MEBS6006 Environmental Services I

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Refrigeration

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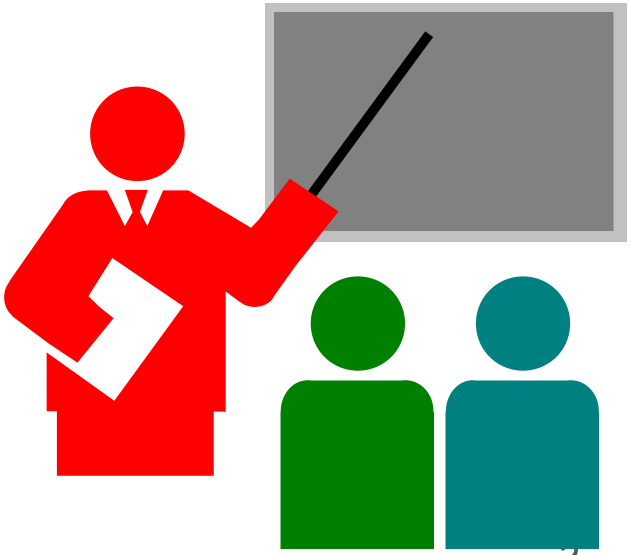
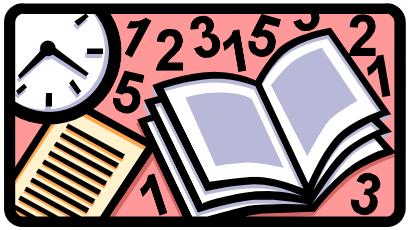


Refrigerants

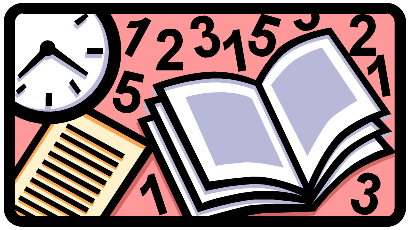


- A refrigerant is a fluid used for heat transfer in a refrigeration system.

- Most refrigerants
  - absorb heat during vaporisation (from liquid state to gaseous state) at low temperature and low pressure, and
  - reject heat during condensation (from gaseous state to liquid state) at a higher temperature and higher pressure.

- Some refrigerants produce a refrigeration effect when they throttle and expand in the refrigeration cycle.

Refrigerants

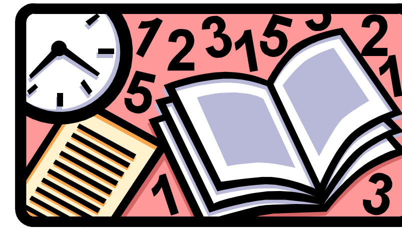


Classification of Refrigerants

Refrigerants most commonly used for refrigeration systems can be classified into the following groups:

- hydrocarbons,
- inorganic compounds,
- halocarbons, and
- Azeotrope mixtures / nonazeotropic mixtures

Refrigerants



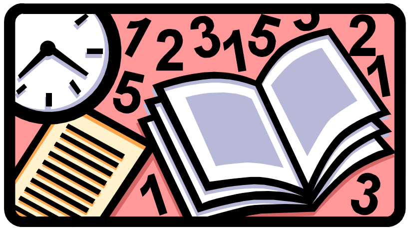
Hydrocarbons

- Examples: ethane, propane, butane and isobutane.
- Source: Produced from petroleum in an oil refinery.
- Used in the refrigeration systems in oil refineries and the petrochemical industry due to their low cost and ready availability.
- Zero ozone depletion potential (ODP) and very low global warming potential (GWP)
- Flammable and so safety precautions are of utmost importance.

Inorganic compounds

- Inorganic compounds : e.g. ammonia NH_3, Lithium Bromide LiBr (as absorber), carbon dioxide CO_2

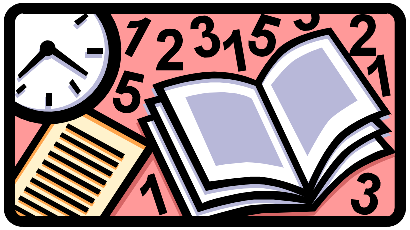
Refrigerants



Halocarbons

- Refrigerants belonging to the halocarbon group are derivatives of the hydrocarbons obtained by substituting chlorine, fluorine or bromine for the hydrogen atoms in methane and ethane.
- As chlorine, fluorine or bromine are both halogens, this group of refrigerants is called the halogenated hydrocarbons or halocarbons. They are sometimes referred to based on the trade names like *Freon.*
- Properties: colourless, non-inflammable, non-corrosive to most metals and generally non-toxic
- Halocarbons containing chlorine or fluorine are most common (so called chlorofluorocarbons, CFCs)
- Common refrigerants in this group are R-11, R-12, R-13 and R-22.

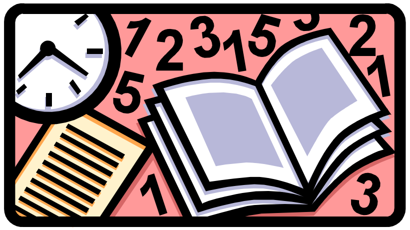
Refrigerants



Azeotropes

- An azeotrope is a mixture of two substances of different properties but behaving as a single substance. It cannot be separated into its components by distillation.
- It evaporates and condenses as a single substance and its properties are completely different from its constituents.
- For example, azeotrope R-500 is a mixture composed of 73.8% R-12 and 26.2% R-152a.

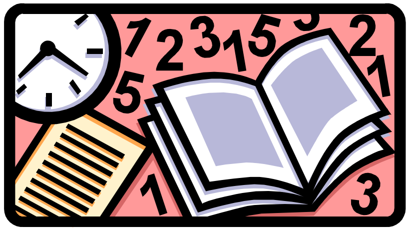
Refrigerants



Nonazeotropes

- A nonazeotropic mixture is a fluid consisting of multiple components of different volatiles that, when used in refrigeration cycles, change composition during evaporation or condensation.
- Also called zeotropic mixtures or blends.
- Research focus on heat pump applications due to the adaptable composition.
- Offers advantages of energy improvement and saving, capacity control, adaptation of hardware components regarding capacity and applications limits.
- Focus on a few types like R-12+R114, R22+R114, etc.

Refrigerants

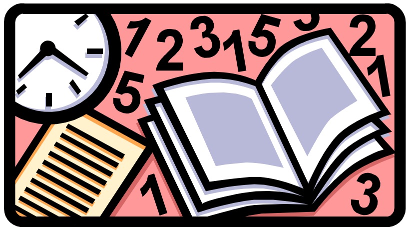


Prefixes and Decoding Refrigerants

Refrigerant number provides complex information about the molecular structure.

- Prefixes : CFC, HCFC, HFC, PFC, Halon
  - CFC & HCFC: first "C" = chlorine, "F" = fluorine, "H" = hydrogen, final "C" = carbon
  - HFC: no first "C", thus no chlorine
  - PFC (perfluorocarbon): "per" = all, thus PFC means all fluorine
  - Halon: containing C, F, Cl, H and Br
- Zeotropic / Azeotropic blend are assigned in series in numbering
  - zeotropic blend : R-400 series (first one R-400)
  - Azeotropic blend : R-500 series (first one R-500)
  - Same components but different percentages are assigned different capital letters, e.g R401A, R401B

Refrigerants

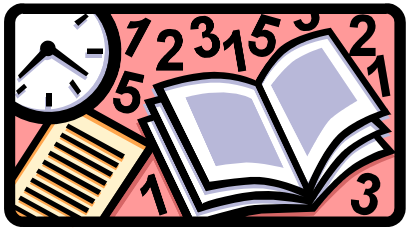


Prefixes and Decoding Refrigerants

Numbering in refrigerants

- Add 90 to the refrigerant number
  - Result shows the number of C, H, F atoms
  - E.g. HCFC-141b: 141+90 = 231 (2 "C", 3 "H", 1 "F")
  - Since 2 "C" should have 6 bonds (saturated)
  - Remaining will be 2 "Cl"
  - Thus, HCFC-141b = $C_2H_3FCl_2$
  - Letter "b" describe the isomer for the chemical
  - So, what is the chemical formula for R-134a?
- Any refrigerant having only 1 "C" will have a 2-digit number, e.g. R-11, and those with 2 "C" or 3 "C" will have 3-digit number

Refrigerants



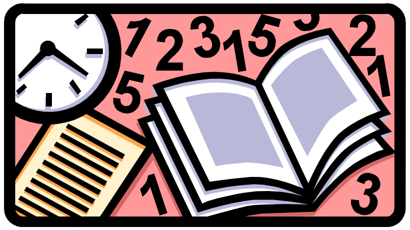
Selection of a suitable refrigerant

Evaporating temperature required during operation, the coefficient of performance (COP), safety requirements, and the size and location of the refrigeration plant, etc.

In order to select a suitable refrigerant for a refrigeration system of known size and evaporating temperature, the following factors must be considered:

- Mass / volume flow rate required per kW of refrigeration capacity
- Coefficient of performance in the refrigeration cycle
- Safety requirements
- Physical properties
- Operating properties
- Cost.

Refrigerants



From CFC to HCFC to HFC

CFCs (chlorofluorocarbons)

High ozone-depleting potential (ODP) contributing to the breakdown of the ozone layer, are banned by the Montreal Protocol (an international agreement to protect the earth's ozone layer) and ceased to be manufactured in the European Community (e.g. R11, R12 and R114.)

HCFCs (hydrochlorofluorocarbons)

These have limited ODP are **classified under** the Montreal Protocol as *transitional substances* and are due to be phased out early in next century. Examples are R22, R123 and R124.

HFCs (hydrofluorocarbons)

These contain no chlorine and therefore have zero ODP and not controlled by the Montreal Protocol. Examples are R125, R134a and R152a. R134a can be substituted directly, requiring replacement of some serviceable components only for R12.

Refrigerants

Global Warming Potential (GWP)
In addition to an ODP classification, refrigerants are also given ratings for global warming potential (GWP), an index providing a simple comparison with carbon dioxide which has an index rating of unity.

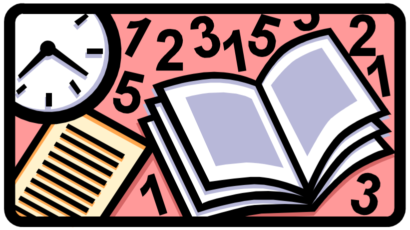
Prevention of Leakage
Consideration should be given to limiting the volume of refrigerant gas in a system together with improved standards of design and installation for refrigerant pipework in order to reduce the risk of leakage.

Source: Refrigeration Systems and Applications, Dincer and Kanoglu, 2nd Ed, Wiley, 2010

Table 2.2 ODPs, GWPs, and CAS numbers of Class I and II ODSs.

Chemical Name	ODP	GWP	CAS Number
Class I			
Group I			
CFC-11 Trichlorofluoromethane	1.0	4,000	75-69-4
CFC-12 Dichlorodifluoromethane	1.0	8,500	75-71-8
CFC-113 1,1,2-Trichlorotrifluoroethane	0.8	5,000	76-13-1
CFC-114 Dichlorotetrafluoroethane	1.0	9,300	76-14-2
CFC-115 Monochloropentafluoroethane	0.6	9,300	76-15-3
Group II			
Halon 1211 Bromochlorodifluoromethane	3.0	1,300	353-59-3
Halon 1301 Bromotrifluoromethane	10.0	5,600	75-63-8
Halon 2402 Dibromotetrafluoroethane	6.0	–	124-73-2
Group III			
CFC-13 Chlorotrifluoromethane	1.0	11,700	75-72-9
CFC-111 Pentachlorofluoroethane	1.0	–	354-56-3
CFC-112 Tetrachlorodifluoroethane	1.0	–	76-12-0
CFC-211 Heptachlorofluoropropane	1.0	–	422-78-6
CFC-212 Hexachlorodifluoropropane	1.0	–	3182-26-1
CFC-213 Pentachlorotrifluoropropane	1.0	–	2354-06-5
CFC-214 Tetrachlorotetrafluoropropane	1.0	–	29255-31-0
CFC-215 Trichloropentafluoropropane	1.0	–	1599-41-3
CFC-216 Dichlorohexafluoropropane	1.0	–	661-97-2
CFC-217 Chloroheptafluoropropane	1.0	–	422-86-6
Group IV			
CCl_4 Carbon tetrachloride	1.1	1,400	56-23-5
Group V			
Methyl chloroform 1,1,1-trichloroethane	0.1	110	71-55-6
Group VI			
CH_3Br Methyl bromide	0.7	5	7-55-6
Group VII		–	–
$CHFBr_2$	1.0	–	–
CHF_2Br (HBFC-12B1)	0.74	–	–

Refrigerants

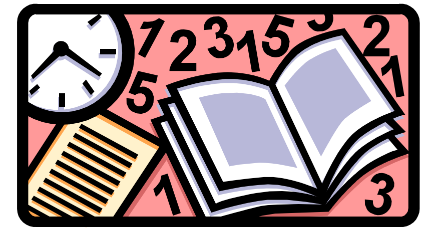


Hong Kong Present Situation on CFC

In line with an international agreement to protect the earth's ozone layer (Montreal Protocol), the enactment in 1989 of the Ozone Layer Protection Ordinance and its subsequent enforcement has brought about a total ban on import of CFCs has been taken into effect on ***1 January 1996.***

No matter how carefully the air-conditioning equipment is maintained, some refrigerants are lost through small leaks in pipes and valves, during equipment overhauls or accidents. There has been no CFCs available to replenish these losses (in principle).

