Advanced chemical Reaction Engineering
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Lecture - 14
Energy Balance - I

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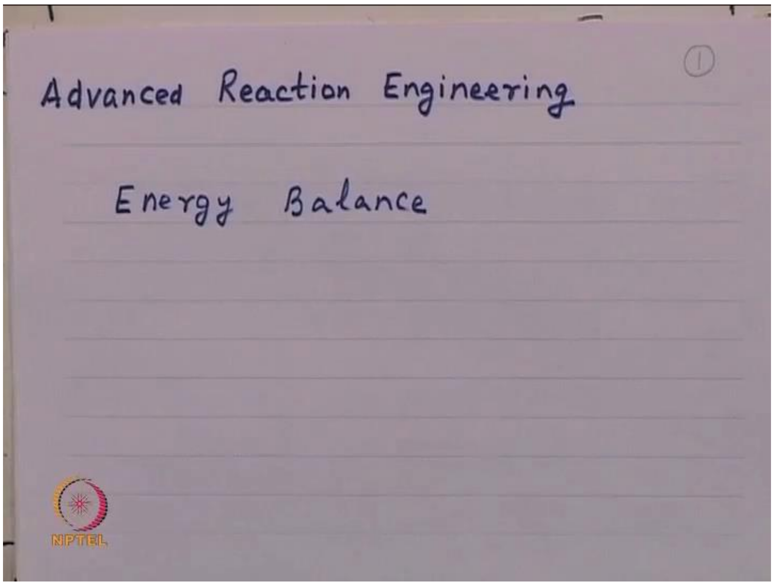

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Advanced Reaction Engineering

Energy Balance

Today, we will be looking chemical reactor energy balances well, energy balance is something that is, so central to chemical reaction engineering because, we have to supply heat or we have to remove heat and then we must design our systems. So, that you know the amount of area that is required for the heat addition or heat removal have to be appropriately correctly done. So, that you know the reaction proceeds as we expected to proceed. So, this is very important part of the course in chemical reaction engineering. So, this something we get started today, and then see how we can understand what happens.

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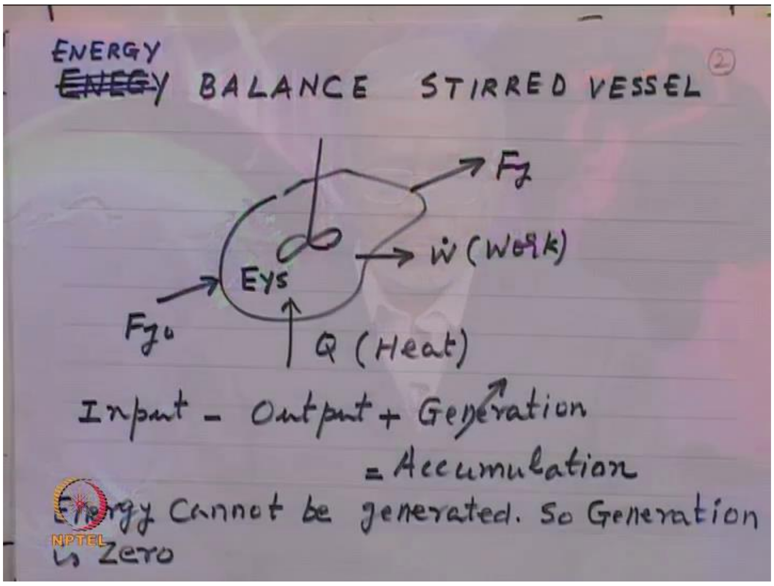
ENERGY

~~ENEG~~Y BALANCE STIRRED VESSEL ②

Input - Output + Generation = Accumulation

Energy Cannot be generated. So Generation is Zero

Now, we write our energy balance for vessel of our interest, I have deliberately taken a vessel of this very ((Refer Time: 01:19)) this not to indicate that the balances that we write take in to account any shape in principle any shape, but of course, we construct shape that are of you know useful to us etcetera. So, we have here a stirred equipment by stirred we mean that the in intensive properties of the system at different positions in the equipment is same. So, the temperature, compositions are uniform everywhere, that is the assumption. So, that stirring means that every point inside the equipment has the same in intensive property like temperature, and composition.

We have here Fj0 moles of component j entering and because of chemical reaction Fj moles of ccomponent j comes out. So, Fj and Fj0 if they are different to the extent that they are different that the extent to which that particular reaction is taking place. If there is1reaction for many reactions also we look at now, as per the first law convention, we have taken heat addition in to the system as positive. And then, heat I mean work that produced by the system we have taken as positive therefore, our statement of conservation says, input minus of output plus generation equal to accumulation, something that we have been writing for a long time our statement of conservation of mass we wrote input minus of output plus generation equal to accumulation.

And we wrote this about conservation with respect to component j, we always wrote with respect to material balance, we wrote generation of that component j. So, since the rate of chemical reaction is known we are able to write the rate of generation of component j. Therefore, input output generation is must be equal to accumulation. Now, when it comes to energy balance since energy cannot be generated, we say that generation term in the energy balance should not be there.

That is why I have removed the generation term. So, input of energy minus output of energy must be equal to accumulation energy. So, our energy balance is different from material balance because of the fact that generation term is not there in the energy balance, but generation term is there in the mole balance not I am not saying material balance mole balance. Now, even if you are talking about material balance in terms of kilogram whatever, they generation of particular terms may be there because, it is getting converted something else. So, the overall balances there no change, but individual components balance that will be a change because of, chemical reaction.

So, what are we saying now? If we talking about energy balance in stirred vessel, there is input of energy because of, component j is bring some energy, there is output of energy because, component j is taking away some energy. Then there is input of heat, which is some energy which is some energy that is coming in, and there is output of work with some energy coming out. Therefore, input minus of output with generation equal to accumulation is a statement of conservation of energy. Let us now translate all this in terms of some symbols, just to understand what might be going on in terms of symbols is easier to work with.

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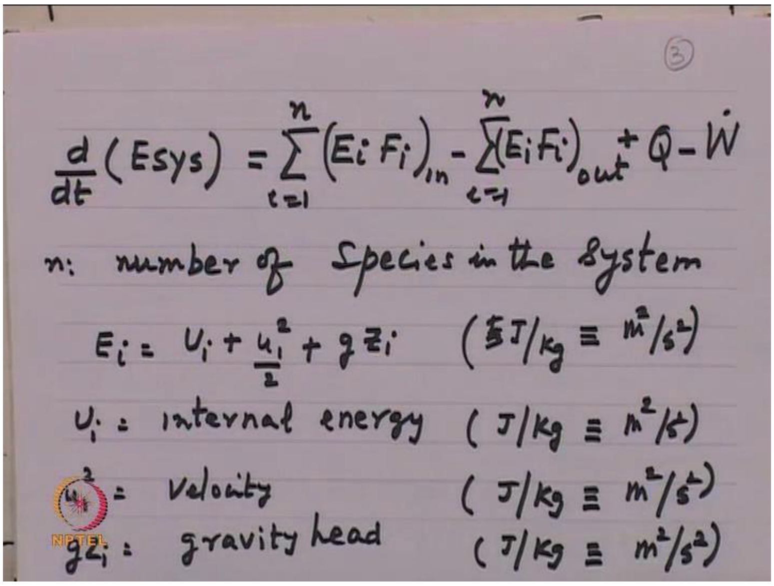

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$$\frac{d}{dt}(E_{sys}) = \sum_{i=1}^{n}(E_i F_i)_{in} - \sum_{i=1}^{n}(E_i F_i)_{out} + Q - \dot{W}$$

n: number of Species in the System

$E_i = U_i + \frac{u_i^2}{2} + g z_i$ ($J/kg \equiv m^2/s^2$)

U_i : internal energy ($J/kg \equiv m^2/s^2$)

u_i^2 : Velocity ($J/kg \equiv m^2/s^2$)

$g z_i$: gravity head ($J/kg \equiv m^2/s^2$)

So, what is mention here is d by dt of E system s y s is refers to the energy inside the system, e is the energy s y s refers to system, E subscript system is energy of the system. So, left hand side says rate at which energy of the system changes with time. So, that is the accumulation term that you can see here, the accumulation term here this the term that is written, E system is the energy inside the system s is missing, and I put s here, d by d t of E system is rate of change of energy inside the system. So, that is left hand side now, the right hand side it is summation i equal to 1 to n Ei Fi, Ei is the energy of the component i and Fi is the molar flow of component i.

Therefore, Ei Fi represents energy that is associated with component i at the input; that means, here at the input here. So, summation over all components tells you the total amount of energy that these components are bringing in to the system. Similarly, if sigma i equal to 1 to n Ei Fi out represents, the energy that is going out, the energy that is going out, with all these materials. So, Ei Fi summation means you are looking at the total amount of energy that is associated with all the components that is going out.

