Chapter 10 Rankine Cycle

One Mark Questions

1. For a given set of operating pressure limits of a Rankine cycle the highest efficiency occurs for **(GATE-ME-94)**
(a) Saturated cycle (b) Superheated cycle
(c) Reheat cycle (d) Regenerative cycle

2. For a single stage impulse turbine with rotor diameter of 2 m and a speed of 3000 rpm when the nozzle angle is 20°, the optimum velocity of steam in m/s is **(GATE-ME-94)**
(a) 334 (b) 356 (c) 668 (d) 711

3. In adiabatic flow with friction, the stagnation temperature along a streamline _____ (increases/remains constant) **(GATE-ME-95)**

4. Consider a Rankine cycle with superheat. If the maximum pressure in the cycle is increased without changing the maximum temperature and the minimum pressure, the dryness fraction of steam after the isentropic expansion will increase / decrease **(GATE-ME-95)**

5. Which among the following is the boiler mounting? **(GATE-ME-97)**
(a) Blow-off cock (b) Feed pump
(c) Economizer (d) Super-heater

6. If V_N and α are the nozzle exit velocity and nozzle angle in an impulse turbine, the optimum blade velocity is given by **(GATE-ME-98)**
(a) $V_N \cos 2\alpha$ (b) $V_N \sin 2\alpha$
(c) $\frac{V_N \cos \alpha}{2}$ (d) $\frac{V_N \sin \alpha}{2}$

7. A Curtis stage, Rateau stage and a 50% reaction stage in a steam turbine are examples of **(GATE-ME-98)**
(a) different types of impulse stages
(b) different types of reaction stages
(c) a simple impulse stage, a velocity compounded impulse stage and reaction stage
(d) a velocity compounded impulse stage, a pressure compounded stage and a reaction stage

8. Which of the following is a pressure compounded turbine? **(GATE-ME-00)**
(a) Parsons (b) Curtis (c) Rateau (d) all the three

9. The Rateau turbine belongs to the category of **(GATE-ME 01)**
(a) pressure compounded turbine
(b) reaction turbine
(c) velocity compounded turbine
(d) radial flow turbine

10. In a Rankine cycle, regeneration results in higher efficiency because **(GATE-ME-03)**
(a) pressure inside the boiler increases
(b) heat is added before steam enters the low pressure turbine
(c) average temperature of heat addition in the boiler increases
(d) total work delivered by the turbine increases

11. Considering the variation of static pressure and absolute velocity in an impulse steam turbine, across one row of moving blades **(GATE-ME-03)**
(a) both pressure and velocity decrease
(b) pressure decreases but velocity increases
(c) pressure remains constant, while velocity increases
(d) pressure remains constant, while velocity decreases.

12. In a power plant, water (density = 1000 kg/m^3) is pumped from 80 kPa to 3 MPa. The pump has an isentropic efficiency of 0.85. Assuming that the temperature of the water remains the same, the specific work (in kJ/kg) supplied to the pump is **(GATE-ME-14-Set-1)**
(a) 0.34 (b) 2.48 (c) 2.92 (d) 3.43

13. Which of the following statements regarding a Rankine cycle with reheating are TRUE ?
(i) Increase in average temperature of heat addition
(ii) Reduction in thermal efficiency
(iii) Drier steam at the turbine exit.**(GATE–15–Set 2)**
(a) only (i) and (ii) are correct
(b) only (ii) and (iii) are correct
(c) only (i) and (iii) are correct
(d) (i) , (ii) and (iii) are correct

14. The INCORRECT statement about regeneration in vapor power cycle is that **(GATE – 16 – SET – 1)**
(a) It increases the irreversibility by adding the liquid with higher energy content to the steam generator
(b) Heat is exchanged between the expanding fluid in the turbine and the compressed fluid before heat addition
(c) The principle is similar to the principle of Stirling gas cycle
(d) It is practically implemented by providing feed water heaters

15. Select the correct statement for 50% reaction stage in the steam turbine. **(GATE – 18 – SET – 2)**
(a) The rotor blade is symmetric.
(b) The stator blade is symmetric.
(c) The absolute inlet flow angle is equal to absolute exit flow angle.
(d) The absolute exit flow angle is equal to inlet angle of rotor blade.

