CLASS TEST

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POWER PLANT

MECHANICAL ENGINEERING

Date of Test : 10/11/2024

ANSWER KEY

1.	(d)	7.	(a)	13.	(b)	19.	(a)	25.	(b)
2.	(c)	8.	(d)	14.	(b)	20.	(d)	26.	(d)
3.	(c)	9.	(c)	15.	(a)	21.	(b)	27.	(a)
4.	(b)	10.	(c)	16.	(c)	22.	(b)	28.	(c)
5.	(b)	11.	(b)	17.	(a)	23.	(c)	29.	(b)
6.	(b)	12.	(b)	18.	(a)	24.	(b)	30.	(b)

DETAILED EXPLANATIONS

1. (d)

For minimum work of compression

$$\frac{P_3}{P_2} = \frac{P_2}{P_1}$$

$$P_3 = \frac{(P_2)^2}{P_1} = \frac{4.7^2}{1.3}$$

$\Rightarrow$ $$P_3 = 17 \text{ bar}$$

2. (c)

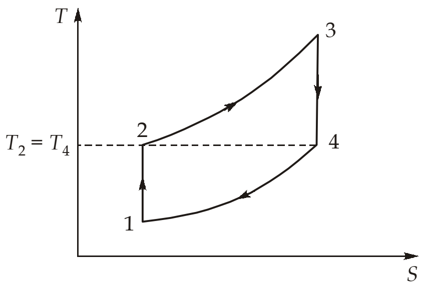
$$r_{bW} = 0.45 = \frac{W_C}{W_T}$$

$\Rightarrow$ $$W_C = 0.45 W_T$$

So, $$\frac{\text{Net Work}}{\text{Comp. Work}} = \frac{W_T - W_C}{W_C} = \frac{W_T}{W_C} - 1$$

$$= \frac{1}{0.45} - 1 = 1.22$$

3. (c)



$$T_3 = 1200 + 273 = 1473 \text{ K}$$

$$T_1 = 27 + 273 = 300 \text{ K}$$

$\because$ For maximum work output,

$$T_2 = T_4$$

and $$T_1 T_3 = T_2 T_4$$

$\Rightarrow$ $$T_2 = T_4 = \sqrt{T_1 T_3} = \sqrt{300 \times 1473}$$

$$= 664.75 \text{ K or } 391.75°\text{C}$$

4. (b)

$$m_w = 205 \text{ kJ/kg}$$

$$\Delta h_w = 145 \text{ kJ/kg}$$

$$m_f = 23 \text{ kg}$$

$$C.V. = 2050 \text{ kJ/kg}$$

$$\eta_{\text{steam generator}} = \frac{m_w \Delta h_w}{m_f \times CV} \times 100 = \frac{205 \times 145}{23 \times 2050} \times 100 = 63.04\%$$

5. **(b)**

for 3 cycles coupled in series the overall efficiency of the combined cycle is given by

$$\eta = 1 - (1 - \eta_1)(1 - \eta_2)(1 - \eta_3)$$
$$0.72 = 1 - (1 - 0.4)(1 - 0.3)(1 - \eta_{\text{steam}})$$
$$0.72 = 1 - (0.42)(1 - \eta_{\text{steam}})$$
$$0.72 = 1 - 0.42 + 0.42\,\eta_{\text{steam}}$$
$$\Rightarrow \quad \eta_{\text{steam}} = 0.3333 = 33.33\%$$

6. **(b)**

Reheating results in increase in net work output, decrease in thermal efficiency (thermal efficiency is directly proportional to mean temperature of heat addition) and improvement in quality of wet steam at turbine exit. But reheating is mainly incorporated in power plant to limit the moisture content in the working fluid at turbine exit. Due to increase in specific output, mass flow rate required is less for the same power output, which results in reduction in plant size.

