Steam Power Engineering
Prof. Vinayak N. Kulkarni
Department of Mechanical Engineering
Indian Institute of Technology Guwahati

Lecture -02
Rankine cycle

Welcome to the class. In today's class we will see about the steam engines till time what we have covered in last class so as about basics of thermodynamics and then we have seen what do you mean by Carnot cycle and then what do you mean by Rankine cycle. And now today's class we are going to see for what does it get comprised for a steam engine and the how different power sources are there.

How will how much electricity generated and then what are the basically ways by which we can do some computations are calculations for steam engine.

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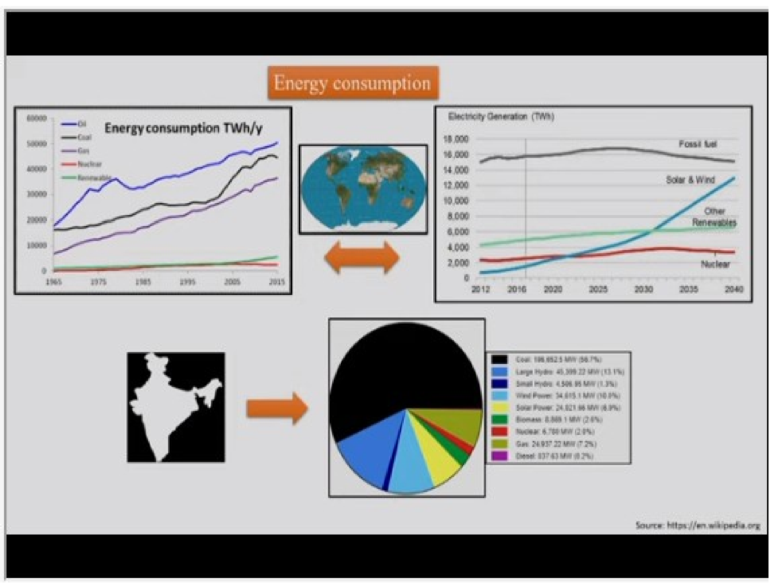

So this slide gives a idea gives an idea for the world energy consumption and it can be seen that world energy consumption is based upon various sources which includes oil, coal, gas, nuclear and renewable. Renewable would have basically hydro, biomass, wind, solar. so these are the different energy sources which people across the world or countries across the world use for consumptions.

And this consumed energy would either get converted into mechanical energy as per the requirement or may be converted into electrical energy as per the requirement. So, or maybe it would be used for some industrial applications like drain. So, the same situation across the world can be seen for India where prominent energy source for India is coal and then we have small and large hydro power plants we will have further gas, nuclear and diesel engines for consumption of energy.

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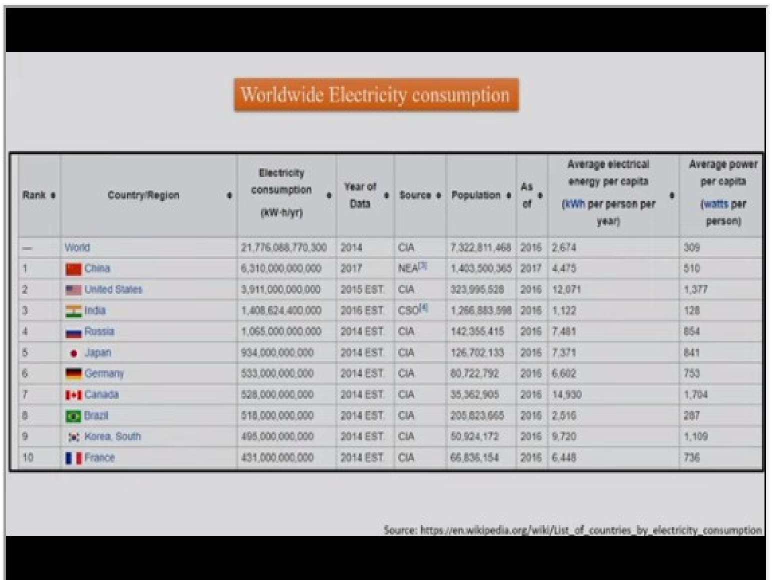
Worldwide Electricity consumption

Rank	Country/Region	Electricity consumption (kW-h/yr)	Year of Data	Source	Population	As of	Average electrical energy per capita (kWh per person per year)	Average power per capita (watts per person)
—	World	21,776,088,770,300	2014	CIA	7,322,811,468	2016	2,674	309
1	China	6,310,000,000,000	2017	NEA[3]	1,403,500,365	2017	4,475	510
2	United States	3,911,000,000,000	2015 EST.	CIA	323,995,528	2016	12,071	1,377
3	India	1,408,624,400,000	2016 EST.	CSO[4]	1,266,883,598	2016	1,122	128
4	Russia	1,065,000,000,000	2014 EST.	CIA	142,355,415	2016	7,481	854
5	Japan	934,000,000,000	2014 EST.	CIA	126,702,133	2016	7,371	841
6	Germany	533,000,000,000	2014 EST.	CIA	80,722,792	2016	6,602	753
7	Canada	528,000,000,000	2014 EST.	CIA	35,362,905	2016	14,930	1,704
8	Brazil	518,000,000,000	2014 EST.	CIA	205,823,665	2016	2,516	287
9	Korea, South	495,000,000,000	2014 EST.	CIA	50,924,172	2016	9,720	1,109
10	France	431,000,000,000	2014 EST.	CIA	66,836,154	2016	6,448	736

Source: https://en.wikipedia.org/wiki/List_of_countries_by_electricity_consumption

If we see worldwide electricity consumption the first slide was more about energy consumption this slide is more about electricity consumption. So electricity consumption the unit is kilowatt hour per year we can see that it's a very big amount were china is the lead country and India followed to be the third country as per this table. So, we need largely electrical energy and that electrical energy would get further utilized for various applications.