16. Which one of the following modifications of the simple ideal Rankine cycle increases the thermal efficiency and reduces the moisture content of the steam at the turbine outlet ?**(GATE – 19 – SET – 2)**
(a) Increasing the boiler pressure
(b) Increasing the turbine inlet temperature
(c) Decreasing the condenser pressure
(d) Decreasing the boiler pressure

Two Marks Questions

01. An economizer in a steam generator performs the function of: **(GATE-ME-89)**
(a) Preheating the combustion air
(b) Preheating the feed water
(c) Preheating the input fuel
(d) Raising the temperature of steam

02. The fundamental objective of employing the condenser in a steam power plant is to (reduce/ increase) the _____ of steam. **(GATE-ME-89)**

03. In the Rankine cycle when superheated steam is used: **(GATE-ME-90)**
(a) Thermal efficiency increases
(b) Steam consumption decreases
(c) Steam dryness after expansion increases
(d) All of the above

04. When initially dry and saturated steam flows through a nozzle, the ratio of actual discharge to calculated discharge is **(GATE-ME-90)**
(a) Equal to 1.0
(b) Greater than 1.0
(c) Less than 1.0
(d) Independent of inlet conditions

05. In a Rankine cycle heat is added **(GATE-ME-91)**
(a) Reversibly at constant volume
(b) Reversibly at constant temperature
(c) Reversibly at constant pressure and temperature
(d) Reversibly at constant pressure

06. Velocity compounded steam turbine known as _____ (Curtis/Rateau) turbine uses the principle of converting entire_____ (pressure / velocity) energy before entering the first stage runner itself. **(GATE-ME-91)**

07. Subsonic and supersonic diffusers have the following geometry: **(GATE-ME-92)**
(a) Divergent and convergent respectively
(b) Both divergent
(c) Both convergent
(d) Convergent and divergent respectively

08. Boiler rating is usually defined in terms of: **(GATE-ME 92)**
(a) Maximum temperature of steam in Kelvin
(b) Heat transfer rate in kJ/hr
(c) Heat transfer area in metre^2
(d) Steam output in kg/hr

09. In steam and other vapor cycles, the process of removing non-condensable is called: **(GATE-ME-92)**
(a) Scavenging process
(b) Deaeration process
(c) Exhaust process
(d) Condensation process

10. A steam turbine operating with less moisture is ____ (more/less) efficient and _____ (less/more) prone to blade damage. **(GATE-ME 92)**

11. The equivalent evaporation (kg/hr) of a boiler producing 2000 kg/hr of steam with enthalpy content of 2426 kJ/kg from feed water at temperature 40°C (liquid enthalpy = 168 kJ/kg) is (Enthalpy of vaporization of water at 100°C = 2258 kJ/kg). **(GATE-ME 93)**
(a) 2000 (b) 2149 (c) 186 (d) 1649

12. A steam power plant has the boiler efficiency of 92%, turbine efficiency (mechanical) of 94%, generator efficiency of 95% and cycle efficiency of 44%. If 6% of the generated power is used to run the auxiliaries, the overall plant efficiency is **(GATE-ME-96)**
(a) 34% (b) 39% (c) 45% (d) 30%

13. The following data pertains to a single stage impulse steam turbine: **(GATE-ME-97)**
Nozzle angle = 20°;
Blade velocity = 200 m/s;
Relative steam velocity at entry = 350 m/s;
Blade inlet angle = 30°;
Blade exit angle = 25°.
If blade friction is neglected the work done per kg steam is
(a) 124 kJ (b) 164 kJ (c) 169 kJ (d) 174 kJ