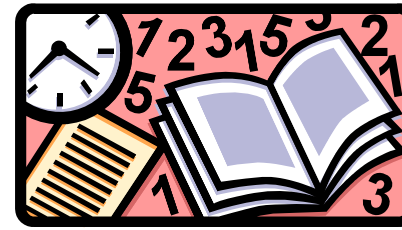
Refrigerants



Eliminate dependence on CFC for AC plant for existing installations

- Routine leak checks at regular intervals
- Installation of a refrigerant leak detection system to minimize the leakage
- Recover and recycle the refrigerant during servicing and maintenance of the refrigerant circuits (a mandatory requirement under LAW to recover the refrigerant from large plant using CFC such as R-12)
- Paying particular attention to joints, seals, and gaskets.
- After completion of any servicing or repair work, thoroughly check for leaks before recharging with refrigerant.
- Replace refrigerants in existing systems by HCFCs (retrofit works allowing the run of HCFCs or azeotrope. Minor modifications to equipment needed and allow for a slight reduction in machine efficiency after conversion.
- Install new chillers running on non-CFC refrigerants

Refrigerants



Ideal refrigerants

- Having the desired thermodynamic properties
- Nontoxic
- Non-flammable
- Completely stable inside a system
- Environmentally friendly - even after decomposition of products-and abundantly available or easy to manufacture
- Self-lubricating
- Compatible with other materials used to fabricate and service refrigeration systems
- Easy to handle and detect
- System not operating at extreme pressures, either high or low

Properties of refrigerants

Properties	*Refrigerant*						
	Ammonia	*R11*	*R12*	*R22*	*R123*	*R134a*	*R407C*
Gauge pressure (kPa)							
condenser (30 °C)	+1060	+24.8	+642	+1100	+8.2	+670	1160
evaporator (−15 °C)	+155	−80.6	+81.2	+195	−85.4	+62.6	189
evaporator (−5 °C)	+404	−52.5	+254	+427	−60.5	+249	321
Boiling point (°C) (standard pressure)	−33.3	+23.8	−29.8	−40.8	+27.8	−26.1	−43.8
Critical temperature (°C)	1333	198	111	96	184	101	87.3
Volume of vapour at −15 °C (m^3/kg)	0.509	0.766	0.093	0.078	0.873	0.121	0.09
Latent heat of evaporation at −15 °C (kJ/kg)	1320	198	162	218	175	187	212
Theoretical energy input per unit ÷ energy output (kW/kW)	0.211	0.200	0.213	0.216	0.203	0.217	–
Coefficient of performance (27 °C to − 15 °C)	4.75	5.00	4.69	4.65	4.93	4.61	–
Ozone depleting potential (ODP)	0	1.0	1.0	0.05	0.014	0	0
Global warming potential (GWP)	0	1500	4500	510	29	1600	1980

Basic Refrigeration Cycle

Refrigeration Cycle: P-h diagram

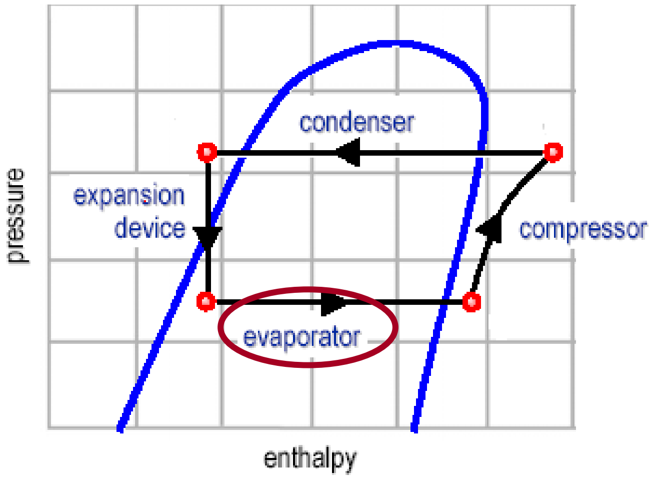
Evaporator

- A diagram of a typical vapor-compression refrigeration cycle is superimposed on a pressure-enthalpy (P-*h*) chart to demonstrate the function of each component in the system.

- The **pressure-enthalpy chart** plots the properties of a refrigerant—refrigerant pressure (vertical axis) versus enthalpy (horizontal axis).

- The cycle starts with a cool, low-pressure mixture of liquid and vapor refrigerant entering the evaporator where it absorbs heat from the relatively warm air/water or other fluid that is being cooled.

- This transfer of heat boils the liquid refrigerant in the evaporator, and this superheated refrigerant vapor is drawn to the compressor.

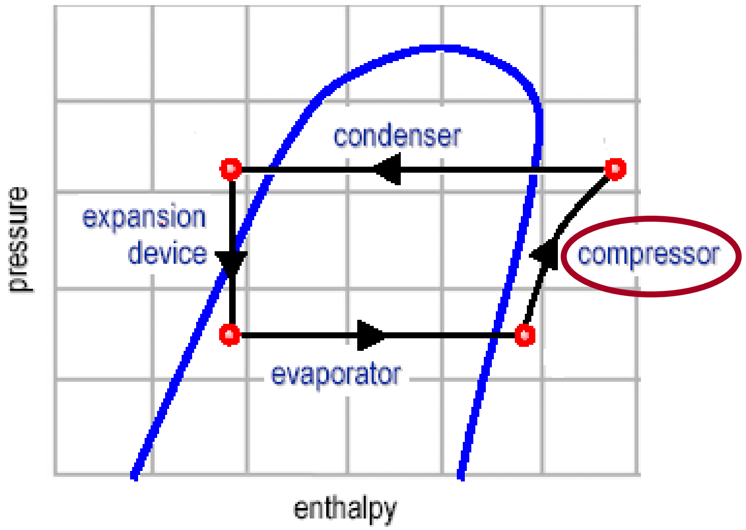


Basic Refrigeration Cycle

Refrigeration Cycle: P-h diagram

Compressor

- The compressor draws in the superheated refrigerant vapor and compresses it to a pressure and temperature high enough that it can reject heat to another fluid.
- This hot, high-pressure refrigerant vapor then travels to the condenser.

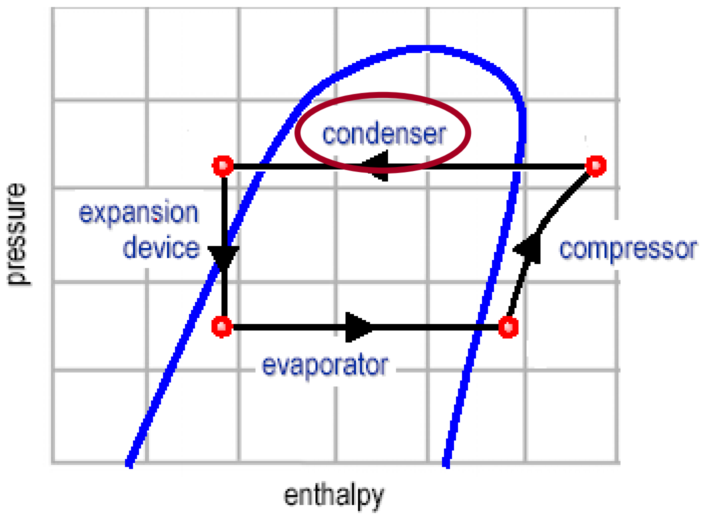


Basic Refrigeration Cycle

Refrigeration Cycle: P-h diagram

Condenser

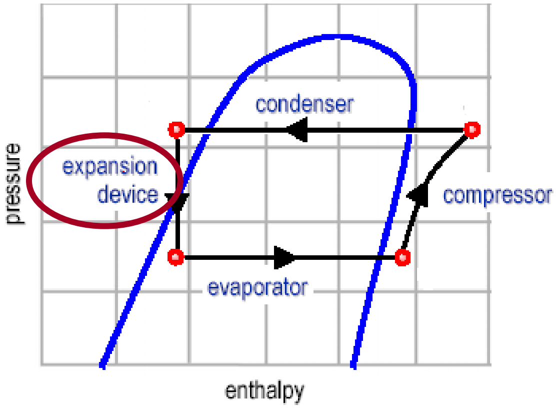
- Within the condenser, heat is transferred from the hot refrigerant vapor to relatively cool ambient air or cooling water.
- This reduction in the heat content of the refrigerant vapor causes it to desuperheat, condense into liquid, and further subcool before leaving the condenser for the expansion device.



Basic Refrigeration Cycle

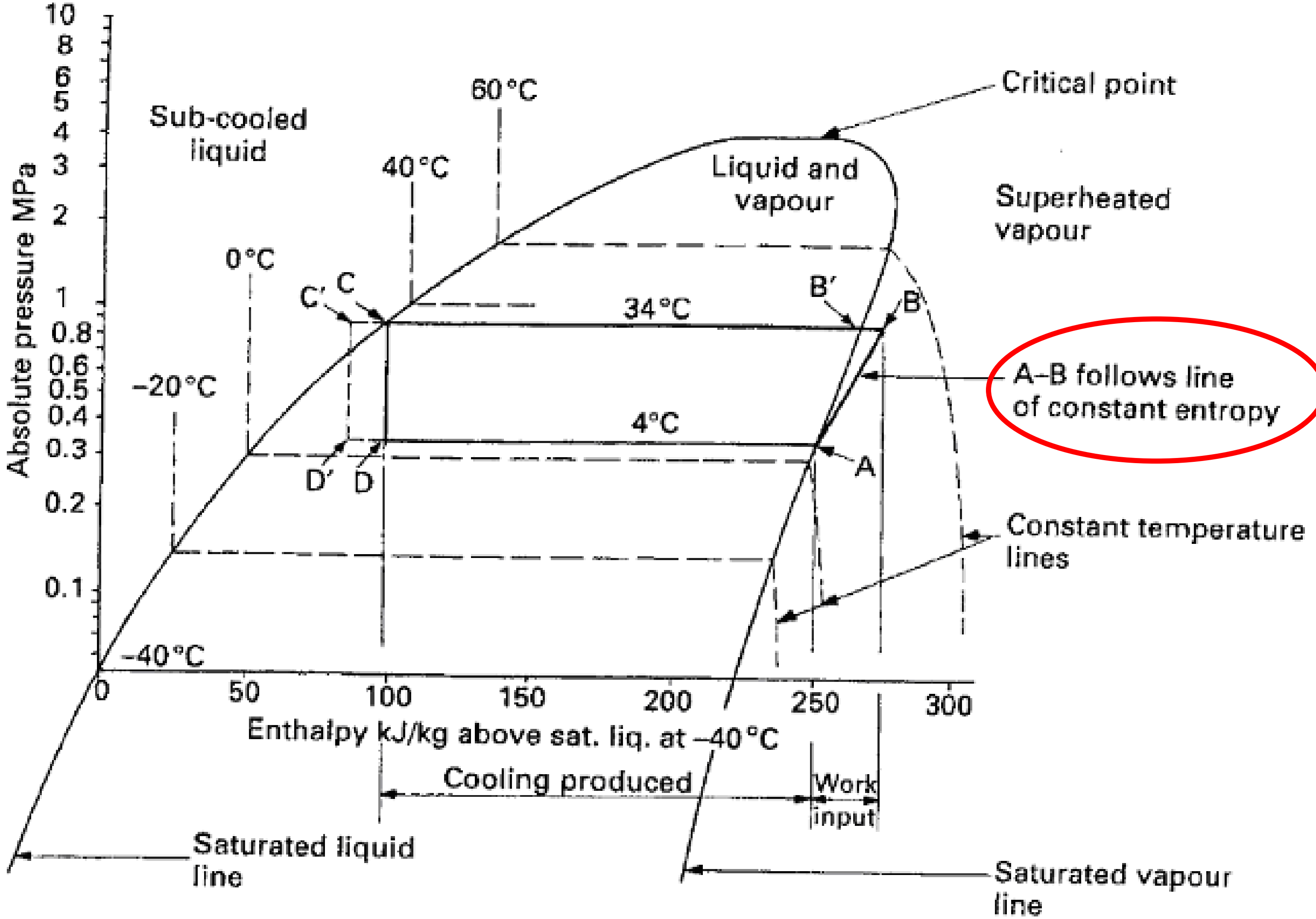
Refrigeration Cycle: P-h diagram

Expansion Device



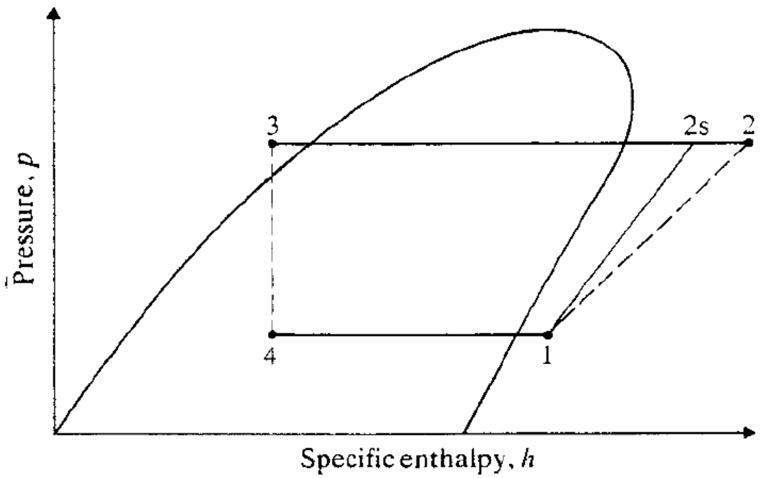
- The high-pressure liquid refrigerant flows through the expansion device, causing a large pressure drop that reduces the pressure of the refrigerant to that of the evaporator.
- This pressure reduction causes a small portion of the liquid to boil off, or flash, cooling the remaining refrigerant to the desired evaporator temperature.
- The cooled mixture of liquid and vapor refrigerant then enters the evaporator to repeat the cycle.

Basic Refrigeration Cycle



Pressure–enthalpy (total heat) diagram for Refrigerant 134a

Major Components of Vapour Compression System



$$\eta_s = \frac{\text{Isentropic work}}{\text{Actual work}} = \frac{\dot{m}(h_{2s} - h_1)}{\dot{m}(h_2 - h_1)} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

Rate of heat *supply* to evaporator $\dot{Q}_E = \dot{m}(h_1 - h_4)$

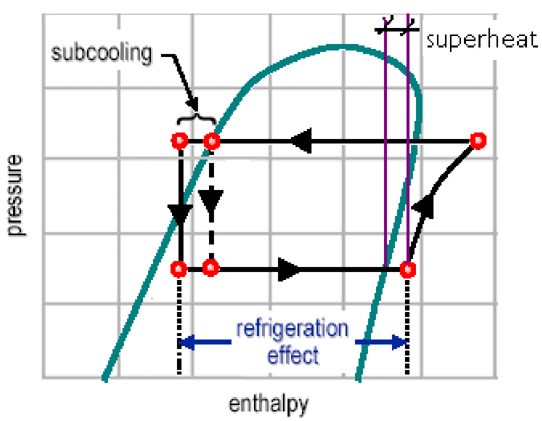
Rate of heat *rejection* from condenser $\dot{Q}_C = \dot{m}(h_2 - h_3)$

Rate of work *input* to the compressor $\dot{W} = \dot{m}(h_2 - h_1)$

Major Components of Vapour Compression System

Refrigeration effect

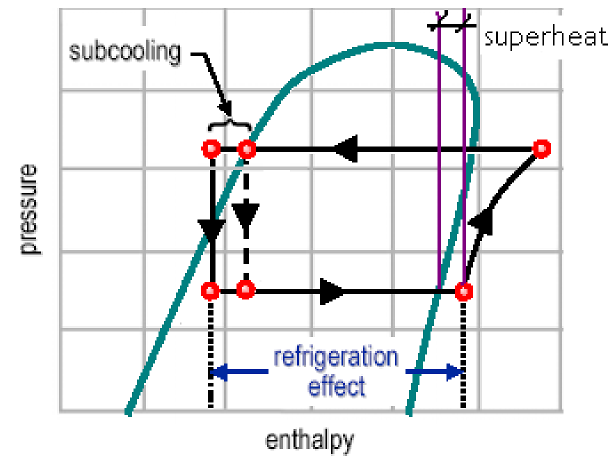
- The change in enthalpy that occurs in the evaporator is called the **refrigeration effect**.
- This is the amount of heat that each kg of liquid refrigerant will absorb when it evaporates.
- In comparison, the same system without subcooling produces less refrigeration effect.