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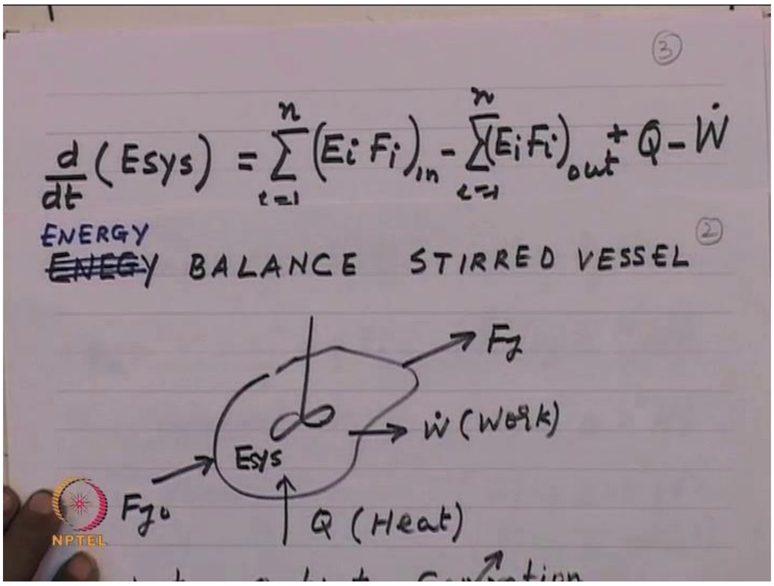

③

$$\frac{d}{dt}(E_{sys}) = \sum_{i=1}^{n}(E_i F_i)_{in} - \sum_{i=1}^{n}(E_i F_i)_{out} + Q - \dot{W}$$

ENERGY ~~ENEGY~~ BALANCE STIRRED VESSEL ②

Notice here, we have not taken into account, what is called is the heat of mixing or if I mean the ((Refer Time: 06:08)) change for mixing. So, as function here is that, Ei Fi this total energy of Ei Fi and total energy of Ei Fi out with the in, there is no what is called is the loss of gain of energy because of mixing. So, that is the all right. So, that is what the assumption here we have plus Q minus WS . So, Q is the amount of heat that input in to the system, and W dot is the amount of work that it take out of the system.

So, accumulation equal to input of energy minus output of energy. There is no generation of energy, but there is amount of heat that is input of this another this is energy that coming in with the materials, this is the energy putting through on your heat transfer pipes and so on. And W dot is the amount of work that you might be getting in to your shaft, that might be may be to spin, which is turning a motor and so on. So, this work, this is heat, this is the energy, that is coming in because of, the fluids that is coming in to the system.

So, you have here Ei as the energy that is associated with component i with consist of 3 component one is internal energy, kinetic energy and potential energy. So, we take total energy of component i consisting of internal energy, potential energy and kinetic energy. So, Ei represents the total energy of the system of the component i, and Ei Fi therefore, represents total amount of energy that component i brings in. And, sum it over all species total amount of energy that is coming in with the species similarly, for the output this one term, which all of us may be familiar, but put it in the context.

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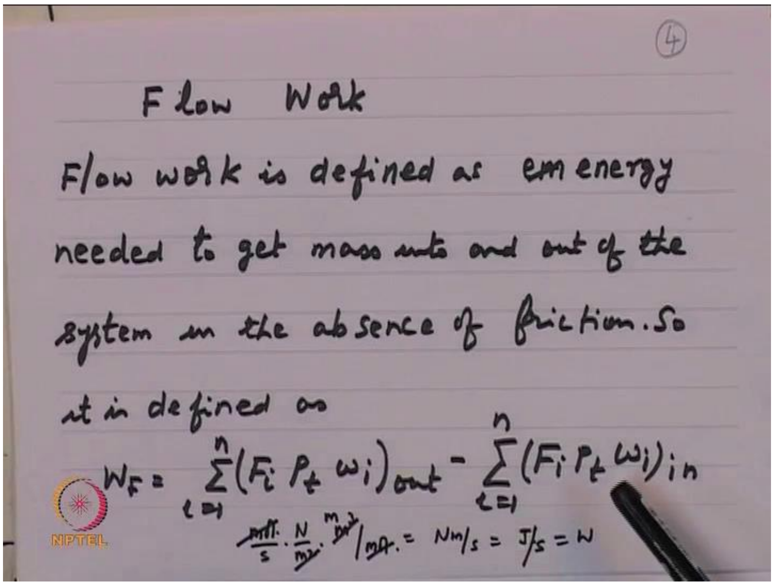

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Flow Work

Flow work is defined as an energy needed to get mass into and out of the system in the absence of friction. So it is defined as

$$W_F = \sum_{i=1}^{n}(F_i P_t \omega_i)_{out} - \sum_{i=1}^{n}(F_i P_t \omega_i)_{in}$$

$$\frac{\cancel{mol}}{s}\cdot\frac{N}{\cancel{m^2}}\cdot\overset{m}{\cancel{m^3}}/\cancel{mol} = Nm/s = J/s = W$$

Suppose, we have some material that is going in to the system and coming out to the system i got here Fi Pt omega i out minus of Fi Pt omega i in, what is this word Fi Pt omega i if we look at the units of Fi Pt omega. Omega i is specific volume Pt is pressure Fi moles per. So, this essentially this is work term we understand here itself. So, let us say moles per time, and this is Newton’s per square meter this is specific volume that is cubic meter per mole cancels off. So, it is meter square meter cube so, this meter. So, it is Newton meter per second, which is joule. So, this is per second. So, this is you know joules per second is watts.

So, essentially it is energy by unit time is what is the. So, Fi Pt omega i in is kind of it is coming in. So, much of energy is coming in the form of Fi Pt omega i. And similarly, so much of energy coming in, so much of energy is going out. This difference, what meaning can we attach to this difference. Now, if we look carefully at this suppose there is a chemical reaction in which Fi, this term sigma Fi Pt omega i and this term sigma Fi Pt omega i in and this out. They are not the same now, here is an instance which says that even in the absence of friction, this term Fi Pt omega i out is different from Fi Pt omega in.

This is greater than this, it means this is positive, if it is this term is less than this the whole term negative. So, what is; that means, WF WF which we call as flow work, the flow work in to a out of a system; that means, in this out of a system, and in to the system this difference if it is positive it means that this particular system gives you some flow work. If this is a negative which means that you have to put in work to make this fluid enter the system, and come out even in the absence of friction. So, what we are trying to say is that there can be instances in which you have to put in work because, even the absence of friction this term is this minus of this is negative.

This is something that is to be understood that you may need to put in work, to be able to get system materials in, and out of the system, even in the absence of friction. So, this is the point that I am trying to get across to you. That flow work represents the difference between Fi Pt omega i out minus Fi Pt omega i in, and this term in a reacting system can be different therefore, this minus this can be positive or negative.

And, if it is negative, you have to put in work to make fluid go in and come out of the system. So, flow work is an instance where you may need to put in work to get system fluid in and out of the system. So, what are we saying then, if we looking at our system here, and we are saying the W dot, is the amount of energy in the form of work, that comes out of our system.

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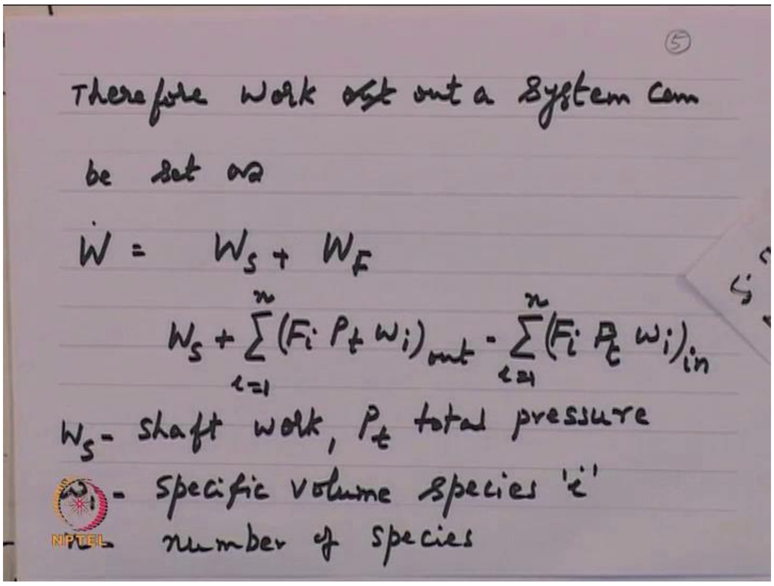

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Therefore work ~~out~~ out a System can be set as

$$\dot{W} = W_S + W_F$$

$$W_S + \sum_{i=1}^{n} (F_i P_t \omega_i)_{out} - \sum_{i=1}^{n} (F_i P_t \omega_i)_{in}$$

W_S - shaft work, P_t total pressure

ω_i - Specific volume species 'i'

n - number of species

We recognize that this w dot actually consist of 2 types of work 1 is WS which is shaft work and 1 is WF, which is flow work. Now, in an instance where WF is negative; that means, you will have to put some energy to get fluids in and out of the system WS is negative. And therefore, the total amount of work this WS is different from W dot, that is the point we are trying to put across to you. So, WS represents the shaft work that we will get out of the system, and therefore, it is that work, which is going to appear to us is going to turn our turbine, and this going to turn motors and so on.