14. Consider an actual regenerative Rankine cycle with one open feed water heater. For each kg steam entering the turbine, if m kg steam with a specific enthalpy of h_1 is bled from the turbine, and the specific enthalpy of liquid water entering the heater is h_2, then h_3 the specific enthalpy of saturated liquid leaving the heater is equal to **(GATE-ME-97)**
(a) $mh_1 - (h_2 - h_1)$ (b) $h_1 - m(h_2 - h_1)$
(c) $h_2 - m(h_2 - h_1)$ (d) $mh_2 - (h_2 - h_1)$

15. Match the following

List – I	List – II
A. Steam nozzle	1. Mach Number
B. Compressible	2. Reaction Turbine
C. Surface tension	3. Biot Number
D. Heat conduction	4. Nusselt Number
	5. Super saturation
	6. Weber Number

16. The isentropic heat drop in the nozzle of an impulse steam turbine with a nozzle efficiency 0.9, blade velocity ratio 0.5, and mean blade velocity 150 m/s in kJ/ kg is **(GATE-ME-98)**
(a) 50 (b) 40 (c) 60 (d) 75

17. For a compressible fluid, sonic velocity is
(a) A property of the fluid **(GATE-ME-00)**
(b) always given by $(\gamma RT)^{1/2}$ where γ, R and T are respectively the ratio of specific heats, gas constant and temperature in K
(c) always given by $(\partial P/\partial \rho)_S^{1/2}$. Where P, ρ and s are respectively pressure, density and entropy
(d) always greater than the velocity of fluid at any location.

18. The efficiency of superheat Rankine cycle is higher than that of simple Rankine cycle because
(a) the enthalpy of main steam is higher for superheat cycle **(GATE-ME-02)**
(b) the mean temperature of heat addition is higher for superheat cycle
(c) the temperature of steam in the condenser is high
(d) the quality of steam in the condenser is low

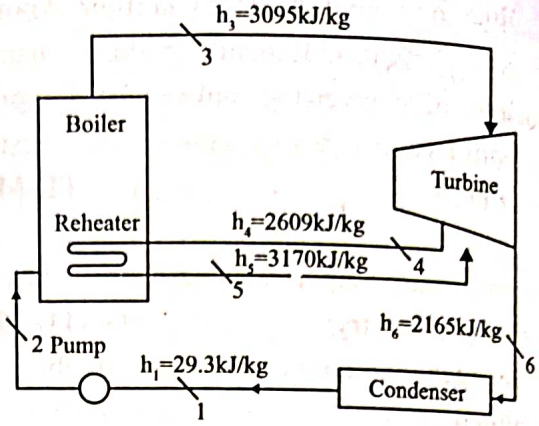
19. Match the following **(GATE-ME-03)**

List – I	List – II
P. Curtis	1. Reaction steam turbine
Q. Rateau	2. Gas turbine
R. Kaplan	3. Velocity compounding
S. Francis	4. Pressure compounding
	5. Impulse water turbine
	6. Axial turbine
	7. Mixed flow turbine
	8. Centrifugal pump

(a) P – 2 , Q – 1 , R – 7 , S – 6
(b) P – 6 , Q – 3 , R – 4 , S – 4
(c) P – 4 , Q – 1 , R – 6 , S – 2
(d) P – 3 , Q – 4 , R – 6 , S – 7

Common Data for Q.Nos. 20 & 21

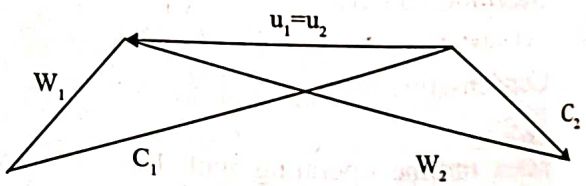
Consider a steam power plant using a reheat cycle as shown. Steam leaves the boiler and enters the turbine at 4 MPa, 350°C (h_3 = 3095 kJ/kg). After expansion in the turbine to 400 kPa (h_4 = 2609 kJ/kg), the steam is reheated to 350°C (h_5 = 3170 kJ/kg), and then expanded in a low pressure turbine to 10 kPa (h_6 = 2165 kJ/kg).



