

Homework 1.3

Ch. 83, 36, 46, 57, 59, 80

9-33. Ideal Otto cycle has compression ratio of 8. Beginning of compression process, air is @ 95 kPa, 27°C, 750 kJ/kg of heat transferred to air during const. vol. heat addition process. Account for specific heats w/ temp.



$r = 8$	①	②	③	④
$C_p = 0.718 \text{ kJ/kg} \cdot \text{K}$	$P_1 = 95 \text{ kPa}$	$v_1 = \frac{1}{8}$	$u_3 = 1241.2 \text{ kJ/kg}$	$v_4 = v_3$
$P_r = 1.3860$	$T_1 = 300 \text{ K}$	$v_2 = 77.65$	$T_3 = 1539 \text{ K}$	$v_{r4} = 40.576$
$R = 0.2870 \text{ kJ/kg} \cdot \text{K}$	$u_1 = 214.07 \text{ kJ/kg}$	$T_2 = 673.08 \text{ K}$	$P_3 = 3898 \text{ kPa}$	$T_4 = 849.33 \text{ K}$
	$v_{r1} = 621.2$	$u_2 = 441.2 \text{ kJ/kg}$		$u_4 =$
	$q_{in} = 750 \text{ kJ/kg}$	$P_2 =$		
	$\frac{v_1}{v_2} = \frac{v_{r1}}{v_{r2}} \Rightarrow v_{r2} = \frac{1}{8} \Rightarrow 77.65$	$T_2 @ v_{r2} = 673.08 \text{ K}$	$T_3 @ v_{r3} = 1539 \text{ K}$	End state

* Use interpolation $T_2 @ v_{r2} \Rightarrow 673.08 \text{ K}$ $q_{in} = u_3 - u_2 \Rightarrow u_3 = 750 \text{ kJ/kg} + 441.2 \text{ kJ/kg} = 1191.2 \text{ kJ/kg}$

$T_3 @ u_3 \Rightarrow 1539 \text{ K}$ (Interpolation)

$v_4 = v_3 \Rightarrow v_{r4} = v_{r3} = 40.576$

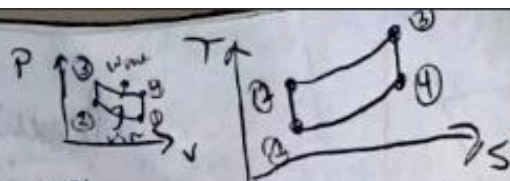
a) Pressure & Temperature at end of heat-addition process:

$$T_3 = 1539 \text{ K} \quad P_3 = T_2 \left(\frac{P_2}{T_2} \right) \Rightarrow 1539 \text{ K} \left(\frac{1705.176 \text{ kPa}}{673.08 \text{ K}} \right) = \boxed{P_3 = 3898 \text{ kPa}}$$

$$P_2 = P_1 \left(\frac{v_1}{v_2} \right)^{\gamma} = \frac{P_1}{v_2} \times \frac{T_2}{T_1} \Rightarrow \frac{95 \text{ kPa}}{300} \times \frac{673.08 \text{ K}}{300} \times 8 = 1705.176 \text{ kPa}$$

b) The net work output:

$$T_4 = 849.33$$



$$Q_{3-4} - W_{3-4} = \Delta U_{3-4}$$

$$U_3 = 1241.4 \text{ kJ/kg}$$

$$Q_{3-4} - Q_{4-1} + U_4 - U_1 - W_{out} = \Delta U_{3-4}$$

$$U_4 @ T_4 = 632.62 \text{ kJ/kg}$$

Interpolation

$$-W_{out} = \Delta U_{3-4} \Rightarrow U_3 - U_4$$

$$W_{out, 3-4} = U_3 - U_4 \Rightarrow W_{out} = C_p(T_4 - T_3) \Rightarrow 1.005 \text{ kJ/kg} \cdot (849.33 - 1539)$$

c) The thermal efficiency

$$\eta_{th} = 1 - \frac{W_{out}}{Q_{in}} \Rightarrow 1 - \frac{392.4 \text{ kJ/kg}}{750 \text{ kJ/kg}} \Rightarrow \boxed{\eta_{th} = 47.68}$$