Major Components of Vapour Compression System

Superheating

- Superheating occurs inside the final length of tubes at which temperature difference between refrigerant and air is highest
- Such large temperature difference increases the rate of heat transfer and the refrigerant vapor absorbs much heat.
- Liquid refrigerant completely evaporated
- Superheating shifts from the liquid/vapor region to vapor
- It ensures the refrigerant vapor is completely free liquid before entering the compressor.



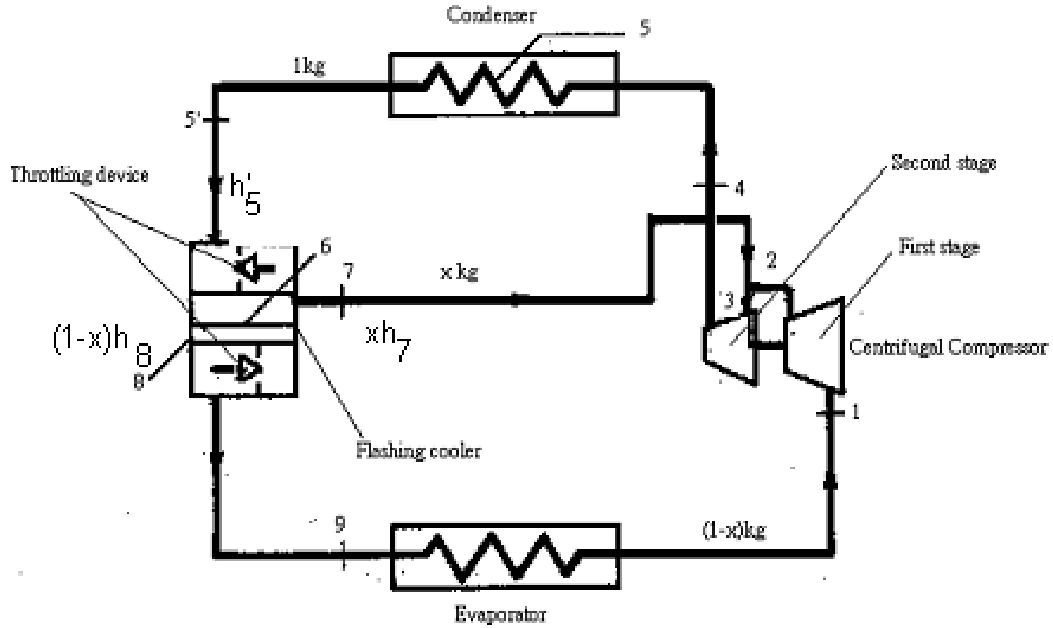
Two-stage vapor compression system

Two-stage vapor compression system

Consists of two stage of compression system

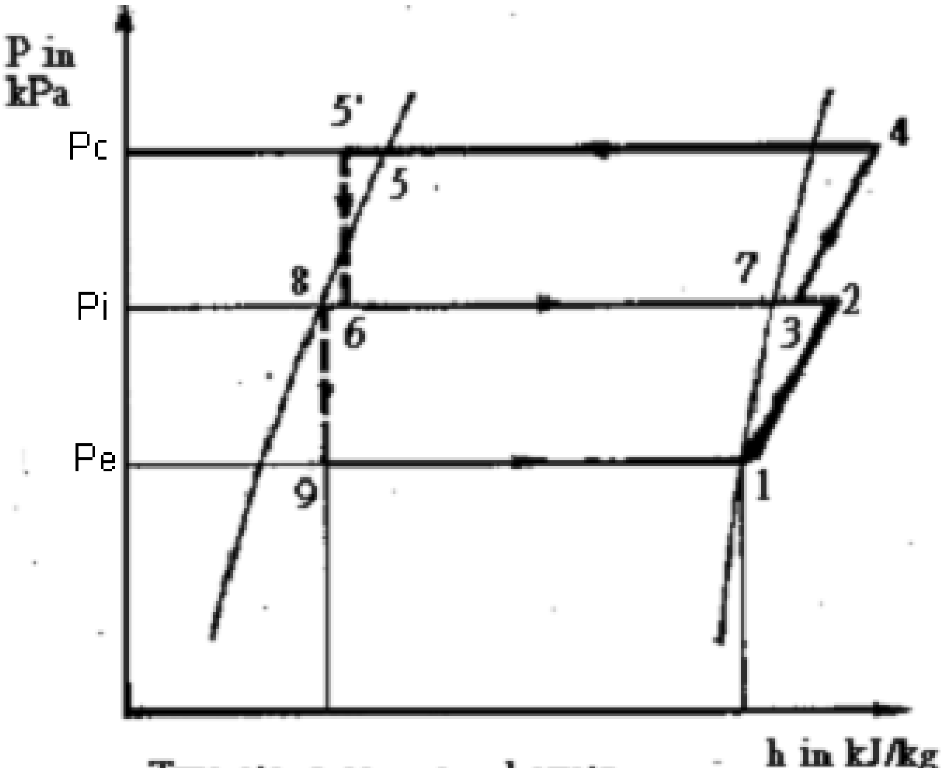
Comprise with a high stage compressor and a low stage compressor or several single stage compressors in series.

The pressure between the discharge pressure of the high stage and suction pressure of the low stage is called inter-stage pressure.



Two stage compound system with a flash cooler

Two-stage vapor compression system



Two stage compound system with a flash cooler

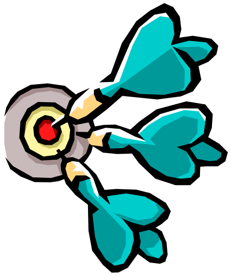
Two-stage vapor compression system

Defining the volumetric efficiency and compression ratio

$$\text{Volumetric efficiency} = \frac{\text{Volume of free air delivery}}{\text{Swept volume of the cylinder of the compressor}}$$

$$\text{Compression ratio} = \frac{\text{Pressure after the compression process}}{\text{Pressure before the compression process}}$$

Two-stage vapor compression system



Advantage of using two-stage vapour compression system compared with a single stage system:

1) The compression ratio of each stage in a two-stage system can be reduced so that the volumetric efficiency can be increased.

2) In two-stage system, the liquid refrigerant can be sub-cooled to the saturation temperature at the inter-stage pressure which in turn increases the refrigeration effect.

3) In two-stage system, the discharge gas from the low stage compressor can be de-superheated that results in reduction of discharge temperature after the high stage compression process.

Disadvantage of multi-stages systems include:

1) The complicated equipment results in high equipment cost comparing with single stage system.

Two-stage vapor compression system

Compound System – one type of 2-stage compression system

Vapor refrigerant at state point (1) enters the first stage of the compressor in dry saturated state.

This vapor is compressed to the inter-stage pressure Pi at stage point (2)

The mixture enters the second stage of compressor at state point(3)

Hot gas compressed to condensing pressure Pc leaves compressor at state point (4)

The hot gas is then discharged to the condenser and condenses into liquid state at state point (5).

Two-stage vapor compression system

Compound System (cont'd)

Upon passing the condenser, the sub-cooled liquid refrigerant at state point (5') flows through the high pressure side flow control device. A portion of liquid refrigerant evaporates into the vapor form in the flash cooler at state point (7)

The flashed refrigerant cools the remaining portion of liquid refrigerant to the saturated temperature at state point (8) at the inter-stage pressure.

The mixture of liquid and vapor refrigerant in flash cooler is at state point (6).

Liquid refrigerant flows through low pressure expansion valve, a small amount of which is pre-flashed and the liquid vapor mixture enters the evaporator at state point (9).

In the evaporator, all liquid refrigerant is evaporated into vapor form and flows to the first stage inlet.

Two-stage vapor compression system

The inter-stage pressure of 2-stage compound system

1) The inter-stage pressure is selected such that the compression ratios at various stages are approximately equal.
2) The inter-stage pressure could be approximated by the following equation:

where

$$p_i = \sqrt{P_{cond} P_{evap}}$$

P_{cond} = Pressure of condenser and

P_{evap} = Pressure of evaporator

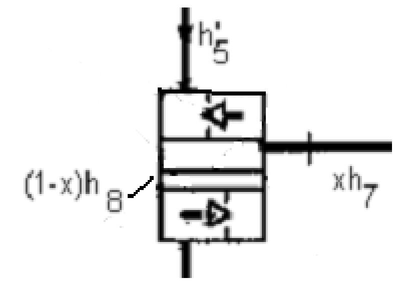
Two-stage vapor compression system

Defining the enthalpy of various state points in the PH diagram:

h_1	=	Enthalpy of saturated vapor leaving the evaporator
h_2	=	Enthalpy of superheated gas at the exit from the first stage compression
h_3	=	Enthalpy of mixture of the super-heated gas from the first-stage compressor and vapor refrigerant from the flash cooler
h_4	=	Enthalpy of the hot gas discharged from the second stage compression
h_5'	=	Enthalpy of sub-cooled liquid refrigerant leaving the condenser
h_6	=	Enthalpy of refrigerant after the throttling device
h_7	=	Enthalpy of saturated liquid refrigerant at the inter-stage pressure pi
h_8	=	Enthalpy of saturated vapor refrigerant at the inter-stage pressure pi
h_9	=	Enthalpy of refrigerant entering the evaporator

The portion of flashed vapour refrigerant in the flash cooler

In the flash cooler, there is x kg of vaporized refrigerant cools down the remaining liquid refrigerant (1-x) kg to the saturation temperature at the inter-stage pressure.
From the heat balance point of view, we have



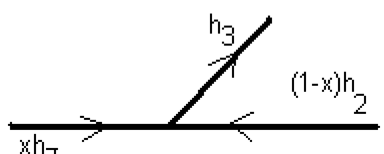
$$h_5' = xh_7 + (1-x)h_8$$

Note that x is also the dryness fraction of the liquid-vapor mixture in the flash cooler at the inter-stage pressure. This equation could be expressed as

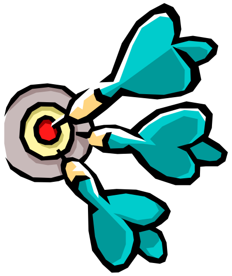
$$x = \frac{h_5' - h_8}{h_7 - h_8}$$

Enthalpy of vapor mixture entering the second-stage compressor

Heat balance at the mixing point before entering the second stage compressor could be show as follows:-



Two-stage vapor compression system



Coefficient of Performance of the 2-stage compound system with a flash cooler

The refrigeration effect in evaporator Qre (per kg of refrigerant through condenser) could be expressed as:-

Qre = (1-x)(h1-hg)

Work input Win to the compressor (first and second stages)

It could be expressed as

$W_{in} = (1-x)(h_2-h_1) + (h_4-h_3)$

Heat Pumps

A heat pump extracts heat from a heat source and rejects heat to air or water at a higher temperature.

During summer, the heat extraction, or refrigeration effect, is the useful effect for cooling.

In winter the rejected heat alone, or rejected heat plus supplementary heating from a heater form the useful effect for heating.

A heat pump is a packaged air conditioner or a packaged unit with a reversing valve or other changeover setup.

A heat pump has all the main components of an air conditioner or package unit: fan, filters, compressor, evaporator, condenser, and a throttling device.

Heat Pumps

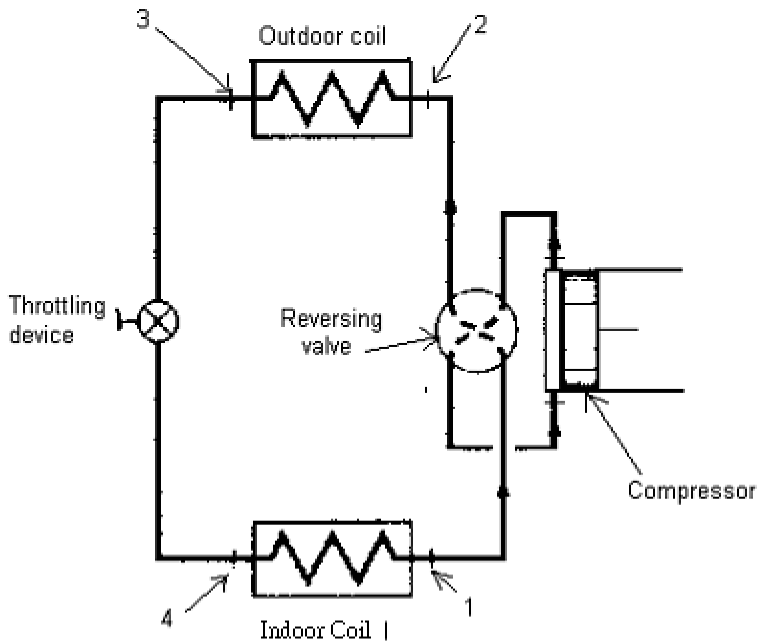
The apparatus for changing from cooling to heating or vice versa is often a reversing valve, in which the refrigerant flow to the condenser is changed to the evaporator.

Alternatively, air passage through the evaporator may be changed over to passage through the condenser.

A supplementary heater is often provided when the heat pump capacity does not meet the required output during low outdoor temperatures.

R-22 and R-134a are the most widely used halocarbon refrigerants in new heat pumps.

Heat Pumps



Heat Pump Cycle

Heat Pumps

Heat Pump Cycle

A heat pump cycle comprises the same processes and sequencing order as a refrigeration cycle except that both the refrigeration effect q_{ref}, and the heat pump effect q_{hp} in are the useful effects,

The coefficient of performance of a refrigeration system: -

$$COP_{ref} = \frac{h_1 - h_4}{w_{in}} = \frac{q_{1,4}}{w_{in}}$$

where $h_4, h_1 =$ Enthalpy of refrigerant entering & leaving the evaporator

$$w_{in} = \text{work input}$$

The coefficient of performance of the heat effect :-

$$COP_{hp} = \frac{q_{2,3}}{w_{in}}$$

Heat Pumps

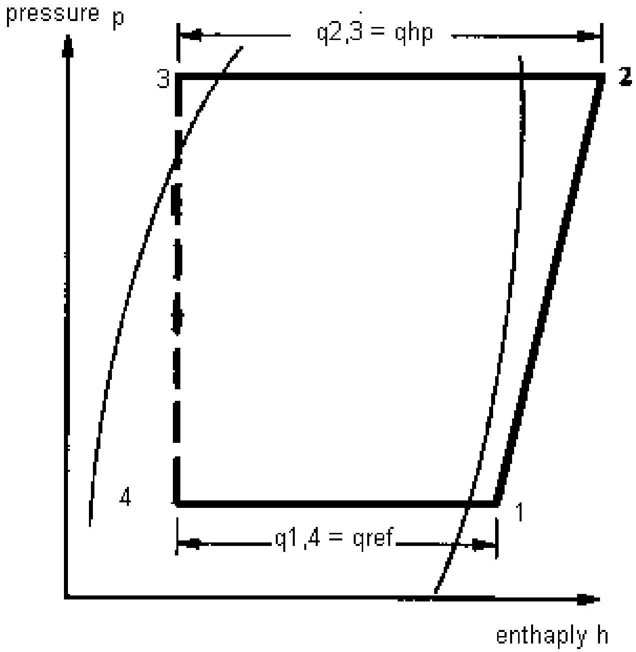
Useful heating effect could be found by the following equation :

$$q_{2,3} = (h_2 - h_3)$$

where h_2 = enthalpy of hot gas discharged from compressor

where h_3 = enthalpy of the sub-cooled liquid leaving the condenser

PH diagram



Vapor Absorption Cycle

The following illustrates the refrigeration cycle using vapour absorption by LiBr solution.

