Material and Energy Balances
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Module No # 07
Lecture No # 35
Introduction to Energy Balances – Part 1

Hello everybody welcome to today lecture for the material and energy balance course in the last lecture we looked at some of the basic concepts and terminologies associated with energy balances. Today we will have a brief introduction for how to perform energy balance calculations for closed and open system.

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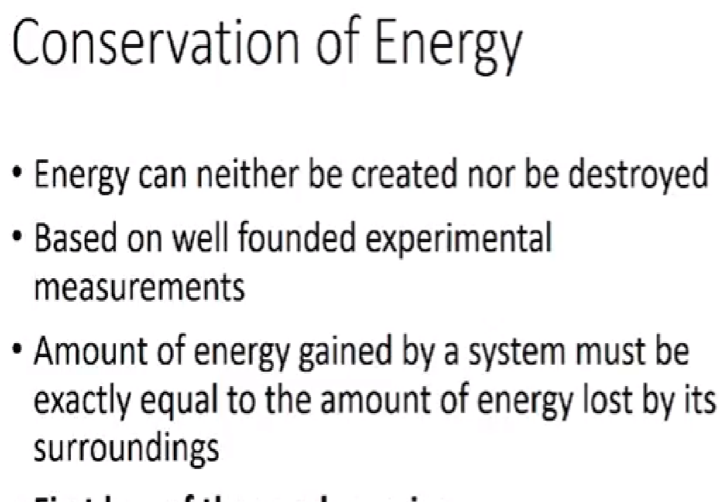

So let us first start with law of conservation of energy. What is law of conservation of energy? It is basically stated as energy can neither be created nor we destroyed it can only be change from one form to another. This is based on well-founded experimental evidences which are proved that any amount of energy it is gained by a system would be exactly equal to the amount of energy which is lost by its surrounding.

So based on this we have established something called the first law of thermo dynamics first law of thermo dynamics is nothing but the law of conservation of energy.

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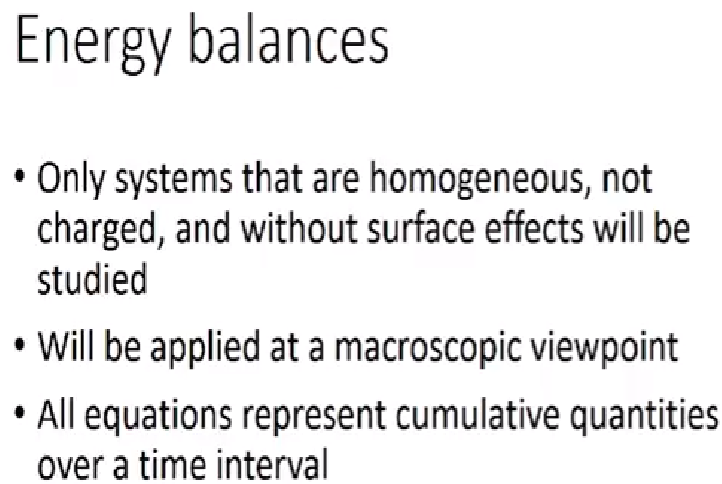

And from this concept we will be performing many energy balances just like how we performed material balances for different types of systems here we will be performing energy balances for different types of system. This will again be like balance sheet or accounting for energy which is supplied and removed from system.

For performing these calculation we will do this only for systems that are homogenous and not charged without surface effects so that we can keep the calculation simple. When we add these complexities the problem becomes much more difficult and combustion which we will not be dealing with throughout the course.

It will also be applied at a macroscopic view point although the law of conservation applies (()) (02:04) from microscopic level we will not be performing calculations at the microscopic levels. All over calculations will be for macroscopic system all equation which we will be using will represent the cumulative quantities over a time interval which is taken as the period of time for observation.

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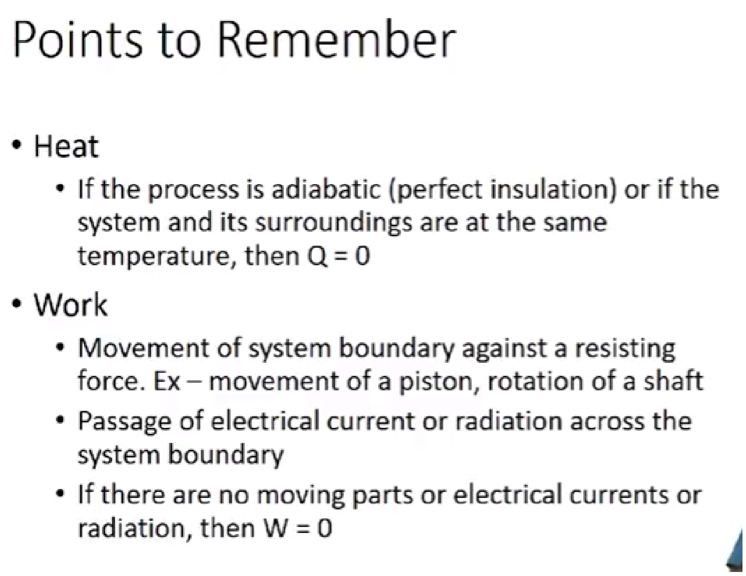

