Thermal Engineering: Basic and Applied

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Lecture – 51
Engine Operating Characteristics MEP and Indicator Diagram

I welcome you all to this session of thermal engineering basic and applied. Today we shall discuss about the engine operating characteristics and in this context we shall introduce a term which is MEP the full form is Mean Effective Pressure. What is mean effective pressure and if we discuss the engine operation, the role of mean effective pressure is very important and also we shall discuss about the indicator diagram.

You know we are discussing about the carburettor in the last few classes and we have seen that internal combustion engine or any heat engine when we design, the sole purpose is to get work output. And to get that work output particularly for the spark ignition engine, carburetor is an important element. For the compression ignition engines, carburetor is not an essential part but the combustion is initiated by utilizing rather the thermodynamic state of the fuel that is that is there in the combustion chamber at the end of the compression stroke. So, now to analyze the engine operating characteristics particularly focusing on the mean effective pressure what we need to do, we need to draw the schematic of a four stroke engine. Maybe we shall discuss everything in the context of four stroke engine but eventually several expression that we shall try to derive in today's class also can be written for the two stroke engines.

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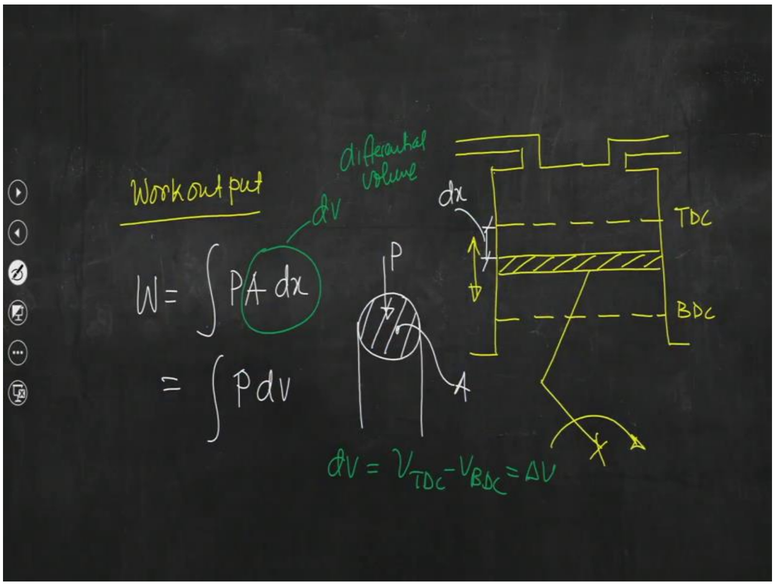

So, if we draw the schematic, this is the top dead center and this is the bottom dead center and piston is having reciprocating motion between these two centers TDC and BDC. So, we need to induct air if it is a CI engine or airflow mixture through this intake manifold to the engine cylinder and piston is having movement between these two stops and we have identified several Strokes.

So, today we shall discuss about the work output this is very important because no matter whether you are supplying only air or air fuel mixture for the CI and SI engines respectively our sole purpose is to get work output. At the cost of some energy that is the energy which is remaining stored within the fuels being supplied. So, the work output is the work generated inside the combustion chamber of the cylinder.

So, the air fuel mixture or air which would be eventually mixed with fuel for the CI engine during the end of the compression stroke, the sole purpose is to have perfect or efficient combustion and it is because of the combustion due to the gas pressure, a force will be acting on the piston face and it is because of that force piston will have movement from TDC to BDC.

So, we will be getting work output. Now, this is the work which is generated by the gas inside the combustion chamber of the cylinder. So, this is the work output now we know the work is basically the force which is acting through a certain distance. So, say that piston has displaced this small distance dx.

Because of the gas pressure which is there inside the combustion chamber and then what would be the expression of work done. So, this is the Piston face on which force due to gas pressure will be acting now if we assume that the pressure is p inside the engine cylinder.
So, work done would be $\int PAdx = \int pdV$. So, this is the expression of the work done, now we need to know this particular quantity to estimate the efficiency of the engine because whether we are going to have a carburetor or we are going to have different other arrangements for its operation the sole purpose is to get this amount of work done. So, dV is the differential volume displaced by this gas. So, basically the pressure which is very important to predict the amount of work will be getting inside the engine cylinder.