Water is the refrigerant in the cycle.

Distilled water is stable, nontoxic, low in cost, readily available, environmentally friendly, and has a relatively high heat of vaporization

The cycle shall be operated in a vacuum, that is, at a pressure below atmospheric pressure.

Large quantities of water are absorbed by the absorbent and separated within the absorption cycle.

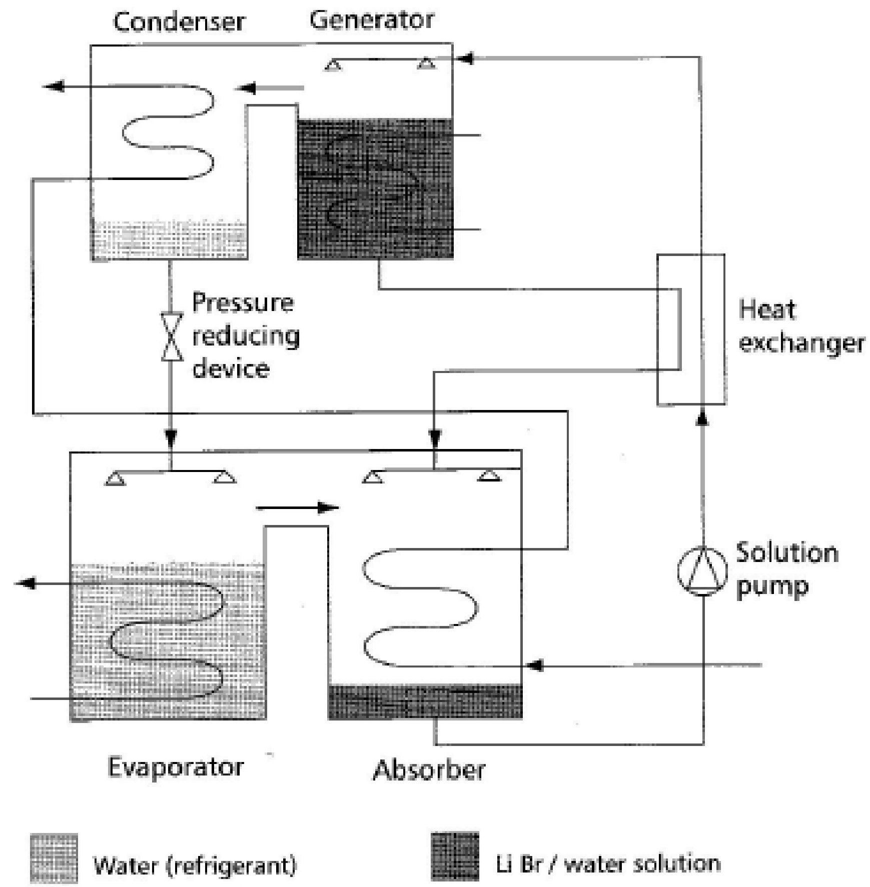
Vapor Absorption Cycle

In the evaporator the refrigerant extracts heat by evaporation

Refrigerant vapour is absorbed and condensed into solution in the absorber, thereby making the solution weaker.

The weak solution is pumped to high pressure and transferred to the generator

The addition of heat in the generator raises the temperature of the solution, separating and evaporating the refrigerant, thus making the solution stronger.

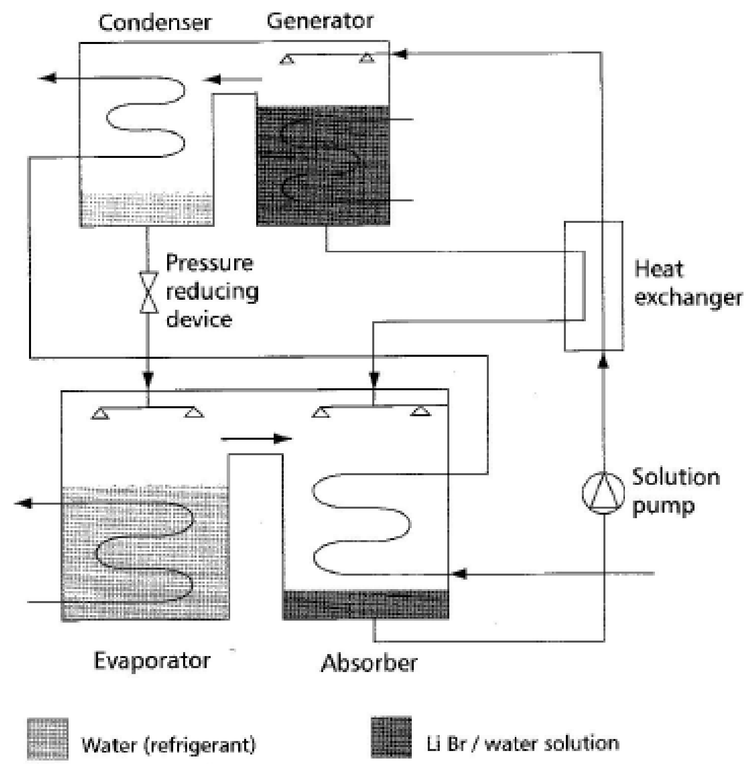


Vapor Absorption Cycle

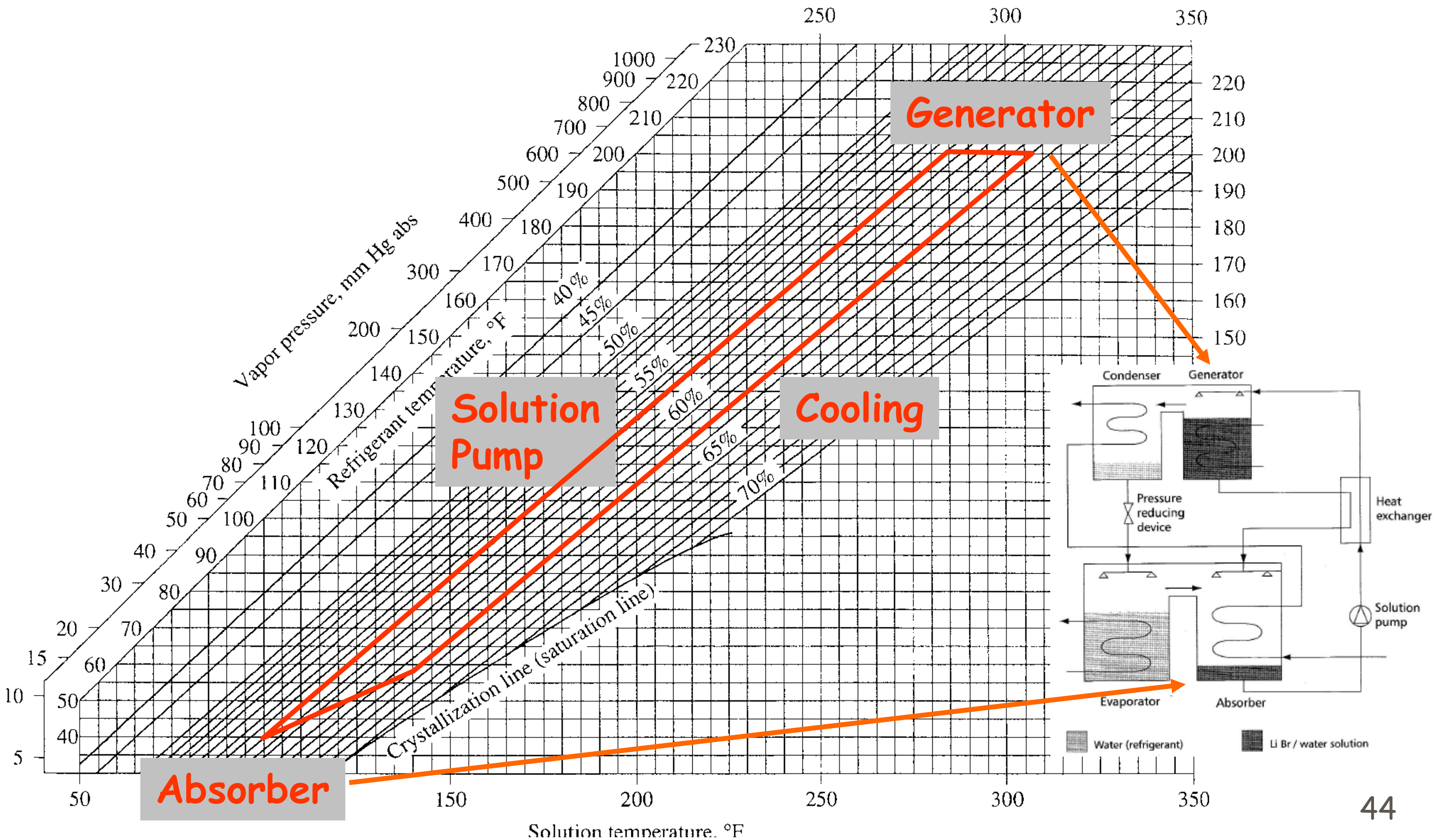
The strong solution is returned to the absorber through the pressure reducing device so maintaining the pressure difference between the high and low sides of the system

The refrigerant vapour driven out of solution at high pressure in the generator flows to the condenser where it is liquefied by removal of heat at constant pressure

The condensed liquid is fed through a pressure reducing device into the evaporator where the cycle re-commences.



