Application of Thermodynamics

Flow Processes

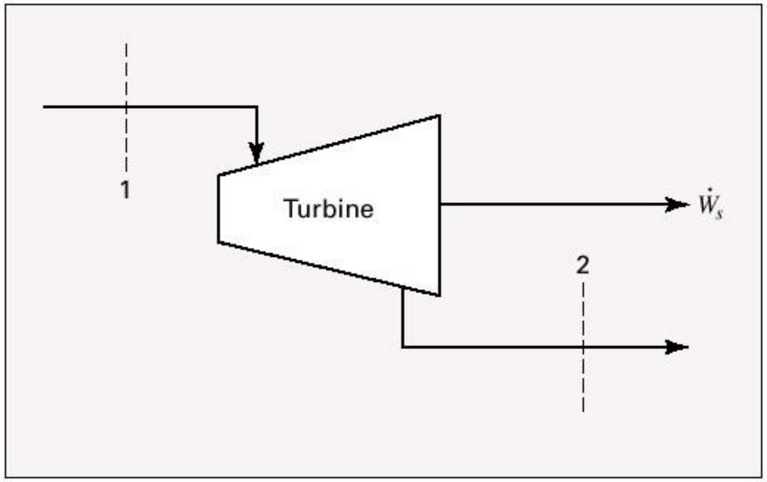
Power Production

Refrigeration & Liquefaction

CHE F213 CHEMICAL ENGINEERING THERMODYNAMICS

Applications of Thermodynamics to Flow Processes

- **Turbines (Expanders)**
  - Consists of sets of nozzles and rotating blades through which vapor or gas flows in steady-state expansion process
  - The overall result is conversion of enthalpy change into shaft work $\dot{W}_s = \dot{m}\Delta H = \dot{m}(H_2 - H_1) \qquad (7.13)$



-If the fluid in the turbine expands isentropically (ΔS constant) the shaft work is maximum. $W_s(isentropic) = (\Delta H)_S \qquad (7.15)$

- Actual turbine produces less work due to irreversibilities

- So turbine efficiency is defined as

$$\boxed{\eta = \frac{W_s}{W_s(isentropic)} = \frac{\Delta H}{(\Delta H)_S}} \qquad (7.16)$$