That is the amount of energy that you and I will be able to make use of. So, what are we saying now? In our first law were W dot represent the work that comes out of the system now, can be broken up into 2 parts; part1 is shaft work and part2, which is what is called as flow work, which is Fi Pt omega i out minus Fi Pt omega i in. So, the total amount of work that comes out of our system, which is W dot we have broken up in to 2 parts. Part1 is shaft work, part2 is flow work. We put the flow work separately let us see, what advantages we get out of doing this what I am saying is that, this flow work, let me sort of going through this once again.

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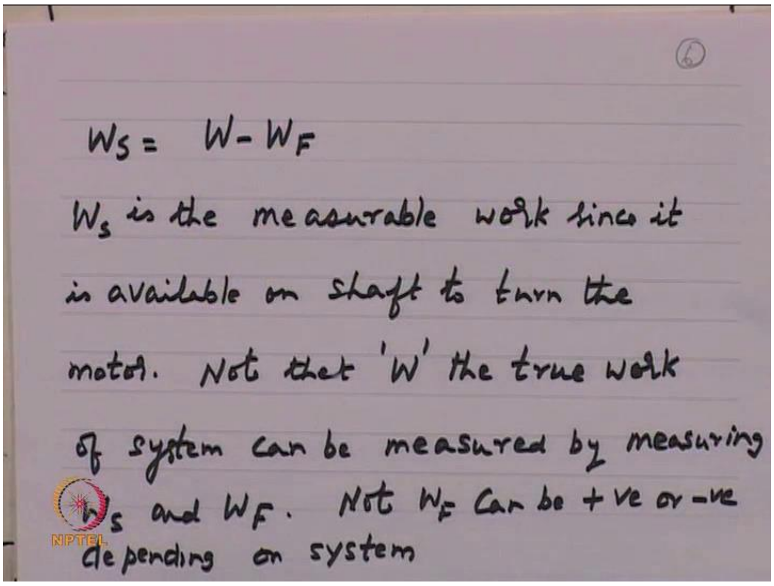

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$W_S = W - W_F$

W_s is the measurable work since it is available on shaft to turn the motor. Not that 'W' the true work of system can be measured by measuring W_s and W_F. Not W_F can be +ve or -ve depending on system

WS is the measurable work since it is available on the shaft; that means, we can actually put in our measuring systems actually measure WS . So, that is why is a measurable quantity and this W which is a true work can be measured only by measuring WF and WS. This can be measured because we know Pt omega i and Fi therefore, this is a known quantity this is an experimentally measured quantity, and therefore, W become that quantity that you and i can determine.

Because, WF is a quantity that we know because, Fi Pt omega i for all the components are known, we can sum over all species at inlet and outlet. And, WS is the work that, we can measure at the motor because its turning and we can measure the work output in various ways. Therefore, W is the quantity that is measured by measuring separately both WS and WF all right. Let us try to illustrate this because some of these may become clearer if we look at a small example.

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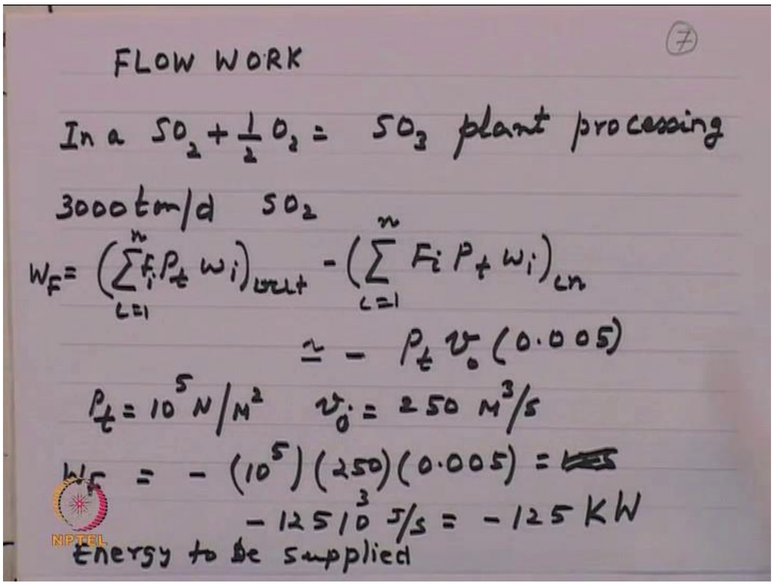

FLOW WORK ⑦

In a $SO_2 + \frac{1}{2} O_2 = SO_3$ plant processing

3000 ton/d SO_2

$$W_F = \left(\sum_{i=1}^{n} F_i P_t \omega_i\right)_{out} - \left(\sum_{i=1}^{n} F_i P_t \omega_i\right)_{in}$$

$$\simeq - P_t v_0 (0.005)$$

$P_t = 10^5 \, N/M^2$ $\quad v_0 = 250 \, M^3/s$

$$W_F = -(10^5)(250)(0.005) =$$

$$-125 \cdot 10^3 \, J/s = -125 \, KW$$

Energy to be supplied

Let us look at a sulphur dioxide plant, reacting with oxygen in air it gives sulphur trioxide, is well known reaction it is been going on in the process industry for last many years. And, it is a catalytic reaction and so on. Generally air is used for oxidation. Therefore, we get air oxygen contained in air is used for the reaction and so on. So, I put some numbers here just taken some data from a factory which processing about 3000 tonnes per day of sulphur dioxide.

So, which is reactive form sulphur trioxide. So, numbers look something like this, for the case of this kind of flow you can calculate all these I made some estimates the flow v not turns out to be about 250 cubic meters per second. And, this flow is measured at some standard at the rector conditions. And, what is the pressure typically the pressure at which you will pump the fluid near atmosphere or slightly near the atmosphere. So, let say 10 to the power of 5 Newton per square meter.

So, our situation here is that, we have a flow of 250 meters cubic per second, and a pressure of 10 to the power 5 per meter square is coming. So, what is to, if v0 Fi times omega i is a volumetric flow. So, if some over all species becomes the total volumetric flow, as in this particular term can be seen as volumetric flow multiplied by the molar flow of the component. This one way we can understand this similarly, you can understand this as flow multiplied by the number of in the sense Fi omega i is flow and Pt is a pressure. So, pressure multiplied by flow gives you units of energy. So, this difference is, what the flow work is.

Now, if you put all the numbers Pt is given v0 is given. So, this Pt omega i, summation experience says that about this difference is typically about 0.5 percent; that means, this minus is this turns out to be about 0.5 percent of, what is at the out let. So, we have written this as in the form of Pt times v0 multiplied by 0.5 percent, which is 0.5 by 100 is 0.005. So, what are we try to do? We are trying to make an estimate of flow work for the case of a 3000 tonnes per day sulphur dioxide plant, and when we make the estimate for the numbers that, we have taken this turns out to be about 125 kilo watt with a minus sign.

Showing that this amount of work we will have to put in for the fluids to be put in to the system, and taken out in the absence even in the absence of friction you need, so much of work put in. So, that the fluid can go in and come out of the system, why is this? So, it is so, because Fi Pt omega i at the inlet and Fi pt omega i at the outlet are not the same. And, this so that energy we will put in appropriately. So, just to cut the long story short what you are said here is that flow work is a term, which is energy that is associated with getting material in and out of the system in the absence of friction. And, for a plant of 3000 tonnes per day sulphur dioxide, we have made an estimate that turns out to be a 125 kilo watt with minus sign, showing that we have to put work to the system.

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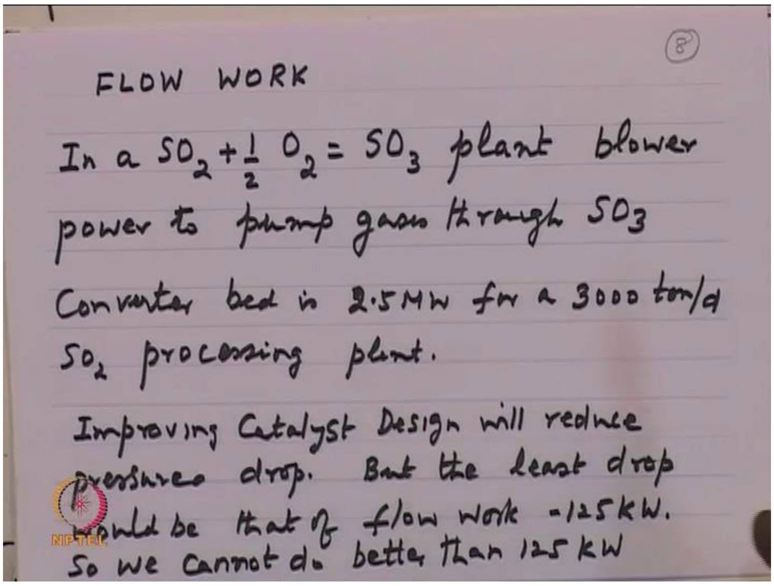

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FLOW WORK

In a $SO_2 + \frac{1}{2} O_2 = SO_3$ plant blower power to pump gases through SO_3 Converter bed is 2.5 MW for a 3000 ton/d SO_2 processing plant.