We shall discuss about several terms of the works that we need in the context of this engine operation but the pressure p it is very unlikely that the pressure will remain constant throughout the process rather as the Piston is traveling from TDC to BDC pressure will keep on changing and if the pressure changes we cannot analytically calculate what would be the work done.

So, we need to go for some computational analysis to calculate what would be the work done because that this is the elemental volume which is displaced. Now for another elemental volume pressure p may change from P1 to P2, let us say not only that inside the engine cylinder if we traverse spatially rather there would be a spatial variation of the pressure.

So, it is not so easy to calculate the work done provided if we introduce another term. So, what we have understood is that we can calculate the work done rather work output from this expression. So, basically we have to calculate what is the pressure at each and every Point inside the combustion chamber and because essentially piston will have the change in volume from V_{TDC} to V_{BDC}.

So, $dV = V_{TDC} - V_{BDC} = \Delta V$. So, volume will be changing like this but it is very unlikely that for a change in volume from TDC to BDC pressure will remain same throughout the process. So, it is changing continuously as the Piston moves from TDC to BDC. So, to get the expression of the work done without going into much complex computational analysis we can introduce the concept of mean effective pressure or average pressure.

So, now let us see why that mean effective pressure or average pressure is very important because this pressure will keep on changing as the piston traverses from TDC to BDC. But if that is the case it is very difficult to get the expression of work done without the computational analysis instead what we can do we can estimate the work done by considering or by invoking the concept of mean effective pressure and that is what is very important in the context of engine operation. Now engines are multi cylinder very often and if engines are multi cylinder, then it is convenient to analyze the engine cycles per unit mass of the gas in the combustion chamber.

So, for multi cylinder engines instead of writing the expression of work done in this form, it is better to write in the specific form that is to analyze the engine cycles per unit mass of the gas in the combustion chamber. So, $w = \frac{W}{m} = \int Pdv$.

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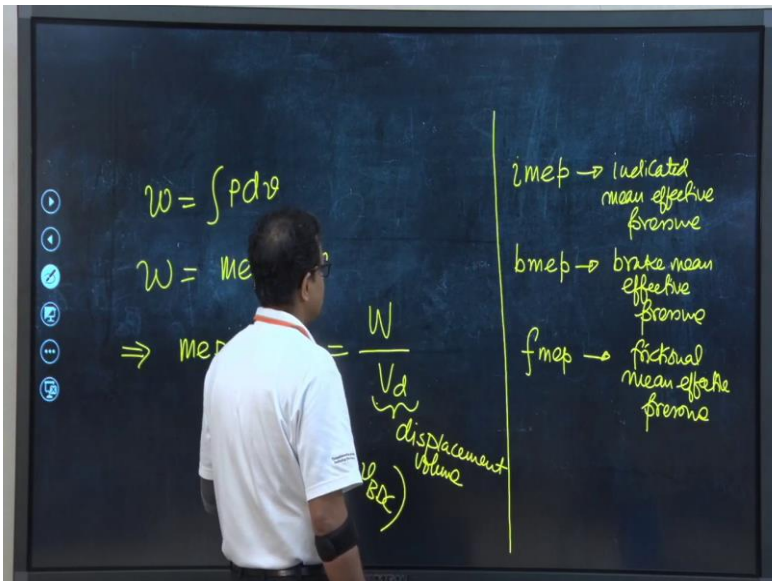

So, basically we can write the expression of work done $w = \int Pdv$. We have discussed about the need of mean effective pressure. So, we can calculate pressure at each and every location inside the cylinder and if we know the change in volume then we can sum up.

So, multiply that pressure with the change in volume and we can sum up that is the integration. So, we can write $w = mep \times \Delta V$. So, this is the work done. So, it is not easy to calculate this integration provided we know the pressure at each and every point and that is very difficult to solve without the help of much complex computational analysis.

Instead we can write this and from there we can write the $mep = w/\Delta v$. So, we have written denominator in their specific form, we also can write W/V_d. So, this is basically displacement volume.