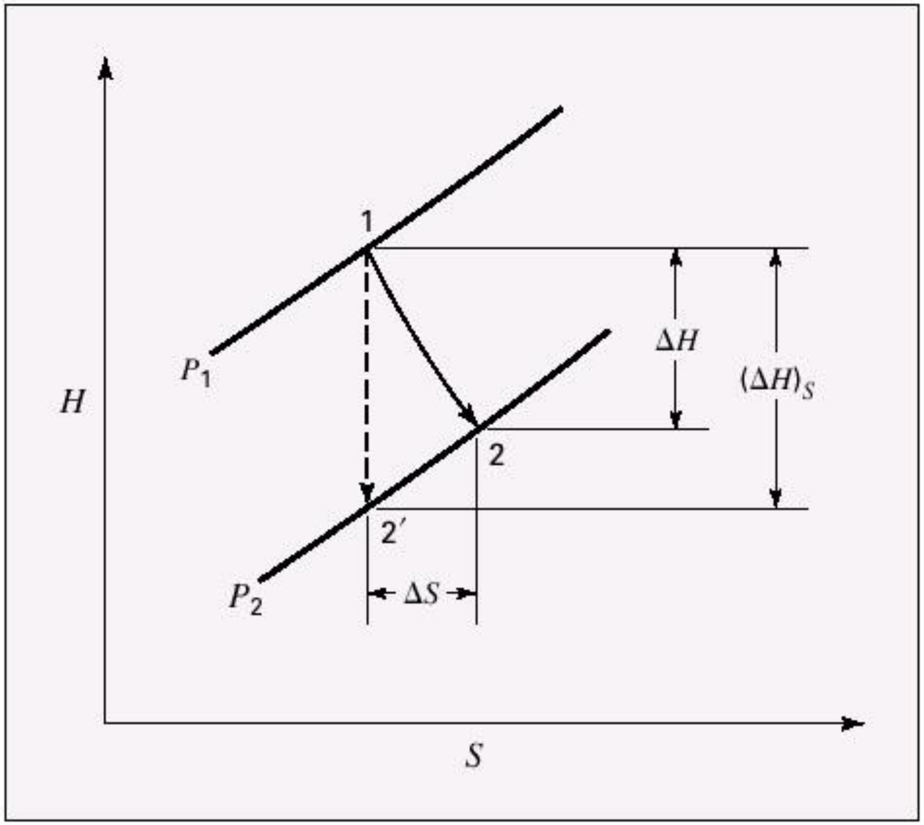
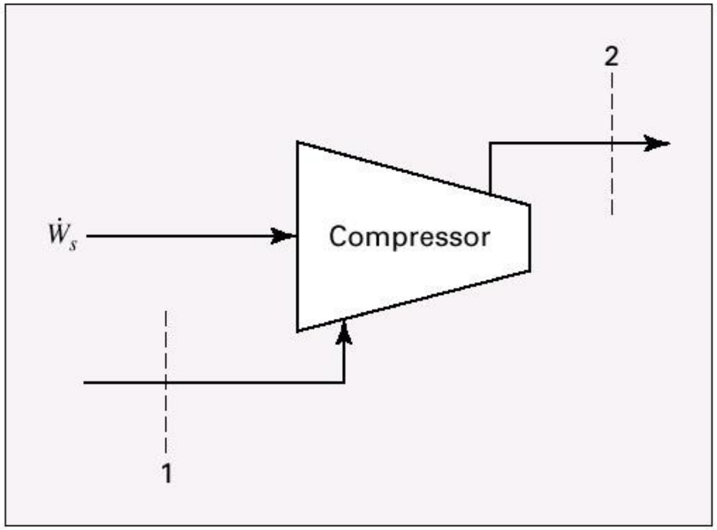
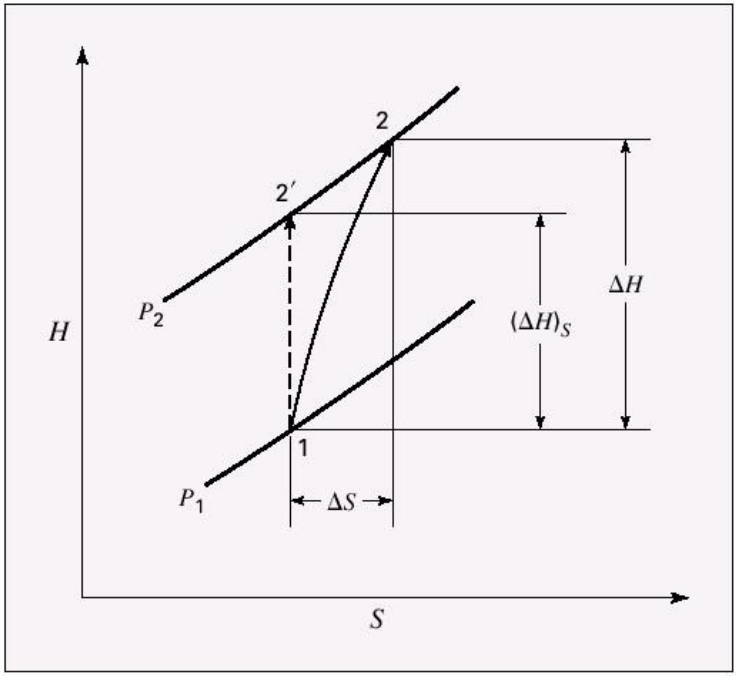


Figure 7.4: Adiabatic expansion process in a turbine or expander.

- **Compressors**
  - Reciprocating type and rotary type
  - The energy equation is same as for turbine or expanders
  - The isentropic work is the minimum shaft work required for compression for a gas





  - Compressor efficiency is defined as

$$\boxed{\eta = \frac{W_s(isentropic)}{W_s} = \frac{(\Delta H)_S}{\Delta H}} \qquad (7.17)$$