7. **(a)**

For maximum blade efficiency of Parson's turbine,

$$\text{Speed ratio, } \rho = \cos\alpha$$

8. **(d)**

$$\text{Net work output, } W_{\text{net}} = 985 \text{ kJ/kg}$$
$$\text{Heat rejected, } Q_R = 2057 \text{ kJ/kg}$$

From 1st law of thermodynamics for cycle,

$$W_{\text{net}} = Q_S - Q_R$$
$$Q_S = W_{\text{net}} + Q_R$$
$$= 985 + 2057 = 3042 \text{ kJ/kg}$$
$$\text{Heat rate, HR} = \frac{Q_S}{W_{\text{net}}} = \frac{3042}{985} = 3.088$$

9. **(c)**

As we know,

$$\text{Specific steam consumption, ssc} = \frac{3600}{W_{\text{net}}}$$
$$3.2 = \frac{3600}{W_{\text{net}}}$$
$$\text{Net work output } (W_{\text{net}}) = \frac{3600}{3.2} = 1125 \text{ kJ/kg}$$
$$\text{Specific pump work } (W_p) = 9 \text{ kJ/kg}$$
$$\text{So, turbine work, } W_T = W_{\text{net}} + W_p$$
$$= 1125 + 9 = 1134 \text{ kJ/kg}$$

10. (c)

Cooling towers are of two types - wet type and dry type

Dry cooling towers can be employed where cooling water is not available in plenty.

Cooling tower uses the phenomenon of evaporative cooling to cool the warm water below dry bulb temperature of air.

11. (b)

$$h_1 + \frac{v_1^2}{2} + gz_1 = h_2 + \frac{v_2^2}{2} + gz_2 + w$$

$$w = (h_1 - h_2) + \left(\frac{v_1^2 - v_2^2}{2}\right) + (z_1 - z_2)g$$

$$= (3500 - 2500) + \left(\frac{200^2 - 150^2}{2 \times 1000}\right) + \frac{4 \times 9.81}{1000}$$

$$= 1000 + 8.75 + 0.03924 = 1008.78 \text{ kJ/kg}$$

$$\text{Power output} = \dot{m}w = 20 \times 10^{-3} \times 1008.78 = 20.1758 \text{ MW}$$

12. (b)

$$\frac{V_c}{V_s + V_c} = 0.08$$

$$V_c = 0.08\, V_s + 0.08\, V_c$$

$$c = \frac{V_c}{V_s} = \frac{0.08}{0.92} = 0.087$$

$$\eta_v = 1 + c - c\left(\frac{p_2}{p_1}\right)^{1/n_e}$$

$$= 1 + 0.087 - 0.087\,(9)^{1/1.35}$$

$$\eta_v = 64.42\%$$

13. (b)

$$h_3 = mh_1 + (1 - m)h_2$$

$$= 0.25 \times 3000 + (1 - 0.25) \times 160$$

$$h_3 = 870 \text{ kJ/kg}$$

14. (b)

$$r_p = 10$$

$$T_{min} = 300 \text{ K}$$

$$T_{max} = 1500 \text{ K}$$

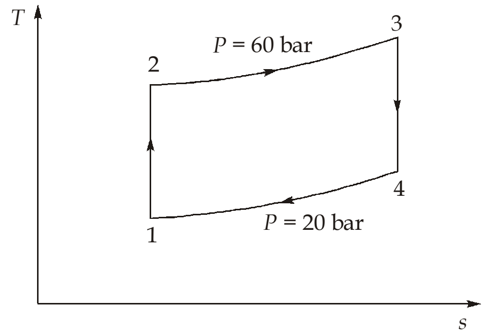
$$\eta_{\text{regenerative cycle}} = 1 - \frac{T_{min}}{T_{max}}\left[(r_p)^{\frac{\gamma-1}{\gamma}}\right] = 1 - \frac{300}{1500}\left[(10)^{\frac{0.4}{1.4}}\right]$$

$$= 0.6138$$

$$\eta_{\text{simple cycle}} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(10)^{\frac{0.4}{1.4}}} = 0.482$$

$$\frac{\eta_{\text{simple cycle}}}{\eta_{\text{regenerative cycle}}} = \frac{0.482}{0.6138} = 0.7853$$

15. (a)