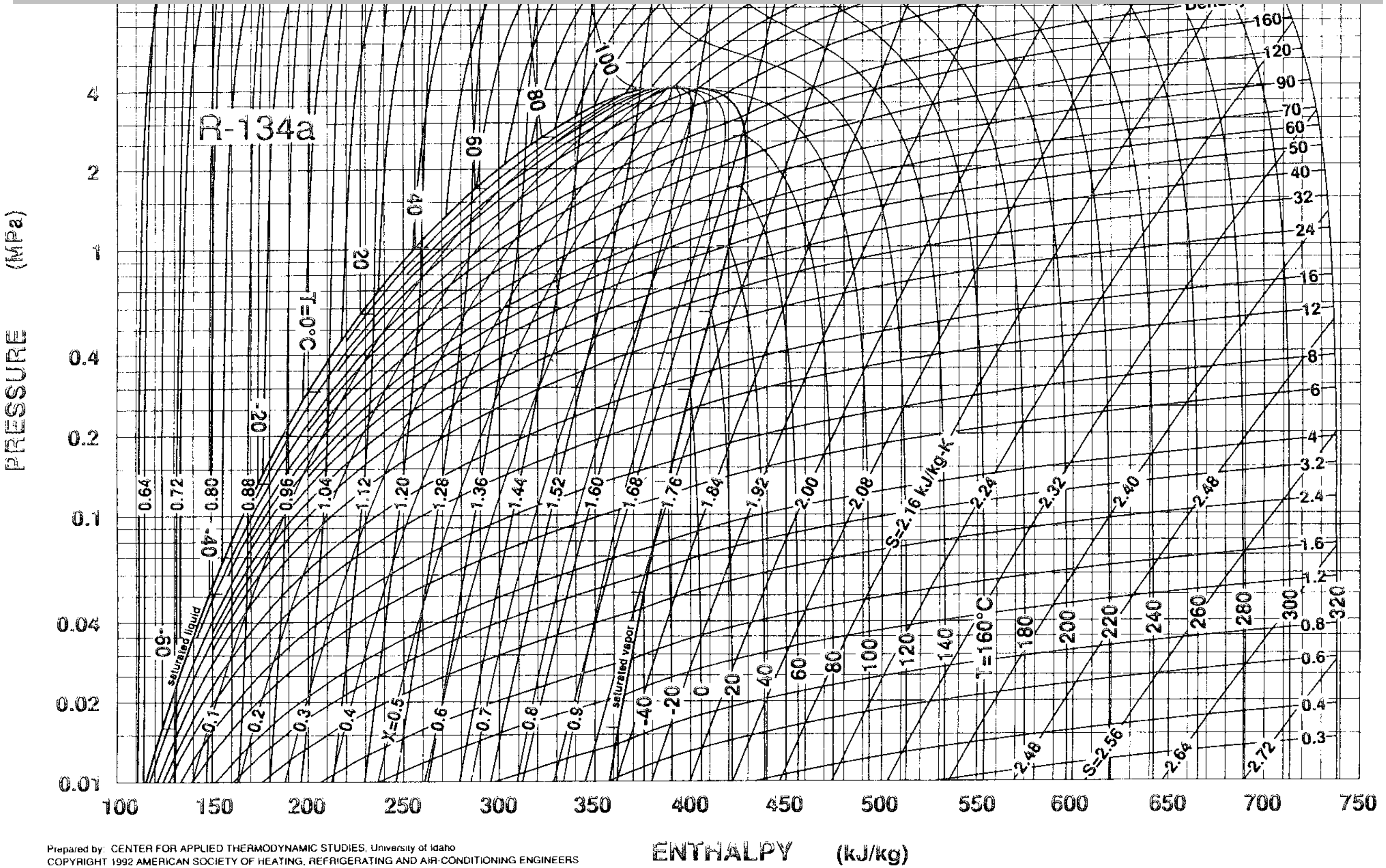
Vapor Absorption Cycle



Supplementary Calculation on Vapour Compression Refrigeration Cycles

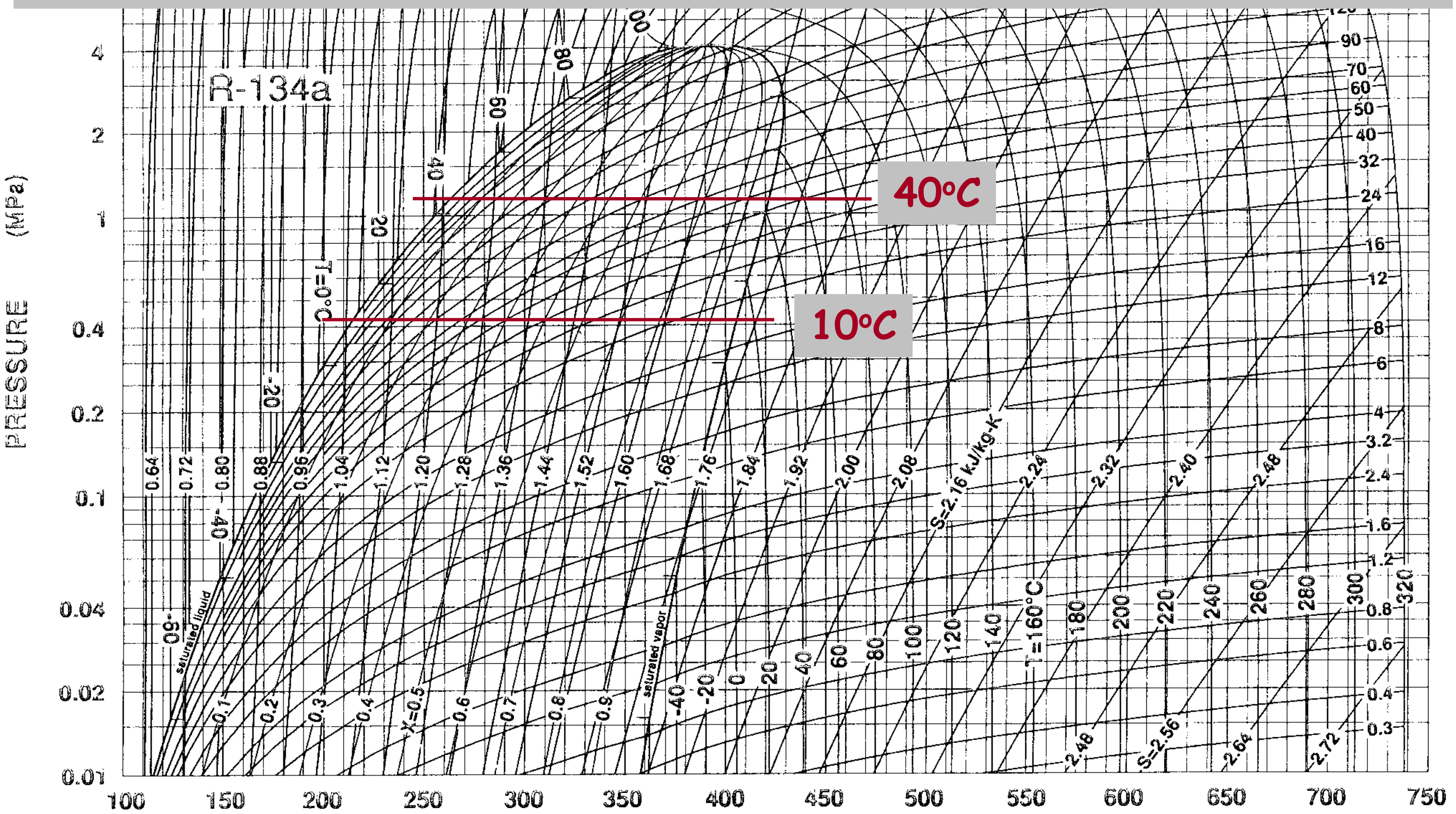
- Consider a refrigeration cycle using R-134a is plotted based on the following information:
  - Condenser temperature = 45^{o}C
  - Evaporator temperature = 10^{o}C
  - Sub-cooling at condenser = 3^{o}C
  - Superheating at evaporator = 3^{o}C
  - Compressor efficiency = 90%
- The refrigeration cycle for single stage compression is plotted
- The refrigeration effect and the COP are to be found.

R134a PH diagram



Pressure–Enthalpy Diagram for Refrigerant 134a

Step 1: Plot the condenser and evaporator pressure line (based on temperature)



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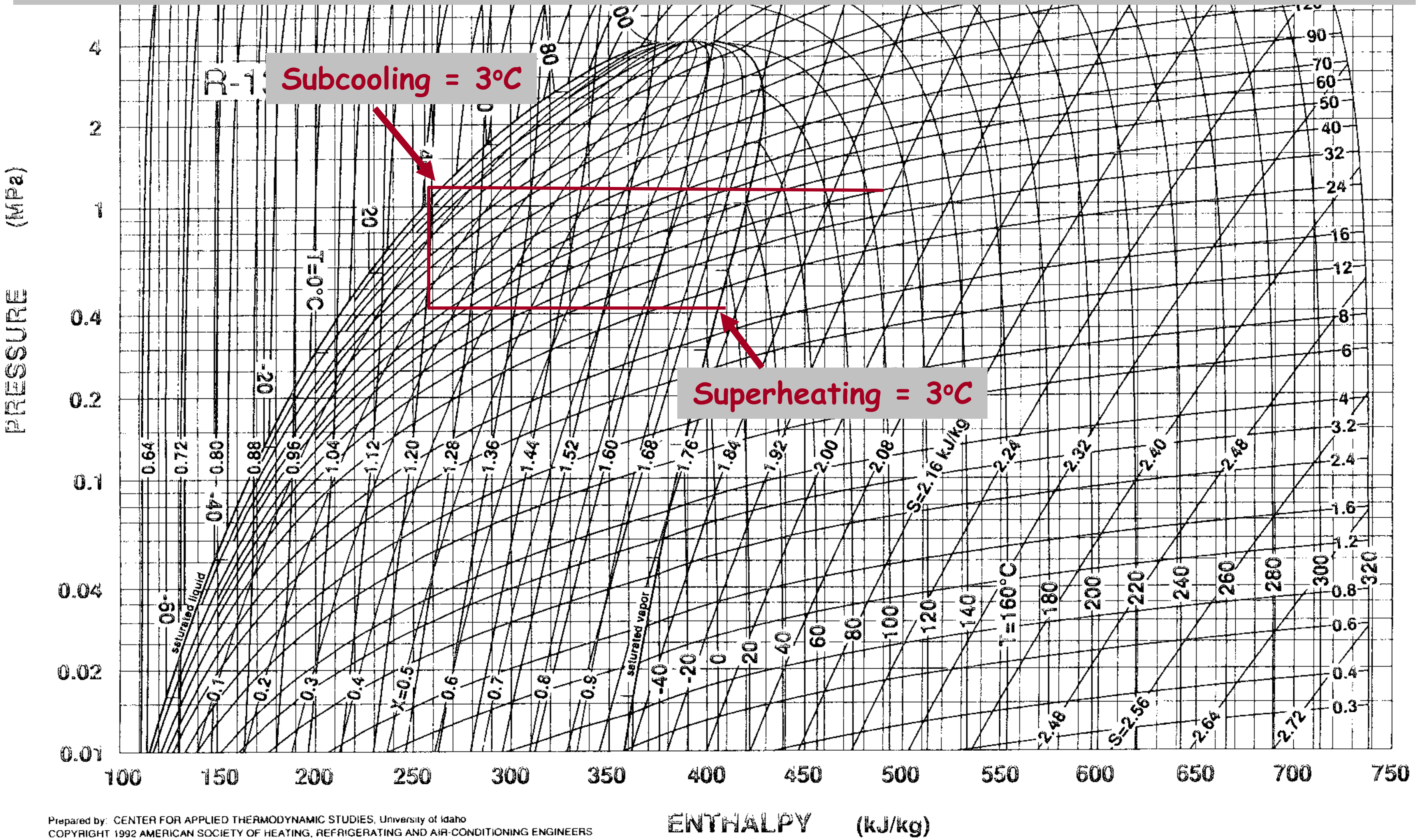
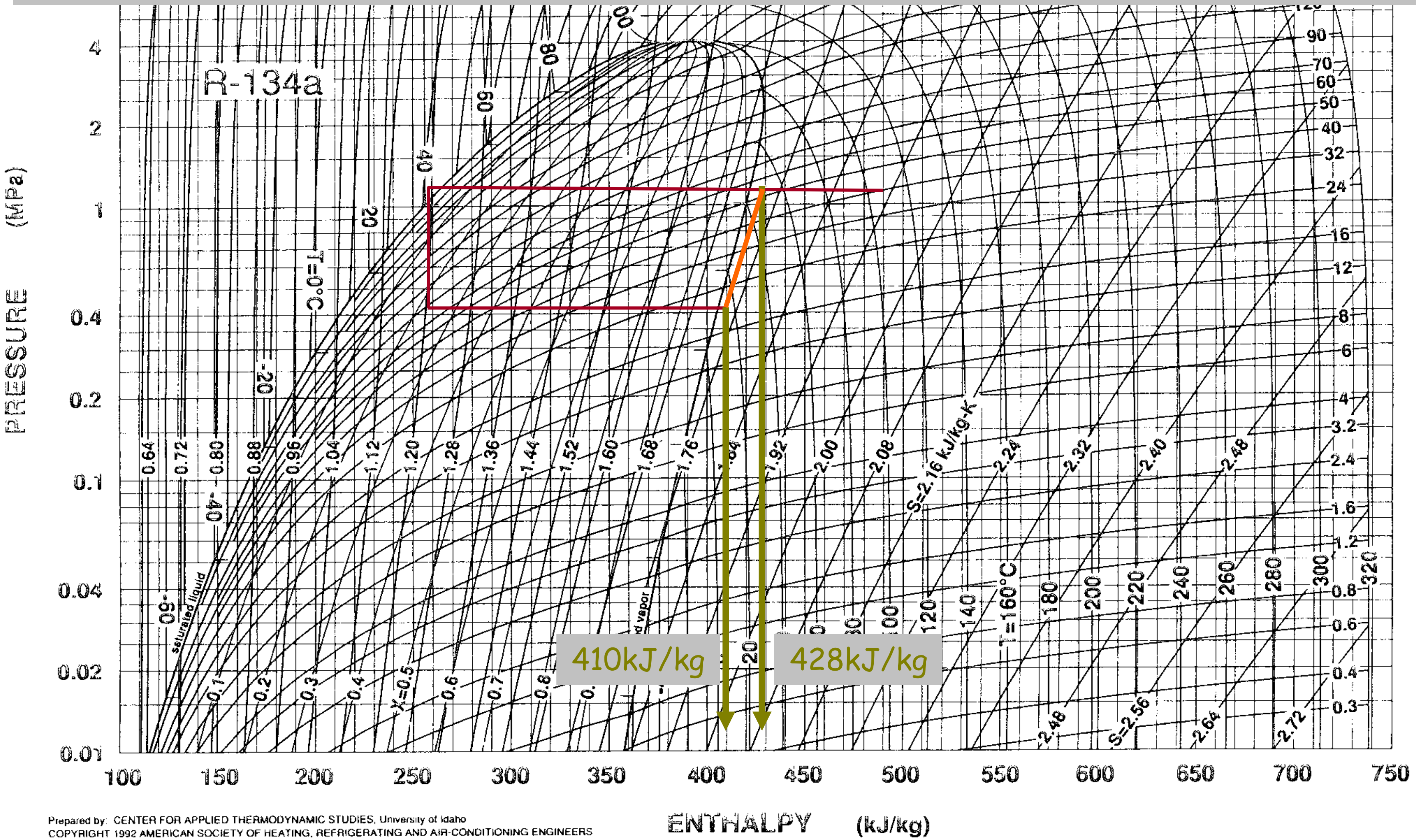
Pressure–Enthalpy Diagram for Refrigerant 134a

Step 2: Locate the sub-cooling and superheating points



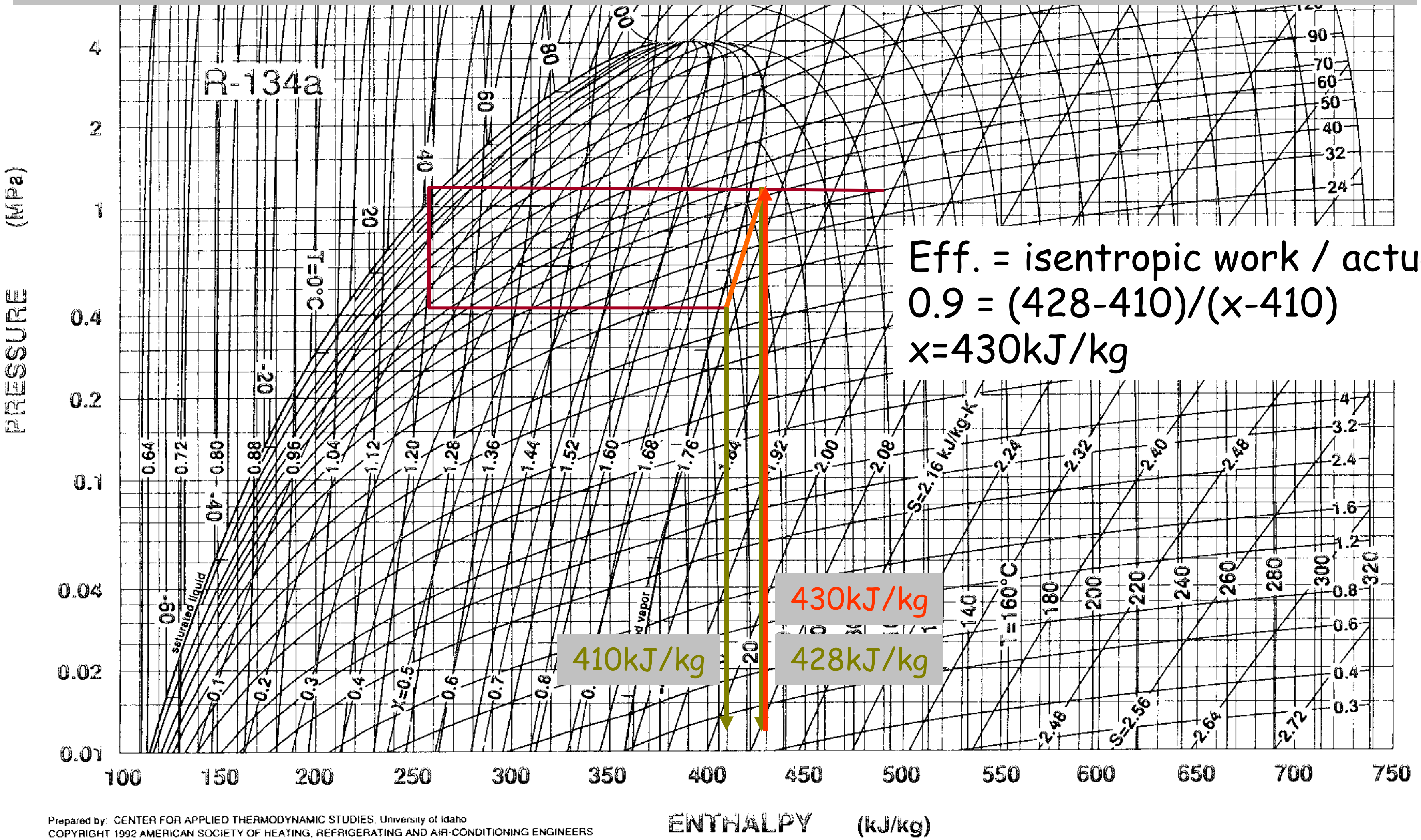
Pressure–Enthalpy Diagram for Refrigerant 134a

