MARINE ENGINEERING

By

Prof. Abdus Samad

IIT Madras

Lecture47

IC engine-Numerical Problems

Good morning everybody. Today's lecture is on numerical problems related to ice engine combustion. So, ice engine combustion we are talking about then you need air plus oxygen, air plus fuel, air plus fuel. So, air means? oxygen plus nitrogen.

If other components are there, for example, small amount of carbon dioxide or what moisture, H2O, CO2, H2O or some other component. So, we are ignoring that one. For our calculation purpose, we will assume that air is containing only oxygen and nitrogen. Normally, air intake will be happening at normal air temperature and fuel will be injected separately or will be mixed by carburetor. combustion will be happening inside cylinder so inside cylinder you may need one spark plug maybe or you can compress C ing only compression will be happening and fuel will be burning so there is the phenomena now if we have very high amount of air then what will happen fuel plus air

it is producing CO2 plus H2O plus maybe some other component. If you have higher amount of air, higher amount of air means you have O2 plus N2. So, N2 is not giving you energy, O2 is giving energy, right? Because O2 will be reacting with fuel and fuel will be releasing the heat. Now, excess energy what will happen?

This burn gas, when it is going out, exhaust gas, exhaust gas so the burnt gas will have lots of air oxygen plus nitrogen so because this oxygen plus air excess oxygen plus air it will be taking lots of heat it will be heated up and it will be going out so actually it is not giving any energy rather it is taking away your heat okay and if you have less amount of air what what will happen if you have less amount of air so in that case maybe hydrocarbon fuel means hydrocarbon right so this hydrocarbon will be in your product or maybe carbon monoxide. So, hydrocarbon means your fuel is not burned completely. So, you are not getting complete value of money.

So, whatever you invested for fuel, so same thing is not burning. So, you are not getting all the energy. But if you have carbon monoxide, again you are not getting complete combustion, means carbon is not producing carbon dioxide. So, in that case, this carbon monoxide is harmful. carbon monoxide production means you are harming your environment again you are not getting enough energy because it is not burnt completely so in that case again it will be negative for your engine so you cannot give very high amount of oxygen or very less amount of oxygen you have to give proper amount of oxygen the term is called stoichiometric ratio or air fuel ratio so exact amount of oxygen or air and fuel ratio that is called stoichiometric ratio

And if you are giving excess amount of air, then you have to calculate accordingly. If you are giving less amount of air, again you have to calculate accordingly. But your target should be to produce, not to produce carbon monoxide. Some amount of fuel, oxygen is there in your combustion product, still fine. But carbon monoxide and hydrocarbon in your fuel, after post-combustion,

that burnt gas is still having carbon dioxide, carbon monoxide or hydrocarbon, it is not beneficial for your engine or for your environment or for your pocket. So, a chemical reaction may be defined as the rearrangement of atoms. So, atoms are becoming rearranged. For example, CH_4 plus O_2, it will be creating CO_2. I am not balancing this equation plus H_2O.

So, just you are rearranging the atoms. You are creating new molecule. And this is called reaction. Sometimes we say combustion or reaction. A chemical field is a substance which releases heat energy on combustion.

So, here when combustion is happening, you are producing lots of heat. So, this is exothermic reaction. Exothermic reaction. Now, total number of atom in each element is constant in the combustion remains constant, but the atoms are rearranged into groups.

So, atoms will not be destroyed. So, same number of atom will be there, but it will be rearranged. So, CH_4 was there, it will be CO_2 plus H_2O when oxygen also will be required for burning CH_4. So, you are rearranging the atoms. The amount of excess air applied varies with the type of fuel.

It may 100% for modern practical engine, but 25 to 50% excess air is okay. Why excess air is okay? Because our target is not to produce carbon monoxide or not to give unburnt hydrocarbon in your exhaust gas. So, we give some extra amount of oxygen so that all fuel will be burnt and you will get sufficient enough power for your engine. Stoichiometric ratio or chemically correct air fuel ratio is defined as stoichiometric air plus fuel ratio.

So, exact amount of ratio, exact amount. You are not giving extra air or less air. So, mixture strength is called stoichiometric air-fuel ratio divided by actual air-fuel ratio. What happens? Stoichiometric air-fuel ratio is say 14.7, this ratio.