Production of Power from Heat

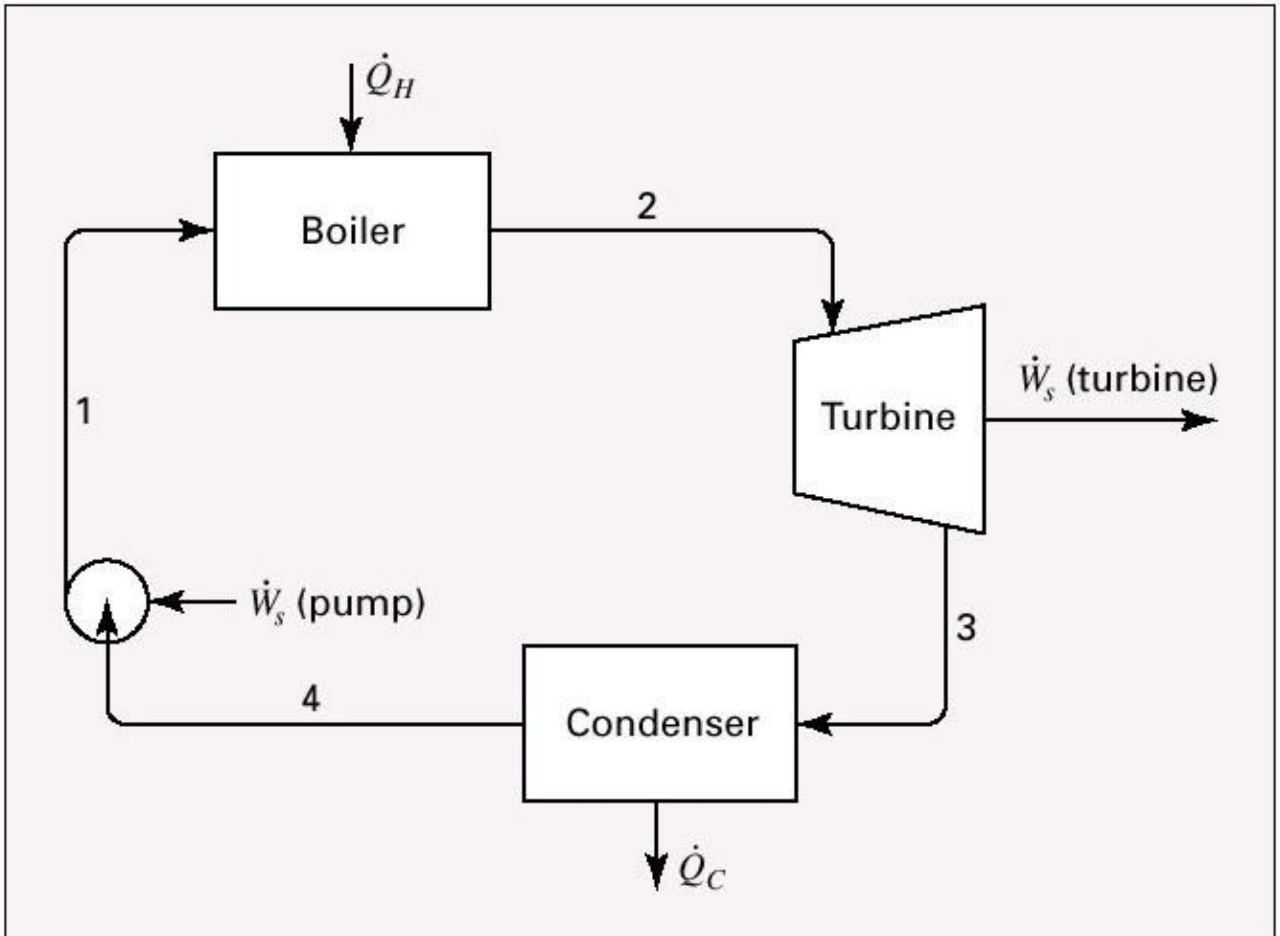


Figure 8.1: Simple steam power plant.

Carnot Cycle

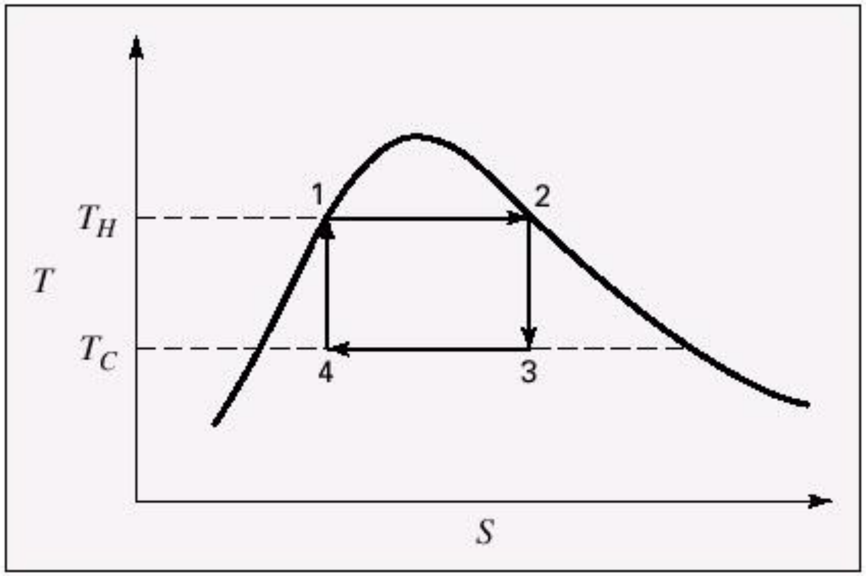


Figure 8.2: Carnot cycle on a TS diagram.

- Limitations
  - Represents ideal cycle
  - Serve as standard of comparison for actual steam power plants
  - Practical difficulties in attaining steps 2→3 and 4→1 isentropic
  - Turbines with high liquid content, cause erosion problems
  - Design of a pump that takes a mixture of liquid and vapor and discharge a saturated liquid is another difficulty.

To overcome above problems, an alternative model cycle is taken as the standard, called ***Rankine Cycle***.