And what has these slides of energy and electricity relevance with our steam power plant. Since steam power plant has what we know is the thermal power plant where thermal energy where if we go back to last slide then among these sources of energies nuclear or coal or oil are the basic sources on which the thermal power plant which is steam power plant it runs. So, our steam power plants needs energy and that energy would be extracted from either coal, oil or nuclear.

And then we largely are interested in convergent of that energy from coal or oil or nuclear to electrical energy. So, this is what the general idea of about how much electricity is basically required for countries like India when we see the per year electricity consumption.

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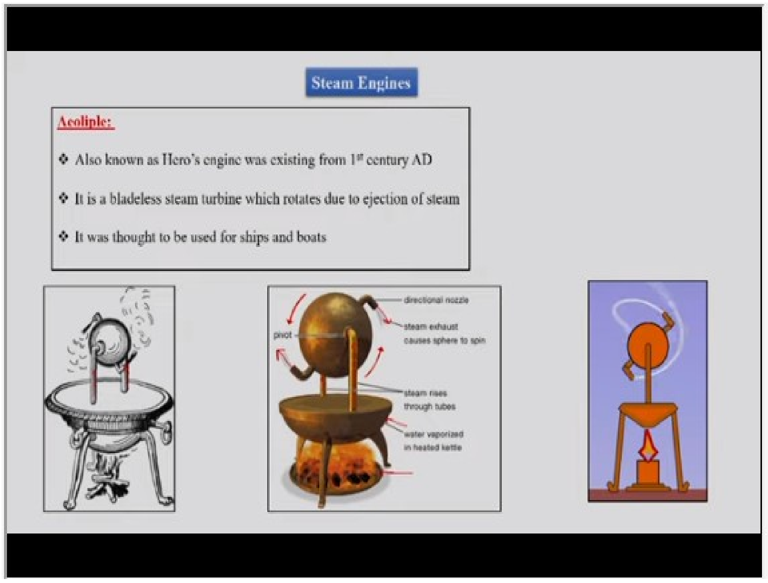

Now we come back to our topic of discussion on steam engine. Steam engines are not the topics of discussions which have recently started. It is known from first century AD itself. The Hero's engine was the name for the aeoliples which are shown in these figures. So, basically aeoliples are the bladeless steam turbine where you can see that there is a drum which is attached with two inputs of the steam from boiler where we have a bottom half circular half spherical drum it is supplied with heat this is water vaporizer it is supplied with heat by burning coal.

So water would get evaporated and then it goes inside this sphere or spherical container through the two limbs which are shown these two fillers. One vapor comes into the spherical drum where vapor would get ejected in these two jets and then accordingly by reaction this spherical drum rotates. So this is the principle of the Hero's engine or aeolipile and this is the basic idea where it has started that there can be steam engine for generating initially mechanical energy and then onwards for electrical energy. It was made initially so that it can be used for sailing the ships or boats.

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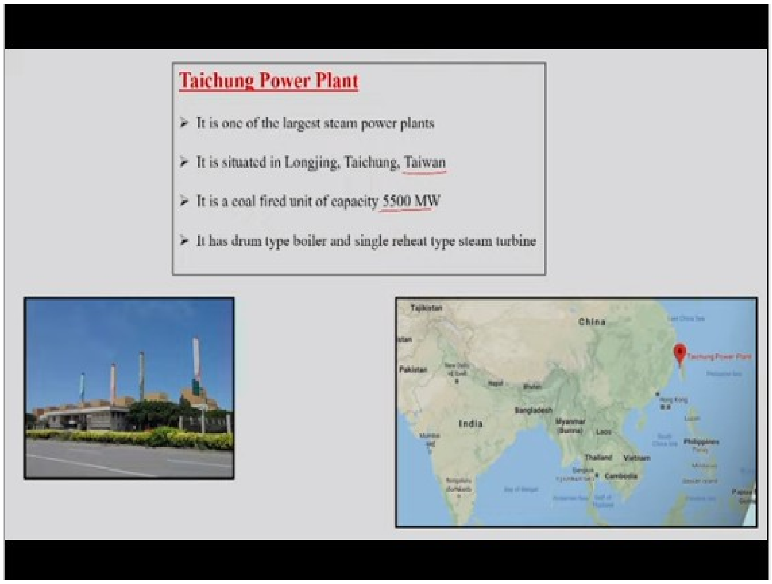

Based upon the concept of steam as a working medium for having the rotary motion generated we can see that there are very big power plants and one such big power plant is in Taichung and then this Taichung power plant and this is one of the largest power plant in Taiwan. It generates electricity of around 5500 megawatt and it has a drum type of boiler with single reheat steam turbine. So, the idea of what can be the largest amount of electricity generated by a steam power plant we can get per year that one of the largest steam power plant generates 5500 megawatt of electricity where coal is working fuel for this.

