Heat transfer in the boiler

$$= \frac{w_s (h_3 - h_2)}{w_f} = 8.5 \times 1539.58 \times 10^{-3} = 13.086 \text{ MJ/kg}$$

Heat transfer in the superheater

$$= \frac{w_s (h_4 - h_3)}{w_f} = 8.5 \times 548.87 \times 10^{-3} = 4.665 \text{ MJ/kg}$$

Heat transfer in the air pre-heater

$$= \frac{w_a c_{p_a} (t_2 - t_1)}{w_f} = 15 \times 1.005 \times (250 - 25) \times 10^{-3} = 3.392 \text{ MJ/kg}$$

Percentage of total heat absorbed in the economiser

$$= \frac{h_2 - h_1}{h_4 - h_1} \times 100 = \frac{625.35}{2713.8} \times 100 = 23.04\%$$

Percentage of total heat absorbed in the boiler

$$= \frac{h_3 - h_2}{h_4 - h_1} \times 100 = \frac{1539.58}{2713.8} \times 100 = 56.73\%$$

Percentage of total heat absorbed in the superheater

$$= \frac{h_4 - h_3}{h_4 - h_1} \times 100 = \frac{548.87}{2713.8} \times 100 = 20.23\%$$

Eample 2.6 Steam at 150 bar, 550 °C is expanded in an h.p. turbine to 20 bar when it is reheated to 500 °C and expanded in i.p. and l.p. turbines to condenser pressure of 0.075 bar. There are five feedwater heaters, one extraction from h.p. turbine at 50 bar, 3 from i.p. turbine at 10 bar, 5 bar and 3 bar, and one from l.p. turbine at 1.5 bar. The middle heater is the deaerator and all others are closed heaters. Assuming ideal conditions, determine (a) the cycle efficiency, (b) the feedwater temperature at inlet to the steam generator, (c) the steam rate, (d) the heat rate, (e) the quality of steam at turbine exhaust, and (f) the power output if the steam flow rate is 300 t/h. Take TTD = 0 for all the heaters.

