Engineering for the Craft Brewer

Lecture 6

Summer 2014

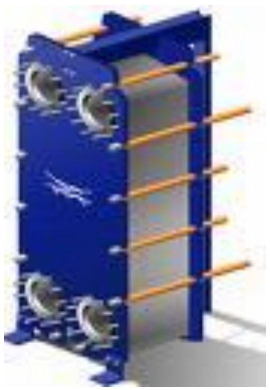
Unit Operations in Brewing

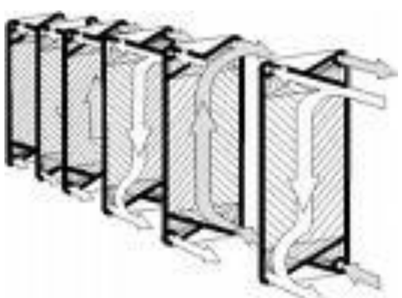
1. Malt Handling and Milling
2. Mashing
3. Lautering
4. Boiling
5. Whirlpooling
6. **Wort Cooling**
7. Fermentation, Conditioning, and Chilling
8. Filtration, Carbonation, and Packaging

Heat Exchanger vs Coolship?

Heat Exchanger vs Coolship?

Wort Cooling





Engineering Concepts

- 1st & 2nd Law of Thermo
- Primary Refrigeration
  Secondary Refrigeration

Heat Exchangers

- Modern Heat Exchangers were invented about 95 years ago and have replaced cool ships.
  - Plate and Frame
  - Double Pipe
  - Shell and Tube
- Fluid flows between closely spaced stainless steel heat exchange surfaces.
  - Parallel Flow
  - Counter Flow

Heat Exchangers

- *Heat Conduction*

$$q = U \cdot A \cdot \Delta T$$

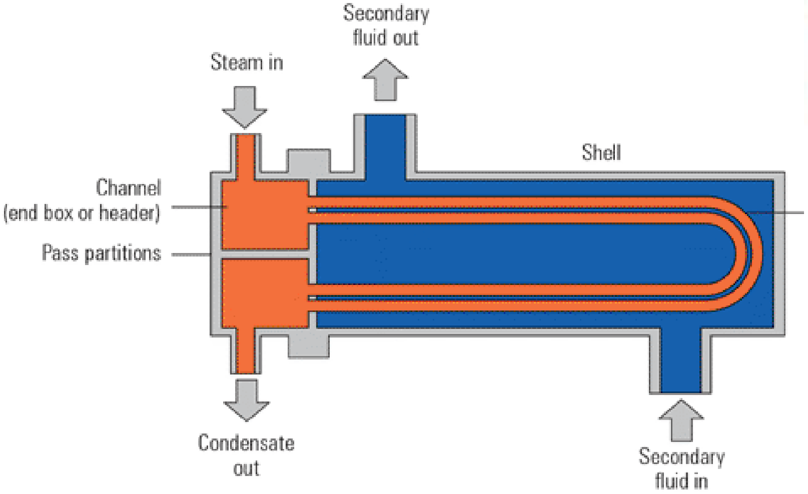
U = Overall heat transfer coefficient, f(Δx and fouling)

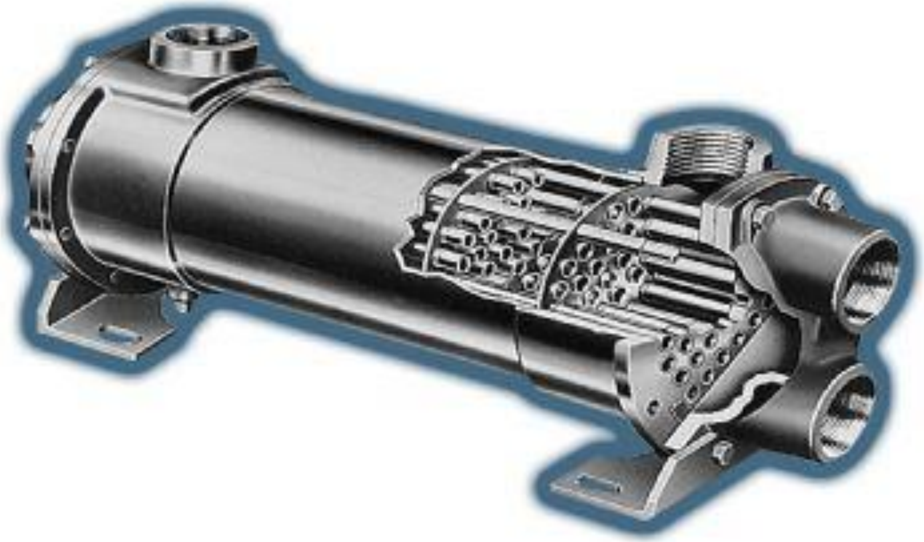
A = cross-sectional surface area

ΔT = temperature difference

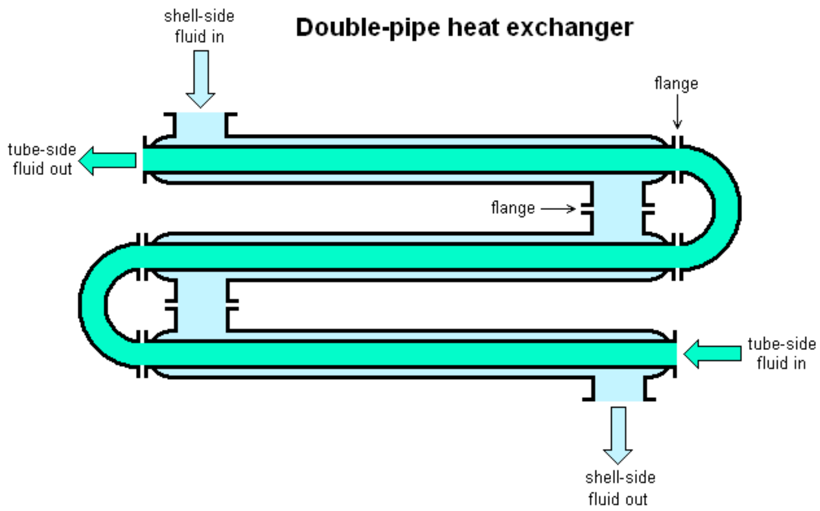
- *Increase surface area*
- *Increase temperature difference*
- *Decrease fouling to increase U*
- *Decrease Δx of the stainless steel plates*