Practical Power Cycle

Rankine Cycle

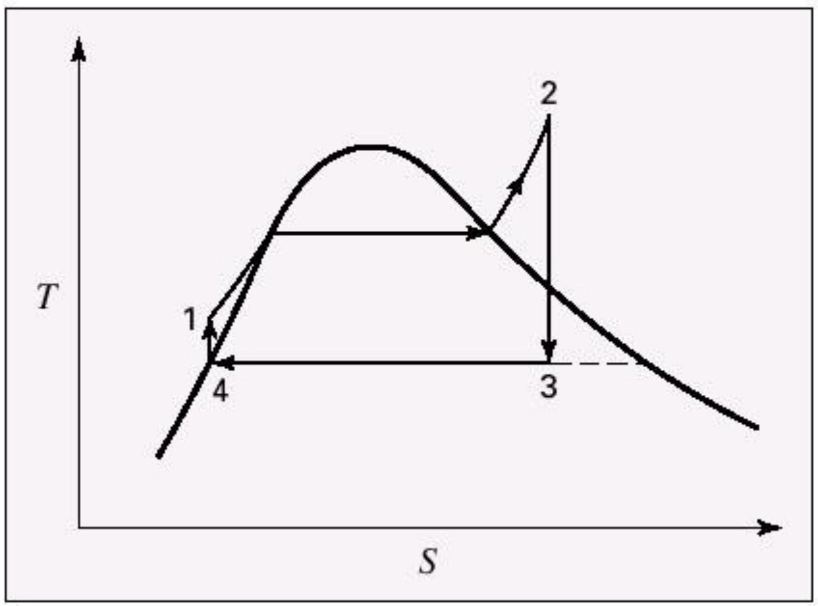
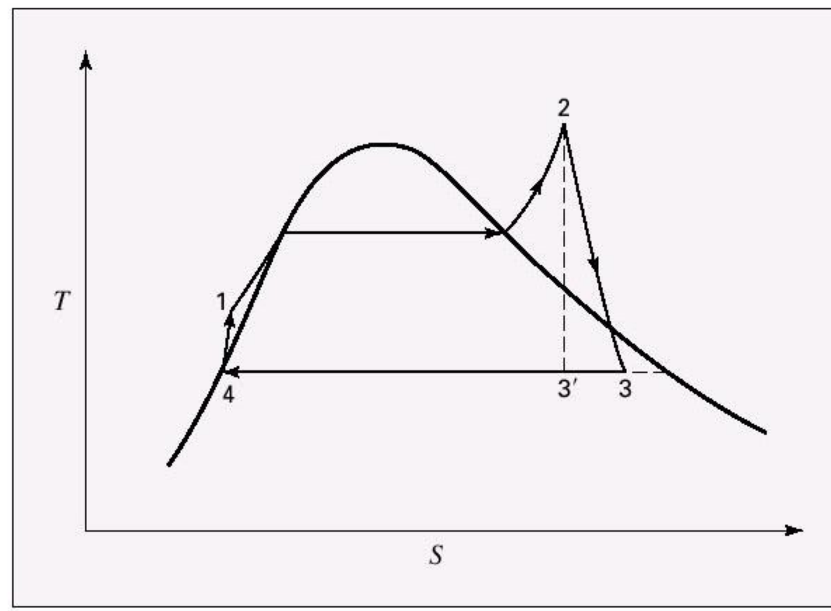


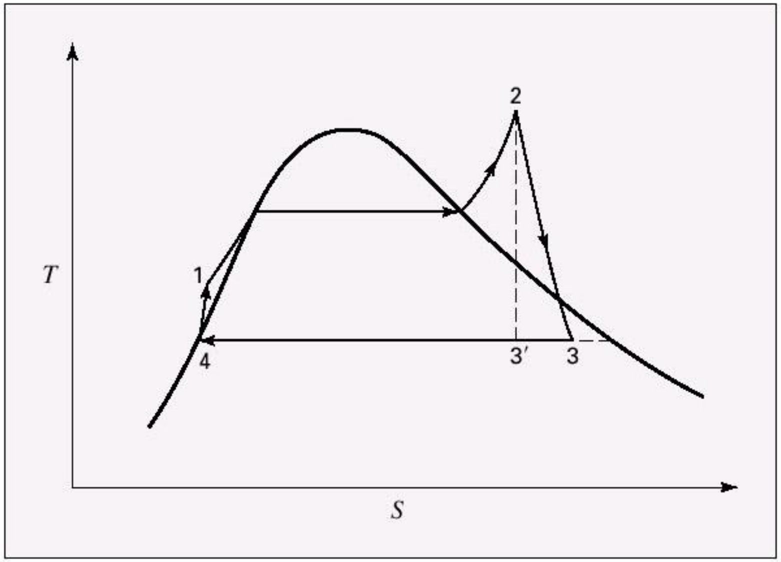
Figure 8.3: The Rankine cycle.

Simple Practical Power Cycle



Problem (8.22)

A steam power plant operates on a cycle as shown in figure. The pressure levels are 10 kPa and 6000 kPa, and steam leaves the turbine saturated vapor. The pump efficiency is 0.70 and turbine efficiency is 0.75. Determine the thermal efficiency of the power plant.