But actually, maybe you will be giving a little bit less or higher. So, that is called actual air-fuel ratio. So, the ratio of stoichiometric divided by giving actual amount, that is called mixture strength. And the content I have taken from the book R.K. Rajput, Lakshmi Publication.

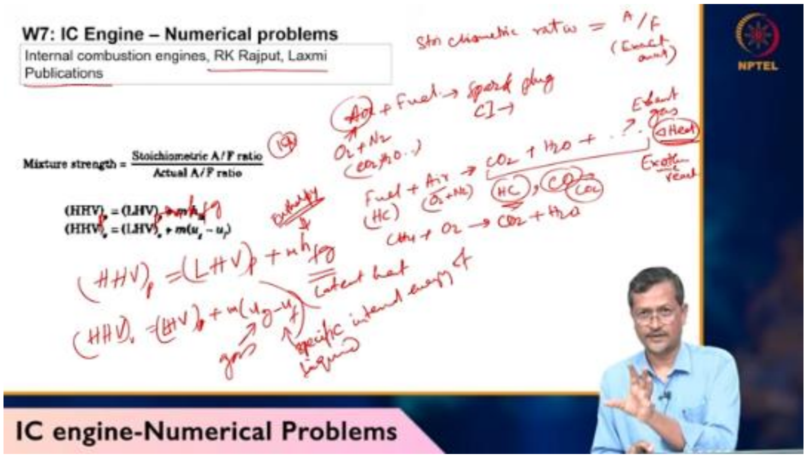
You should get this book in the library. Higher heating value for constant pressure is equals lower heating value plus mass of water plus hfg. So, hhv constant pressure equals lhv constant pressure plus mhfg, hfg means latent heat Previously, I have discussed about the calorific value. So, higher heating value means total amount of heat is there in the fuel.

And lower heating value means total amount of heat is there and how much amount of water it is producing or it is having water particle in the fuel. So, that will be evaporated and it will take lots of latent heat. So, that latent heat we cannot get back. So, that is loss actually, energy loss. So, whenever you will be calculating or you will get power because of this lower heating value.

So, higher heating value if it is given then and mass of water is given then you can get lower heating value at constant pressure. HFG equals latent heat or enthalpy of evaporation. Enthalpy is also energy internal energy. And if you know internal energy of gas and fuel then it will be like this HHV for HHV equals constant volume LHV. plus M UG minus UF.

UG means gas internal energy, UF means fluid internal energy. So, if you can minus this one, so how much energy is there in gas, how much energy is there in fuel, so minus actually it is HFG. Specific internal energy of a liquid, this is specific internal energy. specific internal energy of up liquid Liqid and this is gas specific internal energy of gas. So, lower heating value plus this amount of energy will be lost.

So, equal that if you make total lower heating value plus energy loss that will be higher heating value. In a given combustion process that takes place adiabatically and with no work or change in kinetic energy or potential energy involved, the temperature of the products is referred as adiabatic flame temperature. For given fuel and given pressure and temperature of the reactant, the maximum adiabatic flame temperature that can be achieved is with stoichiometric mixture. Now, we have to see some problems



Now, we will see some problems based on your amount of theoretical or practical air fuel air or fuel required to burn a fuel amount come. Now, we will see the amount of oxygen or air is required to burn certain amount of fuel completely. So, we will try to calculate stoichiometric ratio or stoichiometric ratio and we will try to calculate heating values also. So, how to solve this one? First you have to write down the equation.

C2H2 plus XO2ACO2 plus BH2O because you do not know initially the balanced equation. We are assuming that you do not know, you may be knowing. But if you have bigger long-chain hydrocarbon, for example, this C2H2, maybe C10H20 or 22 will be there. So, in that case, your balancing will be very difficult just to calculate using mental calculation. In that case, you can use the formula.

X, Y, A, B you can put and you can calculate that one. So, here you can first you balance the carbon. So, 2 carbon I have 2 C equals AC, then this is giving A equals 2. Now, balancing hydrogen 2 H equals 2 B H, you can see this B H. So, this is giving B equals 1.

So, now the equation is C2H2 plus XO2 plus, not plus, this is equal sign 2CO2 plus H2O. Now, O2 calculation, O2, how many O2s are there? So, 2X equals carbon 2, now 2X equals 2O2, O2 into 2 and plus H2O, 1O is there. So, therefore, x equals 5 by 2, 2.5.