Heat Exchangers – Shell & Tube

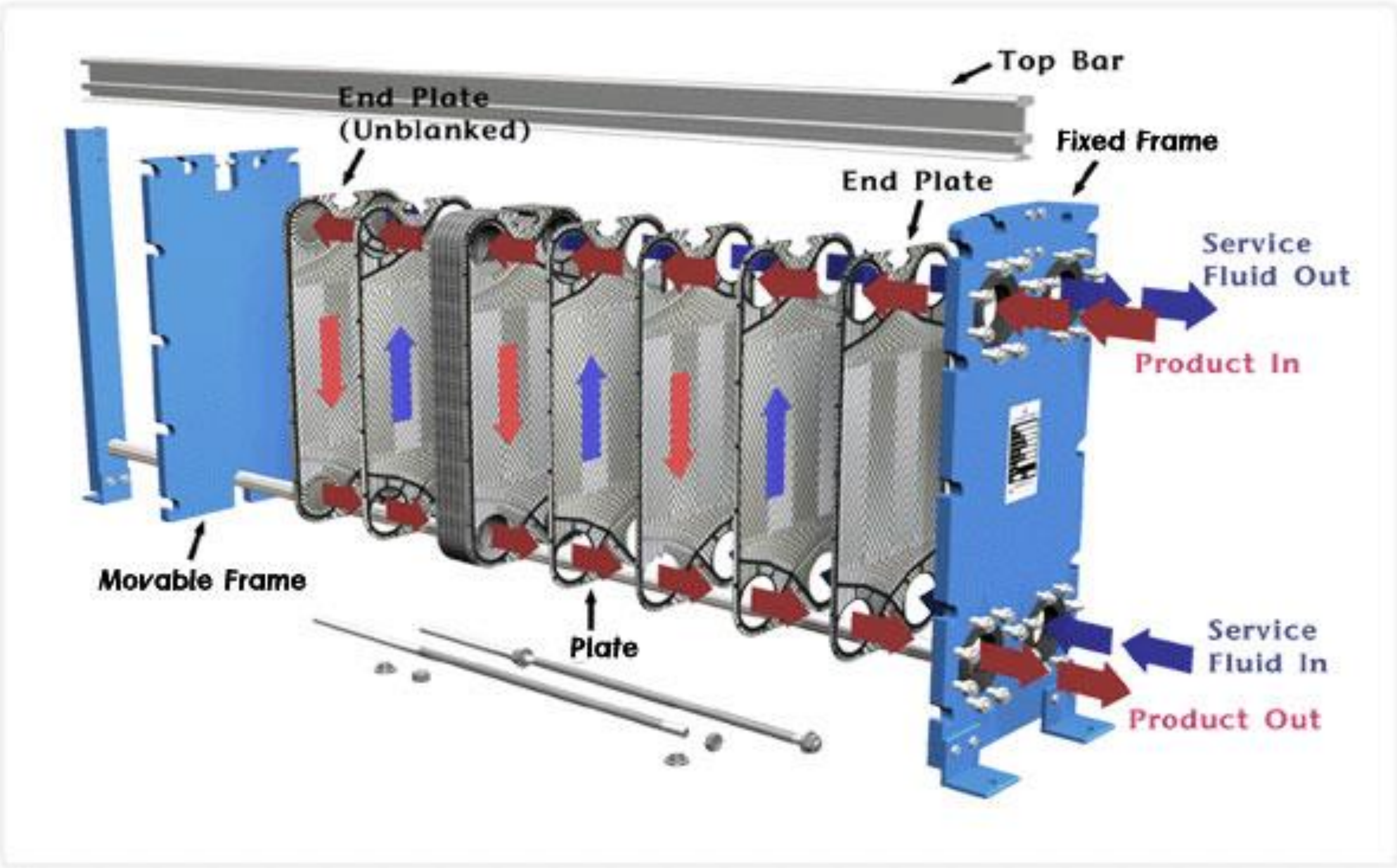




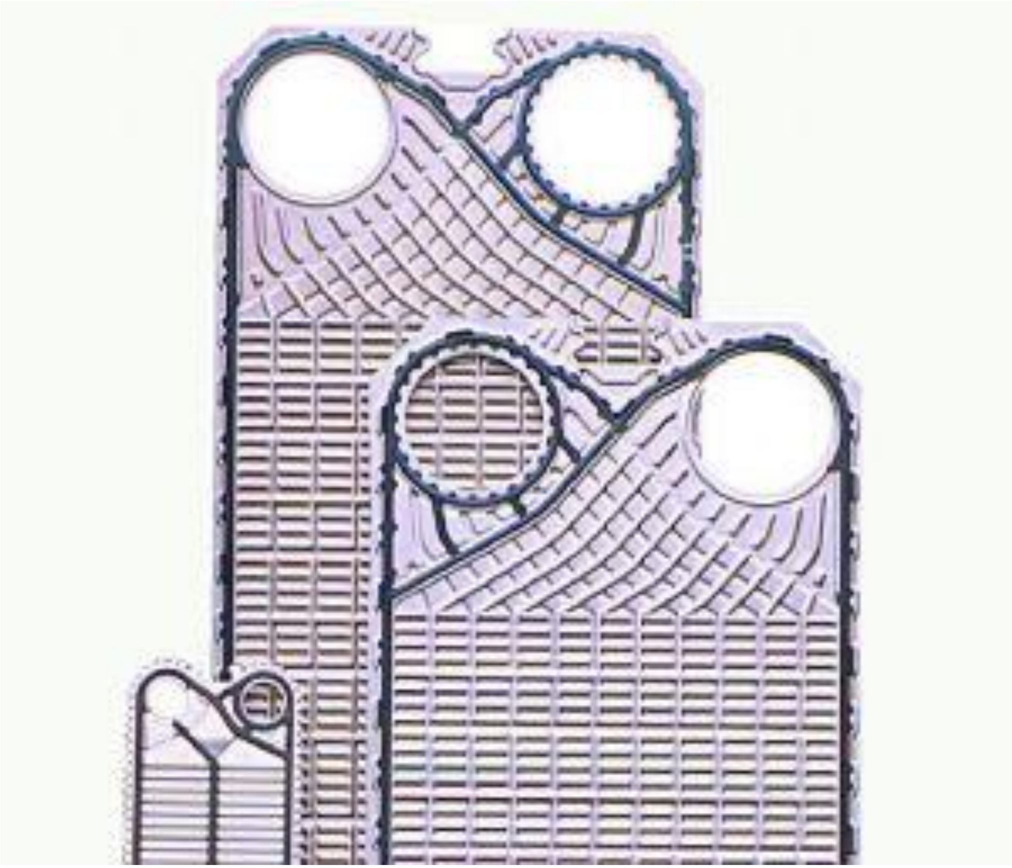
Heat Exchangers – Double Pipe



Heat Exchangers – Plate Frame



Heat Exchangers – Plate Frame



Heat Exchangers

Plate and Frame heat exchangers are most efficient

- Plate and Frame (1.1:1 to 1.5:1)
- Double pipe (4:1)
- Shell and Tube (3:1)

Special patterns are pressed on the plates to cause turbulent flow, and associated high heat transfer rates.

Coolants in Heat Exchangers

- Some Coolants are reused with refrigeration regeneration then in a closed loop:
  - Glycol coolant or a brine solution
- Cool water used as a coolant can adsorb heat and are utilized in brewing process
  - mash in, sparge, cleaning
- Sub optimally designed coolants adsorb heat but are not reused
  - Dumping of heated coolant water is indicative of improper design or improper use

Heat Exchangers

- Maintenance is simple
- Sanitary design
- Easy to increase capacity
- Relatively low capital investment
- Small space requirement
- Regeneration of water = energy benefits
- Fast knock-out time

Heat Exchanger Maintenance

- Only Regular Maintenance: cleaning
  - CIP with caustic at end of every brew day
  - Sanitize immediately before use

- Acid wash product side every two to three brews to remove calcium oxalate.

Heat Exchanger Maintenance

- Most brewers rely on heat sanitation because a filled, 100% flow regime is not guaranteed.
- Some breweries use the hot wort if it can be clarified then returned to the kettle.

Heat Exchanger Maintenance

- These operation tips will help you reduce fouling of surfaces and plate channels:
  - Clarify the wort as much as possible prior to sending it to the heat exchanger.
  - If whole hops are used, whirlpool and strain or filter the wort in a hop back.
  - CIP with a reverse flow rate @ 10-15 feet/sec
  - Hot caustic brink should provide positive pressure to flush out all air bubbles.