Refrigeration & Liquefaction

The Carnot Refrigerator

– In a continuous refrigeration process, the heat absorbed at a low temperature is continuously rejected to the surroundings at a higher temperature

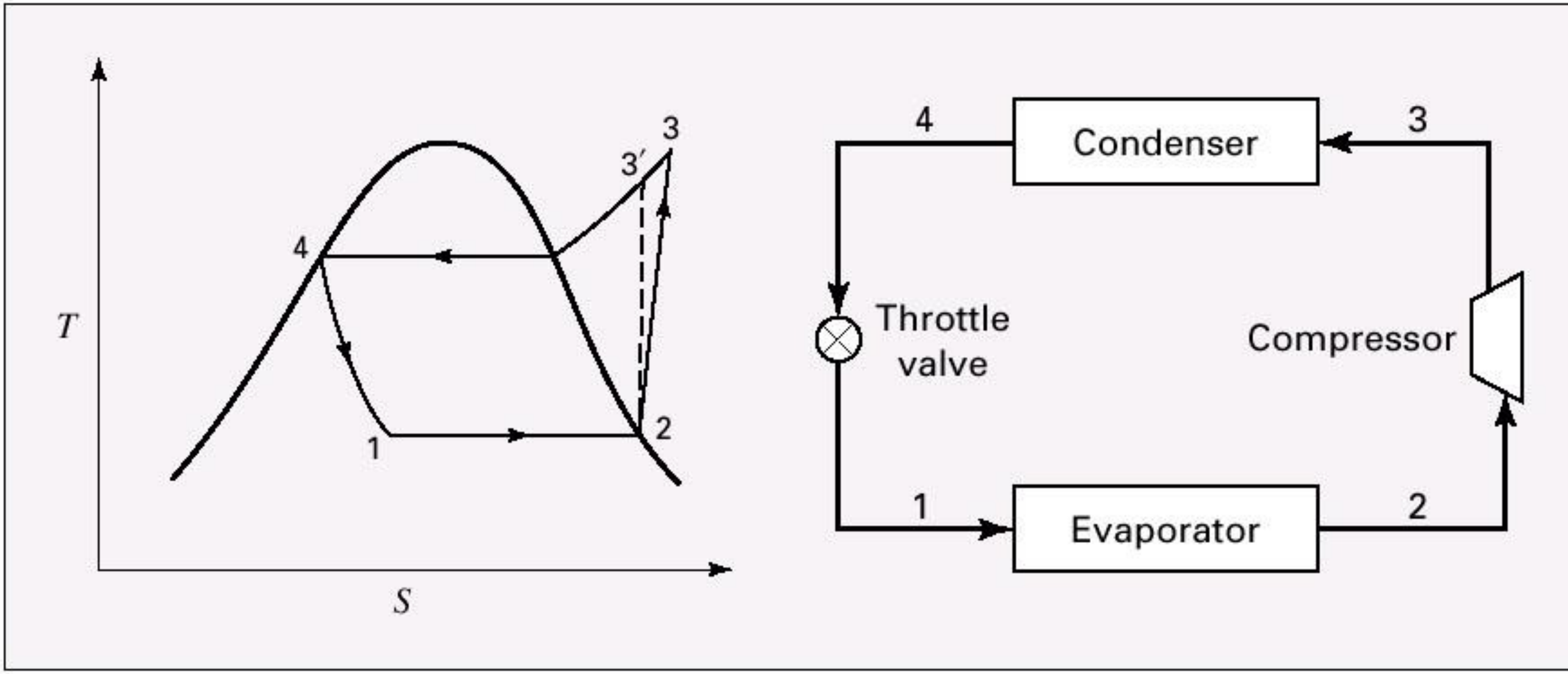
– A refrigeration cycle is a reversed heat engine cycle

– The ideal refrigerator, operates on a Carnot cycle, consists of two isothermal steps $|Q_C|$ is absorbed at the lower temperature T_C and heat $|Q_H|$ is rejected at higher temperature T_H, and two adiabatic steps.

– The measure of the effectiveness of a refrigerator is *coefficient of performance* ω defined as

$$\omega = \frac{|Q_C|}{W} = \frac{|Q_C|}{|Q_H| - |Q_C|} = \frac{T_C}{T_H - T_C}$$