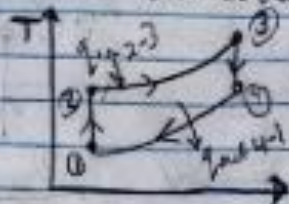
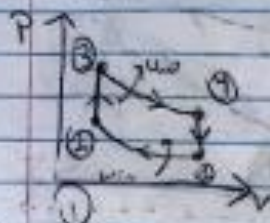
d) Mean effective pressure of cycle:

$$MEP = \frac{W_{net}}{V_{max} - V_{min}} \Rightarrow \frac{392.4}{0.906 - 0.113} = \boxed{495 \text{ kPa}}$$

$$V_3 = \frac{RT_3}{P_3} \Rightarrow \frac{0.287(1539 \text{ K})}{3898} \Rightarrow V_3 = 0.113 \text{ m}^3 \quad V_4 = V_3 \Rightarrow V_4 = 0.113 \text{ m}^3$$

$$V_1 = \frac{RT_1}{P_1} \Rightarrow \frac{0.287(3000)}{95} \Rightarrow 0.906 \text{ m}^3 \quad V_2 = \frac{V_1}{8} \Rightarrow V_2 = 0.113 \text{ m}^3$$

Ch 9:36: Ideal Otto cycle takes in air at 14 psia & 105°F, limited to max cycle of 2400°F. 6 cylinder engine each cylinder has 3.5 in & each piston stroke 3.9 in. Minimum enclosed vol is 9.3 percent of max enclosed volume. Use const. specific heats.



$$R = 0.06855 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}}$$

$$C_v = 0.171 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}}$$

$$C_p = 0.24 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}}$$

$$K = 1.4$$

$$P = \frac{RT}{V}$$

$$m = 1.0017 \text{ lbm}$$

$$P = 14 \text{ psia}$$

$$T_1 = 586.248 \text{ R}$$

$$T_3 = 2459.67 \text{ R}$$

$$T_1 = 586.248 \text{ R}$$

$$V_1 = 2.53 \text{ ft}^3$$

$$\text{Interp. } U_1 = 553.674 \frac{\text{Btu}}{\text{lbm}}$$

$$\text{Interp. } U_2 = 16.271 \frac{\text{Btu}}{\text{lbm}}, U_3 = 99.975 \frac{\text{Btu}}{\text{lbm}}$$

$$V_2 = 2.76 \text{ ft}^3$$

$$P = mRT$$

$$m = \frac{RT}{P \cdot V_1} = \frac{0.06855(586.248)}{14(2.53)}$$

$$m = \frac{V_2}{V_1} \Rightarrow 1.0017 = \frac{2.76}{V_1} \Rightarrow V_1 = 2.75 \text{ ft}^3$$

$$m = \frac{0.06855(586.248)}{14(2.76)}$$

$$V_2 = \frac{V_1}{K} \Rightarrow \frac{V_2}{V_1} = \frac{V_2}{2.75} \Rightarrow V_2 = \frac{2.53}{2.75} \times 2.75 = 2.53 \text{ ft}^3$$

$$\frac{V_{\text{max}}}{V_{\text{min}}} = \frac{V_1 + V_c}{V_2} = \frac{3.9 + 0.044 V_2}{V_2} = V_1 \Rightarrow V_2 = \frac{2.76^3 \times 3.9}{3.9 + 0.044(2.76)} = 2.53$$

$$T_2 = \left(\frac{V_1}{V_2}\right)^{K-1} \times T_1 \Rightarrow T_2 = 586.248 \text{ R}$$

$$U_2 = 99.975 \frac{\text{Btu}}{\text{lbm}}$$

$$T_3 = \left(\frac{V_3}{V_4}\right)^{K-1} \Rightarrow 2771.41 \text{ R}, V_1 = V_4$$

How much

power will this

engine produce

operated 2500 rpm

$$W_{\text{net}} = 0.06855(2771.41 - 99.975) = 18.03 \frac{\text{Btu}}{\text{lbm}}$$

$$W_{\text{net}} = 0.06855(586.248 - 553.674) = 3.69 \frac{\text{Btu}}{\text{lbm}}$$

