IC Engines and Gas Turbines
Dr. Vinayak N. Kulkarni
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture - 33
Basic Thermodynamics

Welcome to the today's class. Till time what we had seen in last class was about open system, and for the gas turbine power plant, like open cycle gas turbine power plant, then what are the advantages of being open cycle gas turbine power plant. Further we had also seen that what are the different arrangements for increasing the compression ratio so as to increase the efficiency, where we had seen there is a multi-spool arrangement, how multiple spools are connected, how they are driving different turbines and compressors. So, this was seen in last class.

So, till time in all the three classes what we had seen was how a gas turbine power plant is there, what are the different components, and why different components are added to a gas turbine power plant, so that it we can increase its power output or we can increase its efficiency. We have also seen that what are the similarities and differences between Brayton cycle based power plant which is gas turbine power plant, and also steam power cycle based power plant.

Then we had also compared the components of turbo machinery with the positive displacement machines. So, having done all these things about the power plant, we are going to go from here and onwards towards the thermodynamic analysis of the gas turbine power plant cycle. So, here we mean cycle by the thermodynamic cycles. So, since our objective here onwards for few lectures is towards thermodynamic analysis of gas turbine power cycle. We are going to understand to start with some basics of thermodynamics, and what is the thermodynamic cycle for gas turbine power plant. This is the topic of today's discussion.

So, you would have undergone a course on Basic Thermodynamics. For some time, we are just going to review the terminologies which are required in this course and which have relevance with the basic thermodynamics.

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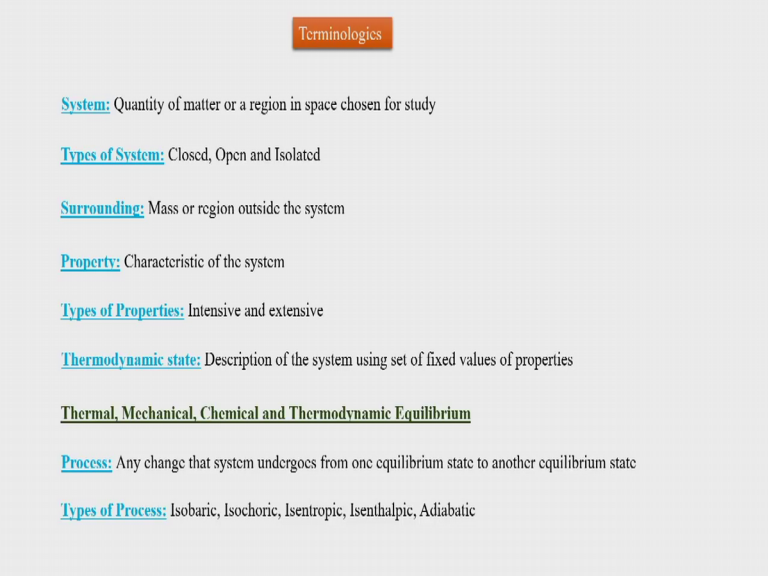

So, we are supposed to know about the system, here we mean that thermodynamic system. So, what is a thermodynamic system? As it is mentioned thermodynamic system is quantity of matter or a region in space for study. We might either be interested in certain mass of matter and what is undergoing or what is happening with that matter that would be our interest or we might be interested in certain region to see what is going to happen or what is happening in that region. So, if we are considering certain amount of mass or if we are considering certain volume in the space, then both are said to be thermodynamic systems.

Then as there are thermodynamic systems, we have types of thermodynamic systems. There are three types of thermodynamic systems, one is closed, one is opened, and another is isolated. So, if we see the thermodynamic system is closed, here if system is closed system, then it is closed for something. And what is it closed for? It is closed for mass. If a system is not allowing mass to enter in itself, then such a system is called as closed system.

But then there is other type which is open system. And this open system is opened for mass, and then both the systems whether it is closed system and it is open system both are open for energy interaction. So, closed system is a system, where mass cannot enter into the system but energy can interact with the system, such system is closed system.

Example is a piston cylinder arrangement without any valves. So, piston can go inside the cylinder, piston can come out of the cylinder, and then such motion of the piston inside the cylinder as what we can see in IC engine when inlet and outlet valves are closed, it is a closed system where we can see that heat can interact and work can work can also interact with the system.