20. The thermal efficiency of the plant neglecting pump work is **(GATE-ME-04)**
(a) 15.8% (b) 41.1 % (c) 48.5% (d) 58.6%

21. The enthalpy at the pump discharge (h_2) is **(GATE-ME-04)**
(a) 0.33 kJ/kg (b) 3.33 kJ/kg
(c) 4.0 kJ/kg (d) 33.3 kJ/kg

22. In the velocity diagram shown below, u = blade velocity, C = absolute fluid velocity and W = relative velocity of fluid and the subscripts 1 and 2 refer to inlet and outlet.



(a) an impulse turbine **(GATE-ME-05)**
(b) a reaction turbine
(c) a centrifugal compressor
(d) an axial flow compressor

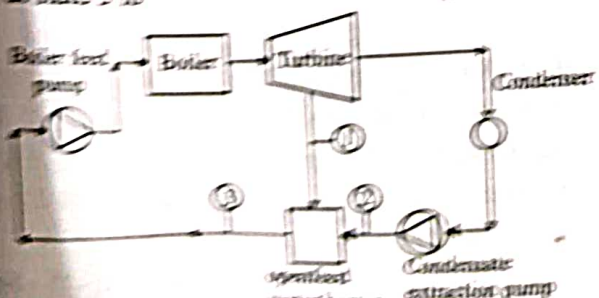
23. Determine the correctness or otherwise of the following Assertion (a) and the Reason(r).
Assertion(A) : In a power plant working on a Rankine cycle, the regenerative feed water heating improves the efficiency of the steam turbine.
Reason(R): The regenerative feed water heating raises the average temperature of heat addition in the Rankine cycle. **(GATE-ME-06)**

(a) Both A and R are true and R is the correct Reason for A
(b) Both A and R are true but R is NOT the correct reason for A
(c) Both A and R are false
(d) A is false but R is true

24. **Assertion (A):** Condenser is an essential equipment in a steam power plant.
Reason(R) : For the same mass flow rate and the same pressure rise, a water pump requires substantially less power than a steam compressor.
(GATE-ME-06)

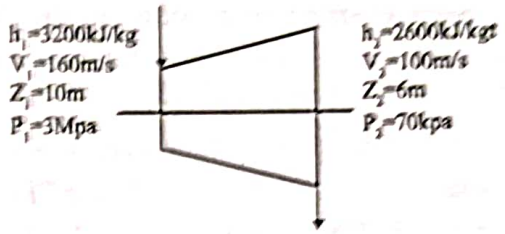
25. Which combination of the following statements is correct? **(GATE-ME-07)**
The incorporation of re-heater in a steam power plant.
P: always increases the thermal efficiency of the plant.
Q: always increases the dryness fraction of steam at condenser inlet.
R: always increases the mean temperature of heat addition
S: always increases the specific work output.
(a) P and S (b) Q and S
(c) P, R and S (d) P, Q, R and S

26. A thermal power plant operates on a regenerative cycle with a single open feed water heater, as shown in the figure. For the state points shown, the specific enthalpies are: $h_1 = 2800$ kJ/kg and $h_2 = 200$ kJ/kg. The bleed to the feed-water heater is 20% of the boiler steam generation rate. The specific enthalpy at state 3 is **(GATE-ME-08)**



(a) 720 kJ/kg (b) 2280 kJ/kg
(c) 1500 kJ/kg (d) 3000 kJ/kg

Common Data for Q.Nos. 27 & 28
The inlet and the outlet conditions of steam for an adiabatic steam turbine are as indicated in the figure. The notations are as usually followed.



