Module

4

Lecture
3

Asansol Engineering College
Department of Mechanical Engineering

Thermodynamics

First Law for Flow Processes

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Topics to be discussed in present lecture

- **Turbines, Pumps, and Compressors**
- **Solved example on compressor**
- **Throttling devices**
- **Solved example on throttling device**

Turbines, Pumps, and Compressors

- In steam, gas, or hydroelectric power plants, the device that drives the electric generator is the turbine.
- As the fluid passes through the turbine, work is done against the blades, which are attached to the shaft. As a result, the shaft rotates, and the turbine produces work.
- The work done in a turbine is positive since it is done by the fluid.

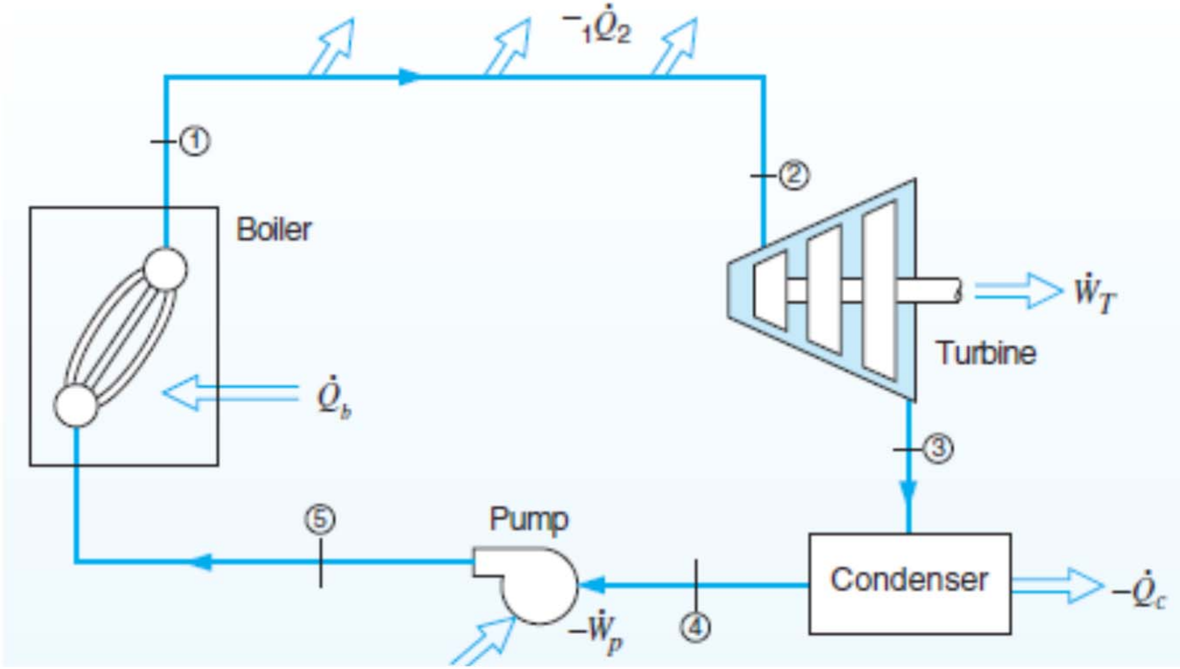
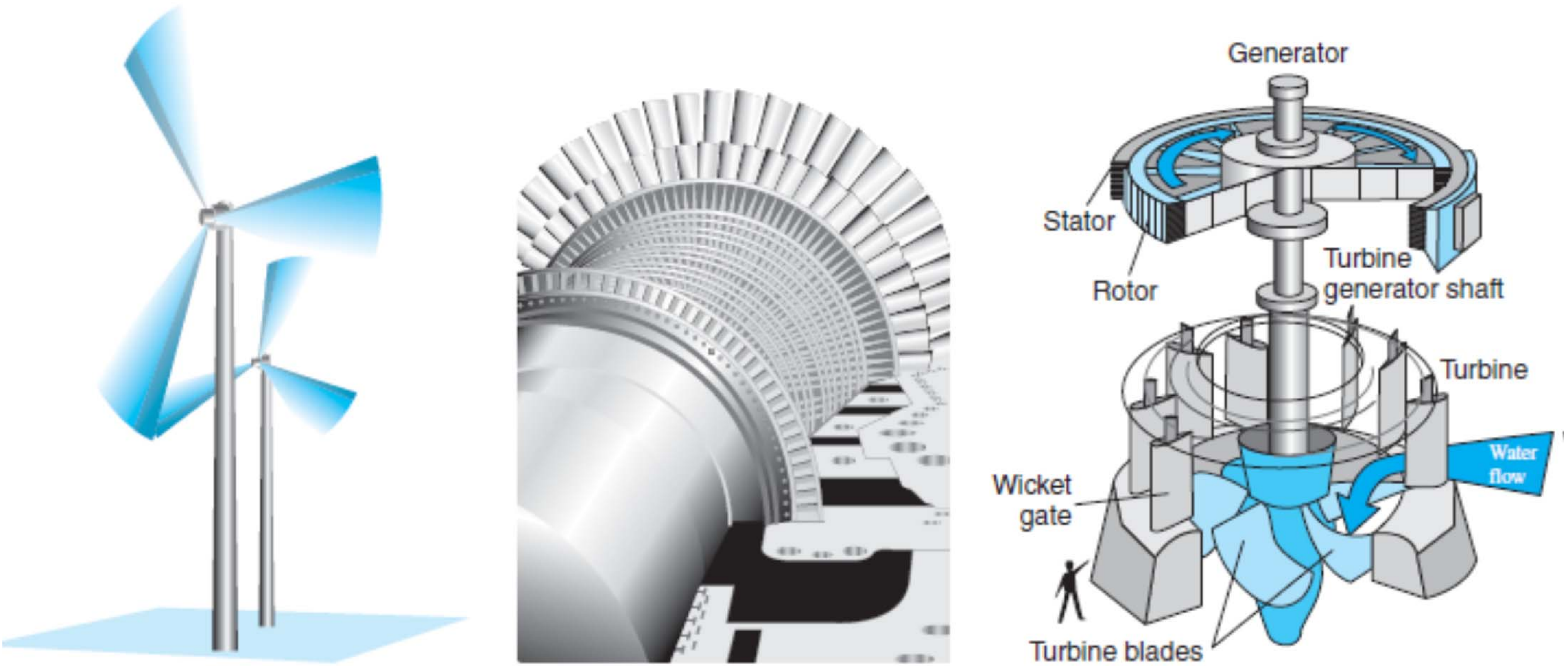