Heat Exchanger Maintenance

- Periodic Maintenance is necessary if heat exchanger becomes fouled with hop leaves, beer stone, or other organic material.
- Indications include:
  - Reduced heat exchange (increased time)
  - Microbiological results (forced wort a first indicator)

Heat Exchanger Maintenance

- Periodic Maintenance typically requires you remove the plates.
  - Good idea to have manufacture specs
  - Have extra gaskets (which are specific to your exact model)
  - Food grade gasket cement
  - Measure distance from end plate to end plate
  - Diagonal line for reference

Heat Exchanger Maintenance

- Periodic Maintenance:
  - Remove process piping
  - Unbolt end plate to loosen the plates
  - Disassemble and stack in order
  - Inspect plates. Where is organic material?
  - Assemble carefully. Tighten exactly.
  - Check for leaks. Replace gaskets if needed.

Heat Exchanger Benefits

- Wort is at its most sensitive stage.
  - You have 80-100 minutes to transfer, whirlpool, and cool wort. Faster than cool ship.
  - Sanitation of heat exchanger is paramount, but easy to do.
  - Unless wort is cooled sufficiently, yeast can not be pitched in a timely manner.
- Energy Transferred during cooling is utilized elsewhere instead of wasted.

Heat Exchanger Design Factors

- Selection of Heat Exchange Medium
- Parallel flow or counter flow design
- Required Heat Transfer, Q

Heat Exchanger Design Factors

- Selection of Heat Exchange Medium
  - Steam is usually used for heating media
  - Coolants vary
- Of coolant choices, cold liquor is the most economical, but utilization and storage of warmed liquor is troublesome in a small brewpub or microbrewy.
- Two stage heat exchanger
  - glycol plus municipal water

Heat Exchanger Design Factors

- Public supplier or private well supply
  - Zero capital cost, low % re-use, so some waste
  - Limiting factor is usually the summer water temperature when ΔT *is smallest.*
- Cold liquor is the most economical, but utilization and storage of warmed liquor is troublesome in many small brewpubs.
- Two stage heat exchanger (glycol/water)

Heat Exchanger Design Factors

- Is parallel flow or counter flow design best?
- Because ΔT varies inside process, we must use a mathematical function, Log Mean Temperature Differential, to describe the overall ΔT.

Heat Exchanger Design Example

- Define design factors
  - Flow regime
  - Coolant
  - Chilling requirements for wort
- Determine required heat transfer rate, q
- Determine maximum $T_{water, initial}$
- Calculate number of plates required given manufacturers Overall Heat Exchange coeff.

Heat Exchanger Design Example

- Counter Flow Heat Exchanger

	Wort	Water
Temp In	100 ˚C	INPUT ?
Temp Out	10 ˚C (50 F)	75 ˚C (167 F)
Volume	17 bbl brewhouse	21.25 bbl
Cp	3.95 kJ/kg-K	4.19 kJ/kg-K

Knock out in 30 minutes

Heat Exchanger Design Example

- Counter Flow Heat Exchanger
  - Each plate is 0.07 m^2
  - $U_{overall}$ = 3.64 kJ / s m^2 ˚K

	Wort	Water
Temp In	212 ˚F	40 ˚F (4.19 C)
Temp Out	50 ˚F	170 ˚F
Volume	18 bbl	22 bbl
Cp, wort	3.95 kJ/kg-K	4.19 kJ/kg-K

- Knock out in 30 minutes
- How does it change with Parallel Flow Heat RX?

Heat Exchanger Design Example

What happens if we add a glycol part to the heat exchanger?

- Formulate problem
- Iterate for an approximate solution of number of plates of each section

Heat Exchanger Design Example

- Counter Flow Heat Exchanger with Glycol

	Wort	Water	Glycol
Temp In	212 ˚F	60	29 ˚F
Temp Out	68 ˚F	170	36˚F
Volume	15 bbl	21.25 bbl	unknown
Cp, wort	3.95 kJ/kg-K	4.19 kJ/kg-K	2.47 kJ/kg-K

- Knock out in 30 minutes

Cooling Load Example

Calculations for from our Plate Heat Exchanger examples are also a Cooling Load Example:

Cold Water

q_{water} = 412.4 kJ/s during knock out

But what would load be throughout day??

Compare this to our glycol + water example….

First Law of Thermodynamics

Total Energy IN = Total Energy Leaving + Accumulated − Loss

- Heat transfer is an energy transfer from one state to another.
- Heat is denoted with the symbol, Q [Joule]
  - Heat per unit of time is a rate of heat transfer
  - q, with the units of J/sec, or watts (W)

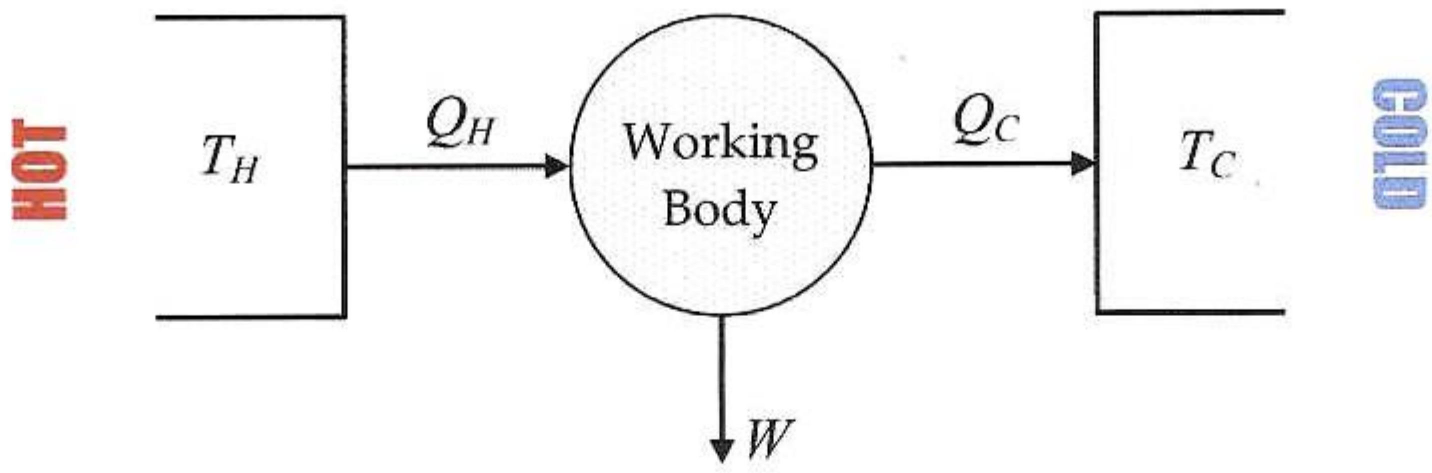
Second Law of Thermodynamics

- Heat travels from warm to cold objects until equilibrium is reached.
- Temperature differences between systems in contact with each other tend to even out and that work can be obtained from these non-equilibrium differences.

Second Law of Thermodynamics

- The Carnot Cycle

Since energy transfers from a hot region to a cold region, in the process you can covert some of the energy to mechanical work—but you don't have to!