Now, the equation becomes C2H2 plus 2.5 O2 plus, not plus, this is equal sign again, I am doing mistake, 2CO2 plus H2O. Now, this is having a oxygen you are getting from air. So, air will have nitrogen also. Now, total amount of nitrogen how much you are adding?

Now, from there you are getting C_2H_2 plus 2.502 plus 2.579 by 21 nitrogen implies 2 CO_2 plus H_2O plus 2.579 by 21 N_2. Why 79 by 21? 79 percent nitrogen by volume is there in air and 21 percent oxygen by volume is there in air. So, this is mole ratio.

So, like for example, 1 mole of Ethylene is reacting with 2.5 mole of oxygen. So, how many moles of nitrogen should be there in the air when we are sucking air? So, air is giving oxygen plus nitrogen. So, 2.5 amount of oxygen when you are sucking.

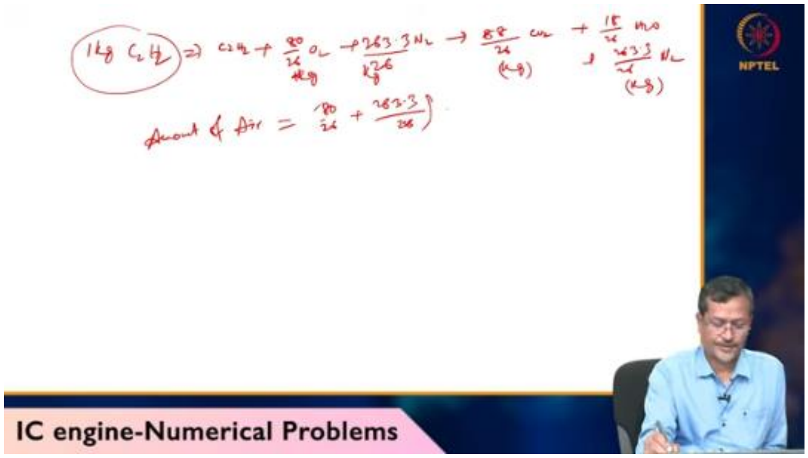
So, how much amount of nitrogen also you are sucking for your combustion? So, that calculation you have to do first. So, right side nitrogen is not doing any reaction. So, right side nitrogen will be as it is. So, 2.579 by 21.

Now, you simplify this one and now you have to calculate into weight ratio on the mass basis. So, when you are calculating mass, then you have to know this C molar mass 12, H 1, oxygen 16, hydrogen 1 and carbon oxygen, nitrogen is there, nitrogen is 14. now you put the values also c2 c2 means 2 into 12 plus h2 first one is acetone hd means 2 into 1. so c2 h2 this much of mass i have for one mole plus 2.5 now how much mass is there 16 into 2 plus o2 2.579 by 21 now nitrogen 14 into 2 nitrogen. So, right side also I will have same balance, right side will have like 212 into oxygen 16 into 2 plus water 2 into 1 plus 16 H_2O plus 2.579 by 21 into nitrogen

So, this equation gives 26 C_2H_2 plus 80 O_2 plus 263 N_2, 88 CO_2 plus 18 H_2O plus 263 N_2. these are in kg. So, you should not mistake assuming that this is a molar thing this is we converted into kilogram. Now, 1 kg of C_2H_2 implies now the equation will be converted into like this C_2H_2 I am going to convert dividing by 26 plus 80 by 26 O_2 plus that nitrogen part it will be if I divide completely then it will be like 263.3 nitrogen 88 kg no 263.3 divided by 26 and this one will be 3.38

sorry, 88 divided by 26 CO_2 plus 18 divided by 26 H_2O plus 263.3 by 26 N_2. So, this is my, for 1 kg of acetylene, how much amount of So, all are kg actually. So, I should write kg everywhere. So, for 1 kg of fuel, if you burn, then how much air is needed?

Now, amount of air equals 80 by 26 plus 263.3 divided by 26. So, it is giving 13.196 kg of air per kg of fuel, fuel or C_2H_2, C_2H_2. Hence the amount of theoretical power, this is theoretical. So, if required, you can give higher amount or lower amount. So, that is differential, we will calculate later.



But actual amount is 13.196 kg of air you have to give. Now, if you have any organic compound or hydrocarbon and you want to go for a reaction, so one simple formula is there C_xH_y plus Xy by 4 O_2 x CO_2 plus y by 2 H_2O. If you have only air and you are reacting, so this will be the common balanced equation. So, in that case, you have to find x and y. If you do not know actual balanced equation, so you can use this formula.