So, you can see that mean effective pressure is very important to quantify the work output from the engine provided we know the displacement volume. But this quantity is always known because the engine has certain stroke length. So, basically the stroke volume is the total displacement volume of the engine cylinder. So, you can understand that the work output will depend on this displacement volume. So, higher is this volume, cc is cubic centimeter that is the stroke volume or displacement volume, higher will be work output.

So, the engine will be much more powerful. So, that is the objective. Now this mean effective pressure $mep = \frac{w}{\Delta v} = \frac{w}{v_{TDC} - v_{BDC}}$.

Think that the work which is produced inside the cylinder that work may not be available at the crankshaft because of the mechanical friction that is what we have studied. So, basically the mechanical friction that would be there that we have studied because these are the mating parts. So, the Piston will be having to and from movement and frictional loss between these two mating parts will consume certain amount of work that is being produced.

So, the work which is available on the piston face inside the engine cylinder is not available at the crankshaft because the frictional losses are there or frictional loss is there. Over and above that frictional loss some parasitic loads are there, because we need to run a pump which will sprinkle the lubricants. So, to run that lubricant pump, to run the compressor because sometimes you need to have compressed air for air conditioner.

So, to run all those units some energy is needed. So, the parasitic loads include the amount of work which would be required to run all those devices. So, the frictional loss between the mating components alongside the parasitic loads, these two effects reduce the work which is available at the crankshaft. So, you can understand we can have several mean effective process depending on the work, if this w is the work which is available on the Piston face inside the cylinder then mean effective pressure will be something if we consider the work which is available at the crankshaft then mean effective pressure will have different name. So, if we now go to discuss about several mean effective pressures.

So, basically we have first imep, this stands for indicated mean effective pressure. Similarly we will be having bmep, this is break mean effective pressure. We may have fmep, this is frictional mean effective pressure. Why all these terms. So, we have added one prefix i for indicated, b for break, f for frictional. So, we are trying to introduce different work that is indicated work which will corresponds to indicated mean effective pressure.

If it is brake work that will correspond to break mean effective pressure, if it is frictional, it will correspond to frictional mean effective pressure. So, basically at least from several mean effective pressure that we have written over here we can see that different works are available in the context of internal combustion engine operation.

So, if the work which is available on the Piston face or inside the combustion chamber is the indicated one. So, that means this is the indicated work.

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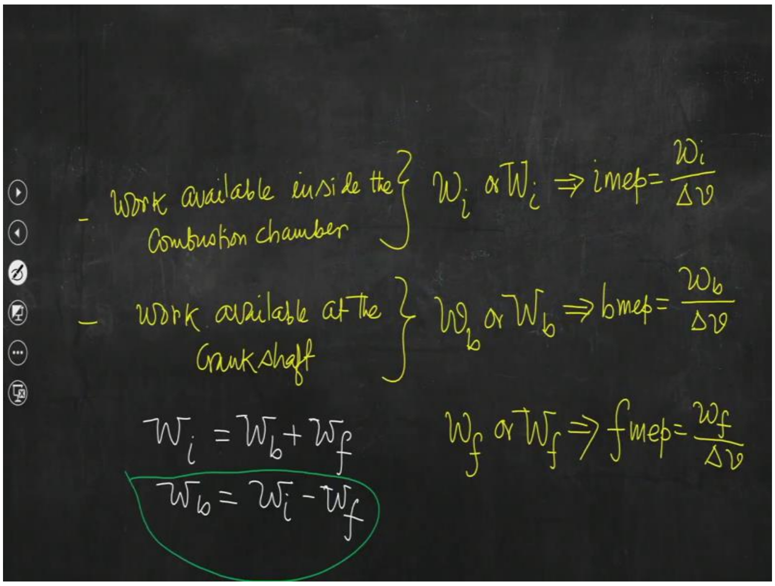

So, if we write, work available inside the combustion chamber, W_i or w_i. So, $imep = w_i/\Delta v$. For the same engine Δv is fixed only the work which is available inside the combustion chamber is the indicated work. And if we define the mean effective pressure considering indicated work it would be indicated mean effective pressure. Similarly work available at the crankshaft and this is w_b.

So, this is the brake work and if we define the mean effective pressure based on the brake work that would be $imep = w_b/\Delta v$. So, the work which is available at the crankshaft that is the brake work but the work which is available inside the combustion chamber is the indicated work, you can understand that means these two works are not same. So, if they are not same some amount of work is needed to overcome the friction and other parasitic loads that I have already discussed.