Improving Catalyst Design will reduce pressure drop. But the least drop would be that of flow work ~125 kW. So we cannot do better than 125 kW

I mean we have shown at an earlier day that, the pressure drop associated with sulphur dioxide sulphur trioxide, there we estimate that the energy required to push the material in and out of the system, in is something like 2.5 mega watt taking pressure drop in to account. So, taking pressure drop in to account the energy required is 2.5 mega watts, if we do not take pressure drop in to account, it is only 125 kilo watt, what are we saying? pressure drop is the huge activity in the process industry.

If it is properly managed, why are we saying the context is saying is that, when a pressure drop in a process is something, we cannot avoid. So, improving catalyst design of course, we reduce pressure drop understood. But, the lest pressure drop would be that of flow work. So, flow work is something that is the minimum, at which you can work that mean, that amount of energy you have to put in any way otherwise fluids will not go in and come out of the system. So, flow work is a measure of minimum amount of energy that is required to put the material in and out of the system.

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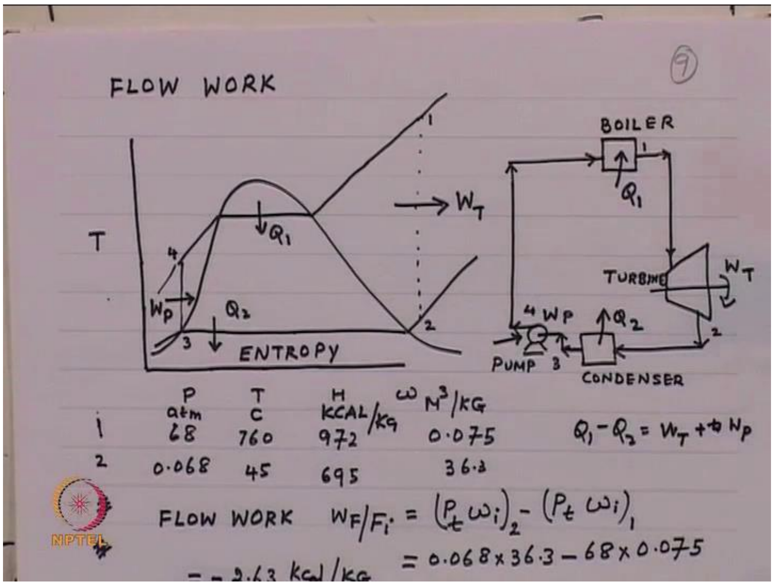

FLOW WORK

	P atm	T C	H KCAL/KG	ω M³/KG
1	68	760	972	0.075
2	0.068	45	695	36.3

$Q_1 - Q_2 = W_T + \cancel{-} W_P$

FLOW WORK $W_F/F_i = (P_t \omega_i)_2 - (P_t \omega_i)_1$

$= 0.068 \times 36.3 - 68 \times 0.075$

$= -2.63$ kcal/KG

So, with this, let us look at some examples to understand energy in terms of our interest. I have taken the example of stream turbine, where what do we have? We have a boiler to which fluids are coming in, and it becomes stream. That stream goes in to the turbine in here, it expands and stream finally, condenses and then comes out in to the condenser where it condenses. And then, that fluid, that liquid again pumps back in to the process. So, what is a boiler of what is power plant? Power plant is an instance of a process in which stream is generated in a boiler.

It is put in to the it is put in to turbine where it turns the wheels of the turbine, which in turns motor and so on or a generator. Now you have, so much of energy form, of heat Q1 going in to the boiler. And, so much of energy Q2, which is thrown in to the environment. So, Q1 minus of Q2 is really the energy that is being lost by the working fluid, which is in your boiler minus condenser. So, this Q1 minus of Q2 is appear as work. So, we have got here WT is the work for the turbine WP is the work in the pump. WT minus WP is, what you will be able to produce in the system, give you where you put in Q1 of heat and then Q2 of heat output Q1 of heat input.

Q1 minus of Q2 under ideal conditions Q1 minus of Q2 equal to WT minus of 4 WT minus of WP. Is that clear, what are we saying? Q1 minus Q2 is the total amount of energy that is absorbed by the system. And therefore, that must appear as the shaft work which is WT minus plus WP. So, so much of shaft work is done therefore, that difference must equal to shaft work that is what you are said. So, what we are saying here, we also once again this also an instance of energy balance where the energy of stream is used to run a turbine. And therefore, Q1 minus of Q2 which is the energy inert energy that is absorbed by stream, must appear as turbine work which is WT and WP. Now, have you said all these things? Let us now, just look at what we are saying in terms of the equations that generate that describe the energy balance.

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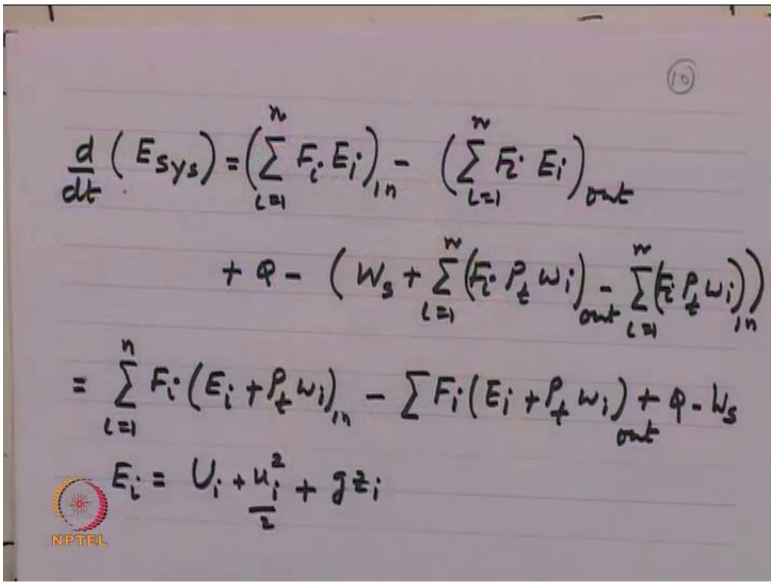

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$$\frac{d}{dt}(E_{sys}) = \left(\sum_{i=1}^{n} F_i \cdot E_i\right)_{in} - \left(\sum_{i=1}^{n} F_i \cdot E_i\right)_{out} + q - \left(W_s + \sum_{i=1}^{n}\left(F_i \cdot P_t \omega_i\right)_{out} - \sum_{i=1}^{n}\left(F_i P_t \omega_i\right)_{in}\right)$$

$$= \sum_{i=1}^{n} F_i \left(E_i + P_t \omega_i\right)_{in} - \sum F_i \left(E_i + P_t \omega_i\right)_{out} + q - W_s$$

$$E_i = U_i + \frac{u_i^2}{2} + g z_i$$

So, we are said that Fi Ei in and Fi Ei out this term, W dot can be replaced as WS plus WF flow work that is what have been done. Here therefore, w dot has been replaced as WS plus flow work that is what has been done. So, essentially the same energy balance we still work with, the left hand side is the state of accumulation energy in the system. This is the amount of energy that is coming in with the fluids, the amount of energy that is going out with the fluids.

This is the amount heat that is heat transfer in to the fluid, and this term minus is the term that is associated with flow work or the work associated with getting material in out of the system in absence of friction. So, with this kind of formulation now, we can take this Fi Pt omega i along with the input terms, and output terms and so on. So, that we can combine this and make it might look for easier to understand now. So, d by d t of energy of the system now we have sigma i equal to 1 to n Fi is the molar flow of Ei and Pt omega i. Notice here, Fi Ei this Fi Pt omega i can be combined. So, that this term now look like Ei, which is the internal energy of the system and Pt omega i is it is external phenomena because of pressure and so on.

So, we have put Ei and Pt omega i together, because of the advantages that it will give us. So, just like we have done for the inlet term we can do the same thing for the outlet term, where Fi is multiplied by Ei Pt omega i. So, what is that we are saying? What we are saying is that; if you have an energy balance, if you take flow work in to account, and then, flow work term appears in the energy balance in this form, you have Fi is the is the molar flow.

And, Ei plus Pt omega, you can notice here in term here is negative correct negative negative is positive. So, therefore, Ei plus Pt omega i this is the energy of this system. Similarly, Fi energy of the system out, so you have internal energy plus Pt omega i is the energy in, and that is the energy out. So, since we shall we say that input energy output energy this is the amount of heat that you putting work putting. Therefore, this represents the statement of energy balance after we have made a substitution for our terms.