Then we have open system. Open system as we said that both mass and energy can interact with the system. So, we have both mass and energy which they can come into the system or they can go out of the system. And this is what prime concern for ours in this complete course, since turbo machinery parts which are turbine or compressor, they are the or maybe combustion chamber they are open systems.

In compressor, we have mass coming in, mass going out and as what we have seen that compressor is a power absorbing machine. So, it absorb the power, the fluid takes the power from the rotor and turbine is a power producing machine. So, there is a work interaction and there is a mass interaction with the systems of mass and work both are coming into the system and both are going out of the system. So, turbines, compressors, they are open systems.

But then there is a third system which is called as isolated system. And an isolated system is closed or rather it is isolated from interaction with of mass and energy with the system. And universally known example for isolated system is thermos flask. We would mostly see the first law of thermodynamics for our consideration or importance as open system in today's class.

So, surrounding as we have defined system a certain quantity of mass or certain volume in space that is our system, so a rest everything, rest everything means the rest of the mass or rest of the volume what we are not interested to be in is called as surrounding. And basically thermodynamics the is the subject where we deal with energy interaction of the mass system with the surrounding.

But then we have to define a system, as a closed system or open system. So, we know there is there is a closed system and there is a open system, but then we have to study thermodynamically that system. So, we have to study means we have to analyze means we need some quantities to be defined some aspects of the system, some terminologies

with the system, something to be defined for the system which we can track latter with the changes in the system, and these things are called as property of the system.

So, they are characteristics of the system. So, if we understand characteristics of the system then we mean that we have done the thermodynamic analysis of a system. So, there are different types of properties of the system, properties like there are intensive properties which are independent of the size or mass of the system, they are called as intensive properties. And then there are extensive properties, which are dependent on the size or mass of the system.

So, intensive properties practically for an example we have pressure, temperature and density, they are intensive properties. Since if we have a room, and in this room if we make four parts of the room, the pressure of the room will change. So, since pressure is independent of the not dependent of the size. So, pressure is intensive property. Similarly temperature if we have a glass of water and if we take measure the temperature in that glass of water, and if we take some water in a spoon and measure the temperature of the water in the spoon then both the temperature should be same since temperature is also insensitive with the size or mass of the system, temperature is also intensive property.

For extensive property, we have to consider mass. So, we have to consider something like total momentum of the system that is the extensive property. Since momentum is mass into velocity. So, we make it dependent on or rather momentum is dependent on size or mass of the system. So, these are properties of the system.

So, we want properties to be known for a particular system, so that we can keep then track when system is undergoing certain changes. So, if I want to describe one system as what we describe our self we can describe our self by our nature, by our height, by or weight so such are our characteristics.

So, similarly we have to describe one system. So, how would we describe a system, we would describe the system with set of properties and giving certain number or associating certain fixed value of a number with each property, then we say that he described state of a system that this system this close system, this open system has one state this system is in one state, this closed system is in one state. So, basically description of the system using set of fixed values of properties is what we called it as thermodynamic state of a system.

Then we need to know as what we say fixed value of the property. For defining the state of the system, we know we should associate only one value of temperature that means, only one value means, suppose there is water at 80 degree Celsius, so we should have value fixed 80 degree Celsius as the temperature of water, then what we say that this is a temperature of water and this is pressure water.

So, this describes the thermodynamic state of water, but what would happen is there might be a problem that if there is a temperature gradient, temperature variation inside our system, then there will be some transfer of heat. And due to that transfer of heat there will be later on after sometime there will be there will be uniform temperature or single temperature of the system attained, then only we can represent temperature as unique value or a fixed value for a system.

So, thermal equilibrium would be a necessary to define the thermodynamic state of the system. So, there is an equilibrium which is called as thermal equilibrium, where there will not be non-uniformity in the temperature of the system. Similarly, there is mechanical equilibrium. In mechanical equilibrium, we will have basically uniform pressure inside our system. If pressure is non-uniform, then there will be motion from high pressure zone to low pressure zone. And that motion would equilibrate the pressure such that we will get a definite amount of pressure after sometime. So, then we will say that system has attained mechanical equilibrium.

Then there is chemical equilibrium. Chemical equilibrium means that there will be uniform or single composition in the system. If there is no uniformity in the composition of the system, again there will be motion from high concentration region to low concentration region, and then we will have uniform composition in the system.