Now that we have understood what our constraints will be for performing energy balances let us refresh the different forms of energy. So we classified the forms of energy based on how the energy is used either to transfer between the system and the surroundings or if it is inherent energy processed by the system. So the different types of energies which are used to transfer energy from the system to surroundings is called as heat and work and the inherent energy possessed by the system are kinetic energy, potential energy or internal energy.

Points which we need to remember when we perform energy balance calculations are heat is 0 if the process is adiabatic. We already looked at what is adiabatic process was it is defined as perfectly insolated process where there is no exchange of heat between the system and the surrounding when such a process exist then we would have to account for Q which is heat for 0.

While we perform energy balance calculations the term for heat which is the energy transferred between the system and then it is surroundings due to temperature difference will be considered to be 0 for such systems. Work is basically the movement of system boundary against a resisting force. This could either be movement of the piston or rotation of shaft and so many other thing you can also have passage of electrical current or radiation across the system boundary which can also cause work.

As I already mentioned in the last lecture we will not be looking at electrical energy as part of this course as chemical and biochemical energies are primarily governed by thermal and mechanical energies we will focus our roles and calculations within those parameters. If there are no moving parts are electrical current or radiation in the system we would have to assume work done by the system or on the system to be 0.

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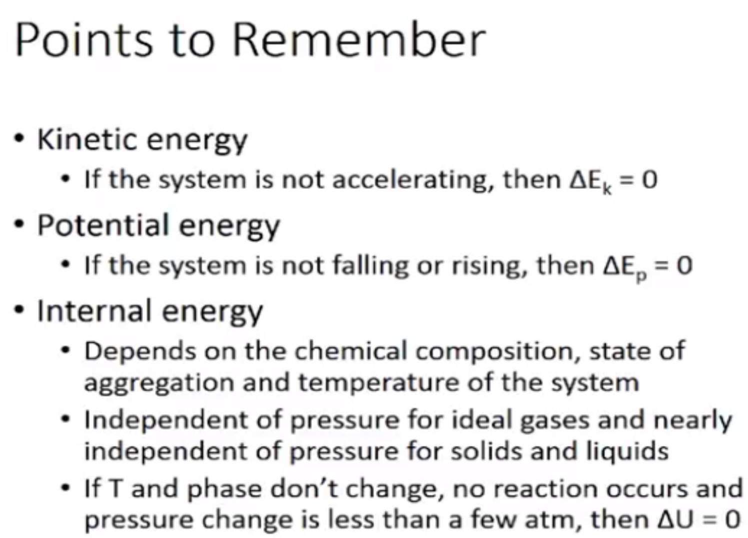

That would mean W would be 0 then we also have the terms where the energy is possessed by the system. The kinetic energy would be considered to be 0 if the system is not accelerated so please understand it is not that system does not have to move. If the system could actually be in motion as long it is not accelerating which means the velocity of the system is not changing the change in kinetic energy is 0.

So the change in kinetic energy is what we will be using for performing energy balance calculations so this change in kinetic energy will be 0 for non-accelerating systems. Potential energy would again be the change in potential energy which means as long as the position of the system which is not changing that is the system is not raising of falling then change in potential energy will be considered to be 0 for performing energy balance calculations.

The last energy which is possessed by the system is the internal this internal energy as I already mentioned depends on the chemical composition state of aggregation of the phase and the temperature of the system it is independent of pressure of ideal gases and it is almost independent pressure for solids and liquids.

So by this what I mean is whenever we have a process where only pressure is changing then we can ignore the effect of change in internal energy for ideal gases and solids and liquids for the most part. If temperature and phase change does not happen when you would have to assume delta 1 equals 0 or change in internal energy is 0 as long as reaction also not happening.

So incase of systems where pressure changes are very high there could actually be small change in effect of change in internal energy for solids and liquid even in that case it will be 0 for ideal gas. So you would use delta U to be 0 in most of cases when pressure changes are happening in the system because of the time changes in pressure are small and the effect of this changes in pressure is numerically very slow.

Now that we have these points which we have to understand and apply let us move on to perform calculations.

