

## Example - Piston

- ◆ A piston-cylinder contains 5 kg of air. During a compression process, 100 kJ of heat is removed while 250 kJ of work is done on the air. Find the change in internal energy in kJ/kg.

Solution

$$Q_{in} = -100 \text{ kJ}$$

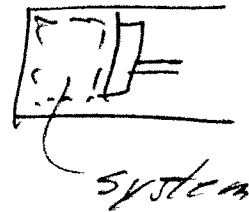
$$-W_{in} = 250 \text{ kJ}$$

$$\Delta U = Q_{in} + W_{in}$$

$$= -100 \text{ kJ} + 250 \text{ kJ}$$

$$m \Delta u = 150 \text{ kJ}$$

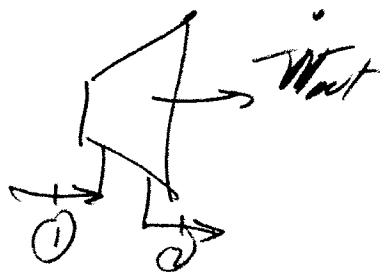
$$\Delta u = \frac{\Delta U}{m} = \frac{150 \text{ kJ}}{5 \text{ kg}} = 30 \frac{\text{kJ}}{\text{kg}}$$



## Example - Turbine

- ◆ Heated air enters a turbine at a flow rate of 5 kg/s. The entering and leaving conditions are shown below. The heat loss from the turbine is 50 kW. Find the power produced.

	Inlet	Outlet
Pressure, kPa	1000	100
Temperature, K	800	500
Specific Internal Energy, kJ/kg	137	85
Specific Volume, m <sup>3</sup> /kg	0.23	1.44



$$\frac{dm}{dt} = m_1 - m_2 \Rightarrow \dot{m} = m_1 = m_2$$

SS

$$\frac{dE}{dt} = \dot{Q}_{in} + \dot{W}_{in} + \dot{m} \left[ h_1 - h_2 + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2) \right]$$

SS  $\dot{Q} = -50 \text{ kW}$

Negligible  
insufficient in Po

$$\therefore -\dot{W}_{out} = \dot{Q}_{in} + \dot{m} [h_1 - h_2]$$

$$h_1 = u_1 + P_1 v_1 = 137 + (1000)(0.23) = 367 \text{ kJ/kg}$$

$$h_2 = u_2 + P_2 v_2 = 229.0 \text{ kJ/kg}$$

$$\dot{W}_{out} = -50 \text{ kW} + \left(5 \frac{\text{kg}}{\text{s}}\right) (367 - 229) \frac{\text{kJ}}{\text{kg}} = \underline{\underline{640 \text{ kW}}}$$

## Example - Property Tables

◆ Fill in the following table for steam (water).

	T, °C	P, kPa	x, %	h, kJ/kg	u, kJ/kg	v, m <sup>3</sup> /kg
a)	200			852.45		
b)		150			1000	
c)	300	800				
d)	200	5000				
e)		300				0.85
f)	300		80			
g)		1000	90			

a)  $P = P_{sat} = 1.5538 \text{ MPa}$ ;  $x = 0$  Sat. Liquid  
 $u = 850.65 \frac{\text{kJ}}{\text{kg}}$ ;  $v = 0.001157 \frac{\text{m}^3}{\text{kg}}$

b) Two-Phase Mix - double interpolation  
 in a Sat. Water-Temperature Table

c) S+V.  $x = \text{Not Applicable}$

$$h = 3056.5 \frac{\text{kJ}}{\text{kg}}; v = 0.3241 \frac{\text{m}^3}{\text{kg}}; u = 2797.2 \frac{\text{kJ}}{\text{kg}}$$

d) Compressed Liquid

$$v = v_f(200^\circ\text{C}) = 0.001157 \frac{\text{m}^3}{\text{kg}}$$

$$u = u_f(200^\circ\text{C}) = 850.65 \frac{\text{kJ}}{\text{kg}}$$

$$h = u_f + Pv_f = 850.65 + (5000)(0.001157) = 856.44 \frac{\text{kJ}}{\text{kg}}$$