So, that work is known as $w_f or\ W_f$ and if we define frictional mean effective pressure that equal to $fmep = w_f/\Delta v$, this work is not obtainable from the engine. Because this is the amount of work which is lost to overcome the frictional loss alongside to run several devices to get the auxiliary facilities in the internal combustion engine.

So, this is all about $imep, fmep, bmep$. So, try to understand from here at least we can write that $w_i = w_b + w_f$. So, whether I am writing in their specific form or the actual form that is irrelevant here.

So, I could have written these quantities in their specific form as well. So, what we can see from this particular expression that this is the work which is not realized in practice, this is the work which is available inside the chamber while this is the work which we get at the crank shaft. So, basically at the cost of some energy eventually you are getting this amount of work though the work which is produced inside the combustion chamber is even higher.

So, certain amount of work is not available at the crankshaft in other words that amount of work is getting lost for some parasitic loads as well as to overcome the friction. So, we write$w_b = w_i - w_f$.

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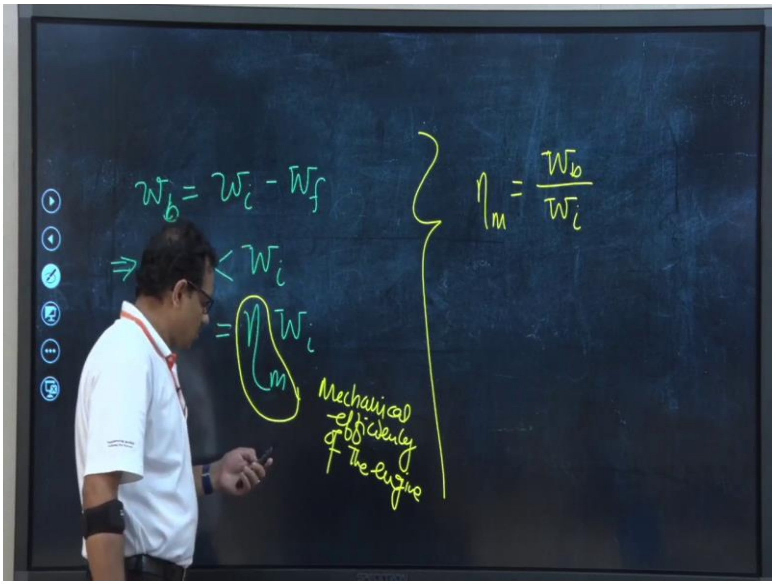

So, $w_b < w_i$. So, we can write $w_b = \eta_m w_i$ and that factor η_m should be always less than 1 and this quantity is known as mechanical efficiency of the engine. So, the fraction of work which is available at the crank soft of the indicated work is the η_m. So, this quantity is always less than one and our objective should be to get more brake work; so that the mechanical efficiency of the engine would be higher. Now we have discussed about the need of mean effective pressure in the context of engine operation.

From there we have defined several mean effective pressures using different forms of work. Now we have talked about indicated work, brake work, frictional work. Now if we try to recall the basic cycle which we have probably discussed in the beginning of this course in this particular module, see we have discussed that parasitic loads.

So, we need to run compressor, we need to run air conditioning unit, we also need to run some pumps if needed because as I told you that we need to supply continuous coolant to reduce the temperature of the engine cylinder. So, if the coolant should be circulated continuously. So, that circulation pump should be there, to run all these mechanical devices certain amount of power is needed and that power will come from the power that is getting produced.

So, if we try to look all these devices consume power and those are known as negative power. So, basically positive power is the indicated power, indicated work that is available inside the combustion chamber while the negative work that is frictional work and other works to overcome to run the parasitic loads.

And that work can be viewed as the negative work from the perspective of this engine operation. So, let me talk again, indicated work is the positive work or break work is the positive work. Now brake work is directly measured at the crankshaft while indicated work is not measured. However a part of the work that is needed to overcome the frictional loss also to run several devices for the parasitic loads the work needed can be viewed as the negative work.