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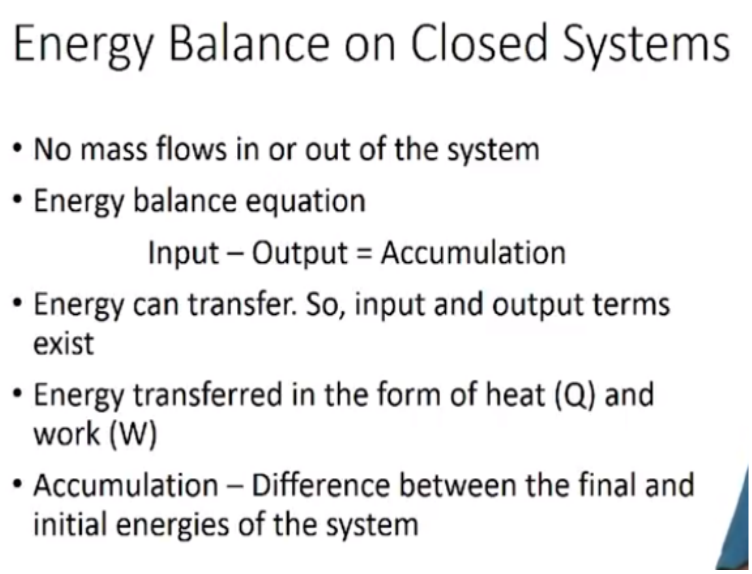

Let us first start with a closed system as I had already mentioned in out material balance calculations we were only talking about open systems most of the times. Because in an open system the material was crossing the system boundary in an energy balance you can have energy crossing the system boundary even in closed system. So understanding how to perform energy balance calculations for closed system is crucial.

We need to understand that there is no mass flowing in or out of the system energy balance for this would be written like input – output = accumulation. So you do not have generation and consumption terms for energy because energy neither be created nor be destroyed. So this means input and output or the only term which would have and accumulation will go to 0 at steady state.

So energy can be transferred from one system to the surrounding or the surrounding to this system this means there always would be input and output terms and energy can transferred in terms of heat and work which is already saw and accumulation would basically be the difference between the final and initial energies of the system.

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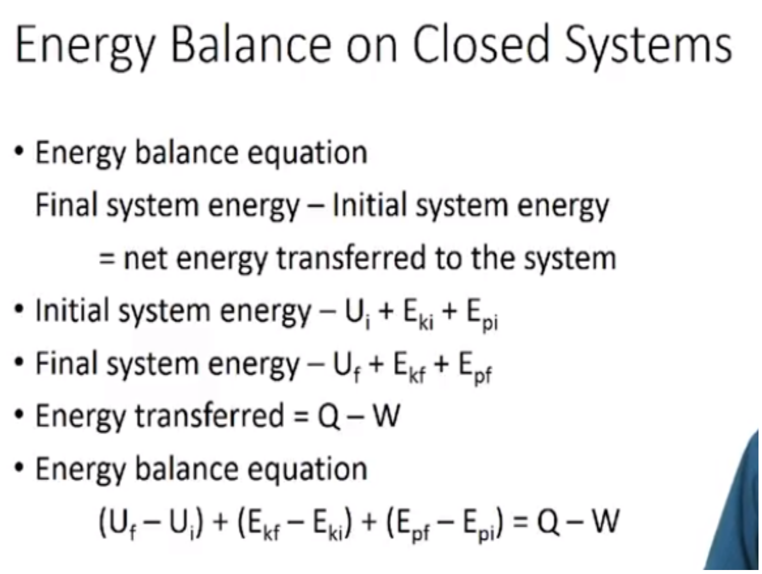

Energy balance equation will basically look like this you would have final system energies – initial system energy giving you the net energy transferred to the system. So initial energy possessed by the system would be 3 components internal energy at initial conditions kinetic energy at initial conditions and potential energy at initial conditions. So summation of all these three energies we choose the total energy possessed by the system at the initial conditions.

Similarly the final energy of the system would again be the summation of internal energy at final condition kinetic energy at final condition and potential energy at the final condition. Energy can be transferred between the system and the surroundings in the form of heat and work. So you remember the convention we agreed to use yes heat would be positive when it is supplied to the system and work will be positive when it is done by the system.

So we will use this convention for rest of the course so based on that energy transferred would be Q – W. So the energy balance equation can be written as delta U which is UF – UI + EKF – EKI + EPF – EPI= Q – W.