So, there is thermal equilibrium, where temperature will be equilibrated. There will be mechanical equilibrium, where pressure will be equilibrated. There will be chemical equilibrium, where there will be uniform composition will be attained. And when a system has thermal equilibrium, mechanical equilibrium, and chemical equilibrium system is said to be in thermodynamic equilibrium. So, all this three equilibriums are essential to make the system in thermodynamic equilibrium. And we try to study the thermodynamic system in thermodynamic equilibrium.

But, if the state of a system, what we defined as association of set of fixed values or properties. And that state is changing from one state to other system is changing its state. So, consider that I have a piston cylinder arrangement, and piston is at a position in the cylinder, and piston is going inside the cylinder. When piston was at a position inside the cylinder, then there was one pressure, and then there was one volume of air inside the cylinder. But, as piston goes inside volume decreases, and then pressure also decreases, and then temperature would also decrease. So, these things are changing.

So, what we can say if the air inside the cylinder is our system, then this system is undergoing change of state. And this change of state from one equilibrium state to another equilibrium state is called as process, but it might happen that as I where I was pushing the piston down, I can take the piston out also. So, what would happen, system started with certain conditions certain state to start with, it went to some another state, and then it is going to come back to its original state.

And if I assume that the piston is friction less, then what would happen that the system would come back to its original state along with the surrounding. And then in such case the process executed by the system would be called as cyclic process, it is a special process, where system is going to go from one state, and then it is going to come back to its initial state. If system is going to go from its one first state or initial state to some other state, then systems is undergoing a non-cyclic process, it is not completing the cycle ok. And that is what the topic of our discussion as I said thermodynamic basic thermodynamics and Brayton cycle, so the cycle are there. And the cycle what I mean by process over here is same.

Then types of processes as what we say that there are processes, where system undergoes change of state, then there might be constraints, that there might be a constraints such that system is undergoing a change of state, but the pressure is going to remain constant for the system. If this is a constraint, then it is called as isobaric process. So, isobaric process is a process in which system is not going to change its pressure, but it is undergoing a change in thermodynamic equilibrium from one state to other state.

Similarly, there can be constraint of isochoricness that means, volume of the system can remain constant during the process. So, if volume of the system is going to remain constant, then process is called as isochoric process ok, then we have isentropic process.

There is a terminology as we know in basic thermodynamics, there is a concept called as entropy, which is a again property of a system. If that entropy is going to remain constant in the process, then it is called as isentropic process.

Similarly, as per first law of thermodynamics, there is one more property which is enthalpy of the system, then if that is going to remain constant, then it is called as isenthalpic process. Parallelly there is one more process, which is called as adiabatic process.

And in the adiabatic process, what is going to happen? Yes, actually in adiabatic process we will have no heat interaction for the system. So, system will have no heat interaction in adiabatic process. Further all these processes are coming under the title as reversible processes. As what we say reversible means, system can be brought to its initial state, if we reverse the process without having any impact on the surrounding. So, there can be as well irreversible process. But, if the process is irreversible, then we cannot know what are the intermediate states, the process has undergone through. These are some terminologies associated with basic thermodynamics ok.

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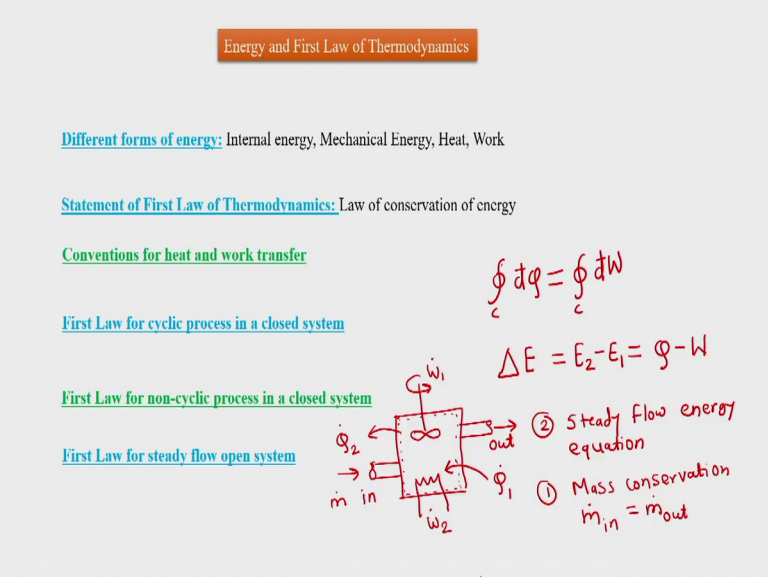

Then we will go next topic for discussion as energy, and first law of thermodynamics. So, first law of thermodynamics would deal with energy, so we have to know what are the different forms of energy. So, a system is actually having certain forms of energy

either with itself or it might interact with the surrounding, as what we know the subject of thermodynamics would deal with.