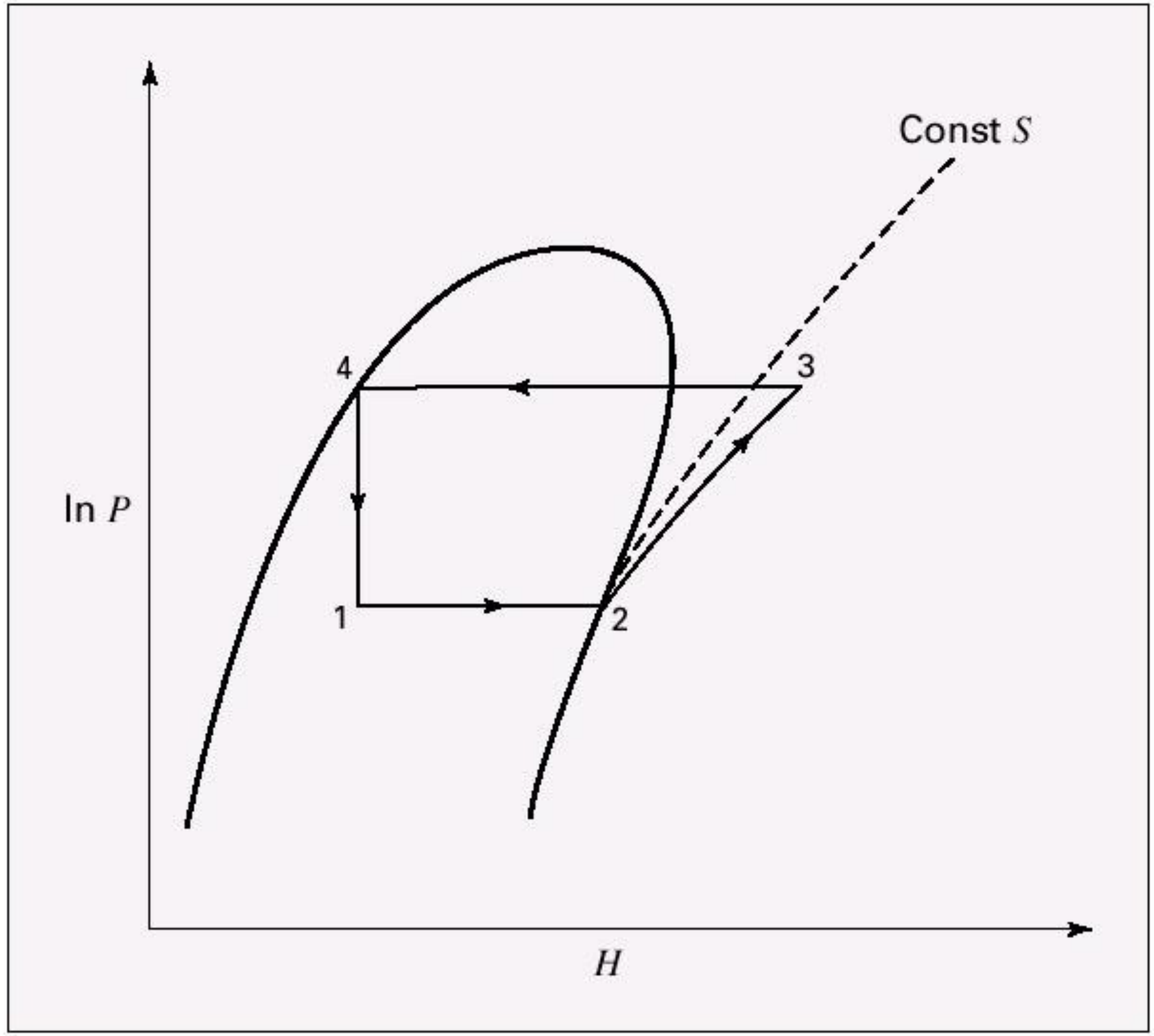
The Vapor-Compression Cycle



A refrigerant is a fluid used for heat transfer in a refrigeration system, absorb heat during evaporation at low P and T and reject heat during condensation at a higher P and T.

Examples: Hydrofluorocarbons (HCFC-123, HFC-134a, HFC-125), Ammonia

Figure 9.2: Vapor-compression refrigeration cycle on a PH diagram.