Fig. 4.8: Simple steam power plant.

Turbines, Pumps, and Compressors (*Contd…*)

- *Compressors*, as well as *pumps and fans*, are devices used to increase the pressure of a fluid.
- Work is supplied to these devices from an external source through a rotating shaft. Therefore, compressors involve work inputs.
- Even though these three devices function similarly, they do differ in the tasks they perform.
- A *fan* increases the pressure of a gas slightly and is mainly used to mobilize a air or gas.
- A *compressor* is capable of compressing the gas to higher pressures.
- *Pumps* work very much like compressors except that they handle liquids instead of gases.



(*a*) Large wind turbine (*b*) Steam turbine shaft with rotating blades (*c*) A turbine in a dam

Fig. 4.9: Examples of turbine

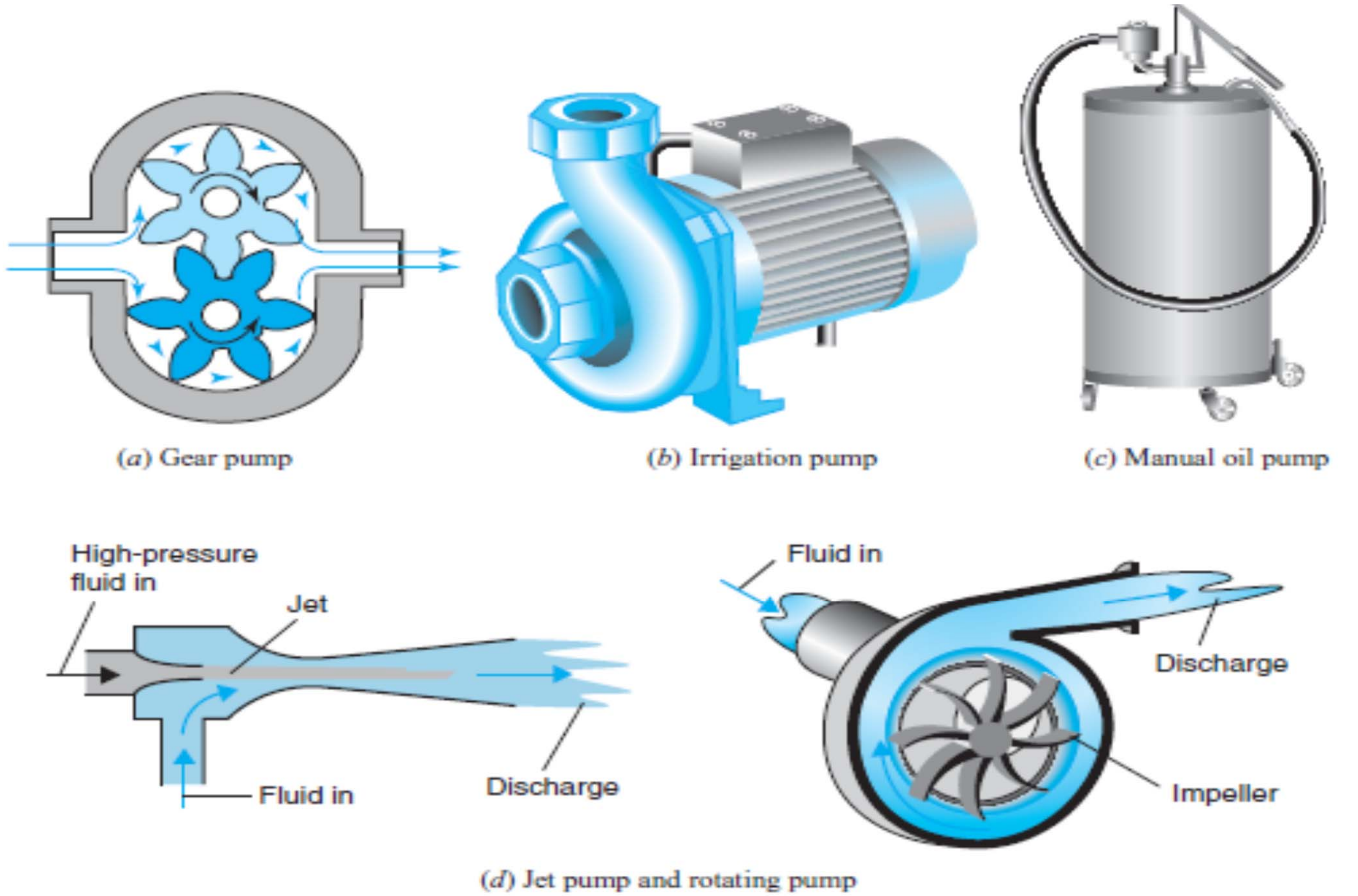


Fig. 4.10: Examples of pump

Turbines, Pumps, and Compressors (*Contd…*)

Assumptions: (1) adiabatic, Q = 0

(2) change in potential energy negligible

(3) steady-state, d/dt = 0

(4) change in kinetic energy negligible

$$\cancel{\frac{dE_{CV}}{dt}} = \cancel{\dot{Q}} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + \cancel{\frac{V_{in}^2}{2}} + \cancel{gz_{in}}\right) - \sum \dot{m}_{out}\left(h_{out} + \cancel{\frac{V_{out}^2}{2}} + \cancel{gz_{out}}\right)$$

$$\boxed{\frac{\dot{W}}{\dot{m}} = h_{in} - h_{out}}$$

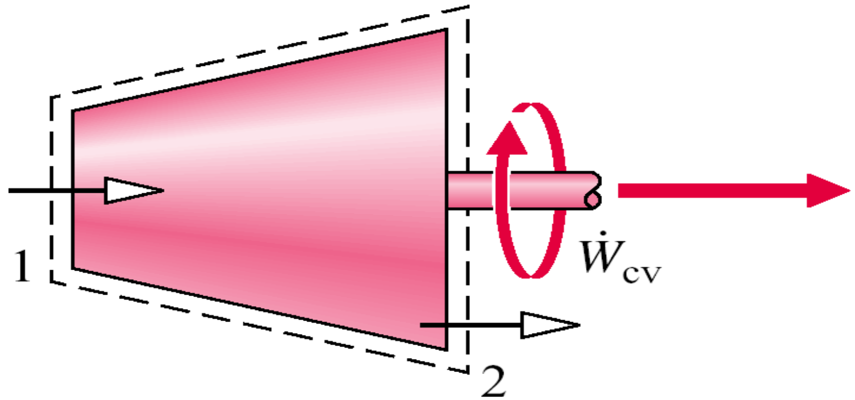


Fig. 4.11: Turbine.

