



**Sharif University of Technology  
School of Mechanical Engineering  
Center of Excellence in Energy Conversion**

# **Advanced Thermodynamics**

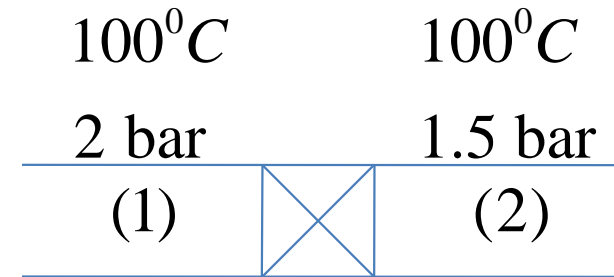
## **Lecture 15**

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Ø Concept of recovering lost work.

Ø Example:



Throttling process  $\rightarrow h_1 = h_2$  ideal gas  $T_1 = T_2$

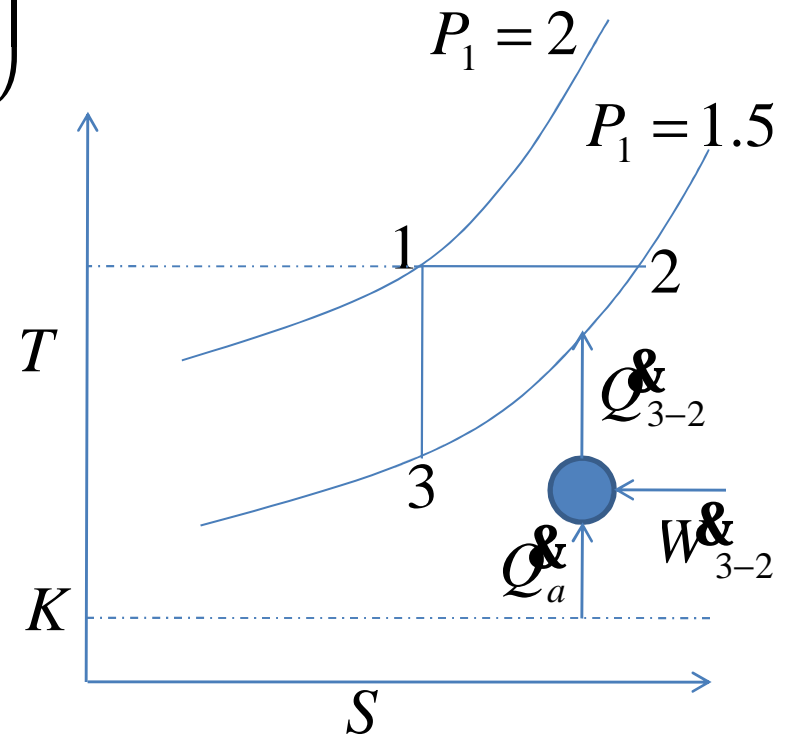
$$\dot{S}_{gen} = \dot{m} \Delta S = \dot{m} c_p \ln \left( \frac{T_2}{T_1} \right) + R_u \ln \left( \frac{P_2}{P_1} \right)$$

$$\Rightarrow \dot{S}_{gen} = 0.082194 \frac{KJ}{K \text{ sec}}$$

$$h_{2^{nd} \text{ law}} = \frac{W_{actual \ 1-2}}{W_{rev \ 1-2}} = 0$$

$$W_{lost} = T_0 \dot{S}_{gen}$$

$$T_0 = 293.15 \text{ K}$$



Ø Process 1-3: Adiabatic expansion through reversible turbine

$$\frac{T_1}{T_3} = \left( \frac{P_1}{P_3} \right)^{\frac{-k-1}{k}} = \left( \frac{2}{1.5} \right)^{0.287} \rightarrow T_3 = T_1 (0.75)^{-0.287}$$

$$\dot{W}_{1-3} = \dot{m}(h_1 - h_3) = \dot{m}c_p(T_1 - T_3) \Rightarrow \dot{W}_{1-3} = 29.44 \text{ KJ/sec}$$