$$\omega = \frac{|Q_C|}{W} = \frac{H_2 - H_1}{H_3 - H_2}$$

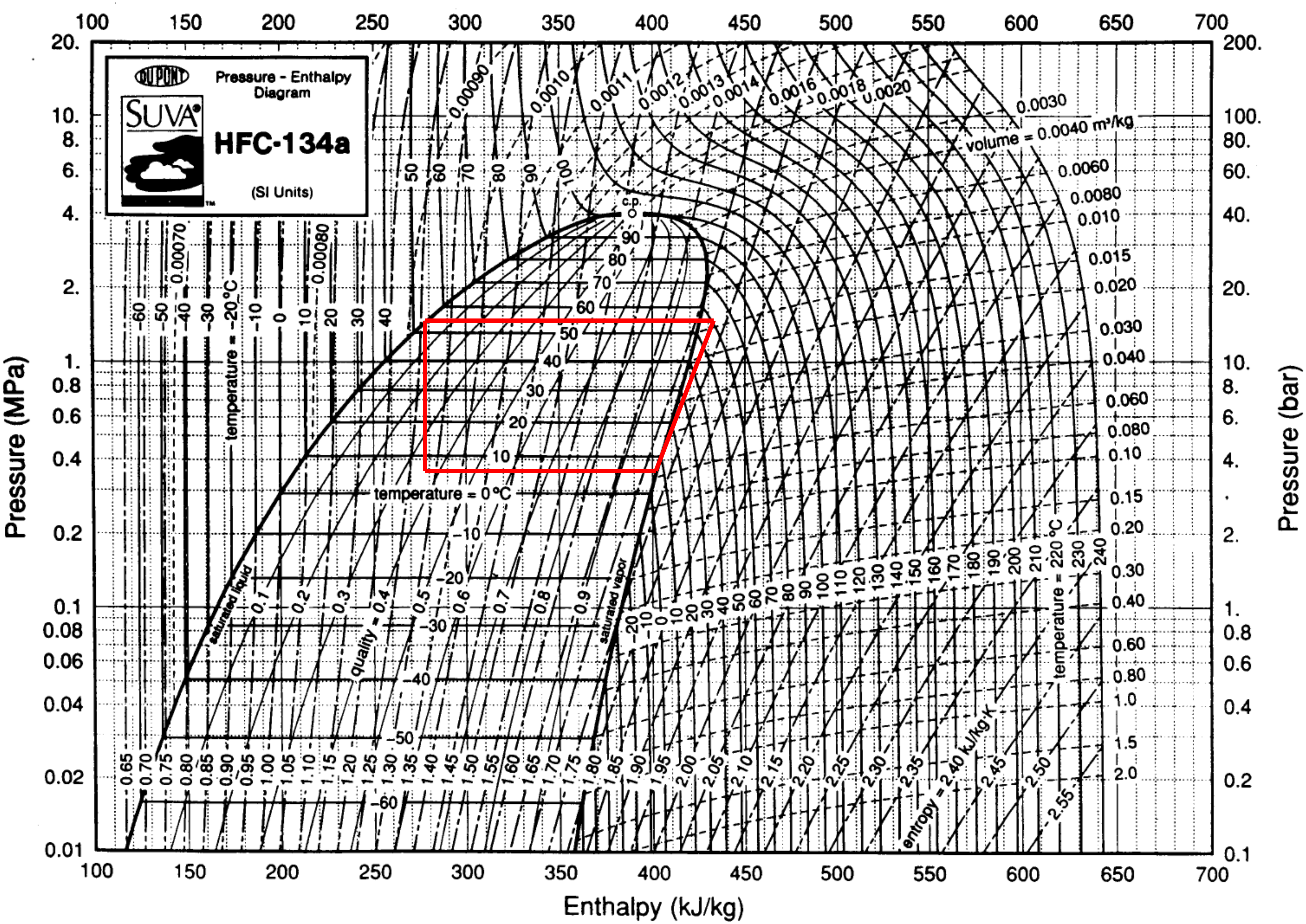
Problem

An automobile air conditioner uses a vapor-compression refrigeration cycle with the environmentally friendly refrigerant HFC-134a as the working fluid. The following data are available for this cycle.

a) Write the missing temperature and pressure in the table.

b) Evaluate the coefficient of performance for refrigeration cycle.

Point	Fluid State	Temperature /˚C	Pressure /MPa
4	Saturated liquid	55	?
1	Vapor-liquid mixture		
2	Saturated vapor	5	
3	Superheated vapor		



Pressure - Enthalpy Diagram
SUVA
HFC-134a
(SI Units)
Pressure (MPa)
Pressure (bar)
Enthalpy (kJ/kg)
volume = 0.0040 m³/kg
temperature = 0°C
temperature = -20°C
temperature = 220°C
saturated liquid
saturated vapor
quality = 0.4
entropy = 2.40 kJ/kg·K
c.p.

Point	Fluid State	Temperature /˚C	Pressure /MPa	H (kJ/kg)	S (kJ/kg.K)
4	Saturated liquid	55	1.5	280	1.26
1	Vapor-liquid mixture	5	0.35	280	1.3
2	Saturated vapor	5	0.35	402	1.7
3	Superheated vapor	60	1.5	432	1.7

$$\omega = \frac{H_2 - H_1}{H_3 - H_2} = 4.07$$

Liquefaction

- Liquefaction of gases is an important industrial process (e.g., natural gas to produce LNG, propane, and refrigerant gases)
  - One way of liquefy a gas is to cool it below its boiling-point temperature at the desired pressure, but it required very low temperatures
  - Commercially liquefaction is done to start with a gas at low pressure, compress it to high pressure (temperature will increase), cool this high temperature gas at the constant high pressure, and then expand it to low pressure-low temperature using a Joule-expansion expansion. This produces a mixture of liquid-vapor, which are separated in a flash drum (insulated constant pressure container)