So, CXHY, CHY plus x plus y by 2 O_2 plus 79 by 21, you can see again We are adding this one, x plus y by 4 N_2 equals x CO_2 plus y by 2 H_2O plus 79 by 21, again the x plus y by 4 N_2. Now, previous problem also you can apply and you can check whether this equation is valid. Now, take one problem. Question C_7H_6 with 10% extra air.

Then calculate mass of air supplied. Mass of extra air, mass of air supplied. per kg of fuel. Solution, how can you do? Like you can put this equation C6HY, the previous from there.

Actually, you can derive C7, CXHY plus XY by 4 equals, I will put arrow, XCO_2 plus H_2O y by 2 now x x and y value given here c 7 so x equals 7 y equals 6 then c 7 h 6 plus x and y value we put here so 7 7 plus 6 by 4 7 o 2 co co 2 plus 7 by 2 h2o. This is your balanced equation. Now, you have given extra.

So, here it is not h6, it is h16. So, it will be like this hy16. So, 16. So, finally, it is becoming x7 h6 plus y by 11 plus 11 o2 7 CO_2 plus 7 by 2 H_2O.

Now, you have a nitrogen also. So, what you can do like this X7 H16. H16 X C_7H_{16} plus 11. Now, you can make O_2 plus 79 by 21 N_2, right side 7 CO_2 plus 8 H_2O, H_2O will be Y by 2, so it will be 8 plus 11 O_2 plus 79 by 21 N_2.

Now, you have 11, 10 percent excess air. So, in that case your this constant becomes 12, 12.1 because 11 into 11 into 1.1. So, it is becoming 12.1. So, now air field ratio A by F air, how much air we are taking? 12.1, 12.1. 12.1 oxygen 32 plus 79 by 21 nitrogen 28 and how much fuel is there 7 carbon 7 into 12 plus hydrogen 16 16 into 1 so this value is coming 16.6 so 16.6 kg of air air

needed to burn 1 kg fuel. So, this is your solution. Now, take another problem propene C_3H_8 with 10 percent deficient with 10 percent deficient. deficient air. So, then assume no hydrocarbon is produced, assume no hydrocarbon, no HC is produced and CO produced.

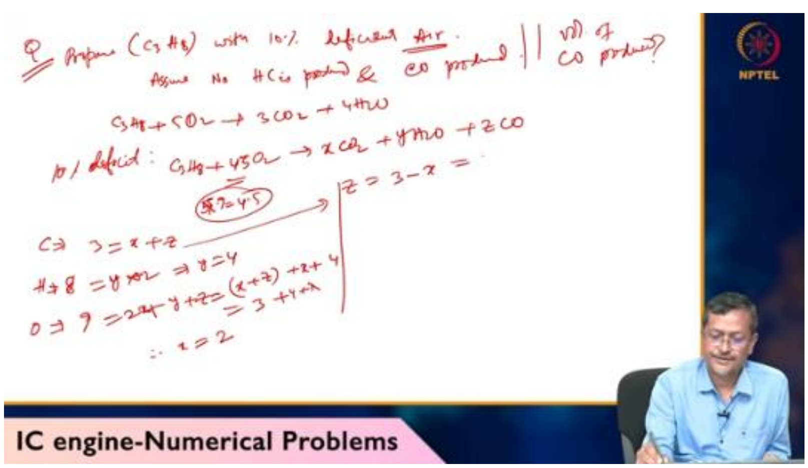
So, first you write down the equation C_3H_8 plus you do previously whatever First, you write down the equation and balanced equation. So, 5 O_2 3 CO_2 plus 4 H_2O. Now, you have to calculate volume of CO produced. Now, 10 percent deficit 10 percent deficit

So, the equation will be like this C_3H_8 plus 4.5 O_2. Why 4.5 A2? Because 5 atoms of oxygen required, but you have actually 0.9 percent. So, it is coming 4.5. X amount of CO_2 producing plus Y H_2O producing plus Z CO producing.

Now, for C balancing, carbon balancing you are doing. So, left side 3 equals X side, right side X amount plus Z amount. Now, for H, left side 8, right side HY So, y becomes 4 and o 9 left side is there 4.5 into 2. So, it is a 9 and right side equals 2x plus 2y plus z.