Solution With reference to Fig. E2.6,

$h_1 = 3448.6$ kJ/kg, $s_1 = s_2 = s_3 = 6.5199$ kJ/kg K

$h_4 = 3467.6$ kJ/kg. $s_4 = s_5 = s_6 = s_7 = s_8 = s_9 = 7.4317$ kJ/kg K

$t_2 = 370$ °C, $h_2 = 3112$ kJ/kg

$t_3 = 245$ °C, $h_3 = 2890$ kJ/kg

$t_5 = 400$ °C, $h_5 = 3250$ kJ/kg

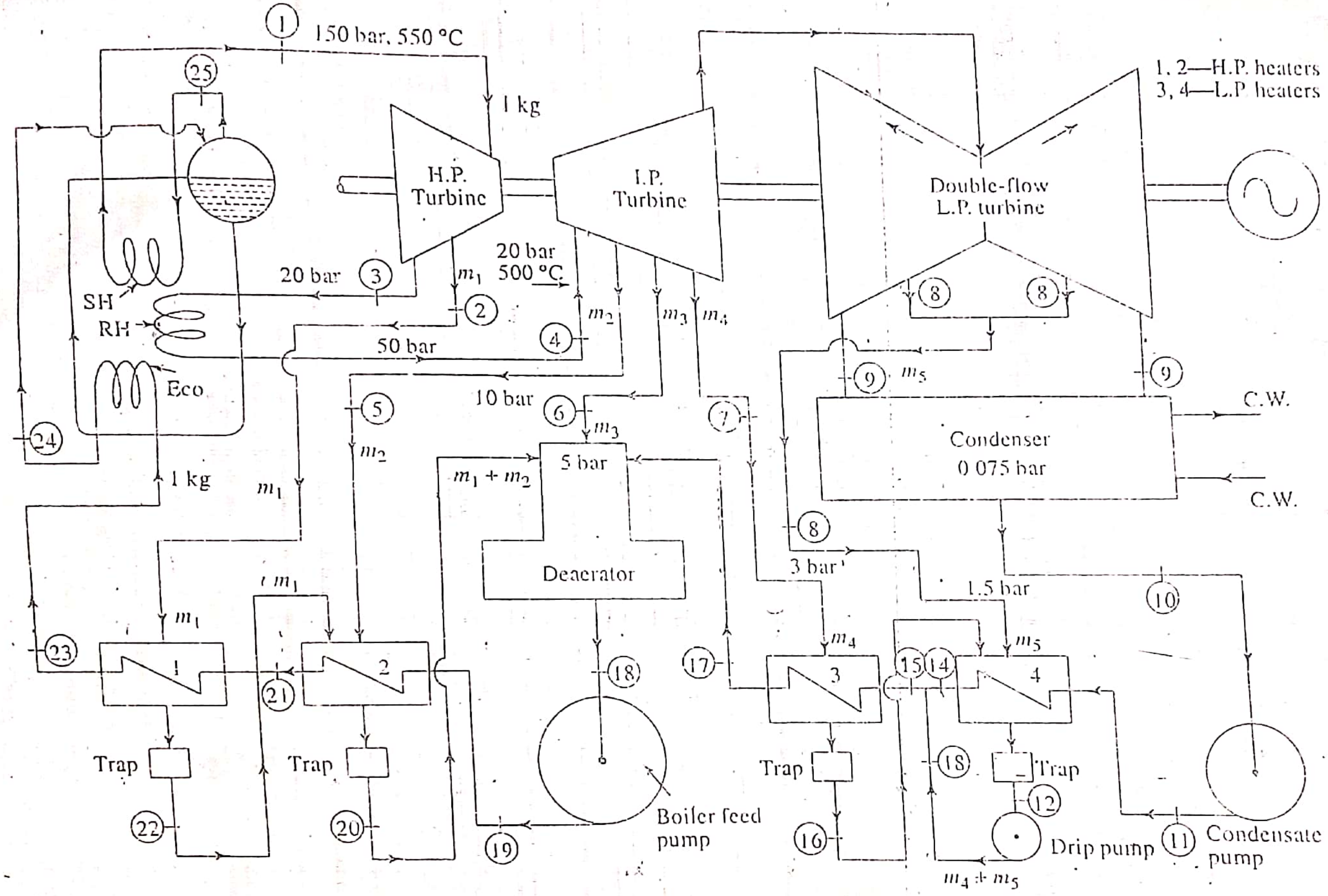
$t_6 = 300$ °C, $h_6 = 3050$ kJ/kg

$t_7 = 225$ °C, $h_7 = 2930$ kJ/kg

$t_8 = 160$ °C. $h_8 = 2790$ kJ/kg

$$7.4317 = 0.5764 + x_9 \times 7.6751$$

$$x_9 = 0.8932$$



150 bar, 550 °C
1 kg
H.P. Turbine
I.P. Turbine
Double-flow L.P. turbine
1, 2—H.P. heaters
3, 4—L.P. heaters
20 bar
20 bar 500 °C
50 bar
10 bar
5 bar
3 bar
1.5 bar
SH
RH
Eco
Condenser 0 075 bar
C.W.
C.W.
Deaerator
Boiler feed pump
Drip pump
Condensate pump
Trap
Trap
Trap
Trap
m_1
m_2
m_3
m_4
m_5
$m_1 + m_2$
$m_4 + m_5$

Fig. E2.6 (a)