Thermodynamic Heat Engine

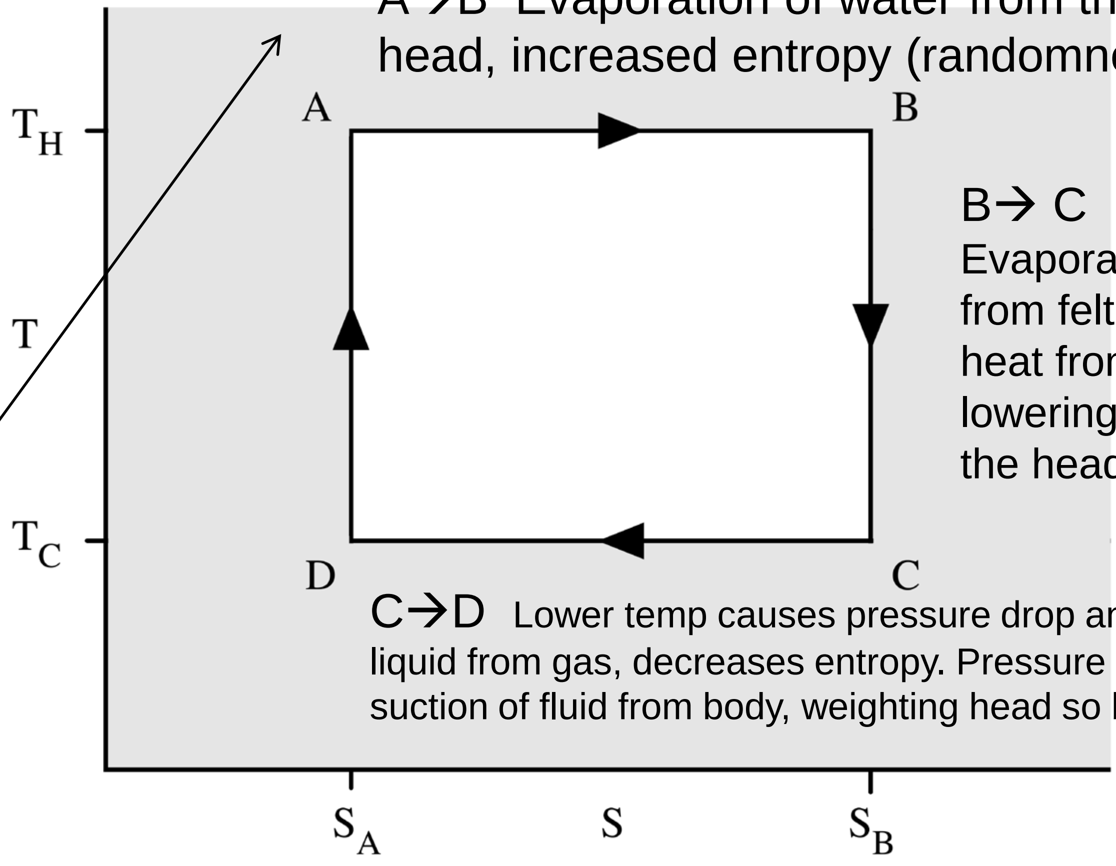
This thermodynamically powered heat engine exploits a temperature differential to covert heat energy to kinetic energy and perform mechanical work.

Thermodynamic Heat Engine

D→ A
"Burp" causes loss of head's "suction", pressure rises, and a slight rise in T.

Fluid flows from head into body and bird tips upright.

A→B Evaporation of water from the head, increased entropy (randomness)



B→ C
Evaporation of water from felt removes heat from the system, lowering the temp. of the head bulb.

C→D Lower temp causes pressure drop and condensation of liquid from gas, decreases entropy. Pressure drop in head induces suction of fluid from body, weighting head so bird tips over.

Refrigeration Systems

- Overview
- Basic refrigeration loop
- 4 Refrigeration System Components
- Operation and maintenance

Refrigeration Systems

- The vapor-compression cycle is the primary engineering system used in breweries for cooling applications

- KEY IDEA: Heat transfer occurs due to induced phase changes in a closed loop system

Uses of Refrigeration

1. Heat exchange of wort to bring it to yeast pitching temperatures
2. Maintain fermentation temperatures as desired for yeast flavor profile
3. Adjust temp for diacetyl rest, cold lagering
4. Flocculation of yeast
5. Allow for dissolved CO_2 prior to packaging
6. Beer storage

Benefits of Secondary Refrigeration

Glycol used as a secondary refrigerant to avoid large ΔT and potential for icing as it removes heat.

- plate heat exchangers
- fermentor and bright tank jackets
- cooling coils submerged in cold liqour tanks or open fermentors
- cold boxes

Glycol Cooling Loads

Cooling load is the rate of heat energy removal.

- Ice used to be the primary method, so cooling capacity is often related to melting of ice.
- “ton of refrigeration” is equal to the latent heat of fusion of one ton of ice.

1 ton = 288,000 btu/24 hr = 12,000 BTUH

303,852 kJ/24 hr = 3.5168 kw

Glycol Cooling Loads

DEMANDS:

1. Unitank at peak fermentation
2. Unitank cooling
3. Cold liquor tank
4. Walk in cooler
5. Future planned demand
6. Loss of heat in piping and bath (15%)

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Basic Refrigeration Loop

The “ideal vapor-compression cycle” is a reverse operation of the Carnot heat engine where a refrigerant cycles to move heat from one region to another.

1. The condenser exhausts heat
2. The expansion valve throttles flow
3. The evaporator adsorbs heat
4. The compressor adds pressure to gas

Basic Refrigeration Loop

"Freon" is the a product made by Du Pont

- Greenhouse gas effects (ozone killers):
  - Fluorinated hydrocarbons (FCs)
  - Chlorofluorocarbons (CFCs)
  - Hydrochlorofluorocarbons (HCFCs)

R-values refer to the number of carbon hydrogen, and chlorine atoms

- Most common: R-22, R-11, R-12, and R-123

Basic Refrigeration Loop

Alternative refrigerants:

- R-404A, R-407C, and R-410A.
- Ammonia R-717

Ask manufacture what alternative refrigerants they certify for their unit:

- Compatible with existing R-__ and desiccant?
- Over time, will it damage nitrile and rubber hoses and O-rings?

Thermodynamic Heat Engine

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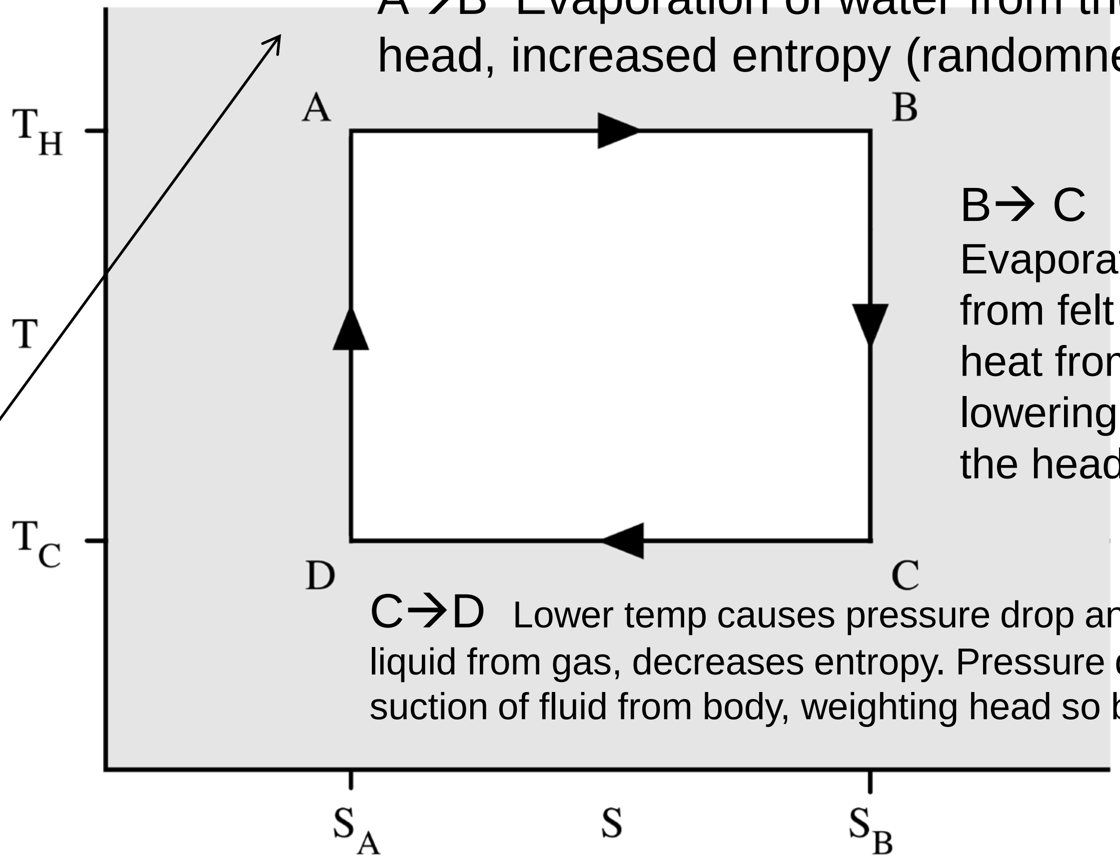

