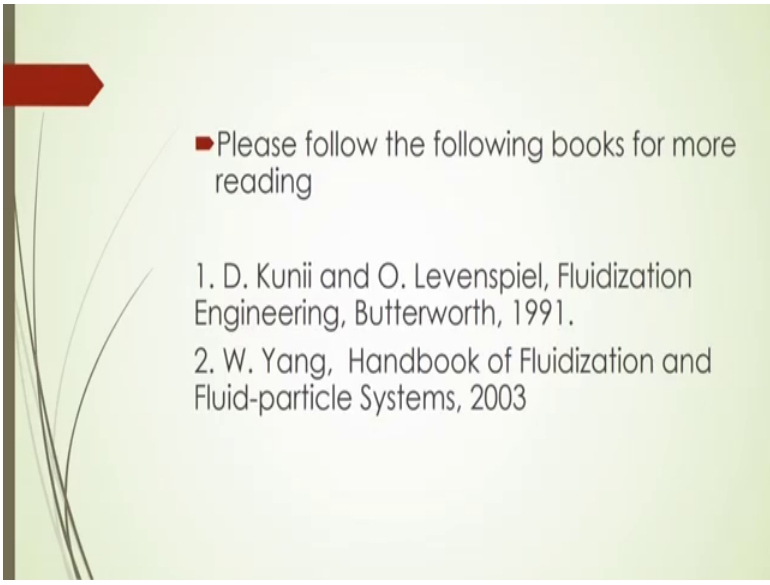

And for this gas distributor you please follow the following books for more reading here Kunii and Levenspiel Fluidization Engineering. And Yang that handbook of fluidization and fluid particle system so that is all today's lecture.

Thank you.