Liquefaction Process

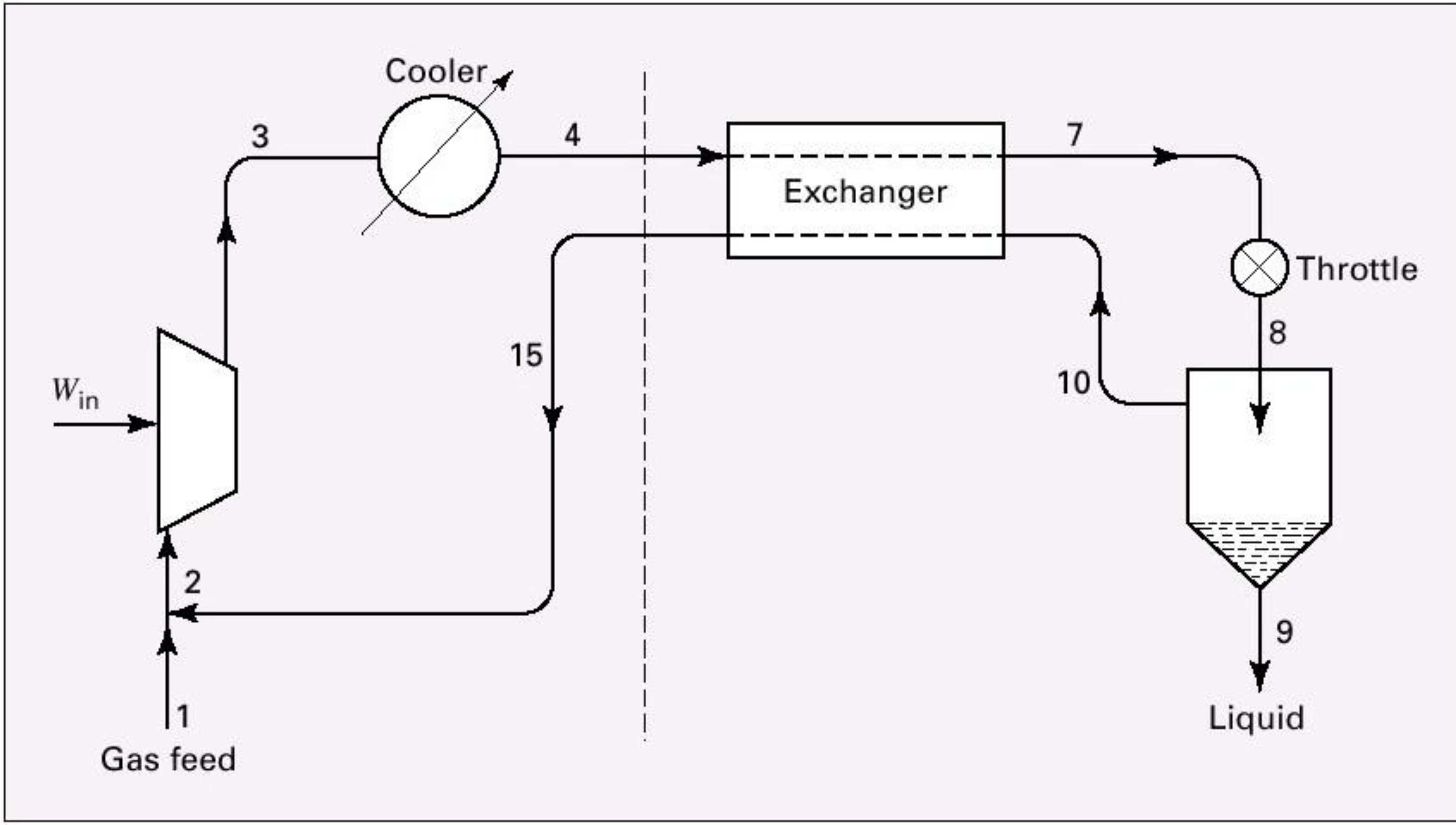


Figure 9.6: Linde liquefaction process.

Illustration

- It is desired to produce liquefied natural gas (LNG), which is considered as pure methane, from that gas at 1 bar and 280 K. Leaving the cooler, methane is 100 bar 210 K. Flash drum is adiabatic and operate at 1 bar, and the compressor can be assumed to be operate reversibly and adiabatically. However, because of the large pressure change, a three stage compressor with intercooling is used. The first stage compress the gas from 1 bar to 5 bar, the second stage from 5 bar to 25 bar, and the third stage from 25 bar to 100 bar. Between stages the gas is isobarically cooled to 280 K.
  - Calculate the amount of work required for each kilogram of methane that passes through the compressor in the simple liquefaction process
  - Calculate the fractions of vapor and liquid leaving the flash drum in the simple liquefaction process and the amount of work required for each kilogram of LNG produced.

Thermodynamic diagram for process calculations