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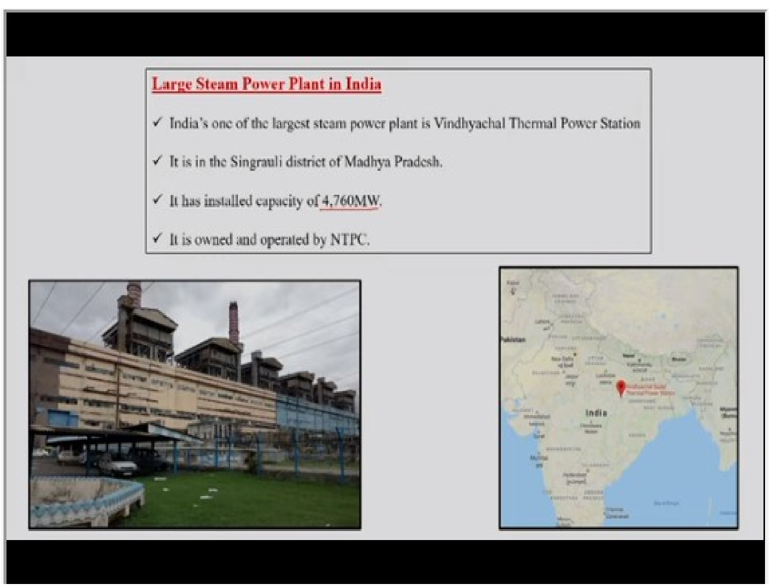

If we come back to India; then in case of India we have one such very large steam power plant called as Vindhyachal Thermal Power Station and it is in Singrauli district of Madhya Pradesh. Its capacity is 4760 megawatt and it is operated by NTPC.

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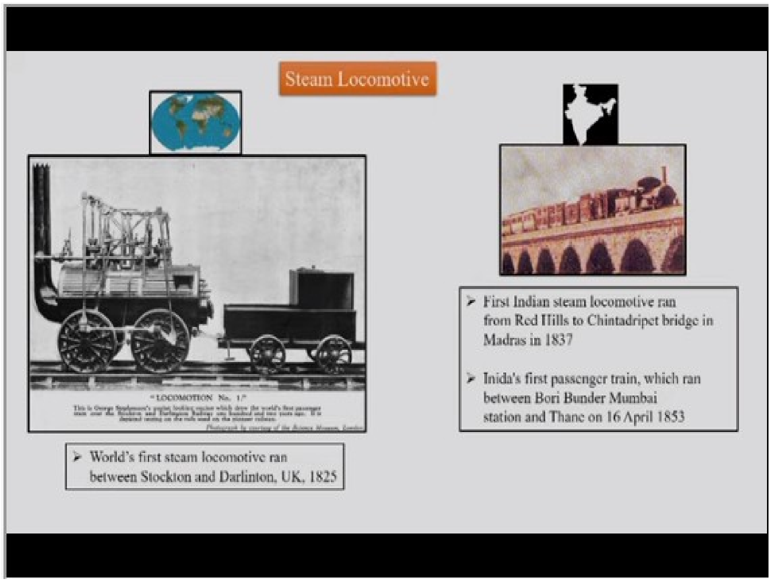

So, as what we can see that we need when electricity then the power plants produce electricity of larger power plant sizes have electricity generation of few megawatts. But it is not only electricity which is the only need of our as I said we might need mechanical energy also to be generated and in such case steam can be acting as a good working medium. We can see that steam had been used has been used as a source for generating mechanical or having drives where mechanical energy would get utilized where first such attempt was to have locomotive which ran between Stockholm to Darlington in UK 1825 where steam based locomotive was used .

Similarly, as in case of world scenario we had Indian locomotive also ran between two stations in Madras in 1837. First such train which had its operation using steam ran between two stations around Mumbai and it took place in 1853. So, as what we can see that steam can be a working medium where we can generate electricity or we can as well have mechanical power generated.

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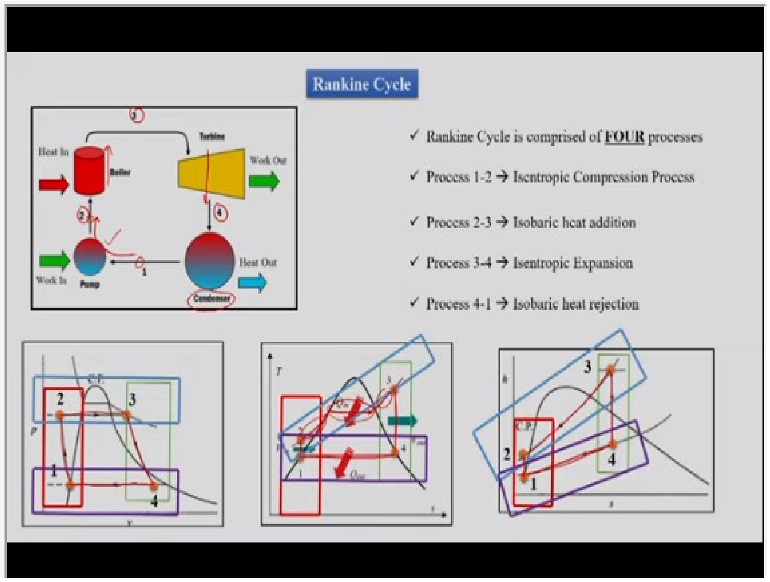

Then how does steam can act as a source where we can use the energy from the steam to generate mechanical energy or mechanical power and hence electricity. We know we have seen in last class that a steam power plant is comprised of four parts. First part is pump where steam would get low pressure to high pressure pumping in the device which is pump. So, steam would get pump from low pressure to high pressure then this process basically is isentropic process.

Then steam would have basically heat addition in isobaric sense in boiler in the process 2 to 3. Then we have expansion of the steam in the turbine in the process 3 to 4 and then the device is turbine. And then we have heat rejection of the steam and that process is 4 to 1 and then that device is condenser. So, these four parts pump, boiler, turbine and condenser comprise a typical steam power plant.

And then there are such four processes if we see such four processes; then first process is isentropic compression we can see that there are 3 diagrams in this. The first diagram on left hand side is $P-V$ diagram then we have T-s diagram and then we have $h-s$ diagram which shows the Rankine cycle. Process 1 to 2 is like this on $P-V$ diagram it's a vertical line, on T-s diagram and again it's a vertical line in $h-s$ diagram then this process is isentropic compression.