Turbines, Pumps, and Compressors (*Contd…*)

Turbine and compressor/pump efficiencies both compare the performance of an actual device to the performance of an ideal, isentropic device operating *between the same pressures.*

- **Turbine Efficiency:** In turbines, the actual power generation will be less than the ideal power generation

$$\eta_t = \frac{\Delta h_{actual}}{\Delta h_{ideal}} = \frac{\left(h_{inlet} - h_{outlet}\right)_{actual}}{\left(h_{inlet} - h_{outlet,s}\right)_s}$$

isentropic

- **Pump/Compressor Efficiency:** In pumps/compressors, the actual power consumption will be greater than the ideal power consumption

isentropic

$$\eta_c = \frac{\Delta h_{ideal}}{\Delta h_{actual}} = \frac{\left(h_{outlet} - h_{inlet,s}\right)_s}{\left(h_{outlet} - h_{inlet}\right)_{actual}}$$

Turbines, Pumps, and Compressors (*Contd…*)

Example 4.2

Calculate the power required to compress 10 kg/s of air from 1 atm and 37 °C to 2 atm and 707 °C.

For low pressure air: T = 310 K; h = 290.4 kJ/kg
T = 980 K; h = 1023 kJ/kg

Analysis:

$$\cancel{\frac{dE_{CV}}{dt}} = \cancel{\dot{Q}} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + \cancel{\frac{V_{in}^2}{2}} + \cancel{gz_{in}}\right) - \sum \dot{m}_{out}\left(h_{out} + \cancel{\frac{V_{out}^2}{2}} + \cancel{gz_{out}}\right)$$

$$\boxed{\dot{W} = \dot{m}(h_{in} - h_{out})}$$

$$\dot{W} = 10\,\tfrac{kg}{s}(290.4 - 1023)\ \tfrac{kJ}{kg}$$

$$\dot{W} = -7326\,\tfrac{kJ}{s} = -7326\text{ kW}$$

$$\boxed{\dot{W}_c = 7326\text{ kW}}$$

Done ON system

Throttling Valves

- Throttling valves are *any kind of flow-restricting devices* that cause a significant pressure drop in the fluid.
- Some familiar examples are ordinary *adjustable valves, capillary tubes, and porous plugs* (Fig. 4.12).
- Unlike turbines, they produce a pressure drop without involving any work.
- The pressure drop in the fluid is often accompanied by a *large drop in temperature,* and for that reason throttling devices are commonly used in *refrigeration and air-conditioning applications*.
- The magnitude of the temperature drop (or, sometimes, the temperature rise) during a throttling process is governed by a property called the *Joule-Thomson coefficient.*

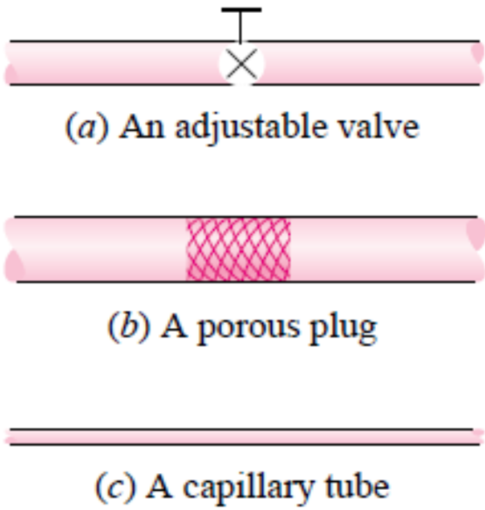
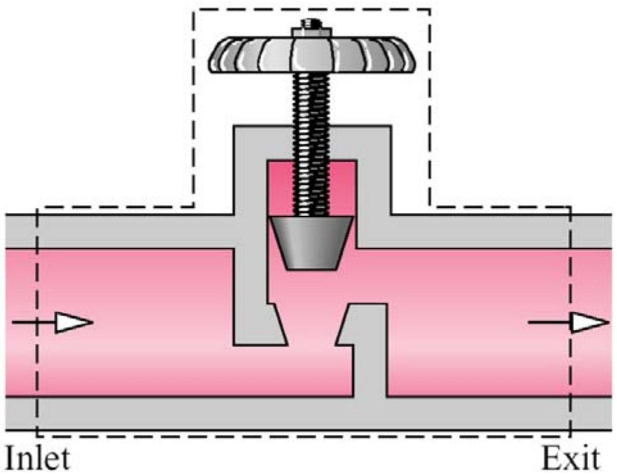