27. If mass flow rate of steam through the turbine is 20 kg/s, the power output of the turbine (in MW) is **(GATE-ME-09)**
(a) 12.157 (b) 12.941 (c) 168.001 (d) 168.785

28. Assume the above turbine to be part of a simple Rankine cycle. The density of water at the inlet to the pump is 1000 kg/m^3. Ignoring kinetic and potential energy effects, the specific work (in kJ/kg) supplied to the pump is **(GATE-ME-09)**
(a) 0.293 (b) 0.351 (c) 2.930 (d) 3.510

Common Data for Q.Nos. 29 & 30
In a steam power plant operating on the Rankine cycle, steam enters the turbine at 4 MPa, 350°C and exits at a pressure of 15 kPa. Then it enters the condenser and exits as saturated water. Next, a pump feeds back the water to the boiler. The adiabatic efficiency of the turbine is 90%. The thermodynamic states of water and steam are given in table.

State	h (kJ/kg)		s(kJ/kg.K)		v(m^3/kg)	
Steam 4 MPa, 350° C	3092.5		6.5821		0.06645	
Water 15 kPa	h_f	h_g	s_f	s_g	v_f	v_g
	225.94	2599.1	0.7549	8.0085	0.001014	10.02

h is specific enthalpy, s is specific entropy and v the specific volume; subscripts f and g denote saturated liquid state and saturated vapour state.

29. The net work output (kJ/kg) of the cycle is **(GATE-ME-10)**

(a) 498 (b) 775 (c) 860 (d) 957

30. Heat supplied (kJ/kg) to the cycle is **(GATE-ME-10)**

(a) 2372 (b) 2576 (c) 2863 (d) 3092

31. The values of enthalpy of steam at the inlet and outlet of a steam turbine in a Rankine cycle are 2800 kJ/kg and 1800 kJ/kg respectively. Neglecting pump work, the specific steam consumption in kg/kW-hour is **(GATE-ME-11)**

(a) 3.60 (b) 0.36 (c) 0.06 (d) 0.01

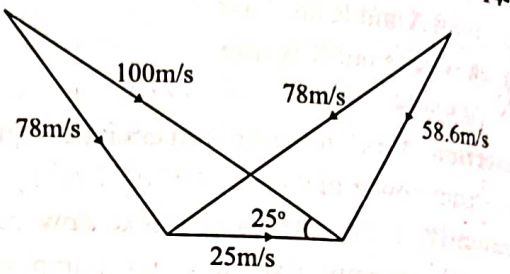
32. An ideal reheat Rankine Cycle operates between the pressure limits of 10 kPa and 8 MPa, with reheat being done at 4 MPa. The temperature of steam at the inlets of both turbines is 500°C and the enthalpy of steam is 3185 kJ/kg at the exit of the high pressure turbine and 2247 kJ/kg at the exit of low pressure turbine. The enthalpy of water at the exit from the pump is 191 kJ/kg. Use the following table for relevant data.

Superheated steam temperature (°C)	Pressure (MPa)	v (m^3/kg)	h (kJ/kg)	s (kJ/kgK)
500	4	0.08644	3446	7.0922
500	8	0.04177	3399	6.7266

Disregarding the pump work, the cycle efficiency (in percentage) is _____ **(GATE-ME-14-SET-1)**

33. Steam at a velocity of 10m/s enters the impulse turbine stage with symmetrical blading having blade angle 30°. The enthalpy drop in the stage is 100 kJ. The nozzle angle is 20°. The maximum blade efficiency (in percent) is _____ **(GATE-ME-14-SET-2)**

34. At the inlet of an axial impulse turbine rotor, the blade linear speed is 25 m/s, the magnitude of absolute velocity is 100 m/s and the angle between them is 25°. The relative velocity and the axial component of velocity remain the same between the inlet and outlet of the blades. The blade inlet and outlet velocity triangles are shown in the figure. Assuming no losses, the specific work (in J/kg) is _____. **(GATE-ME-14-SET-3)**



35. Steam with specific enthalpy (h) 3214 kJ/kg enters an adiabatic turbine operating at steady state with a flow rate 10 kg/s. As it expands, at a point where h is 2920 kJ/kg, 1.5 kg/s is extracted for heating purposes. The remaining 8.5 kg/s further expands to the turbine exit, where h = 2374 kJ/kg. Neglecting changes in kinetic and potential energies, the net power output (in kW) of the turbine is _____ **(GATE-ME-14-SET-4)**