Step 3: Plot the isentropic line & determine the enthalpy of the refrigerant



Pressure–Enthalpy Diagram for Refrigerant 134a

Step 4: Determine the actual work based on compressor efficiency



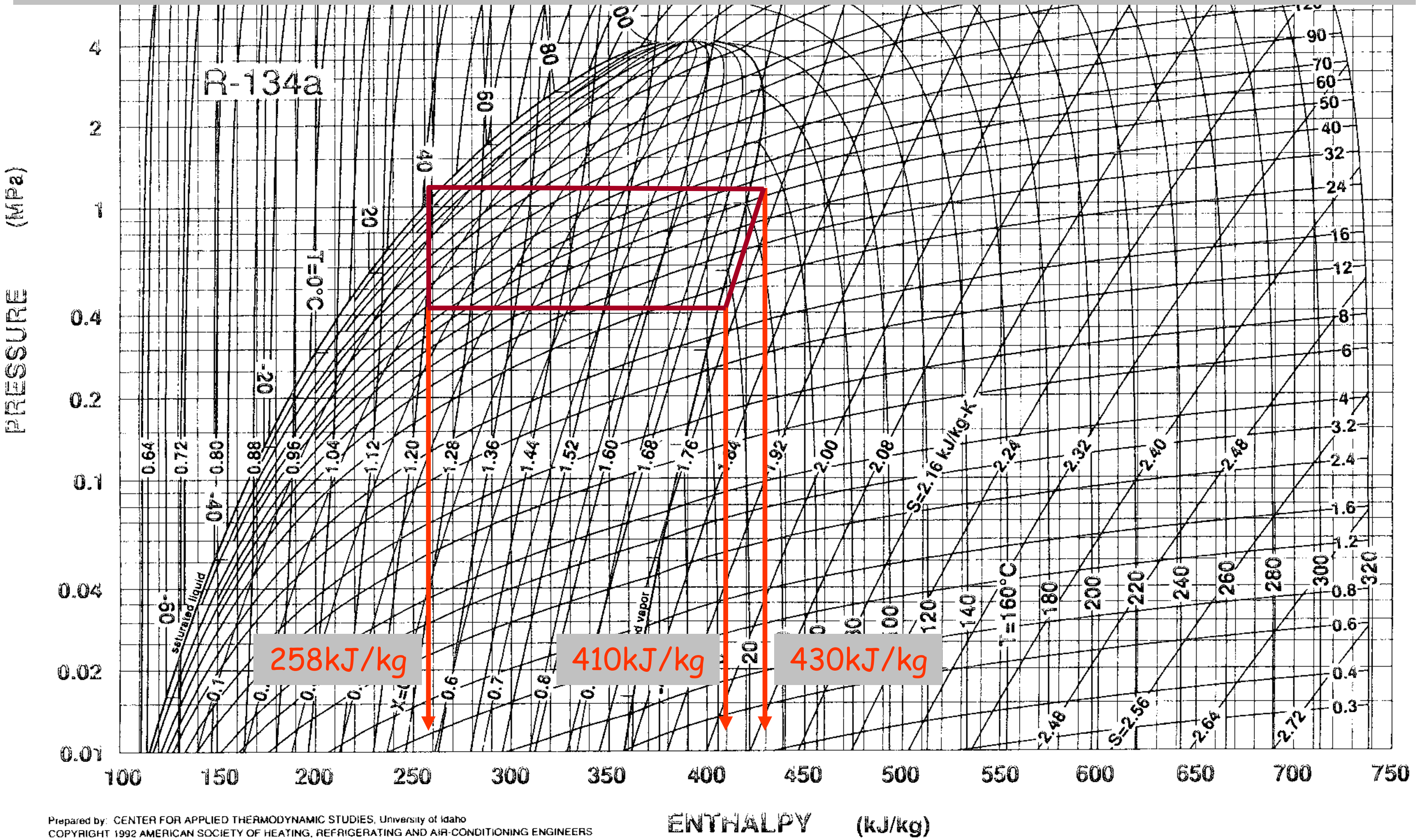
Pressure–Enthalpy Diagram for Refrigerant 134a

Eff. = isentropic work / actual w

0.9 = (428-410)/(x-410)

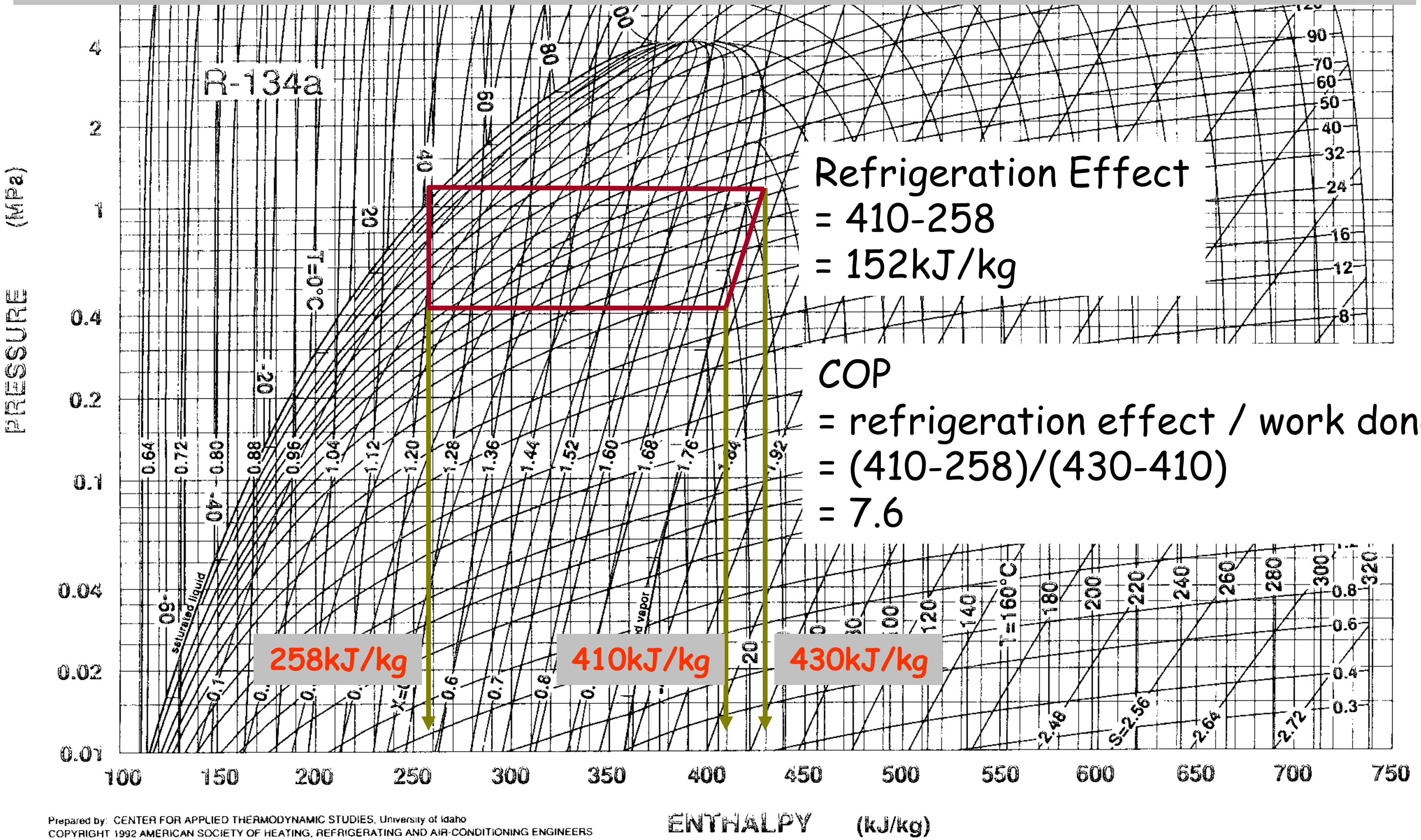
x=430kJ/kg

Step 5: Complete the refrigeration cycle and identify the enthalpy of all the points



Pressure–Enthalpy Diagram for Refrigerant 134a

Step 6: Calculate the refrigeration effect and COP



Pressure–Enthalpy Diagram for Refrigerant 134a

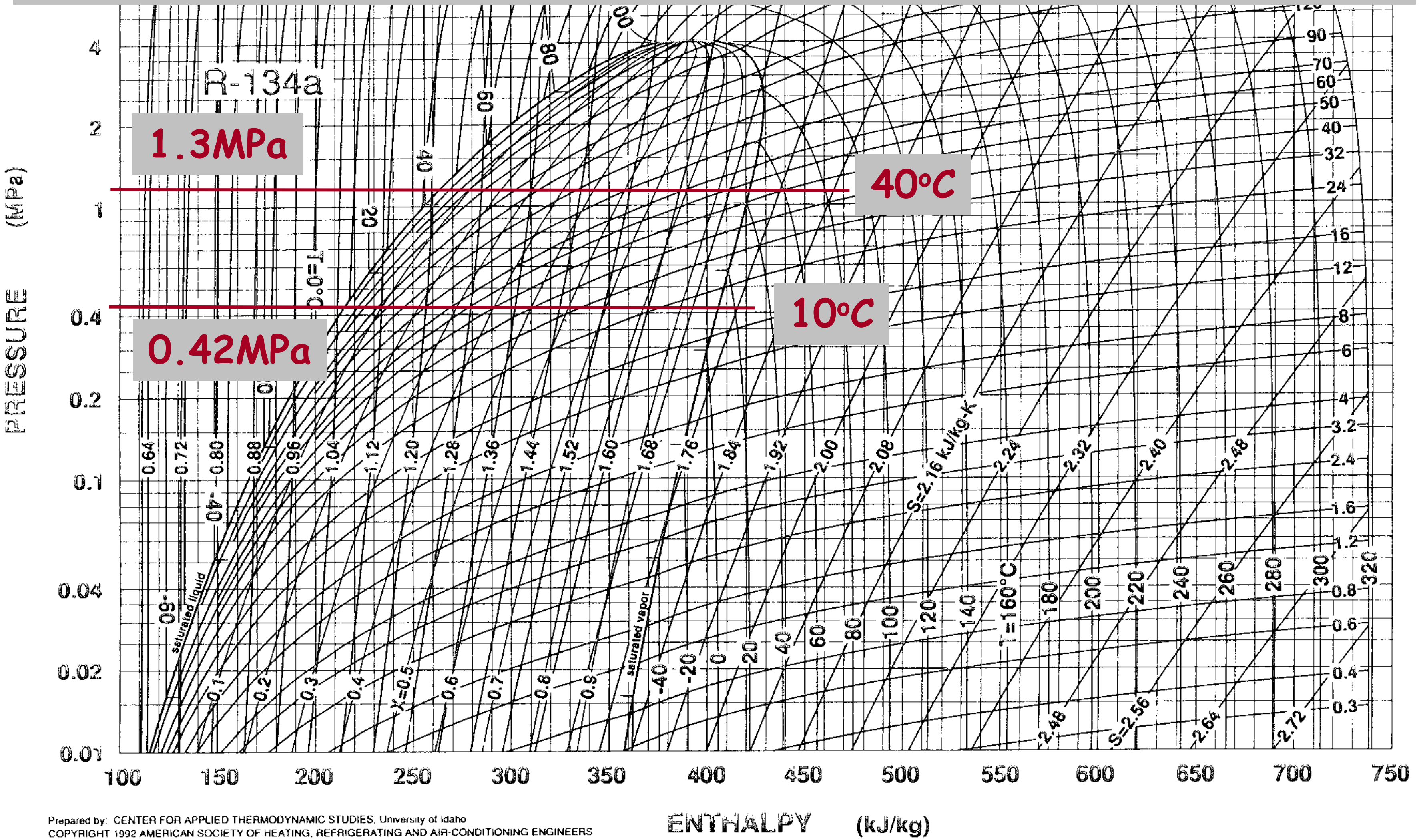
Refrigeration Effect
= 410-258
= 152kJ/kg

COP
= refrigeration effect / work done
= (410-258)/(430-410)
= 7.6

Supplementary Calculation on Vapour Compression Refrigeration Cycles

- With the same set of design data but using two stage compression
- What will be the refrigeration effect and COP?