Ø Process 3-2: Reversible heating from a heat pump at source

$$\left. \begin{array}{l} 1^{\text{st}} \text{ law} \rightarrow \dot{Q}_{3-2} = \dot{W}_{3-2} + \dot{Q}_a \\ \frac{\dot{Q}_{3-2}}{T_{SA, 3-2}} = \frac{\dot{Q}_a}{T_0} \end{array} \right\} \rightarrow \dot{W}_{3-2} = \dot{Q}_{3-2} \left[ 1 - \frac{T_0}{T_{SA, 3-2}} \right]$$

$$T_{SA, 3-2} \equiv \frac{\dot{Q}_{3-2}}{\int_3^2 \frac{dQ}{T}} = \frac{\dot{Q}_{3-2}}{\dot{m}c_p \int_3^2 \frac{dT}{T}} \Rightarrow T_{SA, 3-2} = \frac{\dot{Q}_{3-2}}{\ln \left( \frac{T_2}{T_3} \right)}$$

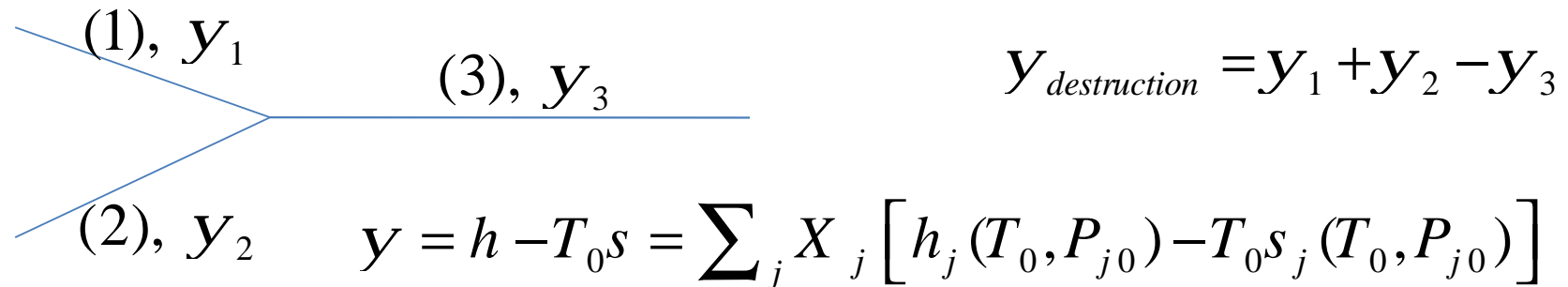
$$\int dW = \int dQ \Rightarrow \dot{Q}_{3-2} = \dot{W}_{1-3} = 29.44 \text{ KJ/sec}$$

$$\left. \begin{array}{l} T_3 = T_1 (0.75)^{-0.287} \\ T_1 = T_2 = 373.15 \text{ K} \end{array} \right\} \rightarrow T_{SA, 3-2} = \frac{\dot{Q}_{3-2}}{\ln\left(\frac{T_2}{T_3}\right)} = 358.23 \text{ K}$$

$$\dot{W}_{3-2} = \dot{Q}_{3-2} \left[ 1 - \frac{T_0}{T_{SA, 3-2}} \right] = 29.44 \left[ 1 - \frac{293.15}{358.23} \right] = 5.3489 \text{ KJ/sec}$$

$$\dot{W}_{lost} = T_0 \dot{S}_{gen} = \dot{W}_{1-3-2} = \dot{W}_{1-3} - \dot{W}_{3-2} = 29.44 - 5.3489 = 24.092 \text{ KW}$$

∅ Mixing of two wet air flows in SSSF process:



∅  $h_j$  and  $s_j$  are the conditions at the reference state and  $h$  and  $s$  are at the mixing.  $X_j$  is the mole fraction of  $j$ th component.

∅ For a single component ideal gas:

$$y = c_{p_j} T_0 \left( \frac{T}{T_0} - 1 - \ln \left[ \frac{T}{T_0} \right] \right) + R_j T_0 \ln \left[ \frac{P}{X_{j0} P_0} \right]$$

∅ If the composition is similar to the reference state ,  $T_0$  and  $P_0$  :

$$y = (h - T_0 s) - [h(T_0, P_0) - T_0 s(T_0, P_0)]$$
$$\rightarrow \Delta y = \Delta h - T_0 \Delta s$$

$$\text{Ideal gas} \rightarrow y = c_P T_0 \left( \frac{T}{T_0} - 1 - \ln \left[ \frac{T}{T_0} \right] \right) + R T_0 \ln \left[ \frac{P}{P_0} \right]$$

For incompressible (liquid, solid)  $\rightarrow$

$$y = c T_0 \left( \frac{T}{T_0} - 1 - \ln \left[ \frac{T}{T_0} \right] \right) + v (P - P_0)$$