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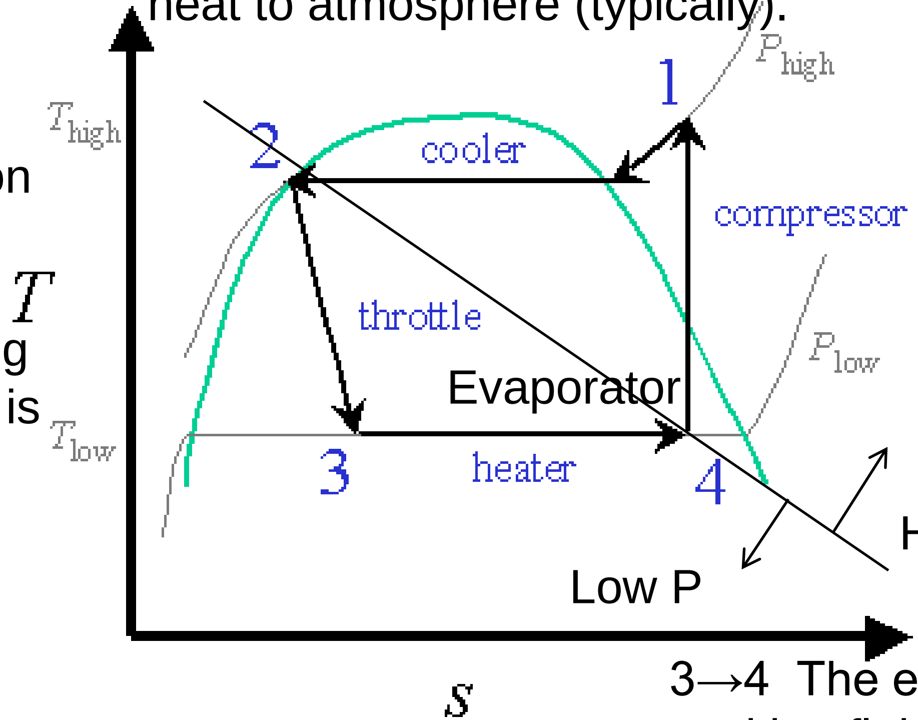
Vapor-Compression Cycle

1→2 The condenser cools the working fluid from a gas to a liquid by exhausting heat to atmosphere (typically).

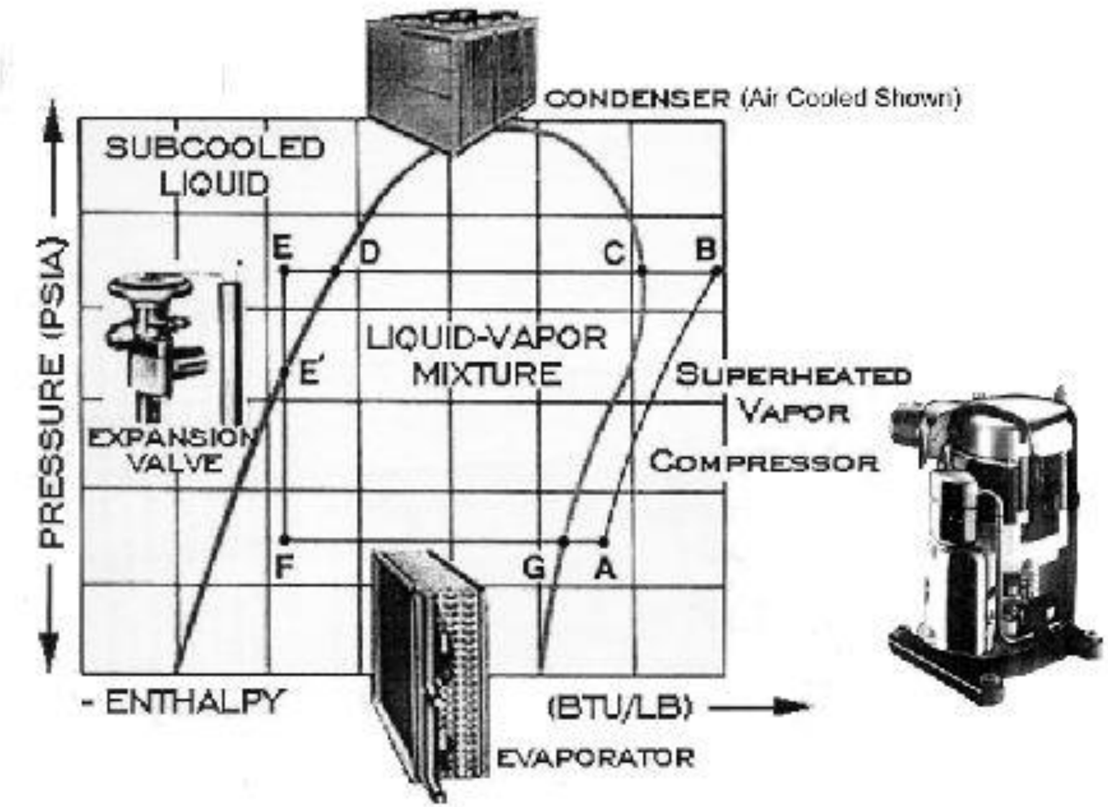
2→3
The expansion valve meters the flow of the working fluid as there is a need for process cooling.