Fig. 4.12: Throttling valves are devices that cause large pressure drops in the fluid

Throttling Valves (*Contd…*)

Assumptions: (1) adiabatic, Q = 0
(2) no volume changes, W = 0
(3) steady-state, d/dt = 0
(4) change in potential energy negligible
(5) change in kinetic energy negligible

$$\cancel{\frac{dE_{C\forall}}{dt}} = \cancel{\dot{Q}} - \cancel{\dot{W}} + \sum \dot{m}_{in}\left(h_{in} + \cancel{\frac{V_{in}^2}{2}} + \cancel{gz_{in}}\right) - \sum \dot{m}_{out}\left(h_{out} + \cancel{\frac{V_{out}^2}{2}} + \cancel{gz_{out}}\right)$$



$$\boxed{h_{in} = h_{out}}$$

Isenthalpic process

Throttling Valves (*Contd…*)

Example 4.3

Refrigerant-134a enters the capillary tube of a refrigerator as saturated liquid at 0.8 MPa and is throttled to a pressure of 0.12 MPa. Determine the quality of the refrigerant at the final state and the temperature drop during this process.

SOLUTION A capillary tube is a simple flow-restricting device that is commonly used in refrigeration applications to cause a large pressure drop in the refrigerant. Flow through a capillary tube is a throttling process; thus, the enthalpy of the refrigerant remains constant

$$\textit{At inlet:}\ \left.\begin{array}{l} P_1 = 0.8\ \text{MPa} \\ \text{sat. liquid} \end{array}\right\} \quad \begin{array}{l} T_1 = T_{\text{sat @ 0.8 MPa}} = 31.33^\circ\text{C} \\ h_1 = h_{f\,@\,0.8\ \text{MPa}} = 93.42\ \text{kJ/kg} \end{array} \qquad \text{(Table A–12)}$$

$$\textit{At exit:}\quad \begin{array}{l} P_2 = 0.12\ \text{MPa} \\ (h_2 = h_1) \end{array} \longrightarrow \begin{array}{l} h_f = 21.32\ \text{kJ/kg} \\ h_g = 233.86\ \text{kJ/kg} \end{array} \quad T_{\text{sat}} = -22.36^\circ\text{C}$$

Obviously $h_f < h_2 < h_g$; thus, the refrigerant exists as a saturated mixture at the exit state. The quality at this state is

$$x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{93.42 - 21.32}{233.86 - 21.32} = \mathbf{0.339}$$

Since the exit state is a saturated mixture at 0.12 MPa, the exit temperature must be the saturation temperature at this pressure, which is −22.36°C. Then the temperature change for this process becomes

$$\Delta T = T_2 - T_1 = (-22.36 - 31.33)°\text{C} = \mathbf{-53.69°C}$$

References:

1. Sonntag, R. E, Borgnakke, C. and Van Wylen, G. J., 2003, 6th Edition, *Fundamentals of Thermodynamics*, John Wiley and Sons.

1. Jones, J. B. and Duggan, R. E., 1996, *Engineering Thermodynamics*, Prentice-Hall of India

3. Moran, M. J. and Shapiro, H. N., 1999, *Fundamentals of Engineering Thermodynamics*, John Wiley and Sons.

4. Nag, P.K, 1995, *Engineering Thermodynamics*, Tata McGraw-Hill Publishing Co. Ltd.

5. Y. A. Çengel and M. A. Boles, Thermodynamics: *An Engineering Approach*, McGraw-Hill

Topics to be discussed in next lecture

- **Heat Exchangers**
- **Solved Example on Heat Exchanger**
- **Boilers, Condensers, and Evaporators**
- **Mixing Chambers**

Thank You