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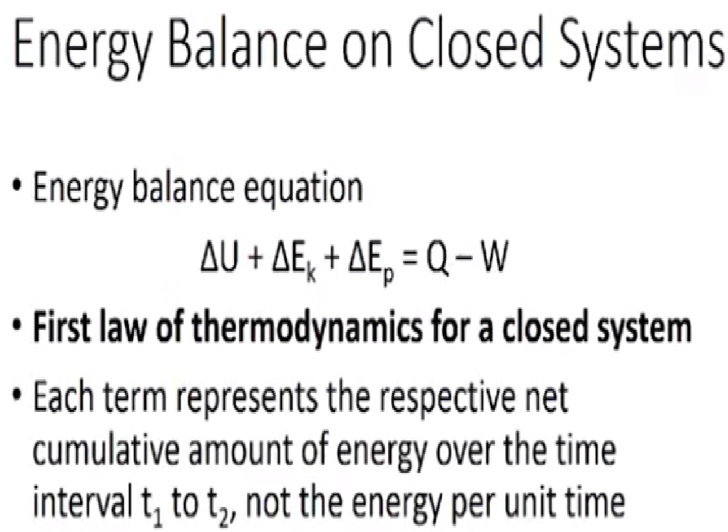

So this equation then becomes delta U + delta EK + delta EP = Q – W so this is the first law of thermodynamics for a closed system. Each term here represent net cumulative amount of energy over a time period of observation which could be from time T1 to T2 this is not energy per unit time.

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Example #1

- An ideal gas is contained in a cylinder fitted with a movable piston. The initial gas temperature is 25°C. The cylinder is placed in boiling water with the piston held in a fixed position. Heat in the amount of 2.00 kcal is transferred to the gas, which equilibrates at 100°C. The piston is then released, and the gas does 100 J of work in moving the piston to its new equilibrium position. The final gas temperature is 100°C. Write the energy balance equation and solve for unknowns. Assume that the gas is the system and ignore change in potential energy due to movement of piston.

So let us move on to an example problem which would help us understand and perform energy balance energy calculation from the closed system. Here is an example an ideal gas which contains it is contained as cylinder which is fitted with a movable piston the initial gas temperature is 25 degree Celsius the cylinder is placed in boiling water which is piston held in a fixed position heat in the amount of 2 kilo calories is transferred to the gas which equilibrates at 100 degree Celsius.

The piston is then released the gas does 100 joules of work in moving the piston to its new equilibrium position. The final gas temperate is still 100 degree Celsius write the energy balance equation and solve for the unknown. Assume that the gas is the system and ignore change in potential energy due to the movement of the system.

So if you were to look at this problem is an ideal gas trapped inside a cylinder with the movable piston so the first step is heat being transferred to the system so that the temperature of gas raises to 25 degree Celsius to 100 degree Celsius and the volume remains the constant because the piton is not moving.

After some point after this process this piston is allowed to move which means the gas expands and 100 joules of work is done on the moving piston and this results in a final equilibrium position where the piston rest. So at this condition the temperature is again 100 degree Celsius indicating this is a isothermal expansion process. So we are asked to calculate the unknowns for in the energy balance equation for both of these process.

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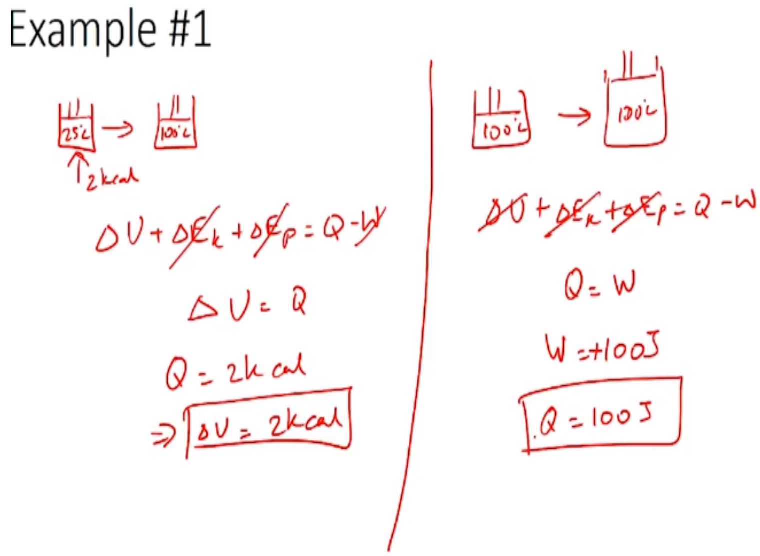

Let us try and do this for this problem so the first process is where you have this movable piston this is at 25 degree Celsius it is moved to the position is not changed but the temperature as changed to 100 degree Celsius because there is a addition of 2 kilo calories of energy in the form of heat. We looked at energy balance for closed system as delta U + delta EK + delta ET = Q – W.

So for this process there is change in temperature which means delta U cannot be 0 the system is not accelerating in anyway so kinetic energy will go to 0 we have been told that change in position of piton can be ignored but here there is not change in position of piston so there is going to be no change in position so potential energy will also be equal to 0. Q is not 0 because you have 2 kilo calories of heat being supplied to the system the piston was not moving this process would W will go to 0.