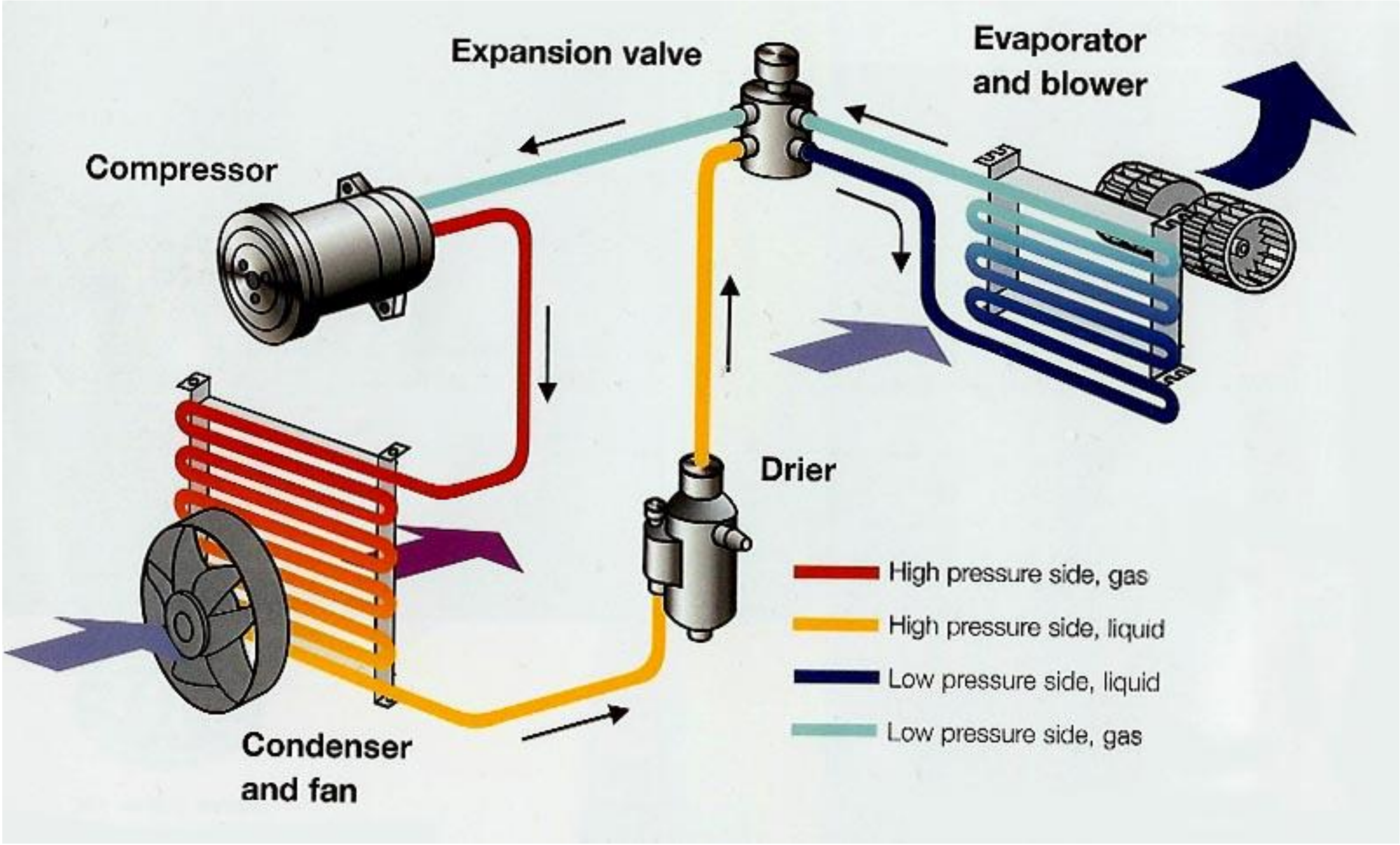
4→1
The compressor increases the pressure of the gas by mechanical work.

3→4 The evaporator heats the working fluid from liquid to gas by adsorbing heat from the process.

Thermodynamic Heat Engine



Thermodynamic Heat Engine



Evaporators

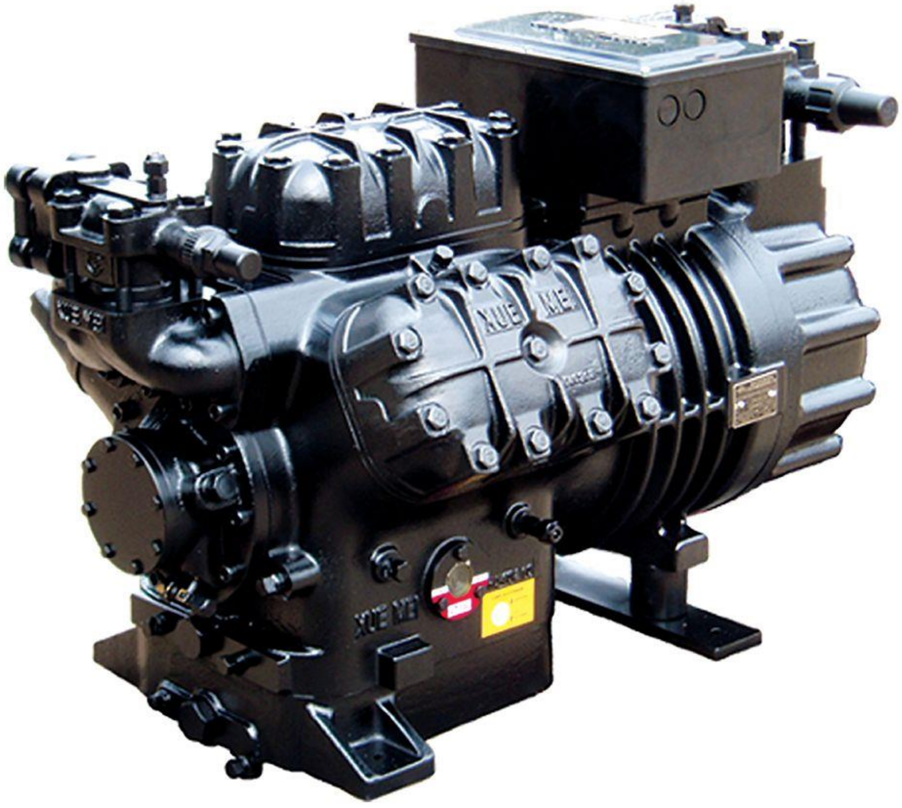
Many different forms

CONCEPT:

R-fluid evaporates in the tubes or lamellar plates and thereby extracts the heat for evaporation from the surrounding fluid (glycol, chlorine-free brine, air)