36. Steam enters a well insulated turbine and expands isentropically throughout. At an intermediate pressure, 20 percent of the mass is extracted for process heating and the remaining steam expands isentropically to 9 kPa. Inlet to turbine P = 14 MPa, T = 560°C, h = 3486 kJ/kg, s = 6.6 kJ/(kg.K)
Intermediate stage: h = 2776 kJ/kg
Exit of turbine : P = 9 kPa, h_f = 174 kJ/kg, h_g = 2574 kJ/kg, s_f = 0.6 kJ/(kg.K); s_g = 8.1 kJ/(kg.K)
If the flow rate of steam entering the turbine is 100 kg/s, then the work output (in MW) is _____ **(GATE-15-Set 1)**

37. In a Rankine cycle, the enthalpies at turbine entry and outlet are 3159 kJ/kg and 2187 kJ/kg respectively. If the specific pump work is 2 kJ/kg, the specific steam consumption (in kg/kW-h) of the cycle based on net output is _____ **(GATE-15-Set 2)**

In a steam power plant operating on an ideal Rankine cycle, superheated steam enters the turbine at 3 MPa and 350°C. The condenser pressure is 75 kPa. The thermal efficiency of the cycle is _____ percent.

Given data:

For saturated liquid, at P = 75 kPa,

$h_f = 384.39$ kJ/kg,

$v_f = 0.001037$ m³/kg,

$s_f = 1.213$ kJ/kg-K

At 75 kPa, $h_{fg} = 2278.6$ kJ/kg,

$s_{fg} = 6.2434$ kJ/kg-K

At P = 3 MPa and

T = 350° C (Superheated steam),

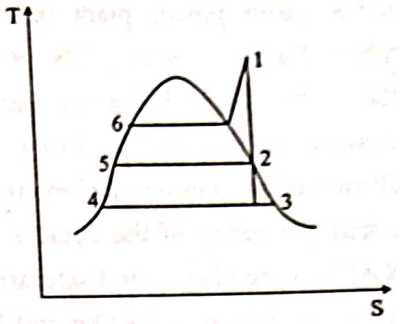
h = 3115.3 kJ/kg,

s = 6.7428 kJ/kg-K **(GATE – 16 – SET – 1)**

39. In the Rankine cycle for a steam power plant the turbine entry and exit enthalpies are 2803 kJ/kg and 1800 kJ/kg, respectively. The enthalpies of water at pump entry and exit are 121 kJ/kg and 124 kJ/kg, respectively. The specific steam consumption (in kg/kW.h) of the cycle is ___ **(GATE–17–SET–2)**

40. A stream power cycle with regeneration as shown below on the T-s diagram employs a single open feed water heater for efficiency improvement. The fluids mix with each other in an open feedwater heater. The turbine is isentropic and the input (bleed) to the feedwater heater from the turbine is at state 2 as shown in the figure. Process 3-4 occurs in the condenser. The pump work is negligible. The input to the boiler is at state 5. The following information is available from the steam tables:

State	1	2	3	4	5	6
Enthalpy (kJ/kg)	3350	2800	2300	175	700	1000



The mass flow rate of steam bled from the turbine as a percentage of the total mass flow rate at the inlet to the turbine at state 1 is _____.