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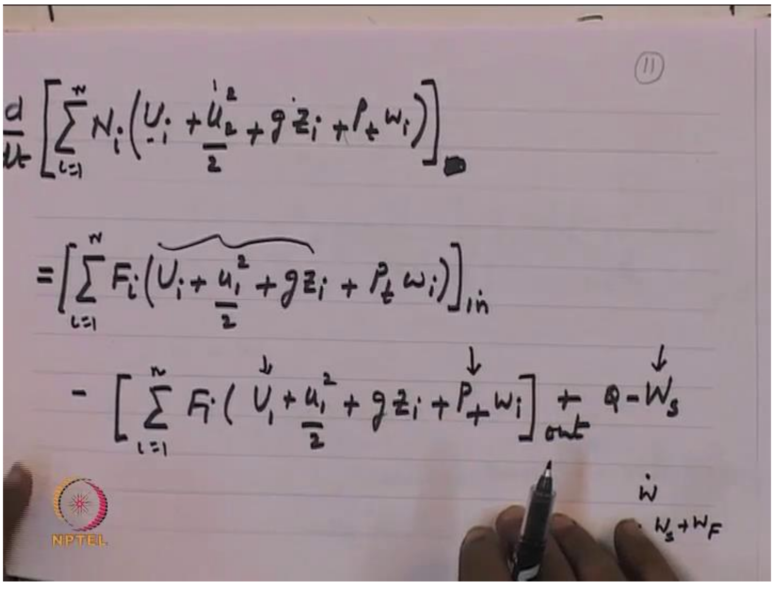

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$$\frac{d}{dt}\left[\sum_{i=1}^{N} N_i\left(U_i + \frac{u_i^2}{2} + g z_i + P_t \omega_i\right)\right]$$

$$= \left[\sum_{i=1}^{N} F_i\left(\overbrace{U_i + \frac{u_i^2}{2} + g z_i} + P_t \omega_i\right)\right]_{in}$$

$$- \left[\sum_{i=1}^{N} F_i\left(\overset{\downarrow}{U_i} + \frac{u_i^2}{2} + g z_i + \overset{\downarrow}{P_t}\, \omega_i\right]_{out} + Q - \overset{\downarrow}{W_s}$$

$$\dot{W}$$

$$W_s + W_F$$

So, statement of energy balance that we are said is d by dt. Now, you can see here on your left hand side the this system on the left hand side also, I have replaced the e system by our energy for each component multiplied by the number of moles of component i inside the system. The number of moles of component i inside the system we have taken as Ni.

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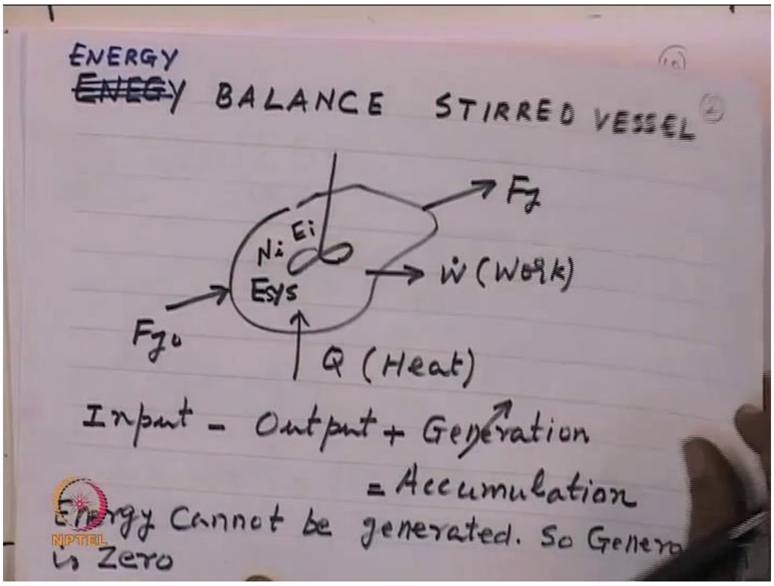

~~ENEGY~~ ENERGY BALANCE STIRRED VESSEL

Input - Output + Generation = Accumulation

Energy Cannot be generated. So Genera
is Zero

See what I am saying here is that the number of moles here that the we are assuming that the Ni moles of components present here each of these Ni moles has specific energy Ei. Then, Ei consist of ui gi zi and then small ui. So, all that taken as in to account that is how our system look like this. So, you have on the left hand side E system this is E system which consist of Ni multiplied by this is internal energy, this is kinetic energy, this is potential, this is the term associated with the flow work, which is now, we have brought in appropriately it goes from i equal to 1 to n number of species.

All these i equal to 1 to n this number of species. So, notice here that this term, this whole term ui plus ui plus this is the total energy. So, this is something like what is called as internal energy, and this is something like p v term. So, which is looks like our conventional nomenclature, what is called as enthalpy. So, you have inputs and you have the outputs plus Q minus WS notice here, this WS previously we called it as W dot which we said was equal to WS plus flow work and that is how we this flow work we put in terms of Pt omega i and so on. And then, rearrange this equation. So, that this equation now looks slightly different from, what we started with. And, the form in which this equation now, looks is something like this. With all the simplification, what we have is this term you notice here this term ui plus Pt omega i its termed as hi that is what we have done.

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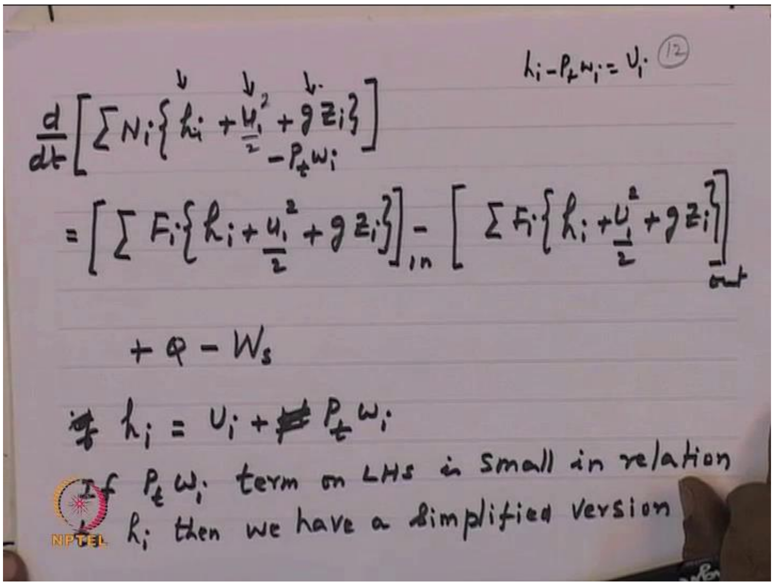

$h_i - P_t w_i = U_i$ ⑫

$$\frac{d}{dt}\left[\sum N_i\left\{\overset{\downarrow}{h_i} + \overset{\downarrow}{\frac{u_i^2}{2}} + \overset{\downarrow}{g} z_i - P_t w_i\right\}\right]$$

$$= \left[\sum F_i\left\{h_i + \frac{u_i^2}{2} + g z_i\right\}\right]_{in} - \left[\sum F_i\left\{h_i + \frac{u_i^2}{2} + g z_i\right\}\right]_{out}$$

$$+ Q - W_s$$

$$h_i = U_i + P_t w_i$$

If $P_t \omega_i$ term on LHS is small in relation h_i then we have a simplified version

Here hi and this you have this kinetic energy this is the potential energy. Notice here, this term is not there.

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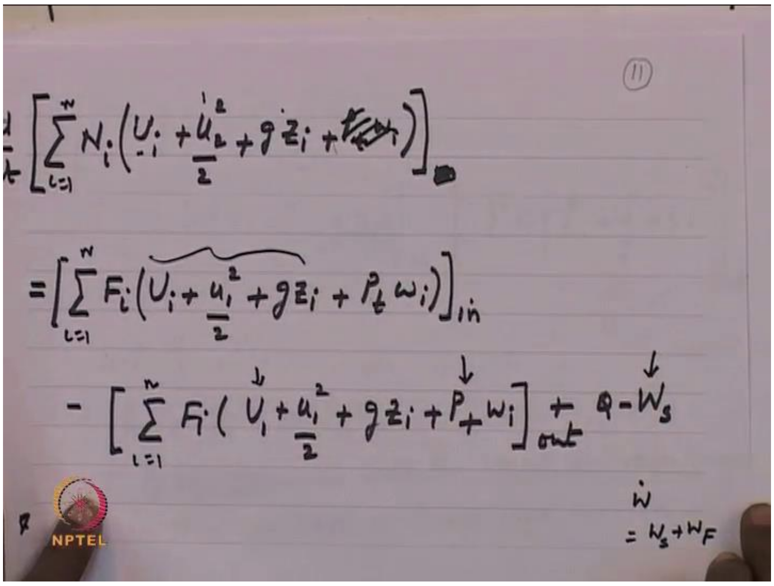

⑪

$$\frac{d}{dt}\left[\sum_{i=1}^{N} N_i\left(U_i + \frac{u_i^2}{2} + g z_i\right)\right]$$

$$= \left[\sum_{i=1}^{N} F_i\left(\overbrace{U_i + \frac{u_i^2}{2}} + g z_i + P_t \omega_i\right)\right]_{in}$$

$$- \left[\sum_{i=1}^{N} F_i\left(\overset{\downarrow}{U_i} + \frac{u_i^2}{2} + g z_i + \overset{\downarrow}{P_t} w_i\right]_{out} + Q - \overset{\downarrow}{W_s}$$

$$\dot{W} = W_s + W_F$$

Notice here, that on the left hand side the term Pt omega i does not appear that on the right hand side it appears. Is it clear? Because this term flow work is associated with flow and therefore, in the left hand side is only accumulation therefore, flow work does not appear that term does not appear. Therefore, on the left hand side i subtracted it by putting Pt omega i, so that this term hi minus Pt omega i by definition hi minus Pt omega i.