So you have delta U = 0 so Q has been given as 2 kilo calories so this means delta U = 2 kilo calories. So the change in internal energy for the process where ideal gas I heated as 25 degree Celsius to 100 degree Celsius by supplying 2 kilo calories of heat is also 2 kilo calories with this is the simple calculations but what I want you to understand here is we first identified that the system was closed system and then wrote down the appropriate closed systems energy balance equation and cancelled out terms which did not exist which are which went to 0 and based on this we were able to calculate the unknown.

Let u look at the second part of the problem where the piston basically which is remaining here at 100 degree Celsius moves to an increased volumes where you have again 100 degree Celsius you have this process which is isothermal process and you will have to write the balance for this. So it is again delta U + delta EK + delta EP = Q – W so here there is no change in temperature so we know that there is some change in pressure but we also know that change in pressure does not affect internal energy for ideal gases this means delta U go to 0.'

There is system itself not accelerating or decelerating so this means EK goes to 0 we have been told to ignore potential energy changed due to the change in the position of the piston so potential energy goes to 0 so you have only work and heat so that could be heat which is released from the system and work which is done by the system. So we will have to calculate Q as equal to W.

We have been told that W = 100 joules so this is positive 100 because the work is done by the gas the gas expands to push the piston. So if we are considering the gas as the system which means work is done by the system on the piston which is the surrounding therefore you have a positive work there by Q is also 100 joules so with this we have performed simple energy balance calculations for a closed system.

So again all we did here was identify the write equation for the process and cancelled out the term that need to go to 0. And finally identified all the parameters that were unknowns. So this is a simple energy balance calculations so we will look at more complicated energy calculations in subsequent lectures. But before we do that we also need to identify and understand another type of system which is the open system.

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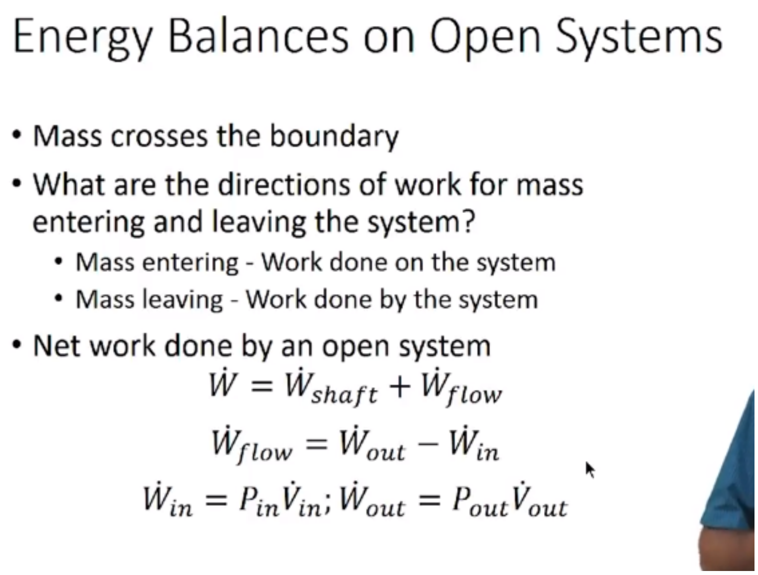

Energy balances on open system could also be performed in similar fashion to closed system but we need to understand that in an open system mass crosses the system boundary this would change the energy balance equations slightly let us see how it affects the energy balance equation. We first need to understand as mass enters and leaves the system we need to understand what would be the work done by the system or on the system when this mass enters and leaves the system.

When mass is entering the system work is actually done on the system we guess the mass forces itself into the system to enter the system. Similarly when the mass leaves the system when system basically pushes the mass out which means work done by the system so that the mass will leave the system. So these are two work aspects which are brought in to the system which were not present in the closed system.

So the network done by the open system could be the summation of shaft work and flow work right the effect of work because of mass entering and leaving the system is called flow work. Shaft work is the work which is done either to move a piston or a rotator shaft and so on. Change in flow work can actually we calculate as flow work for the system for the mass leaving the system – flow work for the mass entering the system.

The work in or W dot in would be PN times V dot in and work which is the flow work for the system mass leaving the system would be P out timed V dot out.