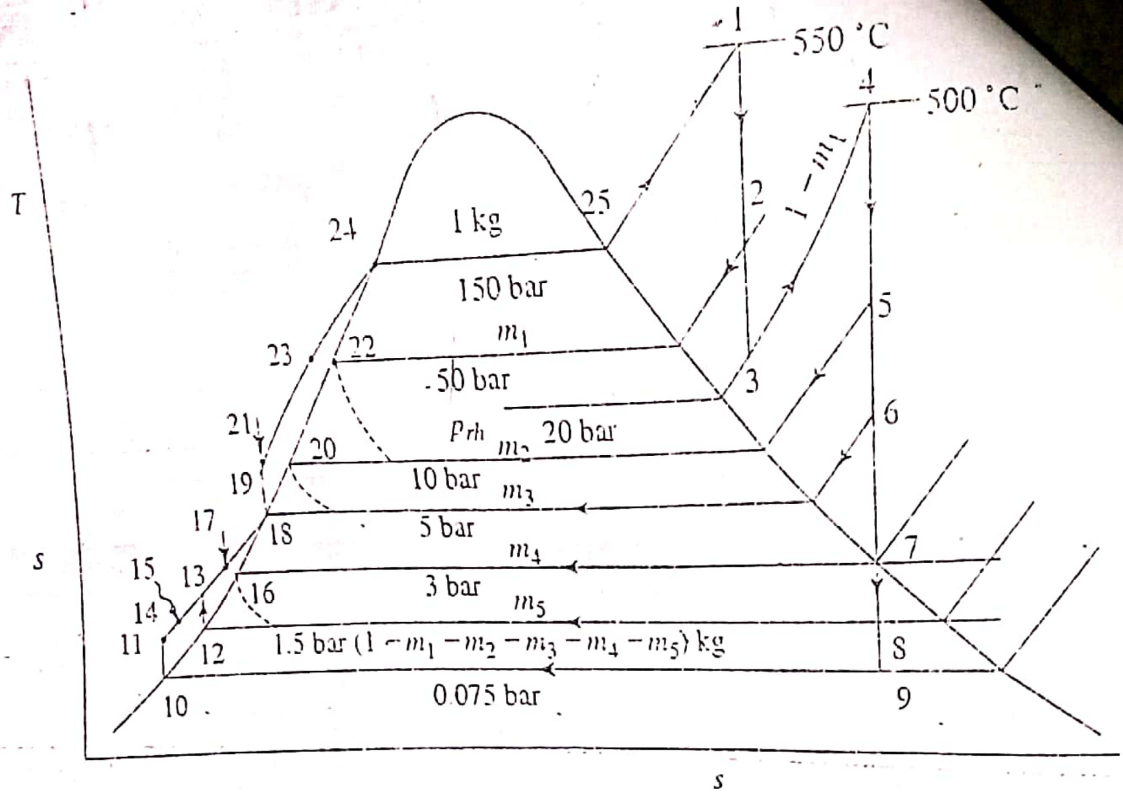


Fig. E2.6 (b)

$h_9 = 168.79 + 0.8932 \times 2406.0 = 2317.83$ kJ/kg

$h_{10} = 168.79$ kJ/kg

$h_{11} = 168.79 + 0.001 \times 5 \times 100 = 169.29$ kJ/kg

$h_{12} = 467.11$ kJ/kg, $t_{14} = 111.37$, $h_{14} = 467$ kJ/kg

$h_{12} = h_{13} = h_{14} = h_{15} = 467$ kJ/kg

$h_{16} = h_{17} = 561.47$ kJ/kg, $h_{18} = 640.23$ kJ/kg

$h_{19} = 640.23 + 0.001 \times 145 \times 100 = 654.63$ kJ/kg

$h_{20} = 762.8$ kJ/kg $= h_{21}$, $h_{22} = h_{22} = h_{23} = 1154.23$ kJ/kg

Heater 1

$$m_1(h_2 - h_{22}) = 1(h_{23} - h_{21})$$

$$m_1 = \frac{1154.23 - 762.8}{3112 - 1154.23} = \frac{391.43}{1957.77} = 0.2 \text{ kg}$$