Step 1: plot the condenser and evaporator pressure line (based on temperature) and determine the pressure



Pressure–Enthalpy Diagram for Refrigerant 134a

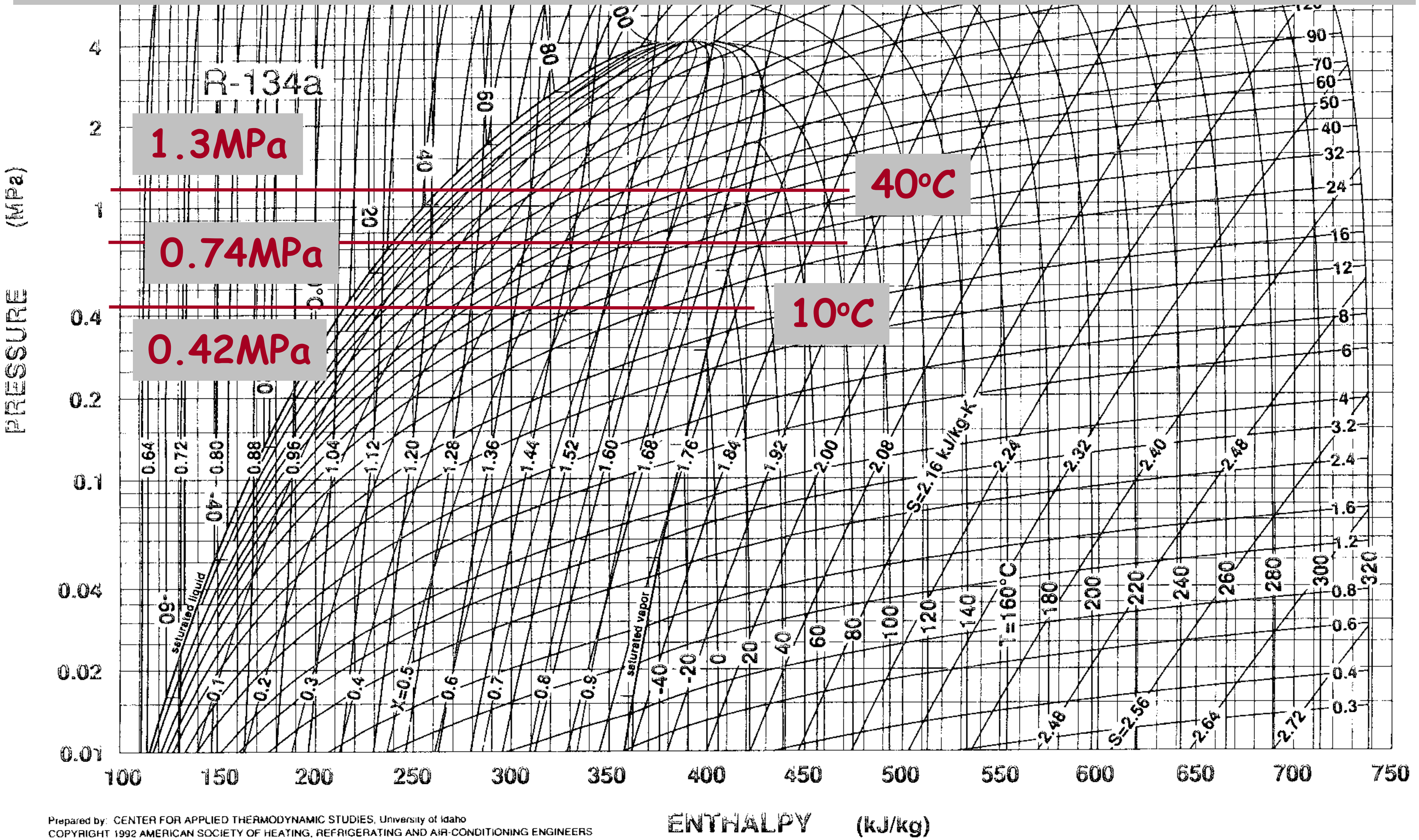
- Determine the inter-stage pressure

$$P_i = \sqrt{P_{cond} \cdot P_{evap}}$$

$$P_i = \sqrt{1300000 \cdot 420000}$$

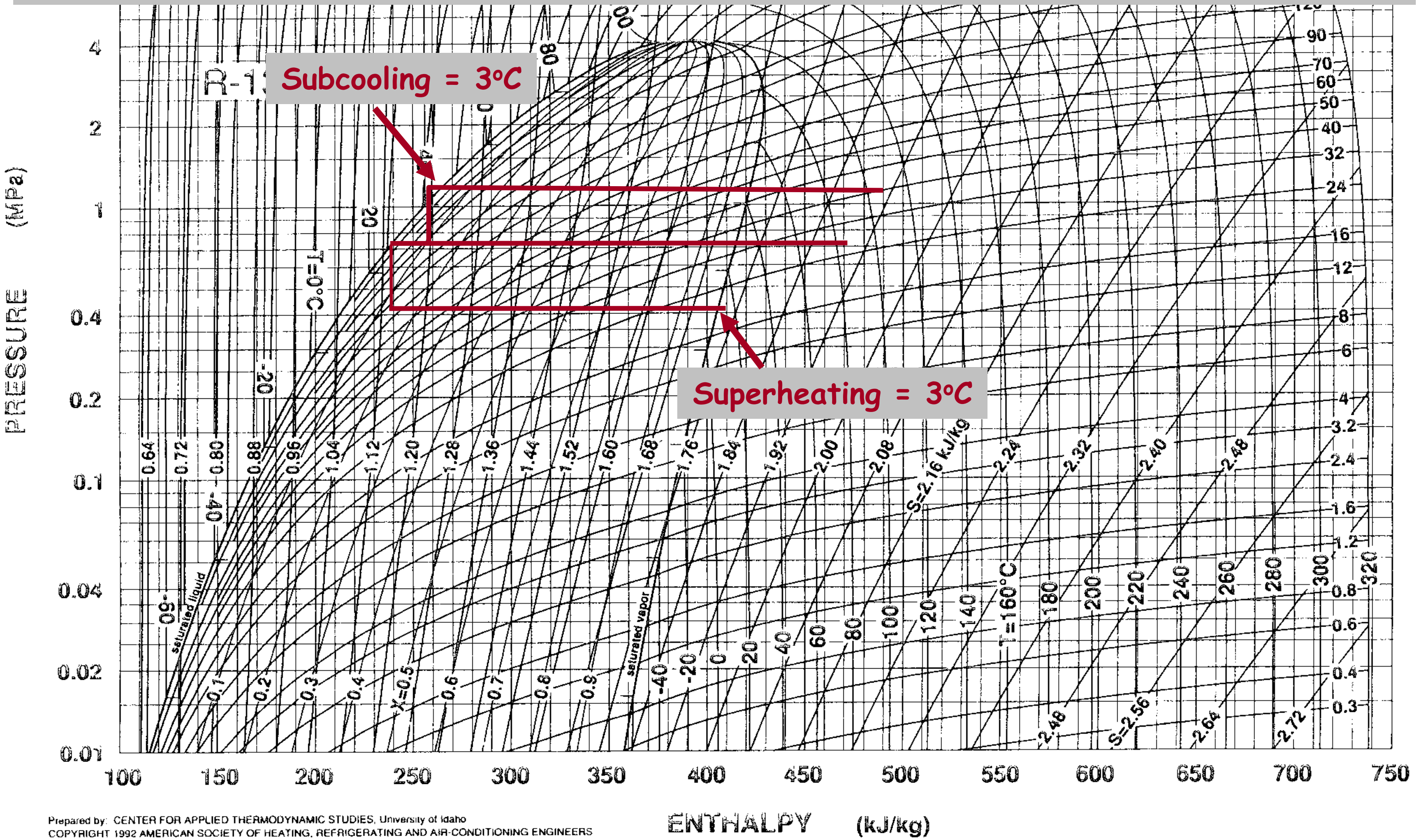
$$P_i \cong 740000$$

Step 2: plot the inter-stage pressure line



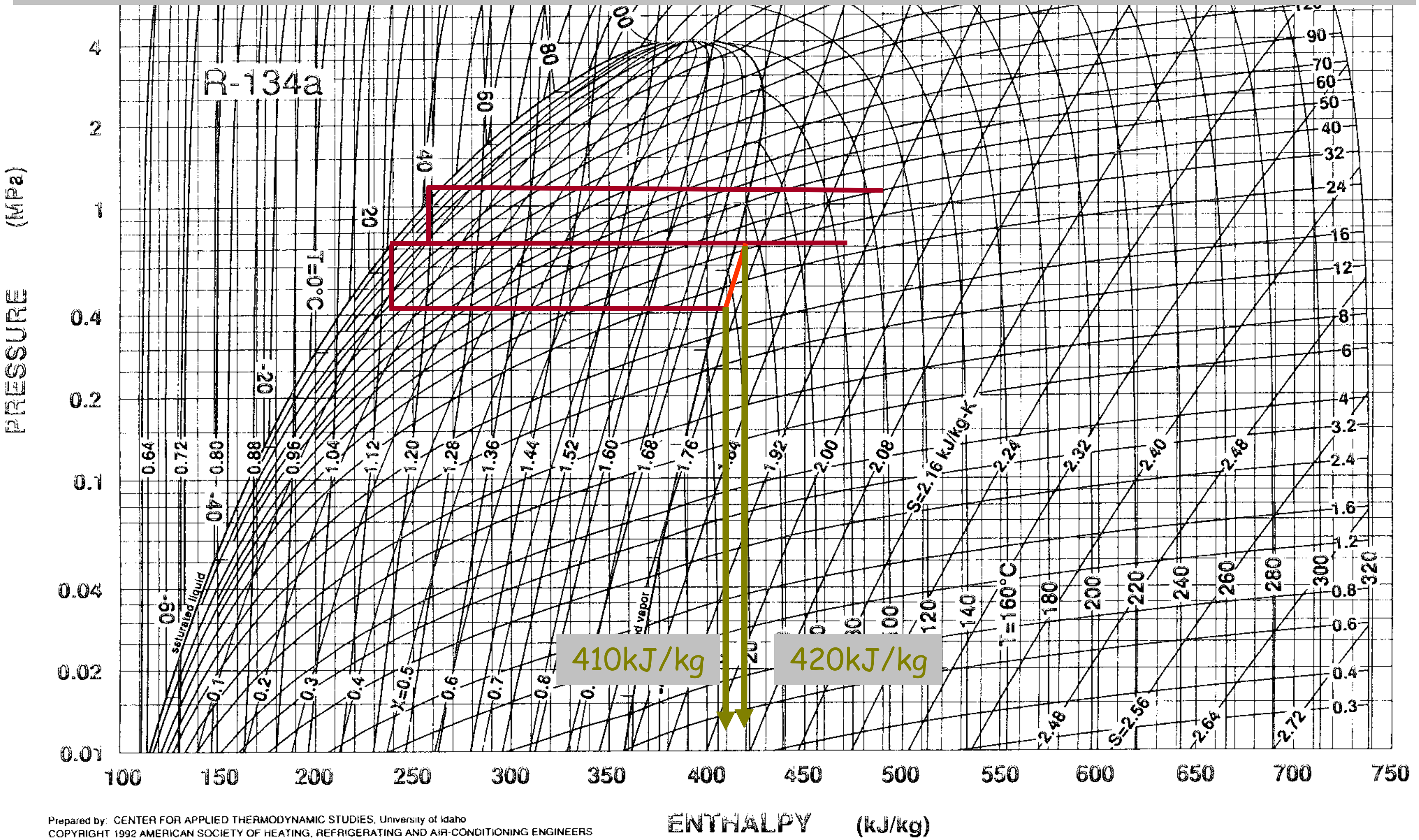
Pressure–Enthalpy Diagram for Refrigerant 134a

Step 3: Locate the subcooling and superheating



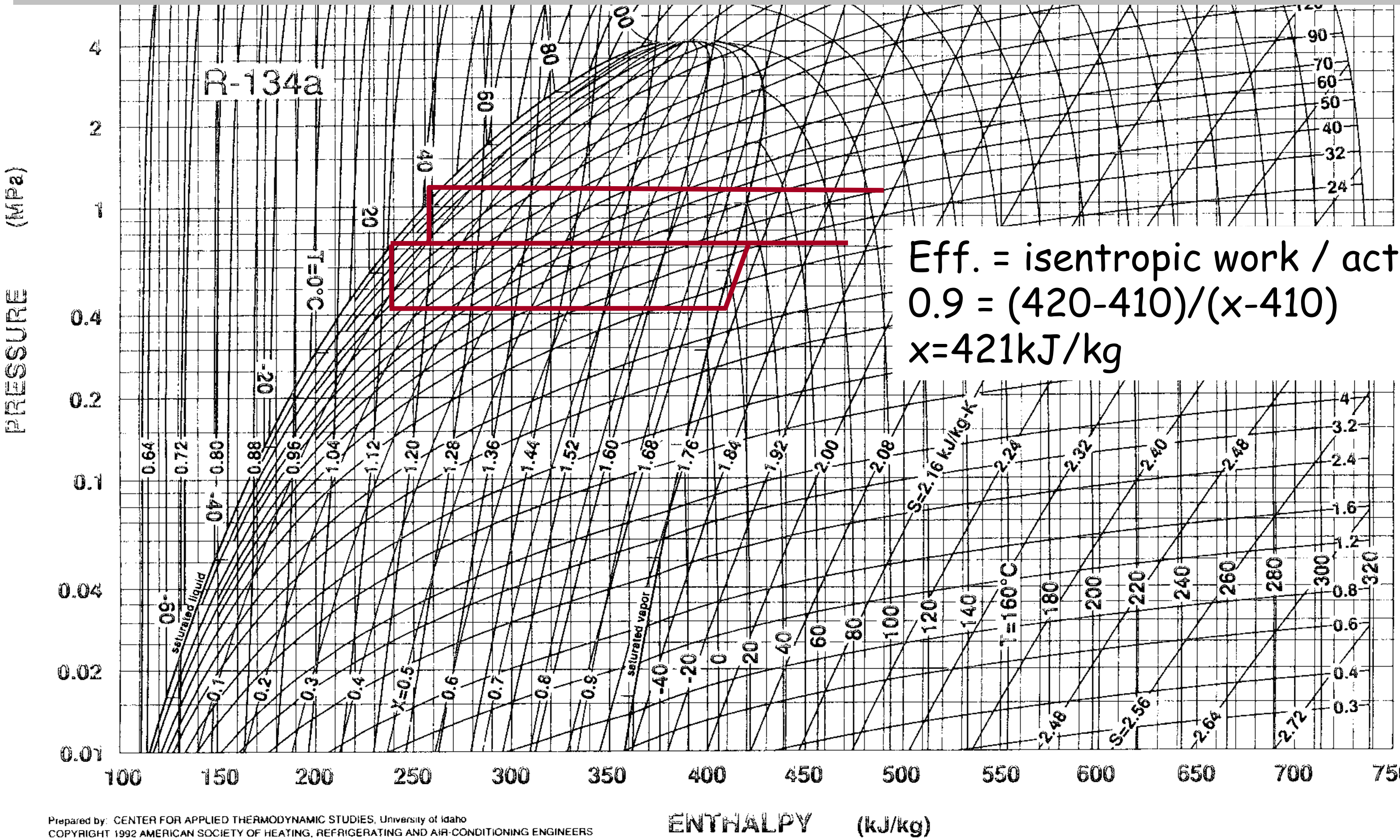
Pressure–Enthalpy Diagram for Refrigerant 134a

Step 4: Plot the isentropic line & determine the enthalpy of the refrigerant (1st stage)