Then we have process 3, 2 to 3 which is isobaric heat addition since the process is isobaric pressure is constant in $P-V$ diagram pressure would constant again in T-s diagram but this constant pressure line is a curved; in T-s diagram in s ensible parts and it's a horizontal line in latent part. As what we know practically we have to sketch a dom first for the drawing of steam power plant steam power cycle which is a Rankine cycle.

Then this is again a curved line 2 to 3 on $h-s$ diagram. Then we have process 3 to 4 which is isentropic expansion; expansion where volume increases and pressure decreases. This process is like this in $P-V$ diagram it's a vertical line; in T-s diagram it is again a vertical line in $h-s$ diagram. And then we have process 4 to 1 which is isobaric heat rejection pressure is constant in the condenser.

So, it's a horizontal line in $P-V$ diagram; it's a horizontal line in T-s diagram but it's an inclined line curved line in $h-s$ diagram. So, what we can see that we have 2 plot T-s, $P-V$ or $h-s$ diagram for better understanding of a steam cycle thermodynamically. And in this process we should understand that in case of T-s diagram we have constant pressure line which is 2 to 3 which has intermediate one of the steps were latent heat is supplied in the boiler.

But before that we have supply of sensible heat where we do not have horizontal line in T-s diagram but heat rejection is completely latent heat in case of condenser. So it's a complete horizontal line in case of condenser but when we see $h-s$ diagram. In $h-s$ diagram has basically slope which is different from the T-s diagram so we have a different line which is 4 to 1. Having said this we know now how to plot the diagrams in T-s, $h-s$ and $P-V$ for a Rankine cycle.

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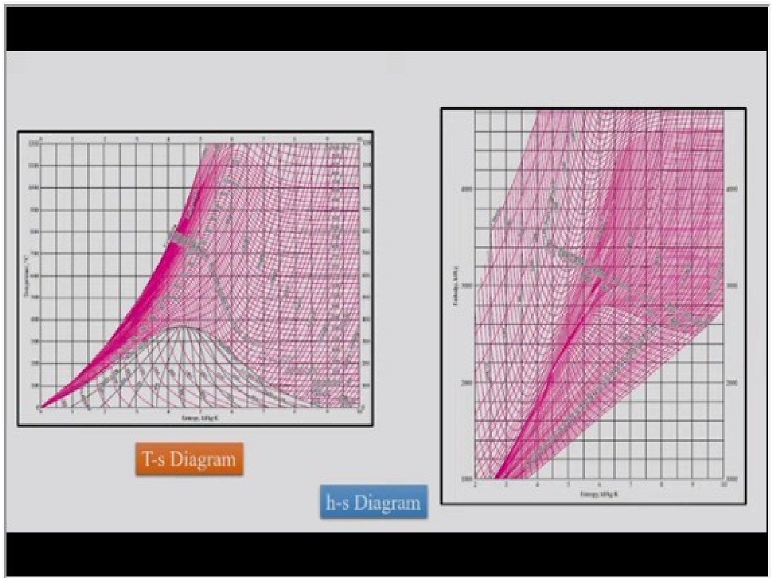

This is a typical T-s and $h-s$ chart from the steam tables. We would need such a steam table to be used for our examples solving or for usage of it when we are dealing with steam turbines or a part of a steam power plant. Then we want here onwards to estimate the properties of practical steam power plant or Rankine cycle.

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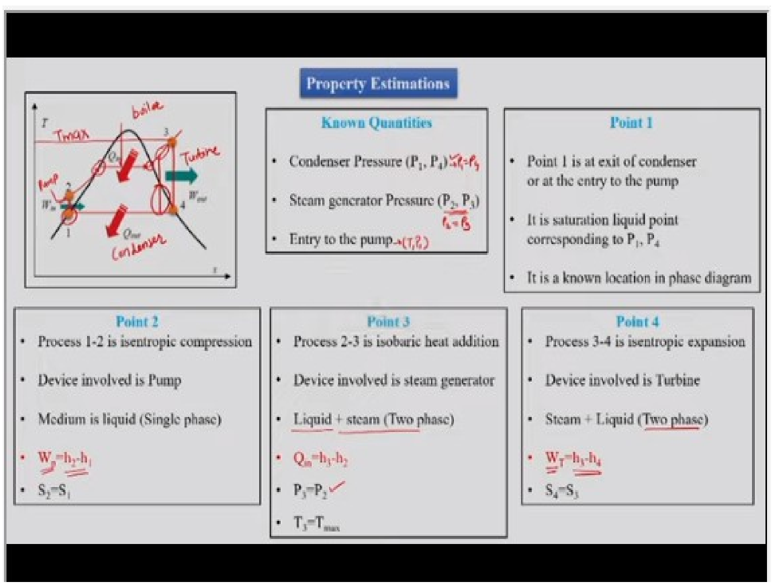

This is our Rankine cycle will typical Rankine cycle there we are saying that we have process 1 to 2 in the pump were we are having work input which is a pump work process 2 to 3 is a heat input in the boiler. So we will say it's a pump here, it's a boiler here, it's a turbine here and it's a condenser here. So, these are the four parts which are dealing with the steam power plant. Now, what would happen in case when we are working with steam power plant and the most general things which would we would be knowing is a condenser pressure which is P_1 and P_4.

Line P_1 line process $4-1$ is a isobaric process. So it's a it is having pressure either P_1 or P_4 rather which is P_1 is equal to P_4 and this pressure would be known to us. In general, whenever we are having steam power plant the condenser where heat is rejected from the steam and water in vapor state would get condensed to liquid water. So, that heat rejection would happen with the use of natural resources like river or ocean.