Heater 2

$$m_2(h_5 - h_{20}) + m_1(h_{22} - h_{20}) = 1(h_{21} - h_{19})$$

$$m_2(3250 - 762.8) + 0.2(1154.23 - 762.8) = (762.8 - 654.6)$$

$$m_2 \times 2487.2 + 78.29 = 108.2$$

$$m_2 = 0.012 \text{ kg}$$

Heater 3

$$m_3(h_6 - h_{18}) + (m_1 + m_2)(h_{20} - h_{18}) = (1 - m_1 - m_2 - m_3)(h_{18} - h_{17})$$

$$m_3(3050 - 640.2) + 0.212(762.8 - 640.2) = (0.788 - m_3)(640.2 - 561.5)$$

$$m_3 \times 2409.8 + 26.00 = 62.02 - 78.7 m_3$$

$$m_3 = 36.02/2488.5 = 0.0145 \text{ kg}$$

Heater 4

$$m_4(h_7 - h_{16}) = (1 - m_1 - m_2 - m_3)(h_{17} - h_{15})$$

$$m_4(2930 - 561.5) = 0.7735(561.5 - 467) = 73.096$$

$$m_4 = 0.031 \text{ kg}$$

Heater 5

$$m_5(h_8 - h_{12}) + m_4(h_{16} - h_{12}) = (1 - m_1 - m_2 - m_3 - m_4 - m_5)(h_{14} - h_{11})$$

$$m_5(2790 - 467) + 0.031(561.5 - 467) = (0.7425 - m_5)(467 - 169.3)$$

$$m_5 \times 2323 + 2.93 = 221.04 - 297.7\, m_5$$

$$m_5 = \frac{218.11}{2620.7} = 0.0832 \text{ kg}$$

$$\begin{aligned} W_T &= 1(h_1 - h_2) + (1 - m_1)(h_2 - h_3) + (1 - m_1)(h_4 - h_5) \\ &\quad + (1 - m_1 - m_2)(h_5 - h_6) + (1 - m_1 - m_2 - m_3)(h_6 - h_7) \\ &\quad + (1 - m_1 - m_2 - m_3 - m_4)(h_7 - h_8) \\ &\quad + (1 - m_1 - m_2 - m_3 - m_4 - m_5)(h_8 - h_9) \\ &= (3448.6 - 3112) + 0.8(3112 - 2890) + 0.8(3467.6 - 3250) \\ &\quad + 0.788(3250 - 3050) + 0.7735(3050 - 2930) \\ &\quad + 0.7425(2930 - 2790) + 0.6593(2790 - 2317.8) \\ &= 336.6 + 177.6 + 174.1 + 157.6 + 92.8 + 104.0 + 311.3 \\ &= 1354.0 \text{ kJ/kg} \end{aligned}$$

$$W_p = 0.5 + 14.5 + 0.15 = 15.15 \text{ kg}$$

$$W_{net} = 1354 - 15.15 = 1338.85 \text{ kJ/kg}$$

$$\begin{aligned} Q_1 &= 1(h_1 - h_{23}) + (1 - m_1)(h_4 - h_3) \\ &= 3448.6 - 1154.2 + 0.8(3467.6 - 2890) = 2756.48 \text{ kJ/kg} \end{aligned}$$

$$\therefore \eta_{cycle} = \frac{1338.85}{2756.48} = 0.4857, \quad \text{or} \quad 48.57\% \qquad \textit{Ans. (a)}$$

$$\begin{aligned} t_{23} &= \text{feedwater temperature at inlet to the steam generator} \\ &= 264\ ^\circ\text{C} \qquad \textit{Ans.(b)} \end{aligned}$$

$$\text{Steam rate} = \frac{3600}{W_{net}} = \frac{3600}{1338.85} = 2.69 \text{ kJ/kWh} \qquad \textit{Ans. (c)}$$

$$\text{Heat rate} = \frac{Q_1}{W_{net}} \times 3600 = \frac{3600}{0.4857} = 7412 \text{ kJ/kWh.} \qquad \textit{Ans. (d)}$$

Quality of steam at turbine exhaust $= x_9 = 0.8932$ *Ans. (e)*

$$\text{Power output} = \frac{1338.85 \times 300 \times 10^3}{3600} \text{ kW} = 111.57 \text{ MW} \qquad \textit{Ans. (f)}$$

Example 2.7 A textile factory requires 10 t/h of steam for process heating at 3 bar saturated and 1000 kW of power, for which a back pressure turbine of 70% internal efficiency is to be used. Find the steam condition required at inlet of the turbine.