So, positive work is the brake work while negative work is the frictional work and associated works which are needed to run several devices. So, with this now we have seen that it is convenient to define mean effective pressure. Now let us briefly discuss about the indicator diagram, what is indicator diagram why it is so important. And should we get anything from this indicated diagram. Now we have discussed that $\int pdv$ and that p is the pressure at any point inside the cylinder at any moment.

So, that pressure is continuously changing, volume is also changing but eventually the total volume integral dv from one to two because eventually we need to integrate from V TDC to V BDC. So, we know the total change in volume would be V TDC minus V BDC but while changing the volume from V TDC to V BDC, pressure is continuously changing. So, let us now look into the change in pressure with the change in volume as the piston is traveling from V TDC to V BDC.

Now the diagram which is used to represent the change in pressure with the change in volume as the Piston is traveling from TDC to BDC and again going back to complete one cycle that diagram is known as indicator diagram. So, let us let us draw this diagram.

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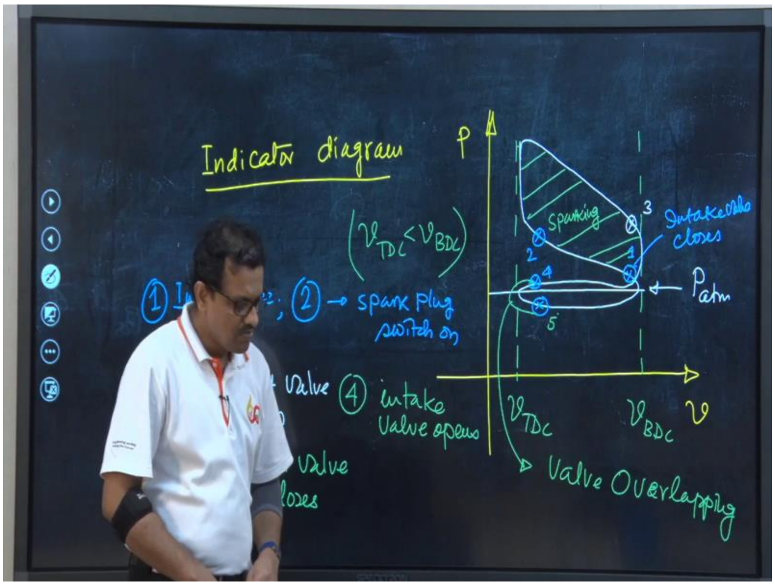

So, if we draw this is indicator diagram. So, change in pressure with a change in volume we need to map the processes in PV plane what are the processes basically you know that compression, expansion, power and exhaust; all these four processes to complete one cycle of a four stroke engine be it a SI engine or be it a CI engine.

So, let us quickly identify. So, this is V TDC and. So, this is V BDC definitely V TDC is less than V BDC because this is the clearance volume. So, still you need to provide some volume and that is the clearance volume and if we draw rather if we try to map several processes. So, say this is atmospheric pressure. So, all valves are now closed this is the atmospheric pressure outside the engine cylinder.

We are bringing the piston from TDC to BDC, pressure inside this engine cylinder should be less than the atmospheric pressure and it is because of this pressure difference either air fuel mixture or pure air will rush into the engine cylinder and that we have seen as the carburetion. Now when the piston is at BDC then next stroke is the compression stroke. So, intake valve will be closed but in real practice intake valve will not be closed immediately when piston start traveling from BDC instead.

So, piston start traveling from BDC it will again come to TDC and the process is like this. So, our entire objective is to reduce volume to increase pressure. So, ideally we should close the intake valve when piston is at BDC but it is not the case we shall discuss all these things later.

So, when the piston is slightly higher from BDC during the compression stroke, this is the point. So, intake valve closes and then exhaust is remaining closed. So, we can see the spark ignition engine, compression ignition engine at the end of the compression stroke, combustion will be there and it is because of this combustion there will be a rise in pressure and temperature inside the cylinder. So, pressure will rise abruptly but if it is a spark ignition engine we need to switch on the spark plug, when we need to switch on this spark plug? So, nowadays it is electronically control unit.

So, spark plug switch will be on when piston is slightly away from TDC during the compression stroke. So, this is point one, this is point two. So, two is spark plug switch on and one is intake valve closes. So, if it is spark plug, spark plug will be needed to initiate combustion or if it is CI engine there is no requirement of spark plug and fuel will self ignite and there will be huge rise in pressure.