So, atmospheric condition or atmospheric temperature remains the temperature at which heat would be accepted by the ambiance. So, this pressure basically correspond the saturation pressure corresponding to the atmospheric temperature. Then what quantity we would below in is P_2 rather $P_2 = P_3$and $P_2$and P_3 they are the boiler pressure. And we would be having idea of this boiler pressure steam power cycle is also called as a constant pressure cycle where heat addition takes place in a constant pressure or heat interaction takes place in a constant pressure sense.

So, both the constant pressure lines would be known to us and then what would be known to us is a condition at one. Entry to the pump means we would be knowing T_1 and P_1. So, these things which would be known to us and using those known things we would have to calculate the efficiency performance or other heat and work interaction. So, at point 1 at point 1; point 1 is basically exit of the condenser or entry to the pump.

It is the saturation point of the liquid water and that saturation point has pressure P_1 and it is known to us. Point 2 from point 1 we have to draw a process which is a isentropic process which is 1 to 2. So, entropy at 2 is known to us which is same as entropy as 1. So, the device involved in this process is pump and medium handled by the pump is liquid then we can calculate the pump work which is $h_2 - h_1$.

We should remember the formulae or the method of interaction of heat and work what we would have discussed about open cycle where we have used steady flow energy equation where we said that $Q-W$ equal to summation of energies like enthalpy, kinetic energy, potential energy at the inlet or summation of all inlets of these energies minus summation of energies like enthalpy, kinetic energy and potential energy at the outlet.

And in the pump we are neglecting kinetic energy we are also neglecting the potential energy at between the inlet and outlet. So, it turns out that heat and work interaction would have balance due to enthalpy change but pump would have process so fast that it we can neglect the heat interaction pump. So, basically pump work turns out the enthalpy change between inlet and outlet.

So, this is the discussion for state 2 then we have state 3; at state 3 we have process point 3 would be obtain from 2 to 3 process which is a isobaric heat addition the device involved is steam generator. The material handled is basically a 2 phase material where initially some part would be liquid from 2 to saturation liquid saturation point. Then we would have partially wet steam at this point and then we get dry saturated steam at this point and there onwards we have only vapor state in the sensible part.

So, but in all steam generator or boiler would handle 2 phase flow which is liquid + steam. The amount of heat added into the boiler or steam generator is equal to the rise in enthalpy of water which is h_3-h_2. The process speed has constant pressure so we have $P_3=P_2$ and as per the $T-s$ diagram we can see that this is the maximum temperature in the cycle. So, $T_3=T_{max}$ having said this we can enter to point 4 and this point 4 is obtained from the process which is 3 to 4 that is an isentropic expansion.

Device involved is turbine. As per this diagram turbine enter has only steam which is a vapor state but it might not be always true. We might have an expansion of turbine like this where this part of turbine handles wet steam also. So, turbine in general can have a 2 phase flow where it would handled steam + liquid; same turbine is a work producing device. So, the work done by the turbine is across the enthalpy drop of the steam which is unlike.

As in case of pump where pump is a work input machine which needs input of the work and then due to this we have rise in enthalpy of water from h_1 to h_2. But in case of turbine we know that is an isentropic process so enthalpy at 4 is sorry entropy at 4 is equal to entropy at 3 this is an isentropic process.

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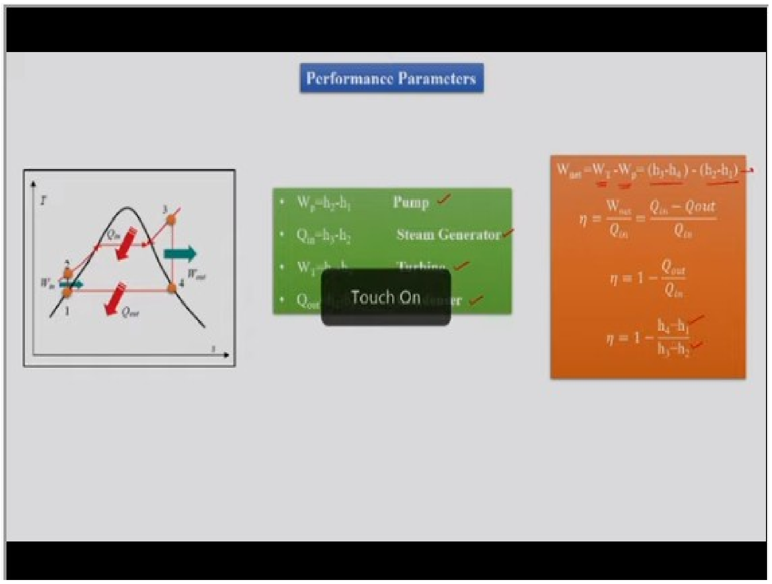

Then once we can know how to estimate all the corners of the cycle like 1,2,3,4 or may be the corners corresponding into saturated conditions. Once we have understanding of this we can point out performance parameters of the steam power plant and those performance parameters initially would include pump work and we have said that pump work is $h_2 - h_1$ across the pump we have enthalpy gain for the water.

And then we have heat addition in the steam generator which is $Q_{¿}$ and in the presence of this Q in; enthalpy of the water rises from h_2 to h_3. Then we have turbine work which is $h_3 - h_4$turbine produces work so enthalpy of the water decreases. Then we have heat rejection process in the condenser and then we have heat rejected is equal to $h_4 - h_1$were enthalpy of the steam or water decreases.

Then using these calculations we can find out net work (W_{net}) which is gain by us in the form of mechanical energy in that work is W_{net} which is equal to turbine work(W_T) - pump work(W_p).

But we know that $W_T = h_3 - h_4$ and $W_p = h_2 - h_1$ so $W_{net} = (h_3 - h_4) - (h_2 - h_1)$. Then we can find out efficiency(η) the classical formulae for $\eta = \frac{W_{net}}{Q_{¿}}$ but $W_{net} = Q_{¿} - Q_{out}$.