Evaporators

Compressors



Compressors

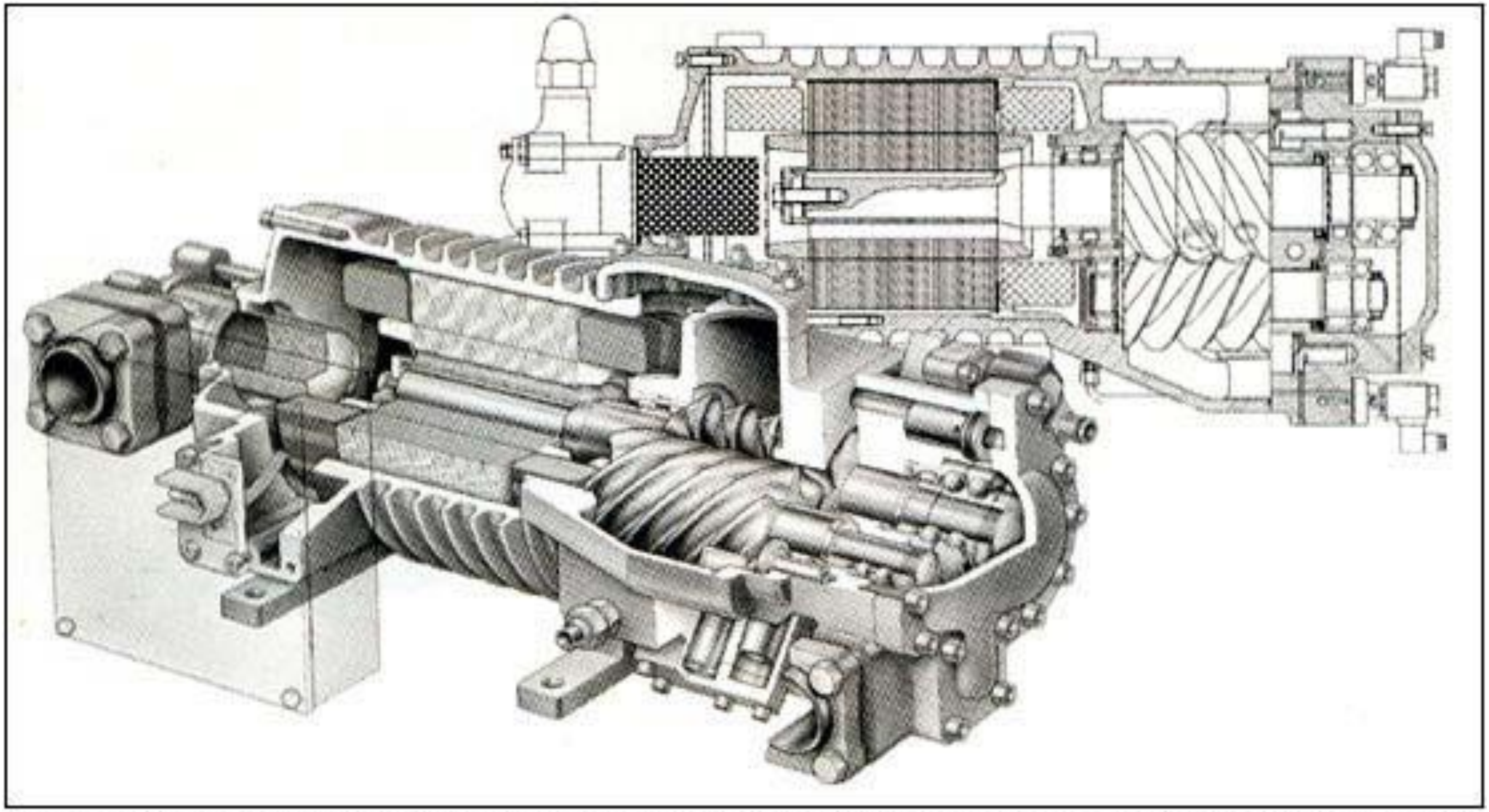
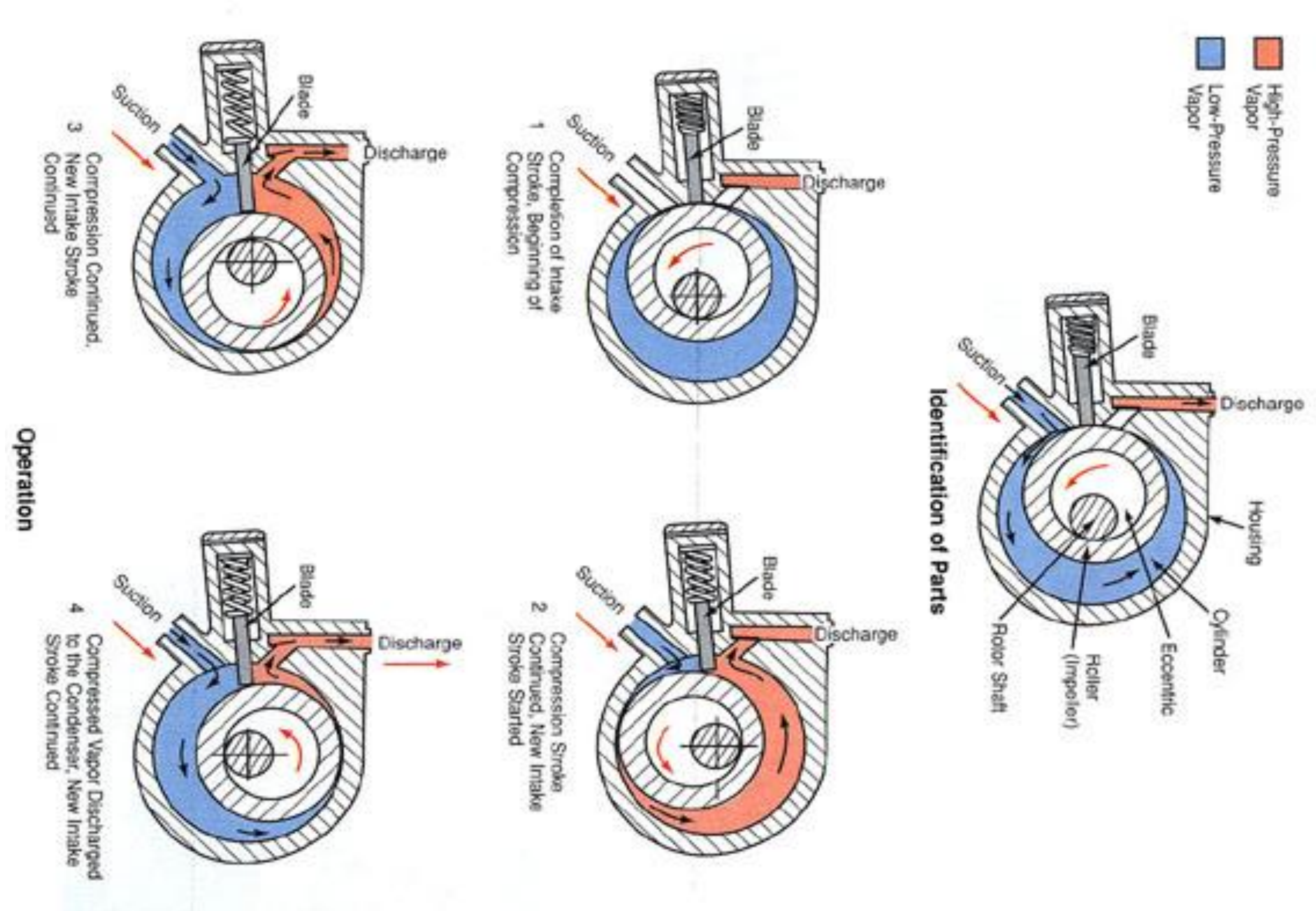


Fig. 1 Cross-section of a semi-hermetic screw compressor with integrated 2-step capacity control (100-75-50%)


High-Pressure Vapor
Low-Pressure Vapor
Identification of Parts
Suction
Blade
Discharge
Housing
Cylinder
Eccentric
Roller (Impeller)
Rotor Shaft
Operation
1 Completion of Intake Stroke, Beginning of Compression
2 Compression Stroke Continued, New Intake Stroke Started
3 Compression Continued, New Intake Stroke Continued
4 Compressed Vapor Discharged to the Condenser, New Intake Stroke Continued