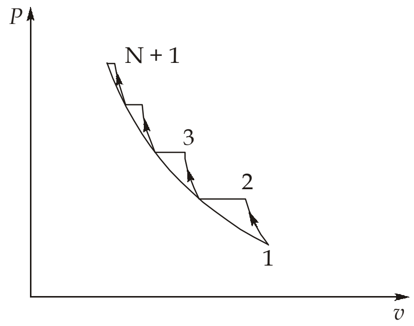


$$\gamma = 1.66$$
$$(c_p) = 5.1926 \text{ kJ/kgK}$$
$$T_1 = 27°C = 300 \text{ K}$$
$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} = 300\left(\frac{60}{20}\right)^{1.66-1/1.66} = 464.32 \text{ K}$$
$$T_3 = 1000°C = 1273 \text{ K}$$
$$T_4 = \frac{T_3}{(P_3/P_4)^{\gamma-1/\gamma}} = \frac{1273}{(3)^{0.66/1.66}} = 822.4 \text{ K}$$
$$W_{net} = W_T - W_C$$
$$= mc_p(T_3 - T_4) - mc_p(T_2 - T_1)$$
$$= 2 \times 5.1926(1273 - 822.4) - 2 \times 5.1926(464.32 - 300)$$
$$= 2972.16 \text{ kJ}$$

16. (c)

In co-generation plant,electric power and heat is produced simultaneously. For heat generation,process heater is used in place of condenser in ordinary Rankine cycle .The pressure at the exhaust from turbine is saturation pressure corresponding to temperature desired in process heater. Such a turbine is called a back pressure turbine.

17. (a)



Let N be the number of stages.

$$P_1 = 1 \text{ bar}, T_1 = 27 + 273 = 300 \text{ K}$$
$$P_{N+1} = 150 \text{ bar}$$
$$T_2 = 160°\text{C} = 160 + 273 = 433 \text{ K}$$

For polytropic process, 1 – 2(n = 1.25)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{1}\right)^{(1.25-1)/1.25}$$
$$P_2 = 6.2637 \text{ bar}$$

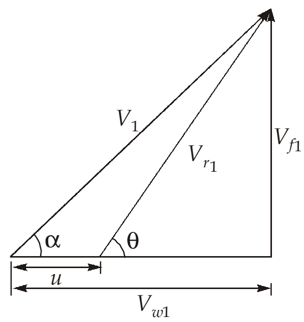
Now,
$$\frac{P_{N+1}}{P_1} = \frac{P_{N+1}}{P_N}\times\frac{P_N}{P_{N-1}}\ldots\ldots\ldots\ldots\frac{P_3}{P_2}\times\frac{P_2}{P_1}$$
$$\frac{P_{N+1}}{P_1} = \left(\frac{P_2}{P_1}\right)^N$$
$$\Rightarrow \quad \frac{150}{1} = \left(\frac{6.2637}{1}\right)^N$$
$$N = 2.731$$
$$N \simeq 3$$

18. (a)

$$\text{Nozzle angle, } \alpha = 19°$$
$$\text{Blade inlet angle, } \theta = 28°$$
$$V_{r1} = 300 \text{ m/s}$$

From inlet velocity triangle,

$$V_{f1} = V_1\sin\alpha = V_{r1}\sin\theta$$
$$V_1\sin 19° = V_{r1}\sin 28°$$
$$V_1 = \frac{300\times\sin 28°}{\sin 19°}$$
$$V_1 = 432.602 \text{ m/s}$$



Inlet velocity triangle

For maximum efficiency,

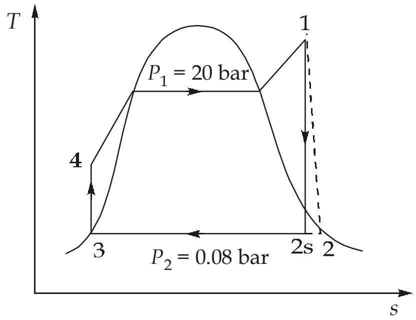
$$u = \frac{V_1\cos\alpha}{2} = \frac{432.602\times\cos 19°}{2}$$
$$u = 204.517 \text{ m/s}$$

Work done per kg of steam,

$$w = (V_{w1} + V_{w2}) \times u$$
$$= [(V_{r1}\cos\theta + u) + (V_{r2}\cos\phi - u)] \times u$$
$$= (V_{r1}\cos\theta + V_{r2}\cos\phi)u$$
$$= 300(\cos 28° + \cos 22°) \times 204.517 \quad [\because V_{r1} = V_{r2}]$$
$$= 111060.796 \text{ J/kg} = 111.06 \text{ kJ/kg}$$