So, where $Q_{¿} - Q_{out} = W_{net}$ and then we have $\frac{Q_{¿} - Q_{out}}{Q_{¿}} = \eta$. So, efficiency becomes $\eta = 1 - \frac{Q_{out}}{Q_{¿}}$ but we know Q_{out} and $Q_{out} = h_4 - h_1$ and $Q_{¿} = h_3 - h_2$. Knowing these enthalpies at these 1,2,3,4 points we can find out enthalpy efficiency of the steam power plant.

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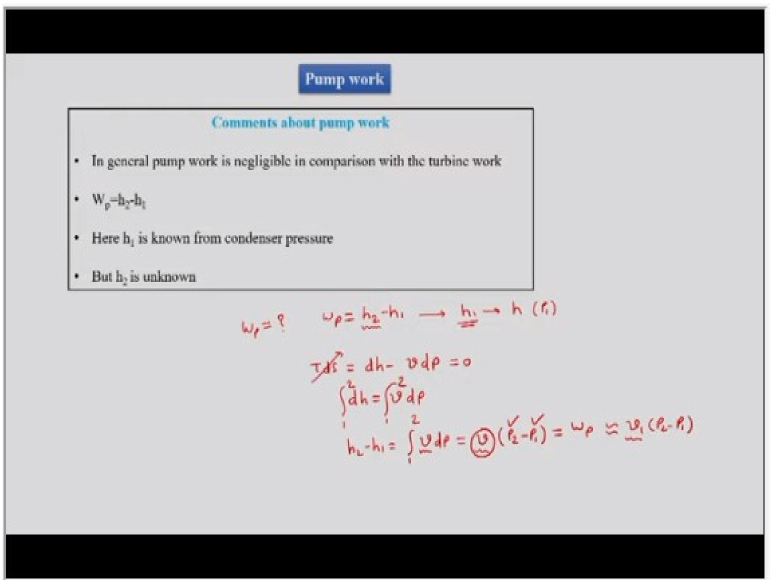

Then discussion on pump work, so here we see that in general pump work as what we can see in this diagram. Pump work is $h_2 - h_1$ where turbine work is $h_3 - h_4$. So, as what we can see that pump work is much less than turbine work or in general pump work is less less than turbine work. So, pump work is negligible in comparison with turbine work. Here our problem is that we have to estimate still what is the pump work.

So, we should know how to point out the W_p although we know that $W_p = h_2 - h_1$. But we say that we said that we know h_1 and h_1 corresponds to saturation enthalpy of liquid at pressure P_1. It is a saturation enthalpy but how to find out h_2 we would have steam tables but steam tables would not generally deal with liquids. The steam table would deal with vapor so h_2 is an unknown parameter for us.

So, to estimate h_2 we have to use different tactics and in that case we know that as per next or combined First and Second law we know that $Tds = dh - v\,dP$. Okay, in the pump we have isentropic process so this is equal to 0. So, $dh = v\,dP$ and we know that if we integrate it from process 1 to 2 this becomes $h_2 - h_1 = \int_1^2 v\,dP$. In case of pump we are so close to the saturation point and further we are handling liquid as what we have said.

So for liquid specific volume or the density they are constant since liquids are incompressible matters. So we can take this v to be constant so we will have this $v(P_2 - P_1)$ and as what we discussed in earlier slide we know boiler pressure, we know condenser pressure and then we should know v then we are done and we can find out W_p. So, this v is practically considered as any specific volume corresponding to the pressures P_2 or P_1 and then this pressure what we are talking about is P_1.

So, what we can say that this is equal to $v_1(P_2 - P_1)$ and this can be $v_2$as well since it is not changing to changing much in the process of pumping. So we can take any specific volume which is a saturation liquid specific volume and then we should know only dP and then we can find out pump work.

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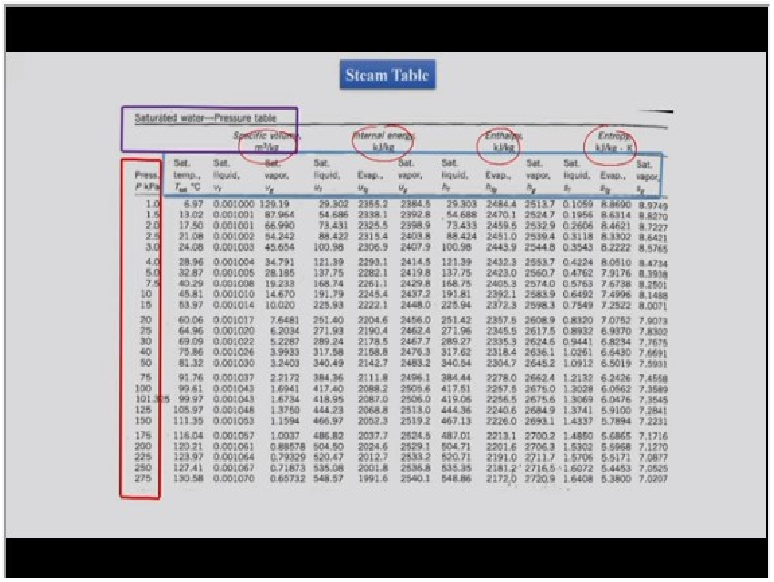

Steam Table

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg · K Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476	7.3545
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100	7.2841
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894	7.2231
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207

This is the steam table. So, in this course we should know how to use steam table. So this is a particular case of a steam table and this part of steam table is called as saturated temperature table. So, this for water so this is the temperature part of the table where first column belongs to temperatures. So, we can see that there are many temperatures given and then these are the properties of steam which are given in the steam table.