Now, 2x plus 2y plus y 2y 2x plus y we have only one water right side in water. So, 2x plus y. So, if I write like this equals x Plus z plus x plus 4 equals x plus z equals 3 plus x plus z plus 4 actually x plus 4. 3 plus 4 plus x. Therefore, x becomes 2. Now, z. z.

Z equals, you see from here actually, 3 minus X equals 3 minus 2 equals 1. So, now the equation becomes C3H8 plus 4.502 XCO2 plus YH2O plus ZCO. Sorry, X value you have to put 2, Y value I have to put 2. Y value I have got 4 and Z is 1. So, CO means 1.



Now, percent molar volume of CO_2. CO, carbon monoxide equals right side is 1 and right side total amount of mole is there 2 carbon dioxide plus 4 water plus 1 carbon monoxide. So, it is becoming 1 by 6, 7. So, it is becoming 14.28 percent, 14.28 percent.

So, this much amount of carbon monoxide is there. Now, another problem, CH_4 is burnt with atmospheric air or CH_4 and methane. But with atmospheric air, the analysis of the product on dry basis is as follows, carbon dioxide 10 percent, oxygen 2.37 percent, carbon monoxide 5.53 percent, nitrogen 87.1 percent. So, you have to determine combustion equation, air-fuel ratio and theoretical air. So, first combustion equation, combustion equation first you have to calculate or you have to establish.

So, for that XCH_4 plus YO_2 plus ZN_2, how much nitrogen we do not know first. So, 10 CO_2 plus 0.53 CO plus 2.37 O_2 plus H_2O plus 87.1 N_2. okay this is on dry basis so determine all the unknown coefficient we have to balance this balance these elements so nitrogen first okay so z equals 87.1 okay now z by y 79 by 21 okay therefore Y equals 87.1 divided by 79 by 21. So, it is going 23.16.

Now, carbon X equals 10 plus 0.53. You see right side 10 in carbon dioxide and carbon monoxide 0.53. So, it is becoming 10.53 and hydrogen hydrogen is giving A equals 2 x. So, 2 into x means 10.53. So, it is becoming 21.06.

So, this much amount of hydrogen is there. Now, oxygen balance. So, all the unknown coefficient have been solved for. Now, this oxygen you have to balance y equals 10 plus 0.53 divided by 2 you can see right side

10 is there 0.53 CO also divided by 2 plus 2.37 plus 21.06 by 2 plus this will be is giving actually 23.16 already this value is coming here. 16. Now, if we divide both sides by 10.53 then we get the equation CH_4 plus 2.202 plus 8.27 N_2 0.95 CO_2 plus 0.05 CO plus 2 H_2O plus 0.225 O_2 plus 8 This is the answer. Now, air-fuel ratio, for air-fuel ratio on molar basis total amount of mole of air.

So, mole of air you see left side 2.2 oxygen, 2.2 oxygen plus 8.27 nitrogen is there, this is happening per kg of air. So, this is your air-fuel ratio equals 10.47 moles of air per kg of fuel. Now, the air-fuel ratio mass basis is found Now, actual air-fuel ratio the air-fuel ratio ideal condition CH_4 plus 2 O_2 plus 79 by 21 nitrogen and 2 times because or I can say like this.

So, right side will be CO_2 plus 2 H_2O plus 279 by 21. So, this will give my actual air-fuel ratio, theoretical air-fuel ratio, this is theoretical. So, it will be like 2, then plus 2 into 79 by 21, 2 into 79 by 21 divide by 2. Okay, here I have to multiply 28.97 air mass, 28.97 that mass of air, 12 into 1, 12 plus 1 into 4. this is fuel mass.

So, it is becoming 17.24 kg air per kg fuel. so this is your answer. Now, percentage of theoretical layer, percent of equals 1896 divided by 1724 into 100 equals 110 percent. So, this is your answer. Now, you will go for calculating a lower heating value.

So, lower heating value. So, lower heating value of propane, so propane you know the formula is C3H8, you are burning with oxygen and it will be releasing heat, so heat also given. 25 degree centigrade, how much heat is getting released? Now, first you write down the equation C3H8 plus 5O2 3CO2 plus 4H2O. So, higher heating value P or higher calorific value in previous lecture I explained as higher calorific value.