By definition is ui that is how it is written on the left hand side. So, this is the statement of energy balance for the system, which is well stirred, which means every position inside the equipment has same composition, same temperature. On other words all in intensive properties are the same at different positions of the system. Now, we can simplify this further which I have done. So, that we have some more advantages which I will do right now.

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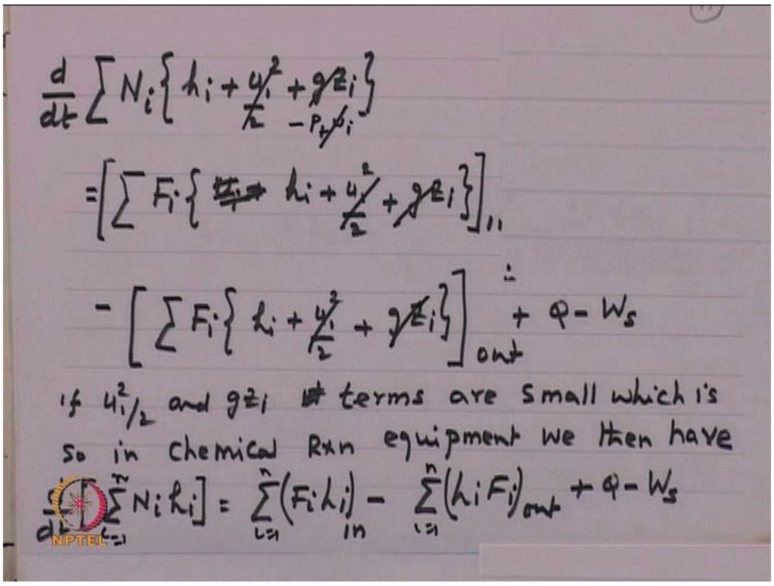

$$\frac{d}{dt}\left[\sum N_i\left\{h_i + \cancel{\frac{u_i^2}{2}} + \cancel{gz_i} - \cancel{P_t\omega_i}\right\}\right.$$

$$= \left[\sum F_i\left\{h_i + \cancel{\frac{u_i^2}{2}} + \cancel{gz_i}\right\}\right]_{in}$$

$$- \left[\sum F_i\left\{h_i + \cancel{\frac{u_i^2}{2}} + \cancel{gz_i}\right\}\right]_{out} + Q - W_s$$

if $u_i^2/2$ and gz_i terms are small which is so in chemical Rxn equipment we then have

$$\frac{d}{dt}\left[\sum_{i=1}^{n} N_i h_i\right] = \sum_{i=1}^{n}(F_i h_i)_{in} - \sum_{i=1}^{n}(h_i F_i)_{out} + Q - W_s$$

So, what we have done now, is that the left hand side Pt omega i minus. So, this term if this term Pt omega i is not very large particularly in our reacting systems, that we are taking about this not a term which is not going to be important. Therefore, it is possible to look at the whole equation in a slightly simpler form by saying the following. The left hand side, this term and this term, and this 2 terms are not very important.

In the sense that the real energy that is associated with our chemical reaction is in hi and therefore, this term ui squared by 2g is zi Pt omega i are terms, which may not be very important now, have you said this? So, of course, this is something that we must verify for our every case we apply these equations, we must convince ourselves, that our assumptions are correct, and if it is not you must come back, and use the general form which you have written now. So, that we do not make mistakes, so but in situations most of our situations of chemical reaction engineering you will find, that these terms can be deleted, these terms can be deleted.

So, that the simplified form of the energy balance might looks something like this d by dt of Ni hi i equal to 1 to n, i equal to 1 to n. So, what is that our equation look like our equations look like that left hand side is Ni h i summation over all species, the right hand side Fi hi summation over all species. And then, again the out term is Fi h i sum all species plus Q minus of WS. So, what we have done, is that is stared with general statement of conservation of energy, and we made certain simplifications, and then we have written our equations now in terms of enthalpy which is term which is well tabulated etcetera.

And then, Ni is number of moles inside the system, hi is the number of moles coming in this is the this term hi Fi the amount of energy that is coming in, and this hi Fi out is amount of energy that is going out. All measured in terms of hi enthalpy, since enthalpy, is well tabulated in this representation form, there was certain advantages. Because, these can be read out of tables and therefore, our effort in trying to put the number becomes much easier. So, just put it in to the context, what we have done is that; we have set up the general balance equation and then we have written our equation in a form.

So, that we can simplify some other terms can be deleted and so on. And got the final form, in which we have on the left hand side Ni hi summed over all species, the right hand side the Fi hi summed over all species. In flow stream versus out flow stream Q and WS are heat and work that goes in to and out of the system. Now, having said this, so we would like to see how this representation, that we have done, how does it sort of explain or shall we say, how it is able to describe? What happens in different situation of our interest? We will apply our equations to variety of reacting system. So, every system that we apply our equation should hold.

So, we want to see, how our equations sort of help us to understand? What goes on in different system? Etcetera. So, what are we said? We said that our energy balance equation looks like this our energy balance equation is f Ni hi summed over all species, Fi hi input summed over all species, Fi hi summed over all species plus Q minus WS . So, let us let us take the example of a power station let us say we have a Hydel power station.

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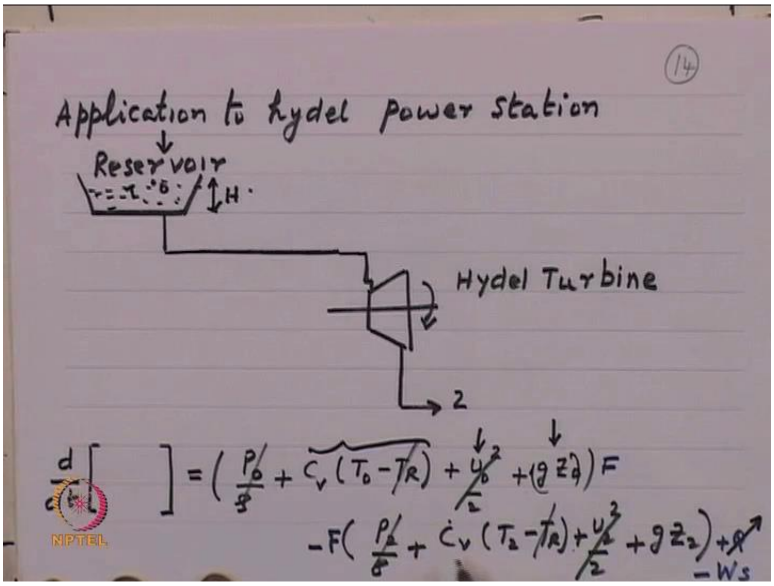

Application to hydel power station

$$\frac{d}{dt}\left[\quad\right] = \left(\frac{\cancel{P_0}}{\rho} + \overbrace{C_v(T_0 - \cancel{T_R})} + \frac{\cancel{u_0^2}}{2} + g z_0\right)F - F\left(\frac{\cancel{P_2}}{\rho} + C_v(T_2 - \cancel{T_R}) + \frac{\cancel{u_2^2}}{2} + g z_2\right) + \cancel{Q} - W_s$$

How does our equations help us to tell what happens in this Hydel power station. So, what is the Hydel power station? Hydel power station is an instance, where you have a reservoir containing large quantity of water. Huge many of our in our irrigation you know, dams are often used to generate energy because, water are available at very high level, and can it be made to run through a turbine.

So, you have a reservoir which holds huge quantity of water, and then it is at al level which is much higher than our Hydel turbine, which is at a lower level. Therefore, you have a difference of height there is a difference of height, so many meters, so many height differences there. And therefore, that height difference can be exploited to derive energy from that water. So, what is it? What is it doing? This water in the reservoir is going through a pipeline in to this turbine, and this turn a turbine, and this turbine turns up generator, and that is how we get electricity and so on.

So, I have taken this as position as 0 and this is position2. So, we are writing our energy balance between 2 positions 0 and position 2. So, we are said on the left hand side our equation, we can see here, that is d by dt of Ni hi, it is equal to i, equal to 1 to n Fi hi in, i equal to 1 to n Fi hi out, plus Q minus WS . So, what is Q? What is WS? Q is the amount of heat that is put in or amount of heat that is lost. Now, if you assume that this Q is not very significant, on other words, for the application of our interest, we may assume that this Q is not very high, is not a such a bad assumption as for as, Hydel power stations are concerned.

By the fact is that; is an assumption an every assumption will have to be appropriately validated checked to make sure in our assumption are consisted with, what happens in the field. So, let us form and assume that Q is not very important; that means, heat loss is not very important therefore, that this statement of energy balance says, that left hand side accumulation of energy equal to input of energy minus output of energy plus flow energy in the form of Q that going in to the system, energy in the form of W going out of the system.