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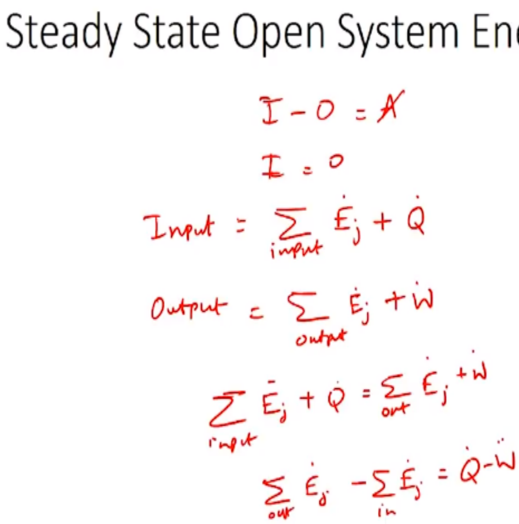

So when we write a steady state open system energy balance equation you would have to understand that you will derive an equation based on all the fundamental about energy possessed by the system and the energy which is used for transferring from the system and the surroundings. Let us start with the general energy balance equation which would be input – output equals accumulation.

As I already mentioned energy balanced equation will not have generation and consumption in terms so at steady state accumulation would goes to 0 which means input equals output. So let us start writing the balance equation for this energy which is fed to the system input would be sigma of input times EJ where E is the total energy possessed by component J and summation of all the energy of different components will give you the total energy of the input stream.

In addition to this you would also have Q dot which is the heat which is supplied into the so this would be a positive term. You can also have output equation which is sigma of output of EJ dot which would again be the energy is possessed by individual components in the output stream and the summation will give the total energy of the output stream + W dot where W dot is the work done by the system.

So because it is work done by the system it is going in the direction from systems to surroundings. So it is the output so energy transferred from the system to the surrounding substituting these two values in the equation we had basically saying input = output you would get sigma input of EJ dot + Q dot = sigma output of EJ dot + W dot. So this equation then becomes sigma output of EJ dot – sigma input of EJ dot = Q dot W dot.

So from here we now need to identify the energies possessed by the system in the output and input condition. in this equation we need to identify what EJ and W dot represent.

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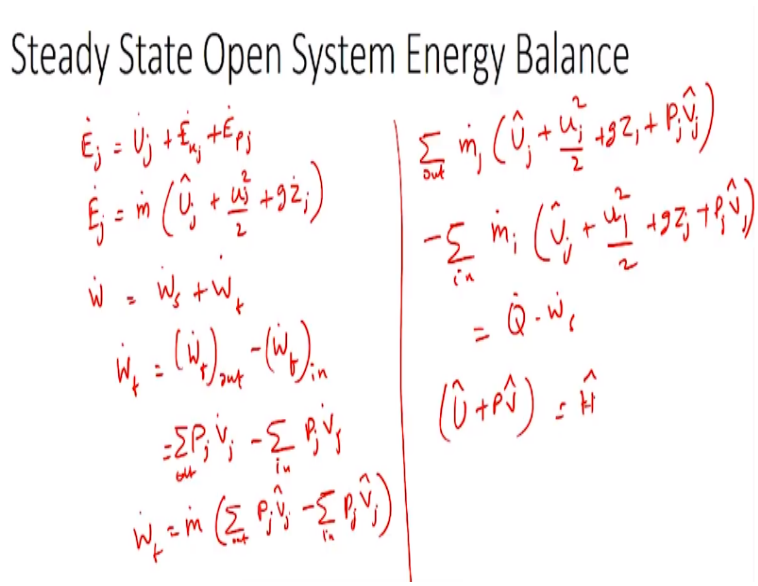

EJ dot is basically the energy possessed by the component J so which would include internal energy which is U dot J + kinetic energy which is EK dot J + potential energy which is P dot J. Now converting them to specific internal energy kinetic energy and potential energy this equation will become M dot times UJ cap + U square divided by 2 + G Z J so where the capital U cap is the specific internal energy UJ is the velocity of component J and ZJ is the height at the component J is present.

So this is your total energy of component J now we have work which is given as W dot this would contain W S dot and WF dot where S is the shaft work and WF is the flow work. So the change in flow work for a system an open system would be output – input of flow work. So you would have flow work output – flow work input so this basically can be written as PJVJ cap sigma of this in the output – sigma input of PJ VJ dot sorry this is VJ cap.

So this then this being converted to specific volume we can have M dot times sigma out of PJ VJ cap – sigma in of PJ VJ cap so this is your flow work. Substituting these into equation we had earlier we would get sigma output of NJ times U cap J + UJ squared / 2 + G ZJ dot + PJ V cap J – input of same thing MJ times VJ cap VJ squared + GZ J + PJ VJ cap.

This would be equal to Q dot – WS dot so what I have done here is split the work into shaft work and flow and taken the term for the flower to the left side the in the equation we had used. So the terminology delta sorry terminology U cap + PV cap can be combined to form the enthalpy which is H cap.