19. (a)

$$h_1 = 3160 \text{ kJ/kg}$$



For isentropic process (1 – 2s)

$$s_1 = s_{2s}$$
$$\Rightarrow \quad 6.992 = s_{f2} + x_2 s_{fg} = 0.5926 + x_2 \times 7.6371$$
$$x_2 = 0.8379$$
$$h_{2s} = h_f + x_2 h_{fg}$$
$$= 173.88 + 0.8379 \times 2403.1$$
$$h_{2s} = 2187.437 \text{ kJ/kg}$$

Ideal work, $W_{ideal} = (h_1 - h_{2s}) = (3160 - 2187.437) = 972.563$ kJ/kg

Brake efficiency, $\eta_b = \eta_{internal} \times \eta_{mechanical}$

$$0.72 = \eta_{internal} \times 0.9$$
$$\eta_{internal} = \frac{0.72}{0.9} = 0.8$$

As we know,

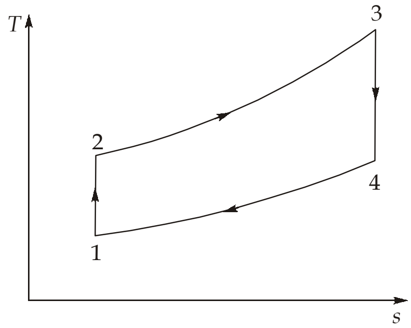
$$\eta_{internal} = \frac{\text{Actual work}}{\text{Ideal work}}$$
$$0.8 = \frac{\text{Actual work}}{972.563}$$
$$\Rightarrow \quad \text{Actual work} = 0.8 \times 972.563 = 778.05 \text{ kJ/kg}$$

20. (d)

$$P_1 = 1 \text{ bar}$$
$$T_1 = 27 + 273 = 300 \text{ K}$$

Pressure ratio, $r_p = 7$

Process 1–2 ($\gamma = 1.4$)



$$\frac{T_2}{T_1} = (r_p)^{(\gamma-1)/\gamma}$$
$$\Rightarrow \quad \frac{T_2}{300} = (7)^{0.4/1.4}$$

$\Rightarrow \quad T_2 = 523.0917 \text{ K}$

Also, Process 3– 4(γ = 1.4)

$$\frac{T_3}{T_4} = (r_p)^{(\gamma-1)/\gamma}$$

$$\frac{T_3}{T_4} = (7)^{0.4/1.4}$$

$$T_3 = 1.7436\ T_4$$

$\Rightarrow \quad T_4 = 0.5735\ T_3$

As per the condition:

$$\text{Compressor work} = 0.4 \times \text{Turbine work}$$

$\Rightarrow \quad c_p(T_2 - T_1) = 0.4 \times c_p(T_3 - T_4)$

$\Rightarrow \quad 523.0917 - 300 = 0.4(T_3 - 0.5735T_3)$

$\Rightarrow \quad 223.0917 = 0.1706\ T_3$

Maximum temperature of cycle, T_3 = 1307.688 K

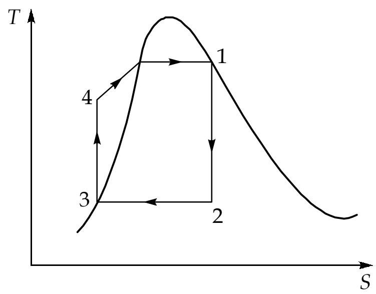
21. (b)

$$T_{\text{mean, H.A.}} = 800 \text{ K}$$

$$(\Delta s)_{\text{condenser}} = 1.5 \text{ kJ/kgK} = (\Delta s)_{\text{boiler}}$$

$$Q_{\text{supplied}} = T_{\text{mean}} \times \Delta s$$

$$= 800 \times 1.5 = 1200 \text{ kJ/kg}$$



$$\eta = 0.3 = \frac{W_{\text{net}}}{Q_{\text{supplied}}}$$

$\Rightarrow \quad W_{\text{net}} = 0.3 \times Q_{\text{supplied}}$

$$= 0.3 \times 1200 = 360 \text{ kJ/kg}$$

$$\text{SSC} = \frac{3600}{W_{\text{net}}} = \frac{3600}{360} = 10 \text{ kg/kW-hr}$$

22. (b)

Condenser efficiency, $\eta = \dfrac{\text{Actual rise in temperature of cooling water}}{\text{Maximum temperature rise of cooling water}} = \dfrac{40-30}{51.06-30} = 47.5\%$

23. (c)

Lancashire boiler is a horizontal type and stationary fire tube boiler. This is an internally fired boiler because the furnace is present inside the boiler. It is mostly used in locomotive engines and marines.