So, what is the energy which system would posses? System would posses one energy which is called as internal energy. System is comprised of molecules and atoms, and then there will be nucleus in the atom, and then there are electrons in the atom. So, every object is associated with some energy. Like if I take an atom, then it has translational motion. If I take a molecule, then it has vibrational motion, it has rotational motion. So, there is translational motion, rotational motion, vibrational motion associated with atoms and molecules.

Further there is nuclear energy, then there is bond energy between two molecules, then all the set of energies which are microscopic forms of energies, they are called as summation over all the forms is called as internal energy of the system. And we represent internal energy later on, we would be using it as it would be a function of temperature for us for the perfect gas assumption calorically perfect gas assumption that we will see, what do we mean by calorically perfect gas.

Then there is one more energy associated with system, which is called as mechanical energy. A system can have three internal forms in the mechanical energy. And summation of all the three is called as mechanical energy. One is called as kinetic energy the system. If system has kinetic energy v square by 2 is one kinetic energy that is kinetic energy of the system, then there is potential energy of the system, and then there is p by rho pressure head of the system.

So, p by rho plus v square by 2 plus g z, and this is called as specific mechanical energy or if we multiply by mass, then it is called as mechanical energy of the system, so and this will be possessed by the system. Then these two energies internal and mechanical, they are possessed by the system, they are within the system.

But, in there are some energies which system will interact with the surrounding or with some other system, and then among that we have heat. Heat is one form of energy, which system is going to interact. And this heat transfer will take place on the boundary of the system. So, we will see heat only on the boundary of the system. And then that heat will be seen during the transfer in the presence of temperature gradient.

Similarly, there is one more energy form which is work. And for work we have different kinds of work, they are like spring work, then there is electrical work, there is displacement work, these will be different forms of the work which system will interact with the surrounding.

Then we have statement of first law of thermodynamic. We know first law of thermodynamics is the law of conservation of energy, and it means to us that energy can neither be created nor be destroyed, but one form of the energy can be converted into other. And that is what thermodynamic deals with where heat will come into the system, and it will remain into the system as its internal energy or mechanical energy depends.

Similarly, system will interact in the form of work, and then when it is stored in the system, it would get stored in the form of either internal energy or mechanical energy. So, this is what first law tells to us. But, then there are certain conventions, when system is interacting with the surrounding for heat and work, then there are certain conventions which are universal.

If heat is received by the system, then it is called to be positive quantity for the system. So, heat if it is received, then it is positive. If heat is lost by the system heat is going out of the system, then this quantity will be taken as negative, but exactly reverse its for work. If system is doing the work on the surrounding, then it is treated as positive.

If heat if work is received by the system from the surrounding, then it is called as it is treated as negative, and we do it in case of compressor. In case of compressor, we say it as power absorbing machine. So, it takes the electrical work or rotary motion can it of the rotor, and then it compresses the fluid. So, this is due to the work transfer. And here we have negative impact on the system, since it is receiving the work.

But, turbine on contrary is a power producing machine. So, what it does is it does the work on the surrounding, so we have expansion process in turbine. And fluid expands while flowing integral turbine, and then does the work on the rotor. So, we get that work output, so it is positive.

So, first law applied to a cyclic process in a closed system. So, if I have a closed system, then we can state give a mathematical statement for first law. And that mathematical statement will be like cyclic integral of all the heat interactions like cyclic integral of d Q

is equal to cyclic integral of d W. This is the statement for the first law, since for the cyclic process. Since system is going to come back to its original state, so system state is same. So, systems all the energies will come back it its original state. So, work and heat will get interacted, and they will get neutralized. So, cyclic integral of d Q is equal to cyclic integral of d W.