And at those temperatures the things which are given us saturation pressure, saturation we have vapor, saturation we again have enthalpies given and we have entropies given. So, we have specific volume, we have internal energy and we have enthalpy and we have entropy and these things are given in the steam table. So, corresponding to temperature we have saturation pressure and then we have specific volume and this first specific volume is saturation volume of liquid; second is saturation volume of vapor.

So, we can see that if we at all we change the temperature saturation temperature there is not much change in the specific volume that is what we were discussing that in the pumping process we can treat specific volume as a constant. After this part we have other part in this team table and that other part is basically pressure part in the steam table were instead of saturation temperature, saturation pressures are given in this grid formats.

And then we can use a particular saturation pressure and we can estimate same quantities which are specific volumes, internal energy, enthalpy and entropy. Then we thus can find out all the corners of the Rankine cycle using steam table.

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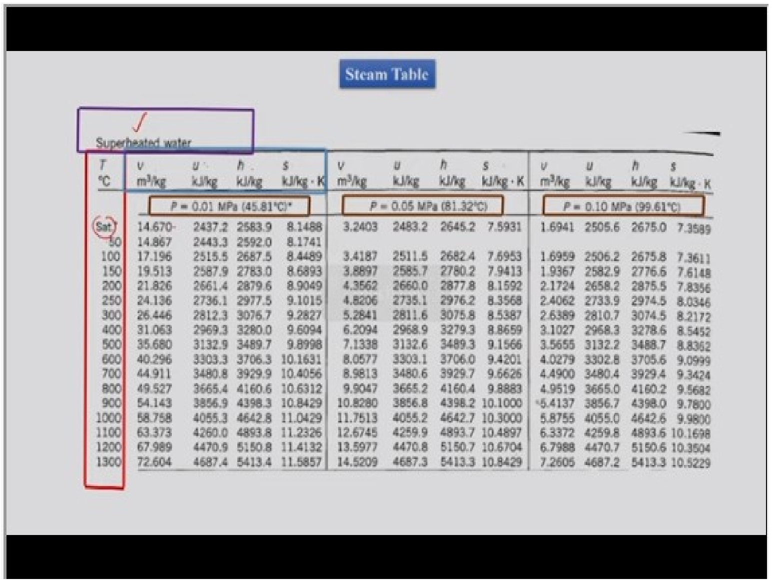

Steam Table

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)				P = 0.10 MPa (99.61°C)			
Sat.	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741								
100	17.196	2515.5	2687.5	8.4489	3.4187	2511.5	2682.4	7.6953	1.6959	2506.2	2675.8	7.3611
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413	1.9367	2582.9	2776.6	7.6148
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592	2.1724	2658.2	2875.5	7.8356
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568	2.4062	2733.9	2974.5	8.0346
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387	2.6389	2810.7	3074.5	8.2172
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659	3.1027	2968.3	3278.6	8.5452
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566	3.5655	3132.2	3488.7	8.8362
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201	4.0279	3302.8	3705.6	9.0999
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626	4.4900	3480.4	3929.4	9.3424
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883	4.9519	3665.0	4160.2	9.5682
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000	5.4137	3856.7	4398.0	9.7800
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000	5.8755	4055.0	4642.6	9.9800
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897	6.3372	4259.8	4893.6	10.1698
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704	6.7988	4470.7	5150.6	10.3504
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429	7.2605	4687.2	5413.3	10.5229

We have to watch out with the units which are given and third part in the steam table is saturated super saturated conditions which are the conditions like conditions in the and take to the turbine. Here, we generally would be given super saturated we would be given that there is a temperature there is basically there is a pressure and for one pressure there will be different temperatures given. And in the superheated part we will have first saturation temperature corresponding to saturation temperature we are given with specific volume, internal energy, enthalpy and entropy.

But these things are also there in the saturation pressure or saturation temperature part but after that if we have temperature which is more $50°C, 100°C, 150°C$. So, if those temperatures are superheated temperatures then what would be the corresponding value of specific volume, internal energy, enthalpy and entropy. They can be found out from this superheated part of the steam table. This is how we can make use of steam table. And then we can solve our examples or we can deal with the particular situations in the steam power plant.

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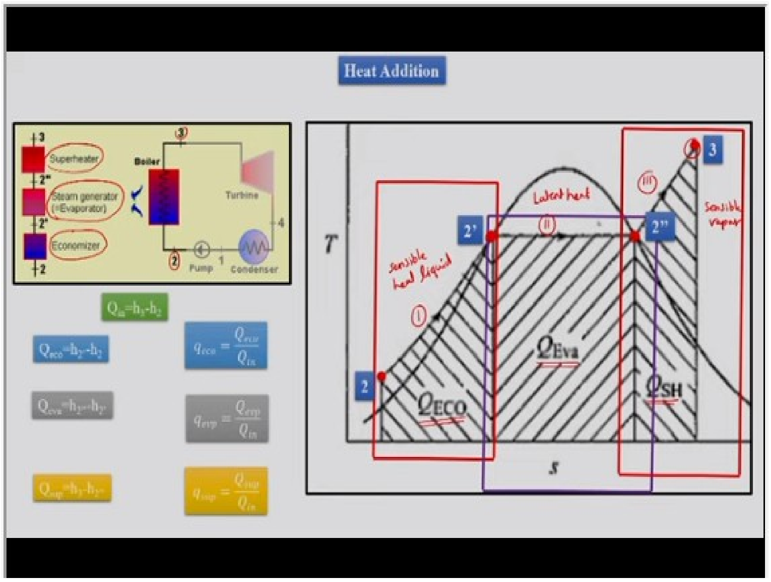

Then we have discussion about heat addition we said that process 2 to 3 is heat addition as what it can be seen here; process 2 to 3 is heat addition process in the boiler. And then, but we know that this is the process 2 to 3 this is process basically. So, the process of heat addition as what we can see it is getting done in the boiler where 2 to 3 is the process of heat addition in the steam power plant.