24. (b)

Circulation ratio refers to the amount of saturated water to be circulated through the downcomer-riser circuit per kg of steam released from the drum.

$$\text{Circulation ratio} = \frac{1}{X_{top}} = \frac{1}{0.9} = 1.11 \text{ kg}$$

25. (b)

Optimum blade speed ratio,

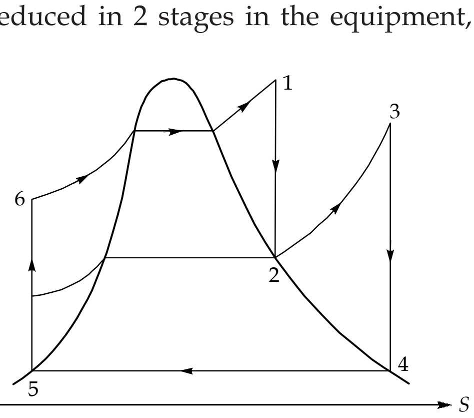
$$K_u = 0.5 = \cos\alpha$$

$$\eta_{max} = \frac{2\cos^2\alpha}{1+\cos^2\alpha} = \frac{2\times 0.5^2}{1+0.5^2} = 0.4$$

26. (d)

As pressure is reduced in first stage only and velocity is reduced in 2 stages in the equipment, equipment is a two row Curtis turbine.

27. (a)



$$h_1 = 3386.1 \text{ kJ/kg}$$
$$h_2 = 2915 \text{ kJ/kg}$$
$$h_3 = 3469.8 \text{ kJ/kg}$$
$$h_4 = 2660.1 \text{ kJ/kg}$$
$$h_6 = h_5 = 379.62 \text{ kJ/kg}$$

$$\eta = \frac{W_{net}}{Q_{total}} = \frac{h_1 - h_2 + h_3 - h_4}{h_1 - h_5 + h_3 - h_2}$$

$$= \frac{3386.1 - 2915 + 3469.8 - 2660.1}{3386.1 - 379.62 + 3469.8 - 2915} = \frac{1280.8}{3561.28} = 35.96\% \simeq 36\%$$

28. (c)

Let Willan's line,

$$\dot{m} = \dot{m}_o + x\cdot L$$

at full load, $L = 100 \times 10^3$ kW

$$\dot{m} = 500{,}000 \text{ kg/hr}$$

$\Rightarrow$ $500{,}000 = \dot{m}_o + x\cdot 100\times 10^3$ ...(i)

at half load, $L = 50 \times 10^3$ kW

$$\dot{m} = 263{,}000 \text{ kg/hr}$$

$\Rightarrow$ $263{,}000 = \dot{m}_o + x\times 50\times 10^3$ ...(ii)

On solving equation (i) and (ii)

$$\dot{m}_o = 26{,}000 \text{ kg/hr}$$

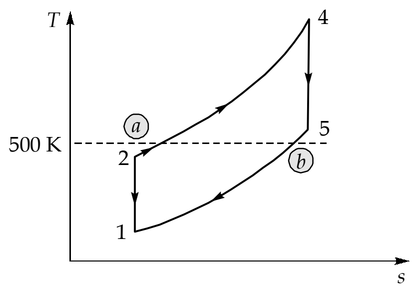
29. (b)

$$\eta_1 = 0.4,\ \eta_2 = 0.5,\ x_1 = 0.4$$

$$\eta_{\text{combined}} = \eta_2 - x_1(\eta_2 - x_1)$$

$$= 0.5 - 0.4(0.5 - 0.4) = 0.46$$

30. (b)



$$T_a = T_b = 500 \text{ K}$$

$$T_2 = 400 \text{ K}$$

$$T_4 = 700 \text{ K}$$

Effectiveness, $$t = \frac{T_a - T_2}{T_4 - T_2} = \frac{500 - 400}{700 - 400} = \frac{100}{300} = 33.33\%$$

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