Condensors

Many different forms

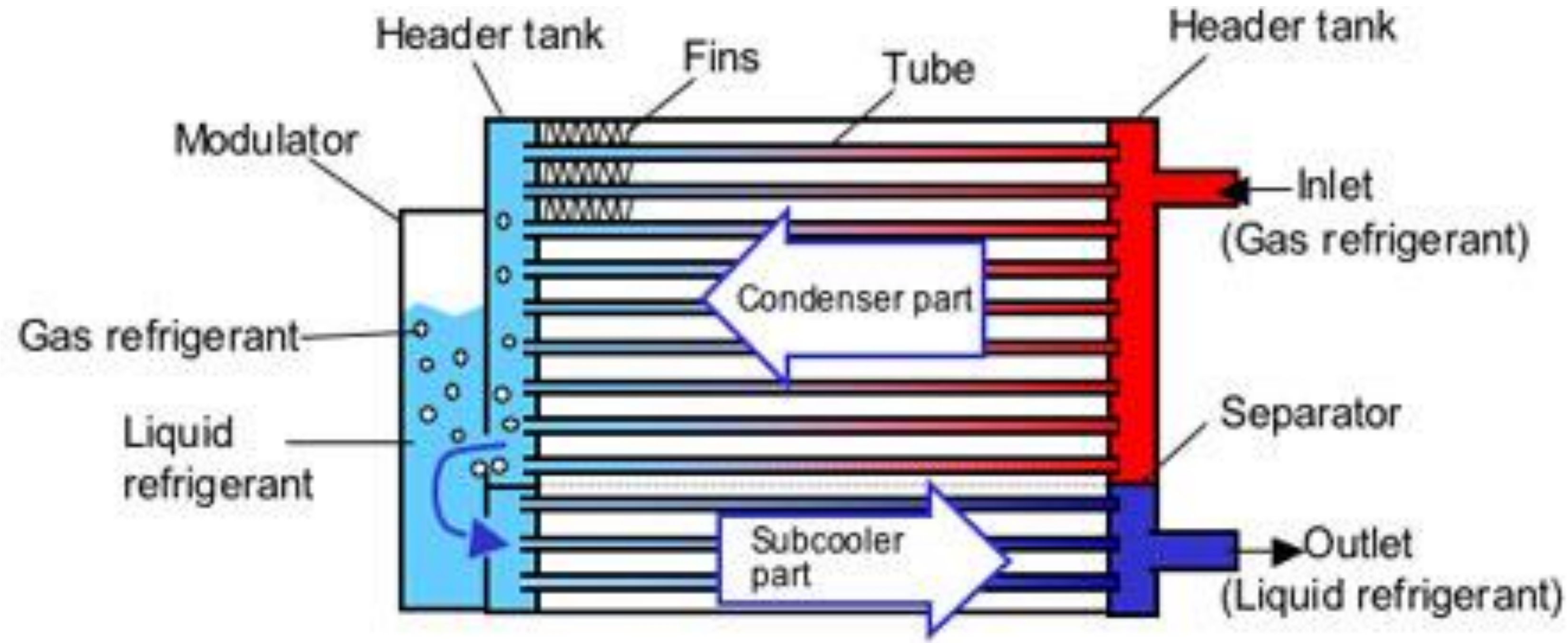
CONCEPT:

R-fluid condenses in the tubes or lamellar plates and thereby evolves the heat of the phase change (condensation) to the surrounding fluid (chlorine-free brine, air)

Condensors at home!

Condensors at a brewery!

Condensor – Three Stages



Expansion Valve

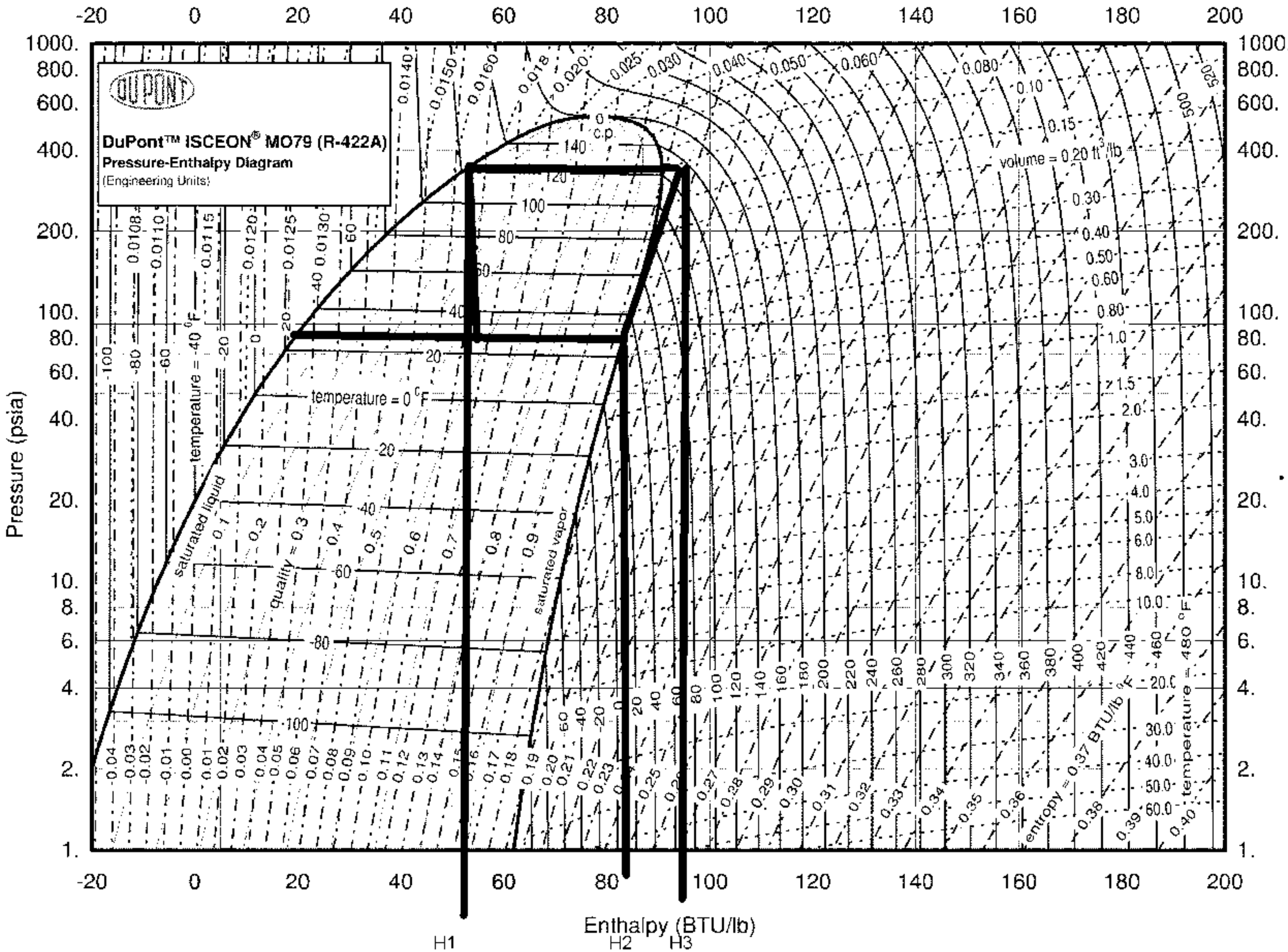
Refrigeration System Operation and Maintenance

- Check for fouling of heat exchange surfaces
- In a secondary refrigerant
  - Check for fouling of heat exchange surface
  - Check actual glycol temperature
  - Top off glycol reservoir
  - Check glycol concentration

Refrigeration Example

- Cool a cold storage room to 35 F. The load on the refrigeration unit is 10 tons/day.
- Vapor-compression cycle uses DuPont Isceon R-422A. Consider operating the evaporator at 23 F & condenser at 122 F.

- Determine theoretical horsepower of compressor



DuPont™ ISCEON® MO79 (R-422A)
Pressure-Enthalpy Diagram
(Engineering Units)
Pressure (psia)
Enthalpy (BTU/lb)
saturated liquid
saturated vapor
quality = 0.3
temperature = 0 °F
temperature = -40 °F
volume = 0.20 ft³/lb
entropy = 0.37 BTU/lb °F
temperature = 480 °F
c.p.
H1
H2
H3