e) Double interpolation in  
Superheated Vapor Tables

f)  $300^\circ\text{C}$  &  $x = 80\%$

$$P = P_{\text{sat}}(300^\circ\text{C}) = 8.581 \text{ MPa}$$

$$v = 0.001404 + (0.80)[0.02167 - 0.001404]$$
$$= 0.01762 \text{ m}^3/\text{kg}$$

$$u = 1332.0 + 0.8(1231.0)$$
$$= 2316.80 \text{ kJ/kg}$$

$$h = 1344 + 0.8(1404.9) = 2467.92 \frac{\text{kJ}}{\text{kg}}$$

g) Double interpolation in Saturated  
Water - Temperature Table

## Example - Processes

- ◆ Air at 27 C is heated to 927 C. Find the change in enthalpy and internal energy, using constant specific heats ( $c_p=1.0047$  kJ/(kg-K),  $c_v=0.717$  kJ/(kg-K) and the air tables.

T, K	h, kJ/kg	u, kJ/kg
300	300.19	214.07
1200	1277.79	933.33

$$\Delta u = u_2 - u_1 = \begin{cases} 933.33 - 214.07 = 719.26 \frac{\text{kJ}}{\text{kg}} \\ 0.717(927-27) = 645.30 \end{cases}$$

$$\Delta h = h_2 - h_1 = \begin{cases} 1277.79 - 300.19 = 977.6 \frac{\text{kJ}}{\text{kg}} \\ 1.0047(927-27) = 904.2 \frac{\text{kJ}}{\text{kg}} \end{cases}$$

## Example - Carnot

- ◆ A Carnot machine operates between a hot reservoir at 200 C and a cold reservoir at 20 C. a) When operated at an engine, it receives 1000 kJ/kg; find the work output. b) Find the COP when operated as a refrigerator and a heat pump.

$$(b) \quad \text{COP}_{\text{REF}} = \frac{T_L}{T_H - T_L} = \frac{20 + 273}{473 - 293} = 1.63$$

$$\text{COP}_{\text{HP}} = \frac{T_H}{T_H - T_L} = \frac{473}{473 - 293} = 2.63$$

$$(a) \quad \eta_{\text{CARNOT}} = 1 - \frac{T_L}{T_H} = 1 - \frac{293}{473} = 0.3805$$

$$W_{\text{out}} = \eta Q_{\text{in}} \rightarrow W_{\text{out}} = (0.3805) 1000 \frac{\text{kJ}}{\text{kg}} = 380.5 \frac{\text{kJ}}{\text{kg}}$$

## Example - Brayton

- An air standard Brayton cycle has air entering the compressor at 27 C and 100 kPa. The pressure ratio is 10 and the maximum temperature is 1350 K. Find all state properties and the thermal efficiency. The value of k for air is 1.4

State	T, K	P, kPa	v, m <sup>3</sup> /kg	K	kPa	m <sup>3</sup> /kg
1				300	100	0.8610
2				579	1000	
3				1350	1000	
4				699	100	

$$\textcircled{1} \rightarrow \textcircled{2} \text{ Compressor: } \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 1.9307$$

$$C_p = \frac{k}{k-2} R = \frac{1.4}{0.4} (0.287) = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$W_{in} = h_2 - h_1 = (1.005) [579 - 300] = 280.4 \frac{\text{kJ}}{\text{kg}}$$

$$\textcircled{2} - \textcircled{3} \text{ HX: } q_{in} = h_3 - h_2 = (1350 - 579)(1.005) = 774.9 \frac{\text{kJ}}{\text{kg}}$$

$$\textcircled{3} \rightarrow \textcircled{4} \text{ Turbine: } \frac{T_4}{T_3} = \left(\frac{1}{10}\right)^{\frac{k-1}{k}} = 0.5179 \rightarrow T_4 = 699.2 \text{ K}$$

$$W_{turbine} = h_3 - h_4 = (1.005) [1350 - 699] = 654.3 \frac{\text{kJ}}{\text{kg}}$$

$$\eta = \frac{W_{out, NET}}{q_{in}} = \frac{654.3 - 280.4}{774.9} = 0.4825$$