Here in this book they are using higher heating value the term. So, both are same. LHV, lower heating value, plus MHFG, this enthalpy of phase change. Now, mass equals 4 into 18, this water mass, water vapor, so 72 kg per mole. Now, HFG,

HAG is your latent heat or enthalpy. This is 2442 kg per kg at 25 degree centigrade. So, HHV equals 2044009 plus 72 into 2442. So, this is giving 2, 2, 1, 9, 8, 3, 3 kg per kg, this is your answer. Now, higher rating value HHV constant HHV at constant volume.

equals HHP constant pressure minus del n R T. So, del U equals del H minus del n number of moles R T. Now, this all the signs are negative. Then H H V V equals H H P V suffix P plus del N R O T. R is universal gas constant. This value is 8.3143 kg per kg mole per kg. So, del n equals np minus nr, np number of mole gaseous product and nr is number of gaseous reactant.

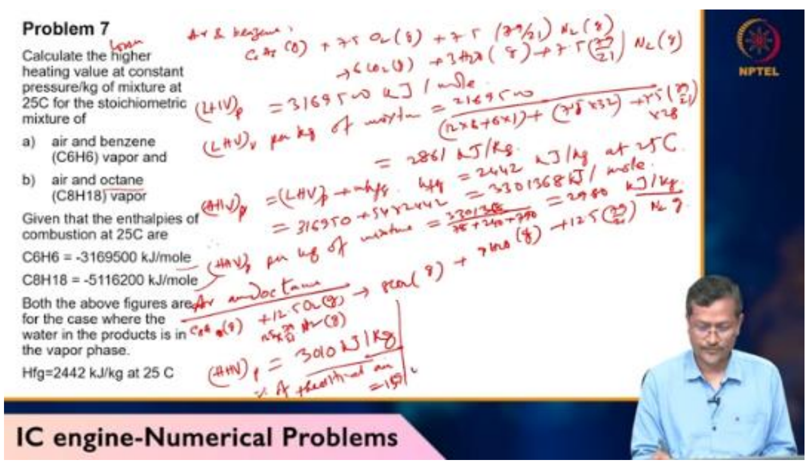
Now, the reaction is like C3H8 plus 5O2 3CO2 plus 4H2O now liquid. Now, del n equals 3 minus 1 plus 5 equals minus 3. hv constant volume, so 2, 2, 1, 9, 8, 3, 3 minus 3 into 8.3, 1, 4, 3 into 25 plus 2, 7, 3. This is giving 2, 2, 1, 2, 4, 0, 0 kg per kg. This is your final answer. So, calculate the lower and higher heating value of constant pressure per kg of mixture at 25 degree centigrade for stoichiometric mixture of benzene and octane.

Now, the value are given Cc, Cc, kg per mole and this also given. Now, first you have to calculate air and benzene vapor, air and benzene. C6H6 gas plus 7.5 O2 gas, 7.579 by 21 nitrogen gas, 6 CO2. gas plus 3H2O gas plus 7.579 by 21 N2 gas. So, since water is the product in wafer phase, so lower heating value becomes LHV suffix P equals 3169500 kJ per mole.

l is v l h v constant v per kg of mixture equals 3 1 6 9 5 0 0 12 into 6 plus 6 into 1 plus 75 7.5 cross 32 plus 7.579 by 21 into 28. So, this is giving value 2861 kg per kg. Now, HHV constant P equals LHV P plus MHFG. Now, HFG equals 2442 kJ per kg at 25C.

So, HHV, suffix P equals 316950 plus 54 into 2442 is going to be 33050. 1368 1368 kg per kg kg per mole thus a higher heating value constant pressure is per kg of mixture h h v per kg of mixture kg of equals 3301368 divided by 78 plus 240 plus 790 is becoming 2980 kg per kg. Now, air and octane vapor. you calculate similar way air and octane whose

So, in that case your equation becomes C_8H_{18} gas plus 12.5 O_2 gas 8 CO_2 gas plus 9 H_2O gas plus 12.579 by 21 nitrogen gas. okay so left side also nitrogen should be there okay now in the same way you calculate and finally you get higher heating value constant pressure five five you get three zero one zero kg per kg so this one i left detailed calculation i left for you because it is same as your benzene calculation so please try yourself now percentage of theoretical air use percent of theoretical air percent of theoretical equals, it becomes like 159.48 percent. you calculate yourself that octane part, benzene part I have done the calculation.



Thank you very much for today's lecture. Next day, we will start with a new topic. Thank you.