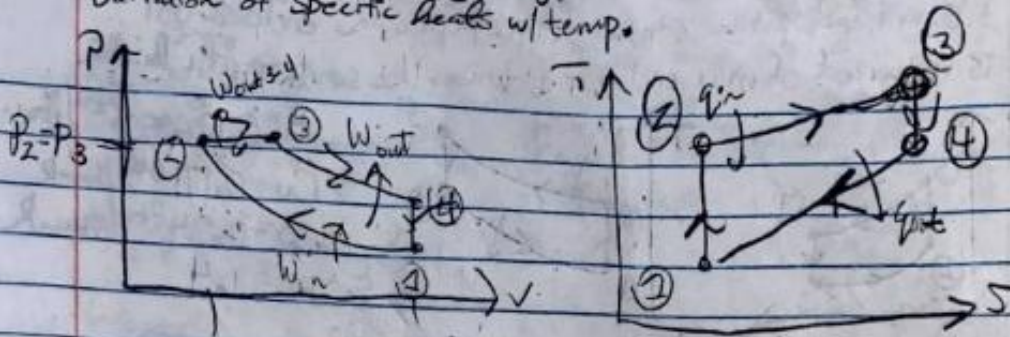
$N = K$

$$W_{\text{net}} = 14.34 \frac{\text{Btu}}{\text{lbm}}$$

$$W_{\text{net}} = \frac{m}{20} \times W_{\text{net}} \times n \Rightarrow W_{\text{net}} = \frac{1.0017 \text{ lbm}}{20} \times 14.34 \frac{\text{Btu}}{\text{lbm}} \times 2500 \text{ rpm}$$

$$W_{\text{net}} = 294.29 \frac{\text{Btu}}{\text{min}}$$

Q46.) Air standard diesel cycle has a compression ratio of 16 & cutoff ratio 2. Beginning air is 95 kPa & 27°C. Acct. for variation of specific heats w/ temp.



$$r_c = 16 \quad R = 0.2870 \text{ kJ/kg}\cdot\text{K} \quad C_v = 0.718 \text{ kJ/kg}\cdot\text{K}$$

$$C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$$

(1)	(2)	(3)	(4)
$P_1 = 95 \text{ kPa}$	$V_2 = \frac{V_1}{16} = 0.0546 \text{ m}^3$	$P_2 = 4372.63 \text{ kPa}$	$P_3 = 4372.63 \text{ kPa}$
$T_1 = 300 \text{ K}$	$V_{r2} = \frac{V_2}{V_1} = 0.0625$	$V_3 = 0.1132$	$T_4 = 150.59 \text{ K}$
$V_1 R T_1 = P_1 V_1$	$T_2 = 862.35 \text{ K}$	$T_3 = 1724.7 \text{ K}$	
$P_1 V_1 = 621.2$	$P_2 = 4372.63 \text{ kPa}$		

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$r_c = \frac{V_3}{V_2} \Rightarrow V_3 = 0.1132 \quad T_3 = \frac{P_3 V_3}{R}$$

a) Temp. after heat-additive process

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4} \right)^{\gamma-1} \Rightarrow T_4 = 150.59 \text{ K}$$

$$T_3 = 1724.7 \text{ K}$$

b) Thermal efficiency:

$$W_{net} = (W_{out, 2-3} + W_{out, 3-4}) - W_{in, 1-2}$$

$$\eta_{th} = 1 - \frac{W_{net}}{q_{in}}$$

$$W_{out, 2-3} = P_2 (V_3 - V_2) = 329.69 \text{ kJ/kg}$$

$$W_{out, 3-4} = R (T_4 - T_3) / (1 - \gamma) = 699.34 \text{ kJ/kg}$$

$$W_{in, 1-2} = R (T_2 - T_1) / (1 - \gamma) = 403.49 \text{ kJ/kg}$$

$$W_{net} = 54.109 \text{ kJ/kg}$$

$$q_{in, 2-3} = C_v (T_3 - T_2) + W_{out, 2-3}$$

$$q_{in, 2-3} = 948.2573 \text{ kJ/kg}$$

$$\eta_{th} = \frac{54.109}{948.2573} = 0.057$$

c) The mean effective pressure:

$$MEP = \frac{W_{net}}{V_{max} - V_{min}} \Rightarrow \frac{574.109 \text{ kJ/m}^3}{.906 - .0566 \text{ m}^3} \Rightarrow \boxed{675.9 \text{ kPa}}$$

$$V_2 = \frac{V_1}{R} \Rightarrow \frac{.906 \text{ m}^3}{16}$$

$$V_1 = .906 \text{ m}^3 \quad V_2 = .056625 \text{ m}^3$$

$$V_3 = \frac{P_1 V_1}{P_3} \Rightarrow$$

$$V_3 = .10735 \text{ m}^3 \quad V_4 = .906 \text{ m}^3$$

$$V_4 = 16V_3 \Rightarrow$$

$$P_1 V_1 = RT_1 \Rightarrow V_1 = .906 \text{ m}^3$$

9-57 Four cylinder 2.4L diesel cycle operates ideal diesel cycle compression ratio of 22. Air 70°C & 97kPa beginning. Using cold air assumption. Find how much power engine will deliver @ 2500 RPM.



$$C_p = 1.005 \text{ kJ/kg} \cdot \text{K} \quad R = 0.287 \text{ kJ/kg} \cdot \text{K} \quad r_{comp} = 22$$

$$C_v = 0.718 \text{ kJ/kg} \cdot \text{K} \quad K = 1.4 \quad r_{cut} = 1.8$$

① $P_1 = 97\text{kPa}$ $T_1 = 370\text{K}$ $V_1 = 1.094 \text{ m}^3$ $U_1 = 264.46 \text{ kJ/kg}$

② $P_2 = P_1$ $T_2 = 1274\text{K}$ $V_2 = 0.04976 \text{ m}^3$ $U_2 = 999.4 \text{ kJ/kg}$

③ $V_3 = V_2$ $P_3 = 7347.90 \text{ kPa}$ $T_3 = 2291.41\text{K}$ $U_3 = 264.46 \text{ kJ/kg}$

④ $V_4 = V_1$ $P_4 = 220.31 \text{ kPa}$ $T_4 = 842\text{K}$ $U_4 = 626.50 \text{ kJ/kg}$

Interpolated $U_2 = 999.4 \text{ kJ/kg}$

Work $W_{1-2} = U_2 - U_1 = 734.94 \text{ kJ/kg}$

Heat $q_{in} = 1022.5 \text{ kJ/kg}$

Energy Balance 2-3: $\Delta E = E_{in} - E_{out}$

$$\Delta U = (Q_{in} + P_{2-3}) - (Q_{out} + W_{2-3})$$

$$U_3 - U_2 = q_{in} - W_{2-3} \Rightarrow q_{in} = U_3 - U_2 + W_{2-3}$$

$$q_{in} = (U_3 - U_2) + P(V_3 - V_2)$$

$$q_{in} = U_3 - P_3 V_3 - (U_2 + P_2 V_2) \Rightarrow h_3 - h_2 = c_p(T_3 - T_2) \Rightarrow q_{in} = 1.005 \text{ kJ/kg} \cdot \text{K} (2291.41 - 1274) = 1022.5 \text{ kJ/kg}$$

Work $W_{2-3} = P(V_3 - V_2) = 292.5 \text{ kJ/kg}$

Work $W_{3-4} = U_3 - U_4 = 0.718(2291.41 - 842) = 1000.676 \text{ kJ/kg}$

Energy Balance 2-3: $\Delta E = E_{in} - E_{out}$

$$\Delta U = (Q_{in} + P_{2-3}) - (Q_{out} + W_{2-3})$$

$$U_3 - U_2 = q_{in} - W_{2-3} \Rightarrow q_{in} = U_3 - U_2 + W_{2-3}$$

$$q_{in} = (U_3 - U_2) + P(V_3 - V_2)$$

$$q_{in} = U_3 - P_3 V_3 - (U_2 + P_2 V_2) \Rightarrow h_3 - h_2 = c_p(T_3 - T_2) \Rightarrow q_{in} = 1.005 \text{ kJ/kg} \cdot \text{K} (2291.41 - 1274) = 1022.5 \text{ kJ/kg}$$