(GATE – 19 – SET – 1)

41. For an ideal Rankine cycle operating between pressures of 30 bar and 0.04 bar, the work output from the turbine is 903 kJ/kg and the work input to the feed pump is 3 kJ/kg. The specific steam consumption is _____ kg/kW.h (round off to 2 decimal places). **(GATE–20–SET–1)**

42. In a steam power plant, superheated steam at 10 MPa and 500°C, is expanded isentropically in a turbine until it becomes a saturated vapour. It is then reheated at constant pressure to 500°C. The steam is next expanded isentropically in another turbine until it reaches the condenser pressure of 20 kPa. Relevant properties of steam are given in the following two tables. The work done by both the turbines together is _____ kJ/kg. (round off to the nearest integer). **(GATE–20–SET–2)**

Superheated Steam Table :

Pressure, p (MPa)	Temperature, T (°C)	Enthalpy, h (kJ/kg)	Entropy, s (kJ/kgK)
10	500	3373.6	6.5965
1	500	3478.4	7.7621

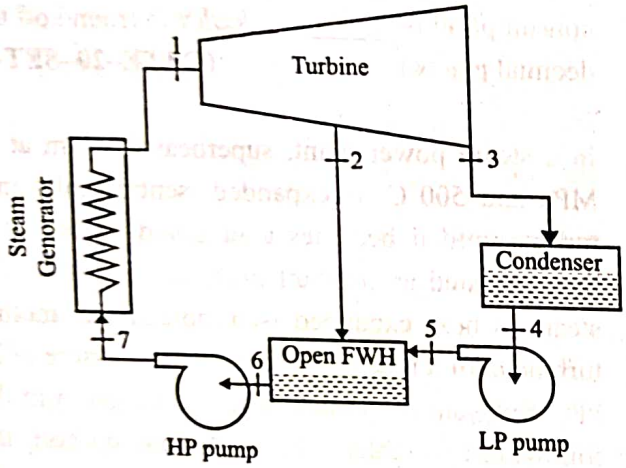
Saturated Steam Table :

Pressure, p	Sat. Temperature, T_{sat} (°C)	Enthalpy, h (kJ/kg)		Entropy, s (kJ/kgK)	
		h_f	h_g	s_f	s_g
1 MPa	179.91	762.9	2778.1	2.1386	6.5965
20 kPa	60.06	251.38	2609.7	0.8319	7.9085

43. Consider a steam power plant operating on an ideal reheat Rankine cycle. The work input to the pump is 20 kJ/kg. The work output from the high pressure turbine is 750 kJ/kg. The work output from the low pressure turbine is 1500 kJ/kg. The thermal efficiency of the cycle is 50%. The enthalpy of saturated liquid and saturated vapour at condenser pressure are 200 kJ/kg and 2600 kJ/kg, respectively. The quality of steam at the exit of the low pressure turbine is _____ % (round off to the nearest integer).

(GATE–21_SET–1)

44. Consider the open feed water heater (FWH) shown in the figure given below :



Specific enthalpy of steam at location 2 is 2624 kJ/kg, specific enthalpy of water at location 5 is 226.7 kJ/kg and specific enthalpy of saturated water at location 6 is 708.6 kJ/kg. If the mass flow rate of water entering the open feed water heater (at location 5) is 100 kg/s then the mass flow rate of steam at location 2 will be _____ kg/s (round off to one decimal place).

(GATE–21_SET–2)

45. In a steam power plant based on Rankine cycle, steam is initially expanded in a high-pressure turbine. The steam is then reheated in a reheater and finally expanded in a low-pressure turbine. The expansion work in the high-pressure turbine is 400 kJ/kg and in the low-pressure turbine is 850 kJ/kg, whereas the pump work is 15 kJ/kg. If the cycle efficiency is 32%, the heat rejected in the condenser is _____ kJ/kg (round off to 2 decimal places).

(GATE-22_SET-1)

46. At steady state, 500 kg/s of steam enters a turbine with specific enthalpy equal to 3500 kJ/kg and specific entropy equal to 6.5 $kJ \cdot kg^{-1} \cdot K^{-1}$. It expands reversibly in the turbine to the condenser pressure. Heat loss occurs reversibly in the turbine at a temperature of 500 K. If the exit specific enthalpy and specific entropy are 2500 kJ/kg and 6.3 $kJ \cdot kg^{-1} \cdot K^{-1}$, respectively, the work output from the turbine is _____ MW (in integer).

(GATE-22_SET-2)