But, if I say that there is first law of thermodynamics for the closed system, if we are having a non-cyclic process, before that for cyclic process, we have something like cyclic integral of d Q is equal to cyclic integral of d W. Work and heat they are not properties of system, since they are path dependent, there is a property of a property. So, each characteristic flows one characteristic that they are independent of path like pressure, temperature. So, but work and heat they are dependent on path, so they are denoted by a little hash on their differential.

So, cyclic integral of heat is equal to cyclic integral of w, d W is for is the expression for the cyclic process. But, if I want to write down first law of thermodynamics for the open system, the closed system, for a non-cyclic process, for non-cyclic process, I will say that system will change its energy. This is change in energy of the system, which is E 2 minus E 1, where E 1 is initial energy of the system, E 2 is final energy of the system.

And this change has taken place due to two things. One is system has interacted with heat, and system has interacted with work. So, E 2 minus E 1 is equal to Q minus W. So, this is the first law of thermodynamics for closed system, and then which is undergoing a non-cyclic process.

Here we mean that E includes internal energy and mechanical energy. But, closed system if it is stationary, then it will not have any kinetic energy, it will not have any potential energy, and then what will happen? We will only internal energy of the system, which will be changing. First law for steady flow system; so, for steady flow system we have to write down the first law of thermodynamics.

And if I want to write it then, we have to first define suppose what is the system. Suppose, I represent a system by a rectangular box and that rectangular box for me has certain inlet. Suppose, this is an inlet for the system, and this is an outlet for the system. This is in, this is out, and then there is certain shaft which is moving inside, and then there is one electrical heater which is again giving certain electrical work output. And

then system is getting some work heat, which is Q 1, and system is releasing some heat which is Q 2.

If I want to write down first law of thermodynamics for this open system, which has certain mass coming in, certain mass going out, it has certain work interaction due to the presence of rotor or a stirrer, and there is certain work interaction due to the presence of some electrical arrangement. So, if I want to write down the first law of thermodynamics for this, then that law is that expression is called as steady flow energy equation. So, it is called as steady flow energy equation.

And steady flow energy equation here a new world is coming for us which is steady that means, if properties of the system are not changing with time, then we call it as steady. Here there one more point to be noted that we will have change in properties of the system. But, if it is steady state is reached for the system, then those changes will not be present, then those changes will be 0.

So, the system is for us this rectangular box is a system. And since it is in steady state energy of the system is not changing with respect to time. When we were considering closed system, we have to keep in mind that we were having mass constant, but in case of open system we are having mass interaction. So, since there is mass interaction only energy equation is not sufficient, we have to balance mass also.

So, whenever we are supposed to study open system, then we will have two equation to write. One equation is mass conservation, and other equation is energy conservation. So, basically this is a second equation, and first equation is mass conservation ok. So, mass for mass conservation, we will have if in this case we have only one inlet and only one outlet, mass conservation equation will be m dot in is equal to m dot out.

Basically, we are talking about the rate in this, so this is work transfer rate, this is heat transfer rate, this is work transfer rate, and this is again heat transfer rate ok. So, if we are saying that this is a steady flow system in case of open system, basically there is certain mass which is coming in and certain mass which is going out, we deal with mass flow rate. So, every quantity which is interacting is in terms of rate. So, this is rate of heat interaction, this is rate of work interaction, and this is rate of mass interaction.

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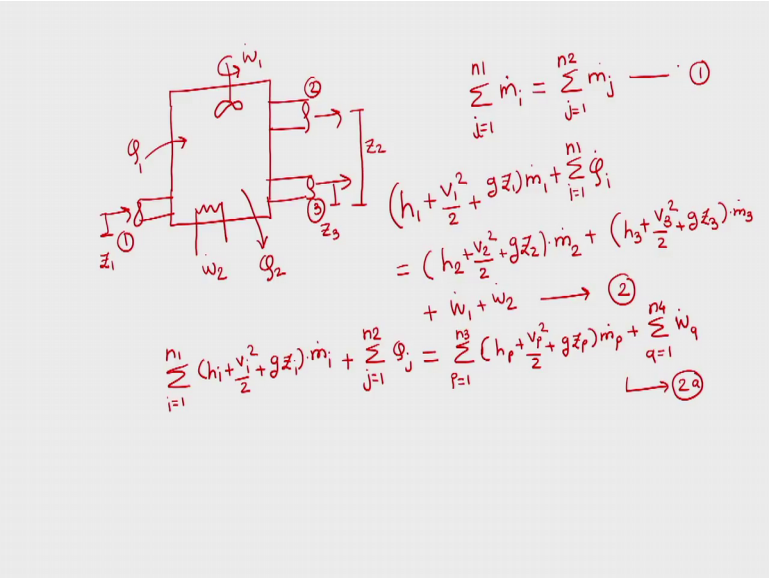