Work $W_{2-3} = P(V_3 - V_2) = 292.5 \text{ kJ/kg}$

Work $W_{3-4} = U_3 - U_4 = 0.718(2291.41 - 842) = 1000.676 \text{ kJ/kg}$

$$\dot{W}_{net} = \frac{m}{120} \times \dot{n} \times W_{net}$$

$$V_L = 10^{-3} \text{ m}^3$$

$$V_1 = \frac{V_L}{m}$$

$$W_{net} = 1332.68 \text{ kJ/kg}$$

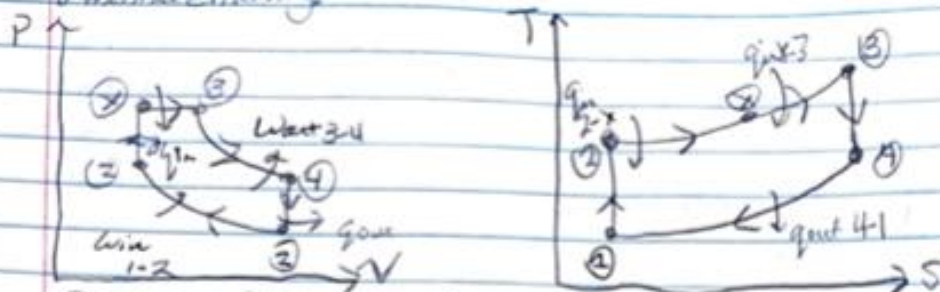
$$\dot{n} = 3500 \text{ rev/min}$$

$$m = \frac{V_L}{V_1} \Rightarrow \frac{.6 \text{ L}}{1.094 \frac{\text{m}^3}{\text{kg}}} \times \frac{1 \text{ m}^3}{1000 \text{ L}}$$

$$\dot{W}_{net} = \frac{0.000548 \text{ kg}}{120 \frac{\text{rev}}{\text{min}} \times \frac{1 \text{ min}}{60 \text{ sec}}} \times 3500 \frac{\text{rev}}{\text{min}} \times 1332.68 \frac{\text{kJ}}{\text{kg}} \quad m = 0.000548 \text{ kg}$$

$$\dot{W}_{net} = 21.31 \text{ kJ/s}$$

9-59E Ideal dual cycle has compression ratio of 15 & cutoff of 1.4. Pressure ratio during constant-volume heat addition is 1.1. Stroke of air at beginning of compression 14.2 in & 750F. Use const. specific heats @ Room Temp. Find cycle's net specific work & specific heat addition & thermal efficiency.



$$R = 0.06855 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}} \quad k = 1.4$$

$$C_p = 0.240 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}} \quad C_v = 0.171 \frac{\text{Btu}}{\text{lbm} \cdot \text{R}}$$

$$\begin{array}{llll} \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} \\ P_1 = 14.2 \text{ psia} & V_2 = \frac{V_1}{15} = 0.947 \text{ ft}^3/\text{lbm} & V_3 = V_2 \cdot 1.4 = 1.326 \text{ ft}^3/\text{lbm} & V_4 = 2.579 \text{ ft}^3/\text{lbm} \\ T_1 = 750 \text{ R} & T_2 = 1580 \text{ R} & P_3 = 69.86 \text{ psia} & P_4 = 25.036 \text{ psia} \\ V_1 = 14.2 \text{ in}^3 & P_2 = 629.87 \text{ psia} & T_3 = 1739 \text{ R} & V_4 = 2.579 \text{ ft}^3/\text{lbm} \end{array}$$

$$V_1 = \frac{RT_1}{P_1}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow T_2 = 1580 \text{ R}$$

$$P_2 = \frac{RT_2}{V_2} = 629.87 \text{ psia}$$

$$r_p = 1.1 = \frac{P_3}{P_2}$$

$$T_3 = \frac{V_3 P_3}{R} = 1739 \text{ R}$$

$$r_c = \frac{V_3}{V_2} = 1.4$$

$$T_3 = \frac{P_3 V_3}{R} = 1739 \text{ R}$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{k-1} \Rightarrow T_4 = 942 \text{ R}$$

$$P_4 = \frac{RT_4}{V_4} = 25.036 \text{ psia}$$

$$W_{\text{net}} = W_{\text{out}} + W_{\text{out}} - W_{\text{in}} = 123.85 \frac{\text{Btu}}{\text{lbm}} = W_{\text{net}}$$

$$W_{\text{out } 2-3} = P_2 (V_3 - V_2) = 47.64 \frac{\text{Btu}}{\text{lbm}}$$

$$W_{\text{out } 3-4} = \frac{R(T_3 - T_4)}{1 - k} = 258.35 \frac{\text{Btu}}{\text{lbm}}$$

$$W_{\text{in } 1-2} = \frac{R(T_2 - T_1)}{1 - k} = 179.14 \frac{\text{Btu}}{\text{lbm}}$$