So, you notice here what I done is, I have written the energy Fi hi and Fi hi Ni these 2 terms. I have written it as a pressure energy p by rho, plus cv times T0 minus of TR plus u not squared by 2 gz0; that means, the energy that is associated with our reservoir at this point0, what are the energy that is contain? It is there is an atmospheric pressure. So, this p0 by rho, what is this T0 minus of TR? T0 is the temperature at which this fluid is there taken as TR T0, and our reference is TR, we always take a reference, whatever that may be TR. Therefore, the energy associated with this fluid present in the reservoir at temperature T is given by c v T0 minus TR.

So, you have, so much of energy in the reservoir. Now, you also have situation where u0 is the velocity of the fluid and z0 is the potential energy of the fluid. So, in this particular case if we assume that the energy or the velocity of the fluid on the surface of the reservoir is not very high or not very, it is not very important. Therefore, this term u0 square can be neglected, why can we neglect this? Because on the top of the reservoir, where you have fluid essentially at rest are may be moving at small velocity and so on. So, for our purpose, we can take it as 0. On other words, u0 is 0, what is gz0 it is the potential energy, at which water is available gz0 is the amount of potential energy.

So, what is that we have? The right hand side we have pressured energy this is sensible heat energy that is associated with fluid at temperature T0, this is kinetic energy, potential energy. You multiply with by f, f is what? Is a molar flow of fluid that is going through the Hydel turbine. So, you have the input, what is the output? Output is pressure at p2 and then cv which is the energy associated with the sensible heat and so on. That we written as cv times T2 minus TR, and this is kinetic energy, this is potential energy.

So, what we have done is that; we have use this equation, and then based on our understanding of the situation. We have converted the hi in hi out in terms of cv dt, so that we can take care of the change in change in the enthalpy of the fluids. So, that is taking care of cv T0 minus of t, this is for the reagents, this is for this one. Is it all right? you have pressure, you have enthalpy, you have kinetic energy, you have potential energy, this minus this, how does it look? Now, when you look carefully at this Hydel reservoir, what is the pressure at this point? It is atmospheric pressure. Similarly, at point2, which is emerging in to atmosphere therefore, pressure at position0 and position2 are atmosphere. So, what have you done here I put p0 equal to p2.

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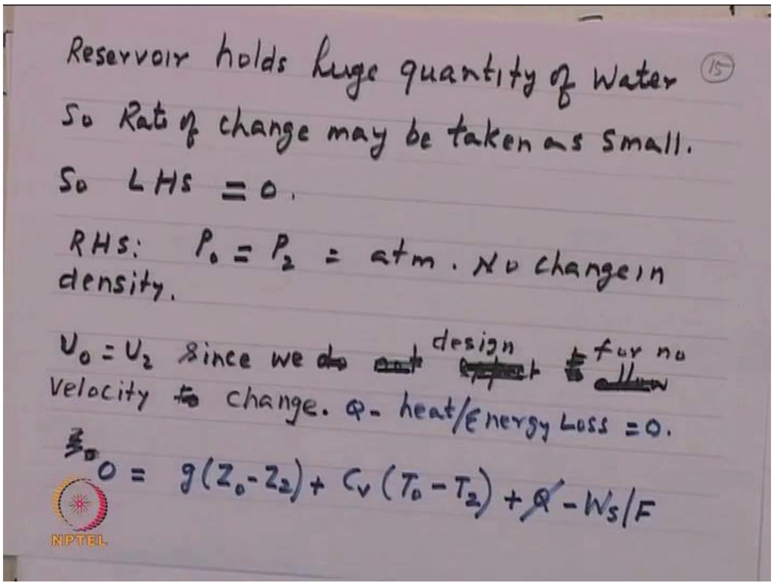

Reservoir holds huge quantity of Water ⑮

So Rate of change may be taken as small.

So LHS = 0.

RHS: $P_0 = P_2$ = atm. No change in density.

$v_0 = v_2$ Since we ~~do not~~ design ~~expect to~~ for no ~~allow~~ velocity ~~to~~ change. Q - heat/Energy Loss = 0.

~~So~~ $0 = g(Z_0 - Z_2) + C_v(T_0 - T_2) + \cancel{Q} - W_s/F$

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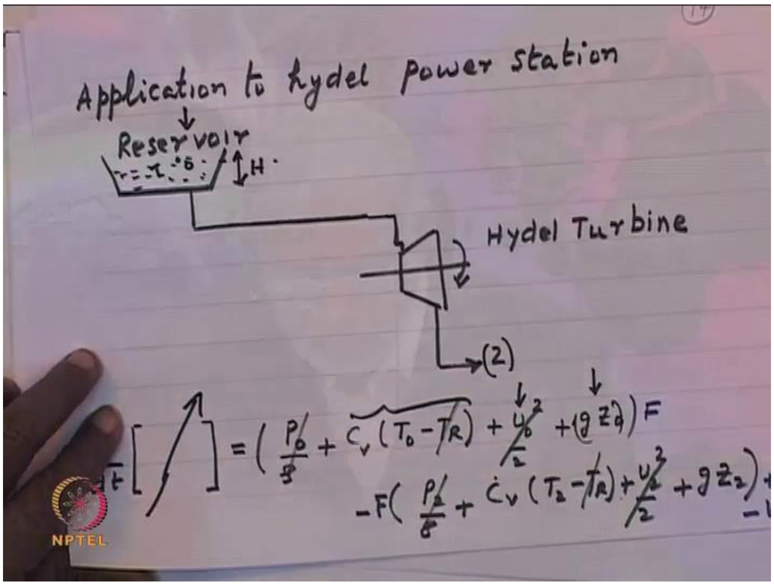

Second thing I have done here is that; the rate of change of reservoir capacity or reservoir fluid accumulation is not very large. Therefore, we may be delete the accumulation term in our energy balance, what we are saying is that; we can delete this term because, this term is not very large. So, putting these two simplifications, left hand side is 0, and the right hand side we knock out terms which we think is not important.

Therefore, we have left with a slightly simpler form of the energy balance, which says 0 which is on the left hand side equal to g times z0 minus z2 plus cv T0 minus T. So, we have now said, that the energy that is associated with the height or in the with the fluid at a height. Now, able to exchange it, and converted it in to this term cv T0 minus T2 are enthalpy. So, what is that our Hydel turbine doing? It is using the energy of energy of potential energy, and converting it into energy that you and I can use. This is the statement of conservation. So, let us do a small example, to illustrate how far we can go.

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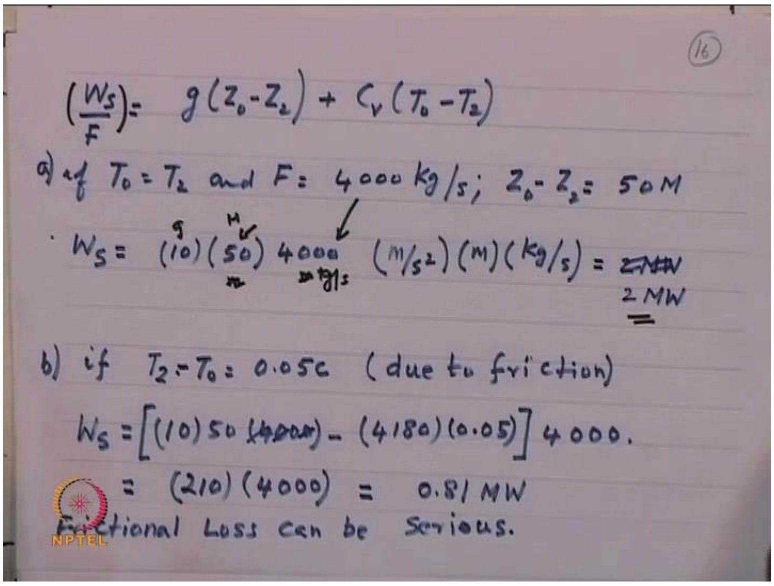

⑯

$$\left(\frac{W_s}{F}\right) = g(Z_0 - Z_2) + C_v(T_0 - T_2)$$

a) if $T_0 = T_2$ and $F = 4000$ kg/s; $Z_0 - Z_2 = 50$ M

$$W_s = \overset{g}{(10)}\overset{M}{(50)}\,4000\;(m/s^2)(m)(kg/s) = \cancel{2\,MW}\;\underline{\underline{2\,MW}}$$

b) if $T_2 - T_0 = 0.05$ C (due to friction)

$$W_s = \left[(10)50\,\cancel{(4000)} - (4180)(0.05)\right]4000.$$

$$= (210)(4000) = 0.81\ MW$$

Frictional Loss can be Serious.

This is an example where, what we have done is? We have done is that WS by f we have written our energy balance equation.