So, rate of mass coming in from the inlet is equal to rate of mass going from the outlet. Then this is the mass conservation equation, then what we have to write is the energy conservation equation. So, I will draw the bigger system suppose, and then suppose instead of having one, if we have multiple inlets and multiple outlets for a system.

Like we are having this inlet, but we have two outlets. This one is one outlet, and this is other outlet ok. This is one inlet, this is two outlet, and this is three also outlet. In this case, mass conservation equation would be written something like this. This if suppose i is number of inlets, then i is equal to 1 to n 1, let there be n 1 number of inlets into m dot i that is equal to let j is equal to 1 to n 2 that there are j, which is n 2 number of outlets, so m dot j. So, this is the mass conservation equation, what we had given as number 1.

But, now as what we have said that there are different amounts of work interaction. And then there are different amounts of heat interaction, there is electrical work interaction, there is shaft work interaction, and all these work interactions are leading to different amount of quantities. I will say this is w 1, I will say this is w 2. Now, we have to write the energy conservation equation for that, and that we would write like this h 1 plus v 1 square by 2 plus g z 1.

Obviously, there is certain amount of potential energy associated with each inlet, each inlet has its own potential energy. This is z 2, this is z 3, and this is z 1, so this n 2 m dot 1. Then we will mention that there are all form of Q's should be considered for and as

what we know that we can write it as i is equal to 1, n 1 forms of Q, which are interacting with the system. And then this is equal to for this particular case, we can write it as h 2 plus v 2 square by 2 plus g z 2 into m dot 2 plus h 3 plus v 3 square by 2 plus g z 3 into m dot 3 plus there are certain work interactions, which is w 1 dot plus w 2 dot, and then this becomes our steady state energy equation.

So, if I want to write steady state energy equation in a generalized form, I would mention it as summation of i is equal to 1 to n 1 h 1 plus h i plus v i square by 2 plus g z i into m dot i. This one thing has scattered all the inlets, this one expression has scattered all the inlets plus there might be j amounts of heat interactions. So, let there will be n 2 number of interactions per heat. So, it is Q j, and this is equal to summation, then let there will be p outlets. 1 to p is equal to 1 to n 3, n 3 number of outlets. Then I can mention it has h p plus v p square by 2 plus g z p into m dot p plus, we have q as n 4 starting from 1 to n 4 as work interaction.

So, this expression is basically modified expression or generalized expression for steady state or steady flow energy expression. So, this is mass conservation expression 1, and this is steady flow expression 2 a. We are going to use basically, this steady flow equation for our complete understanding of thermodynamic cycle of the gas turbine power plant. So, we will take its consequence, and what is that? We can see suppose that we want to use this steady flow energy equation for compressor, then we have to consider compressor.

In case of compressor, we will have only one inlet, and there will be only one outlet. So, rest of the things would not be present. So, n 1 is equal to 1, and n 3 is equal to 1. In case of turbine also we have to use the same expression, again there will be one inlet, and one outlet. So, this expression although looks complicated will get simplified, when we are using it for the turbine and compressor, we have to use the same expression for the combustion chamber as well.

So, in case of combustion chambers also some mass is coming in, some mass is going out, and then there is heat addition the chemical reaction. So, we have to write down this expression. So, here we are going to start, from here onwards for the Brayton cycle, which is the basic cycle for gas turbine power plant. And here through this lecture, we have basically laid the foundation which we would be using in the next class for which

we will use draw Brayton cycle, we will describe different processes of Brayton cycle, we will try to calculate for the Brayton cycle its different parameters such as work, efficiency, work ratio, and then we will try to see how those can be altered with different attachments. So, I hope this lecture of basic thermodynamics will equilibrate us with the terminologies, which we are going to use.

Thank you.