But the same process when we represent it in the $T-s$ diagram we said that 2 to $2'$ is a partially one part of heat addition; then $2'$ to 2 is second part heat addition and 2 to 3 is third part of heat addition. So, here 2 to $2'$ is done in economizer, $2'$ to 2 is done in the steam generator, 2 to 3 is done in a super heater. So the heat which is h_3-h_2 which is added in the boiler gets added in 3 parts.

So this is one part, this is second part and this third part. So this is called as Q economizer (Q_{eco}), this is called as Q evaporator(Q_{evp}),, this is called as Q super heater$(Q_{¿})$,. So we have $Q_{eco}=h_2^{'}-h_2$ so q small(q_{eco}), q economizer is fraction of heat added in the economizer out of total heat addition. Then we have $Q_{evp}=h_2^{\} - \{h\} rsub \{2\} rsup \{'¿}$. So, fraction of heat added in the evaporator is Q evaporator divided by total $Q_{¿}$.

Then we have heat added in the super heater where $h_3-h_2^{\} = \{Q\} rsub \{sup\} ¿}$. So fraction of heat added into the super heater is Q super heater divided by total amount of heat added into the super heater. So, we know how to find out pump work and then we should also know apart from the fact total amount of heat added how much is the fraction of heat added into the different parts of the steam generator or boiler.

This, the composition of heat addition is practically helpful since Q economizer practically deals with sensible heat for liquid. This evaporator deals with latent heat and Q super heater deals with again sensible heat but this is for vapor. So, we are decomposing the total heat into different parts; these 2 points we would be knowing from the steam table. So this steam table would tell us these 2 points this point we would have known it from the some constraints and then this point we have found out after the assumption of pump work with $v\,dP$.

So, thus we could know all the 3 points and then we can find out what are the different fractions of heat added in the different parts.

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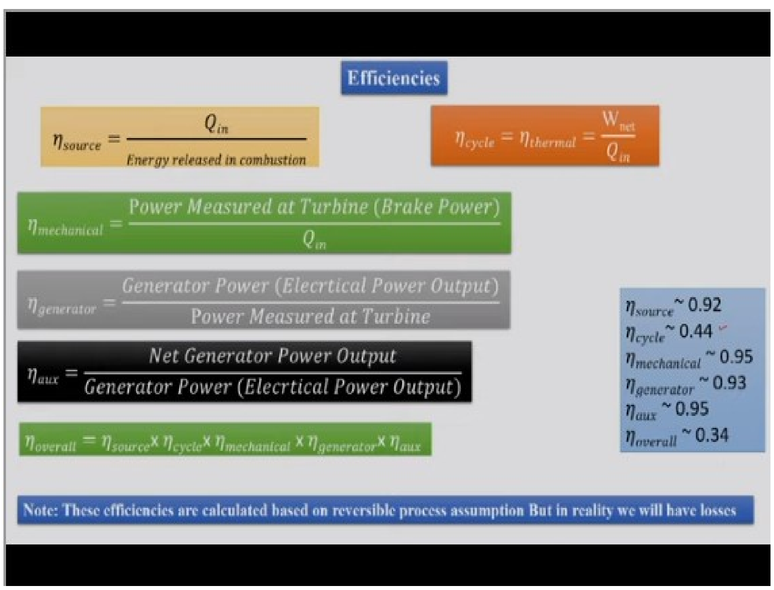

So, then we have efficiencies; then first we have source efficiency(η_{source}) source is something like coal or oil were source efficiency $\eta_{source} = \frac{Q_{¿}}{Energy\,released \in combustion}$ this is source efficiency. Then we have cycle efficiency(η_{cycle}) as what we have seen cycle efficiency as

$\eta_{cycle} = \frac{W_{net}}{Q_¿}$. Then we have mechanical efficiency$(\eta_{mechanical})$; mechanical efficiency is the

$$\eta_{mechanical} = \frac{amount\ of\ power\ measured\ at\ the\ turbine\ (brake\ power)}{Q_¿}$$

Then we have generator efficiency$(\eta_{generator})$ which is $\eta_{generator} = \frac{generator\ power\ (electrical\ power\ generated)}{power\ measured\ at\ the\ turbine\ outlet}$. And then we have auxiliary efficiency $\eta_{aux} = \frac{net\ auxiliary\ power\ output}{general\ generator\ power}$ or power required for auxiliaries to run divided by general generator power. And then we have overall efficiency$(\eta_{overall})$ which is multiplication of all efficiencies which is source efficiency, cycle efficiency, mechanical efficiency, generator efficiency and auxiliary efficiency.

These efficiencies have the ranges which are 0.92 for source efficiency 92%, cycle efficiencies in general around 40%. We have mechanical efficiency which is around 95%. We have generator efficiency again around 93%, auxiliary efficiency around 95%. So, overall efficiency for a steam power plant turns out to be 34%. So, this is all discussion about efficiencies of the thermal power plant.

So here basically these efficiencies are calculated under the assumption that the process like 1 to 2 which is pumping process, heat addition, isentropic expansion or heat rejection that all the process are ideal. So, based on this we have found out efficiencies and these efficiencies turned out to be the performer parameters of the steam turbine. So, here we end our discussion for today’s class were we started with steam engines.

Then we saw how to find out different corners of the Rankine cycle and then we headed to ours how to see the steam table and how to make use of the steam table for further use to solve some examples. And then we went and discussed what are the different ways by which we can find out pump work. What are the different factors or what are the different parts of a boiler were heat is added in different parts and then we have seen what are the different performance parameters. Rest of the things about steam power we will see in the next class. Thank You.