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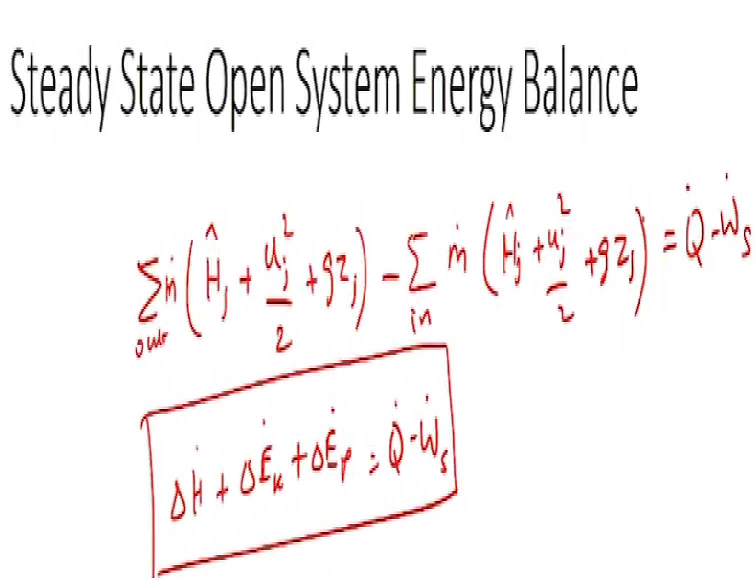

So this means this equation which we have can then be simplified and written as sigma of out times H cap J + UJ squared divided by 2 + GZJ all of these times M dot – sigma of input times M dot H cap J + UJ squared divided by 2 + GZJ would be equal to Q – WS Q dot WS dot. So from here we can basically simply this equation as delta H dot + delta EK dot + delta EP dot equals Q dot – WS dot.

So this is here equation for energy balances in open system so the first term which is M dot times H cap would become the total enthalpy of the out let stream the total enthalpy of the output – the total enthalpy of inlet stream forms delta H dot so similarly the total kinetic energy of the outlet stream – the total kinetic energy of inlet stream gives you a delta EK dot and the difference between the total energy of the outlet stream and the total outlet potential energy of inlet stream gives you delta EQ dot.

So substitute these values we get delta H dot + delta EK dot + delta EP dot = Q dot WS dot which will used in place delta U + delta EK + delta EP = Q – W which was used for closed system. What we need to understand here is for a closed system energy balances are performed using internal energy and for open system energy balances are performed using enthalpy this is because the flow work associated with the flow of material in and out of the system is accounted for using enthalpy.

So internal energy + this flow work ends up becoming enthalpy in the mathematical expression therefore we used enthalpy instead of internal energy while we perform energy balance calculation for a open system.

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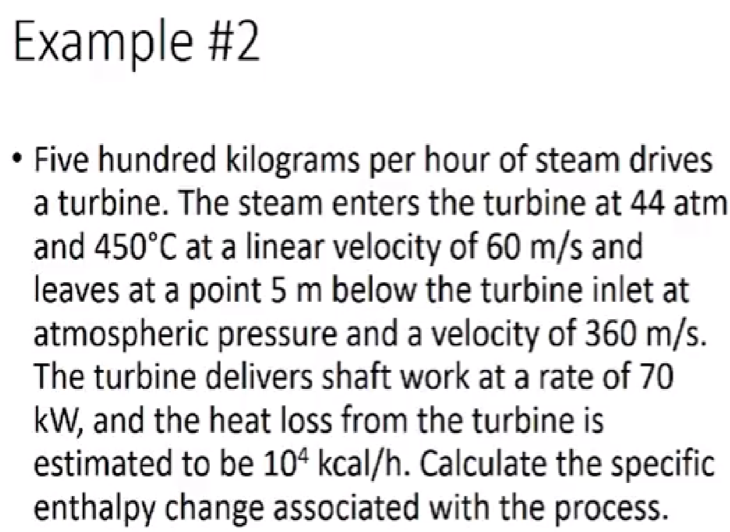

So here is another example which will illustrate how to perform energy balances for an open system. 500 kilograms of stream drives at turbine the stream enters the turbine at 44 atmosphere and 450 degrees Celsius at a linear velocity of 60 meters per second and leaves at a point of 5 meter below the turbine inlet at atmospheric pressure of and the velocity of 360 meter per second.

The turbine delivers shaft work at a rate of 70 kilowatts and the heat loss from turbine is estimated to be 10 power 4 kilo calories per hour. Calculated this specific energy enthalpy state associated with this process.