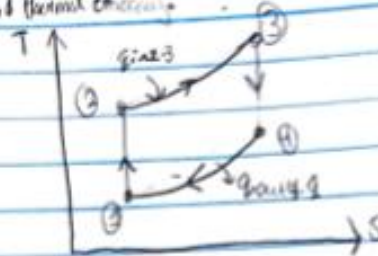
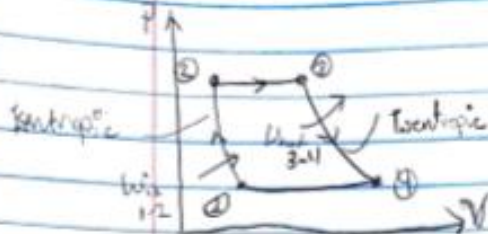
$$q_{\text{in } 2-3} = U_3 - U_2 + W_{\text{out } 2-3} \quad \text{Interpolated } U_3 @ T_3 = 463.54 \frac{\text{Btu}}{\text{lbm}}$$

$$q_{\text{in } 2-3} = 463.54 - 282.095 + 47.64 = 229.1 \frac{\text{Btu}}{\text{lbm}}$$

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{q_{\text{in}}} = \frac{123.85}{229.1} = 0.545 = \eta_{\text{th}}$$

9-80E:

Simple ideal Brayton cycle of air as the working fluid has a pressure ratio of 10. Air enters compressor @ 520R & turbine @ 2000R. Acct. for the variation of specific heats w/ temperature. Find a) air temperature at compressor exit. b) Back work ratio, & thermal efficiency.



①	②	③	④
$T_1 = 520R$	$P_2 = 12.147$	$T_3 = 2000R$	$P_4 = P_3/10$
$P_1 = 1.2147$	$T_2 = 996.48R$	$P_3 = 174$	$P_4 = P_1$
			$T_4 = 1099.31R$
			$\frac{P_4}{P_3} = \frac{P_1}{P_2} \Rightarrow P_{r4} = 17.40$

Interpolation: $T_2 @ P_2$

a) Air temperature at compressor exit:

$T_2 = ?$

$T_2 = 996.48R$

$T_4 @ P_4 = 1099.31R$

Interpolation

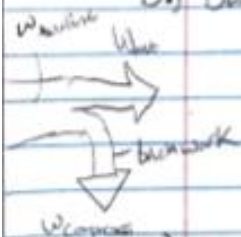
$h_1 @ T_1 = 124.27 \text{ Btu/lbm}$

$h_2 @ T_2 = 240.11 \text{ Btu/lbm}$

$h_3 @ T_3 = 504.71 \text{ Btu/lbm}$

$h_4 @ T_4 = 265.83 \text{ Btu/lbm}$

b) Back work ratio:



$$\frac{W_{\text{compressor}}}{W_{\text{turb}}} = \frac{W_{\text{in } 1-2}}{W_{\text{out } 3-4}} = \frac{h_2 - h_1}{h_3 - h_4} \Rightarrow \eta_b = 0.4849$$

c) The Thermal efficiency:

$W_{\text{in } 1-2} = 115.84 \text{ Btu/lbm}$

$W_{\text{out } 3-4} = 238.85 \text{ Btu/lbm}$

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{q_{\text{in}}} = \frac{W_{\text{out } 3-4} - W_{\text{in } 1-2}}{q_{\text{in } 2-3}} = \frac{238.85 - 115.84}{264.6} = 0.465$$

$q_{\text{in } 2-3} = h_3 - h_2 = 264.6$

$\eta_{\text{th}} = 0.465$