So, pressure will rise like this and then at the end of the compression stroke when piston is at TDC, pressure will be like this and then again piston will come back from TDC to BDC, pressure will fall that is the power stroke. So, piston has arrived at BDC still some amount of pressure and next stroke is exhaust. So, we need to open the exhaust valve.

So, again piston will travel from BDC to TDC, when piston is traveling towards TDC, we need to open the exhaust valve say this is 3, before reaching piston at BDC exhaust valve is allowed to open. So that the pressure inside the cylinder will reduce and when piston is coming back from BDC to TDC again during exhaust stroke we will face relatively lesser resistance that is the objective.

So, that is why exhaust valve is allowed to open when piston is about or yet to reach at BDC. So, 3 valve opens and then piston is coming from BDC to TDC, the combustion gases inside the cylinder will go out from the chamber and then when piston is coming to TDC, ideally we should open the intake valve but what is done in reality that exhaust valve is exhaust valve is remaining open.

Ideally intake valve will open when piston is at TDC but in reality what is done that intake valve is allowed to open when piston is yet to reach at TDC. So, this is four. So, not exactly when piston is reaching at TDC but when piston is yet to reach at TDC, slightly higher from TDC, the intake valve is allowed to open, again there is a logic behind it.

Because if we open the intake valve, exhaust valve is remaining open, opening intake valve will allow Fresh Starts to come in and that fresh charge will you know allow the exhaust valve the exhaust gases to completely remove from the engine cylinder but it is not even possible to complete removal of the exhaust gases. So, you know that ideally at TDC intake will open and exhaust will closed but we are allowing this intake valve to open when piston is little air from TDC during exhaust stroke.

So, that Fresh charge will come and that Fresh charge will allow exhaust gases that would be there in the clearance volume to remove from the engine cylinder that is why exhaust valve is remaining open until piston is again traveling back from TDC to BDC during next cycle in take stroke. So, exhaust valve is allowed to close when piston is little away from TDC during next cycle intake stroke.

So, 4 is intake valve opens, 5 is exhaust valve closes. So, this is the part of the total process wherein both the valves are remaining open. So, 4, intake is allowed to open, exhaust is remaining open until point 5. So, this is known as valve overlapping in this indicated diagram.

So, we have tried to map all the processes for four stroke cycle engine. So, if it is not the SI engine then point two will not be there because we will be utilizing the self ignition properties of the fuel, but the diagram that we have drawn today is for the four stroke cycle engines and we have mapped several processes to complete a cycle of a four stroke cycle engine. And from there we have understood several timings of valve opening both intake and exhaust Valves and we have also identified an interesting point that there is reason in which both valves are remaining open and this particular zone is known as valve opening.

So, need of allowing both valves will remain open, we have discussed because we are allowing intake valve to open when piston is little higher from TDC during the end of exhaust stroke. Then fresh charge will come or fresh air will come and that fresh charge or air will allow the combustion gases which will otherwise remain there in the clearance volume to go out from the engine cylinder.

Because the exhaust valve is already open and that is why we are not closing the intake valve again exactly at TDC instead we are allowing exhaust valve to close at point 5 that is little away from TDC during the intake stroke of the next cycle and in this particular regime or in this particular zone the both valves are remaining open and as if two valves are overlapping each other.

So, that is called valve overlapping so if we summarize today we have tried to discuss about the concept of mean effective pressure relating with the engine operation of both SI and CI engines, from there we have introduced several mean effective pressure by using different works and finally we have talked about the indicator diagram which is very important and if we look at the positive work that is the brake work that we are getting if we try to hatch the portion.

So, basically this is the positive work right while the work that is below P atm that is a negative work. So, we have talked about both positive and negative work because brake work is the positive work while negative works are the part of the indicated work which is needed to overcome the frictional loss and to run several devices as a parasitic loads.

So, we have discussed this indicator diagram and quite interesting to see that there is a zone in which both valves are remaining open and we have discussed about the need of allowing both allowing these valves to be opened in this particular Zone and this is known as valve overlapping zone. So, with this I stop here today and we shall continue our discussion in the next class, thank you.