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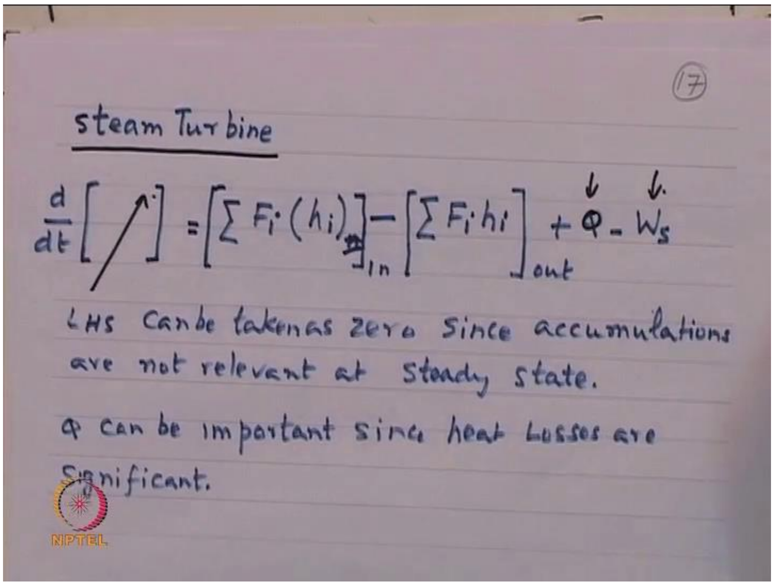

⑰

steam Turbine

$$\frac{d}{dt}\left[\cancel{\ \ }\right] = \left[\sum F_i (h_i)\right]_{in} - \left[\sum F_i h_i\right]_{out} + \overset{\downarrow}{Q} - \overset{\downarrow}{W_s}$$

LHS Canbe takenas zero Since accumulations are not relevant at Steady state.

Q can be important since heat Losses are Significant.

This energy balance equation, We have deleted all term excepting the term corresponding to gz0 and z2 and T0 and T2 are the terms of disappearing excepting of course, the flow work from the flow. So, when we do all this when we do all this, what is that we get? We get that fs WS by f is given by this relationship. It is fairly straight forward because, simply by replacing this terms simply by replacing this terms in terms of that we know we will find that; WS by f which is the energy that is produced divided by the throughput of fluids is given by gravity plus this term.

So, what we are saying now is that; the energy in gravity term can be converted to energy in fluids in the form of cv, and then that relationship is what is given here. We have do small calculation to understand these numbers let us let us look at 1 such numbers. I have taken here T0 is T2 and f is 4000kilogram 4000tonnes per second say you large very large. And, z0 minus z2 is 5. So, these are the things some numbers, we assume to get feel for the size of the plan that you are going to building.

So, I have done here, you have 10, what is 10 50 and 4000? 4000 is the flow this is the flow. And, what is 50? This is m, this is g, this is m g h, this is h this is m. So, this is g this is h. So, what we are trying to do is that; we have a fluid a Hydel reservoir, in which you have fluid available at a height of 50 meters. Now, if it flows through a hydraulic turbine with the g value 10, what will we get? that is what is the answer we mention here. Then if you multiply all this, you get something like 2mega watts, what we are saying is that; if you had a Hydel power station, which is able to supply at a head of 50 meters. That means lift the water to that height, g is the gravitational acceleration concentration, for 4000 is the flow.

So, m g h that is the term associated with the shaft work that turns out to be 2mega watts, what we are trying to say here is that; if you had a Hydel power station in which a water is available at50 meters height. And then, if kg per seconds and if, so many k g per second water was flowing then you will be able to generate 2mega watt power. So, this is the point we mention is that if you have a water flow of 4000kg per second, and then if you have a water flow such that the gravitational acceleration is still 10 meters per second square. And then, this h this 50 refers to the 50 refers to height at which the water available. So, now, what we have done is that we are shown that our energy balance, can explain the situation that happen in a Hydel power station.

So, we go on to see how best we may use make use of what we know for running our daily activities. Now, let us say instead of doing hydraulic turbine we do a stream turbine, what are we doing? Now instead of doing a hydraulic turbine we are doing a stream turbine, how does it help us on what difficulty does it bring us in to? Let just quickly understand this. Once when we have a stream turbine instead of hydraulic turbine we want to apply the energy balance, our basic procedure is identical there is no change. You have a stream turbine, where d by d t left hand side equal to in minus of out Fi hi in Fi hi out plus Q minus WS.

So, this Q and this is WS and this is in and this is out, this is 0, why has we taken left hand side as 0? Because, accumulation terms of quiet small in relation to the flow of energy, that is through the system. Therefore, we find taking left hand side equal to 0, is not a serious compromise on the quality of the description that we provide. Now, what might happen is that this Q this Q is the amount of energy that we put in, now we may be thinking that we have putting 100 units of energy, but what actually goes in is only 30.

This could happen to us, how do you overcome this? You overcome this by recognizing that this Q may not be a complete description of what is going on. Therefore, we must know all the heat path ways to understand, where the problems are. So, what this equation explains to you is that, how we can interpret the information to understand our system appropriately. Now, having said this, I want you to go through this exercise fully. So, that we appreciate, what we are saying? Our Hydel turbine water was coming in and going out and g z water coming out50 meters.

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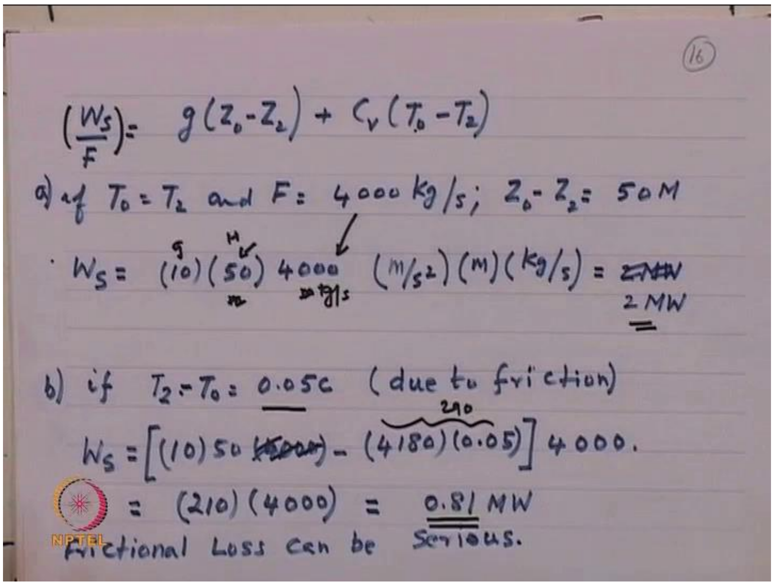

⑯

$$\left(\frac{W_s}{F}\right) = g(Z_0 - Z_2) + C_v(T_0 - T_2)$$

a) if $T_0 = T_2$ and $F = 4000$ kg/s; $Z_0 - Z_2 = 50$ M

$$W_s = \overset{g}{(10)}\,\overset{M}{(50)}\,4000\;(m/s^2)(m)(kg/s) = \cancel{2 MW}\;\underline{\underline{2\,MW}}$$

b) if $T_2 - T_0 = \underline{0.05}$C (due to friction)

$$W_s = \left[(10)50 - \overbrace{(4180)(0.05)}^{210}\right]4000.$$

$$= (210)(4000) = \underline{\underline{0.81}}\;MW$$

Frictional Loss can be Serious.

Now, you put all our numbers, let us take an example of water was coming in T2 4000 k g per second of water coming in. And, let us say z0 which is minus of z2 is 50 meter; that means, water is flowing from50 meter height down. Now if this term if T2 minus of

T0, if T2 equal to T0, what we are saying is that; the temperature here T2 and temperature here which is T0, if they are same then, we would produce for this 4000k g per second of flow 2mega watt of power.

If the flow is 4000 if z0 minus of z2 is 50 then, we will produce in the shaft; that means, in the generator because shaft is shaft work is so much 2 mega watts of work. Now, if it so happens, that if T2 minus of T0 there is a slight temperature difference of 0.05degree centigrade. Suppose, which means what this term is not 0 this term is T0 minus this is actually T2 minus T0 0.05 therefore, T0 minus T2 is minus 0.05.

So, I have just put those things here; that means, our shaft work now it is not 10 multiplied by 50 multiplied by 4000, but it is subtract you have to subtract this term. Let me notice here, that this term this term is something like 290 this whole term turns out to be 290 units. So, that 500 minus of 290 is 210 multiplied by 4000. Now, you are producing 0.81 mega watt instead of 2mega watt now, what we are trying to put across here is that; in the energy balance because, we have taken in to account the effect of change in the temperature of the fluids that is going in and coming out going in and coming out.

That effect, in a Hydel turbine as per these calculation says, can be very significant. In fact, we would expect after all energy in water form of mechanical energy therefore, we would have thought mechanical energy can be can be transmitted without any loss of efficiency. Here, is an instance where you transferring mechanical energy with efficiency of only 50 percent or less there is something that should bare in mind. And therefore, we have take in to account the fact, how do we design our pipelines? Taking the water in to our turbine, without allowing it to get heated up, even by a very small margin, this is an important part, of design which we should take care. I will stop there when we come next time we will take this idea further.

Thank you very much.