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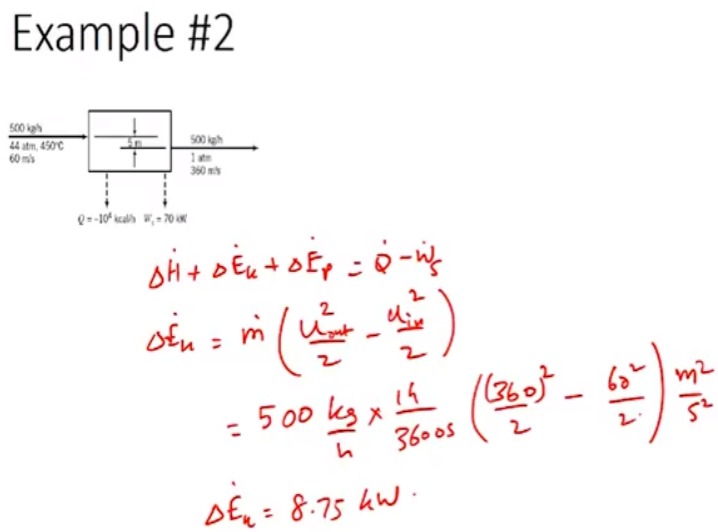

Let us perform the calculations for the system so this is the flow chart you have 500 kilograms of stream entering and the condition for it also given you have work dene and heat supplied the system heat moved from the system and change in height which is also represented. Let us now perform from the calculations so as this is an open system the equation for energy balance should be delta EH dot + delta EK dot + delta EP dot = Q dot – W s dot.

So we already know the value for Q dot and WS dot which have been given in the problem we need to calculate delta H dot delta EK dot and delta EP dot so from the parameters which have been given we can calculate delta EK dot which is the change in kinetic energy as M dot times U squared U out squared divided by 2 – U in squared divided by 2. So we know the velocities for the inlet and outlet streams for the outlet stream travels at 360 meters per second and the inlet stream travels at 60 meters per second.

So this means our mass flow rate would be 500 kilograms per hour so this needs to be converted to seconds kilograms per second because we have the velocity in terms of meters per second so this would be 1 hour into 2600 seconds times U out squared which is 360 squared divided by 2.

So the units will be meters squared per second squared both. So this would be 60 squared divided by 2 in the units of meter square per second square.

So performing these calculation we can get delta EK dot as 8.75 kilowatts so which is kilo joules per second which have represented as kilo watts.

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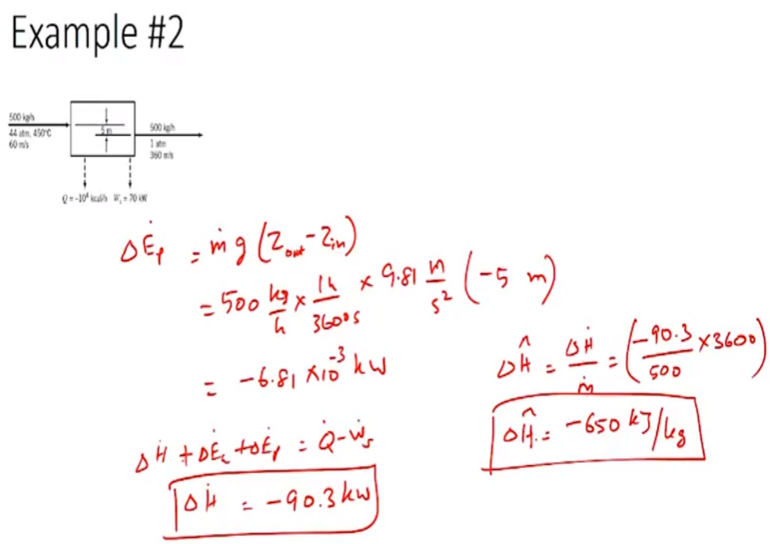

Similarly we can calculate change in potential energy as delta EP which would basically be M dot G times Z out – Z in. So here there is a drop of 5 meter which means Z out is 5 meters below the Z in. So you have negative 5 as the change in height so this would become 500 kilograms per hour times 1 hour in 3600 seconds times 9.81 meters per second square times – 5 meters.

So this gives you a value of -6.81 times 10 power 83 kilo watts now that we have the potential energy and kinetic energy we can substitute it back to equation delta H dot + delta EK dot + EP dot = Q dot – WS dot by substituting it here we can calculate delta H dot as we already know H dot as WS dot by converting them a appropriate to appropriate units we can use it in this equation and get H dot as -90.3 kilowatts.

The problem ask us to calculate the specific enthalpy change so this is the total enthalpy change for the system so we now need to calculate in terms of specific enthalpy this means this needs to be divided by the mass flow rate so this would be delta H dot divided by M dot. So M dot here is

500 / 3600 kilograms per second so you would have -90.3 divided by 500 timed 3600 giving you a numerical value of roughly -650 kilojoules per hour.

So this is your change in specific enthalpy so from this we have calculated the change in specific enthalpy by using energy balance calculations. So with this we come to the end of today lecture in the next lecture we will talk about performing such energy balance calculation for multi component system and also using thermo dynamic table talking values for enthalpy and internal energy form these tables until them thank and good bye.