Pressure–Enthalpy Diagram for Refrigerant 134a

Step 5: Determine the actual work based on compressor efficiency



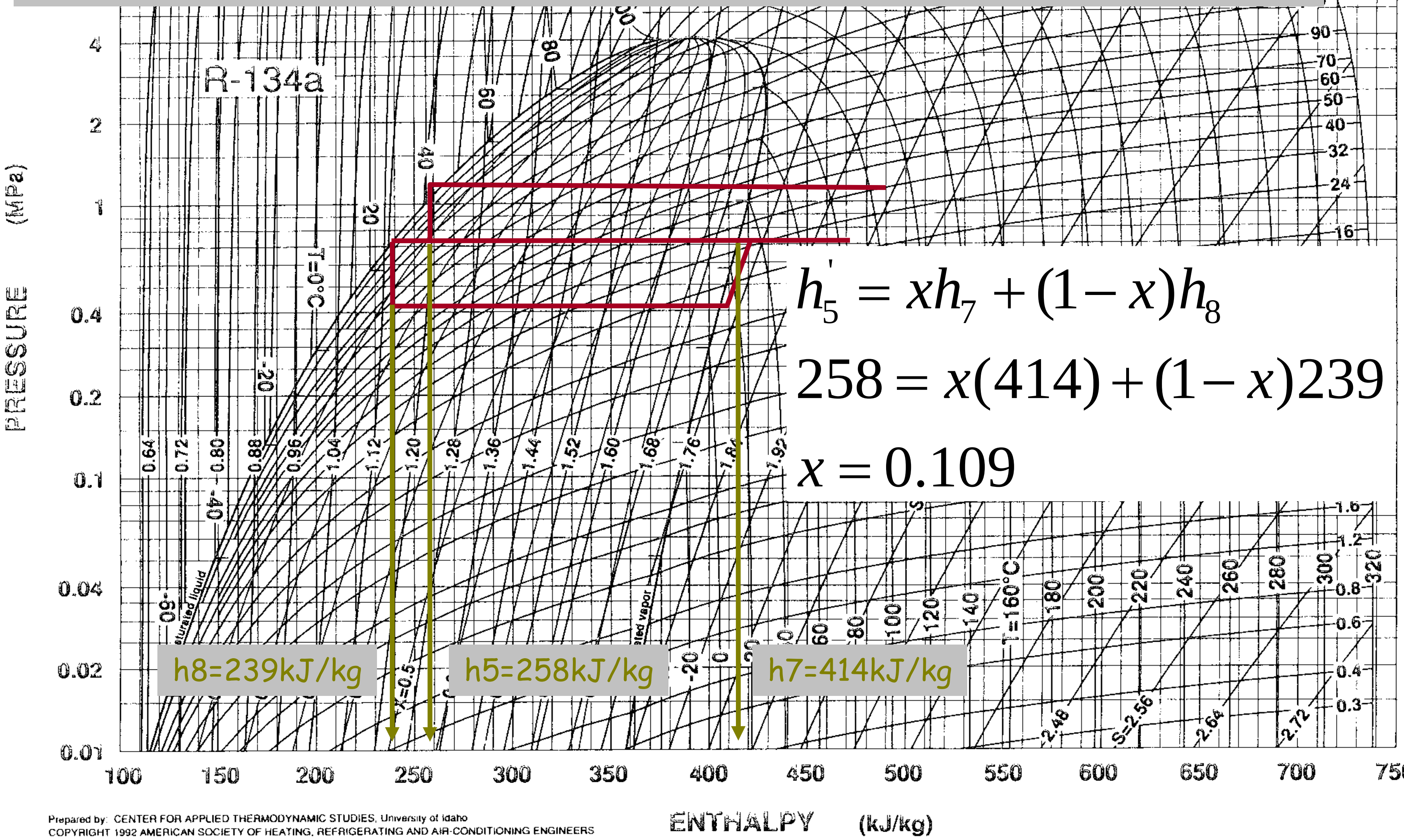
Eff. = isentropic work / actual w

0.9 = (420-410)/(x-410)

x=421kJ/kg

Pressure–Enthalpy Diagram for Refrigerant 134a

Step 6: Calculate the portion of flashed vapour in the flash cooler



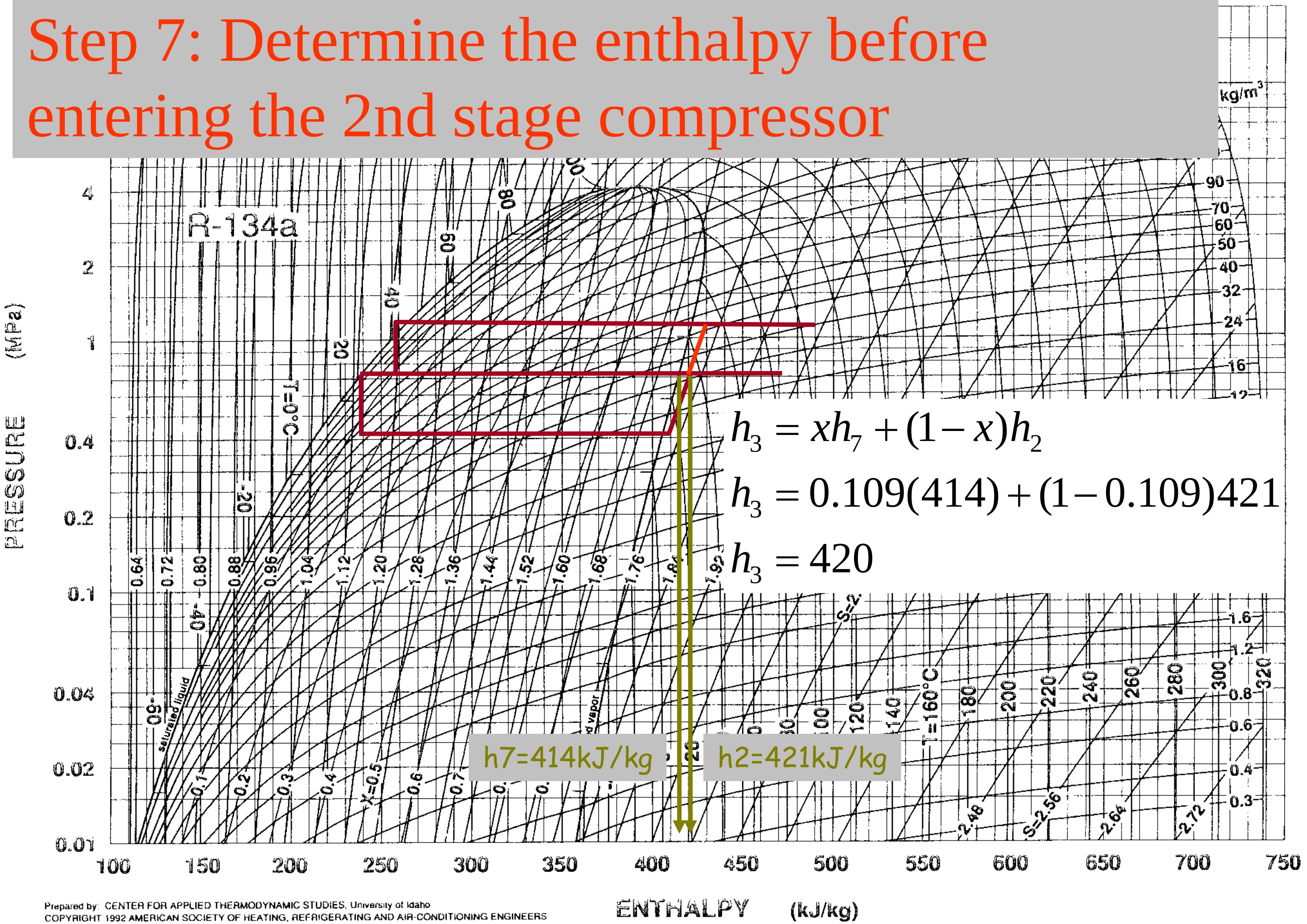
Pressure–Enthalpy Diagram for Refrigerant 134a

$$h_5' = xh_7 + (1-x)h_8$$

$$258 = x(414) + (1-x)239$$

$$x = 0.109$$

Step 7: Determine the enthalpy before entering the 2nd stage compressor



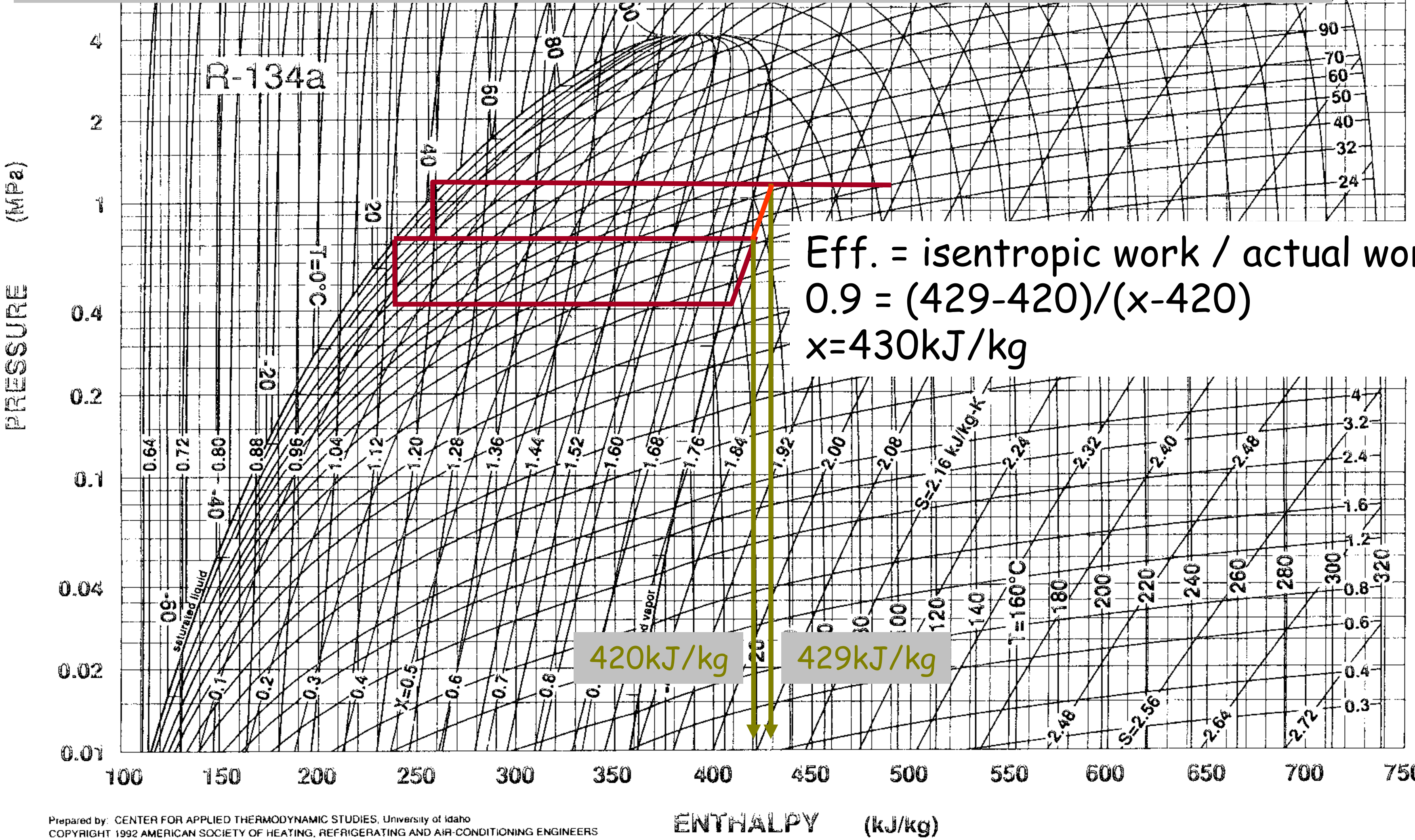
$$h_3 = xh_7 + (1-x)h_2$$

$$h_3 = 0.109(414) + (1-0.109)421$$

$$h_3 = 420$$

Pressure–Enthalpy Diagram for Refrigerant 134a

Step 8: Repeat for 2nd stage compressor



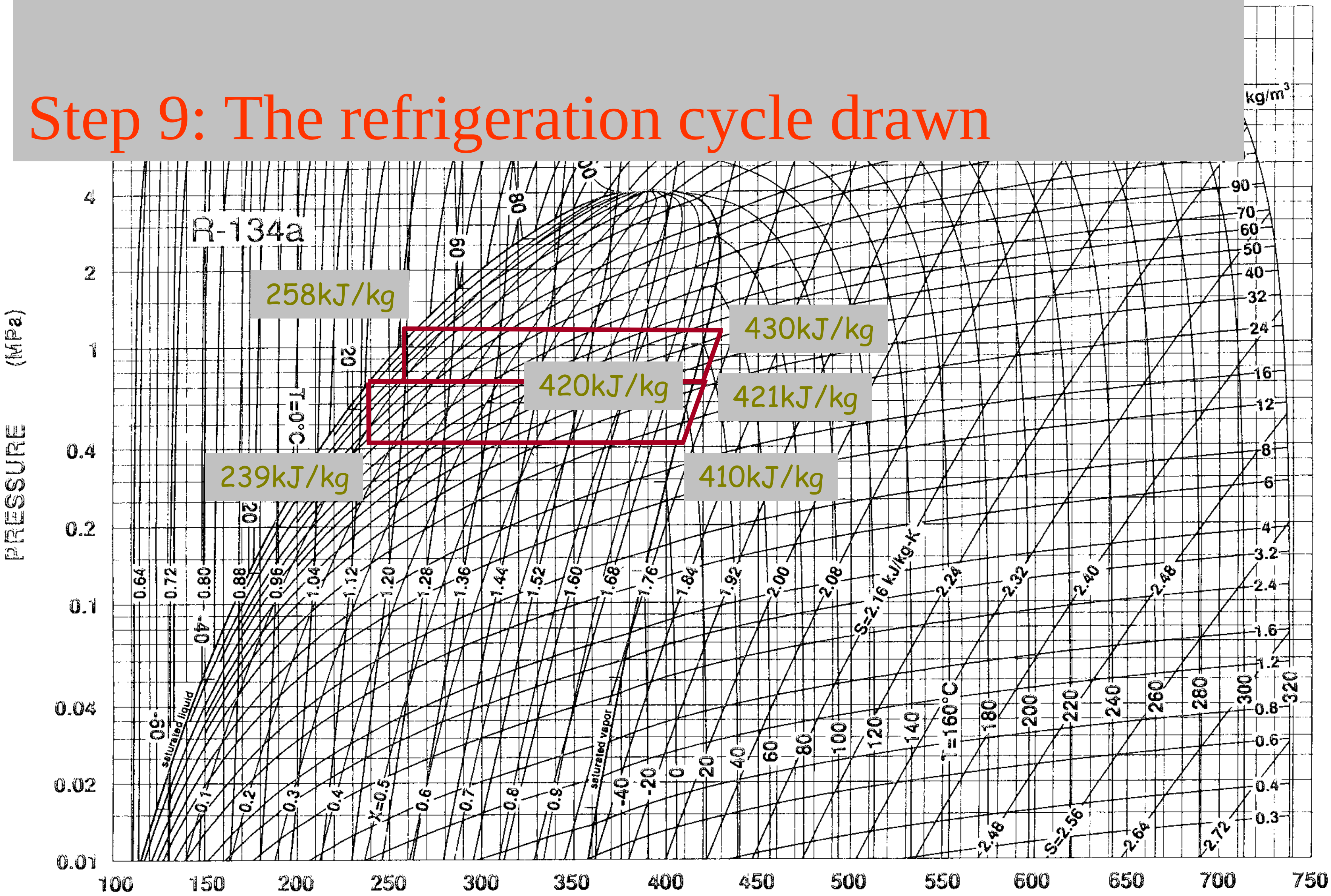
Pressure–Enthalpy Diagram for Refrigerant 134a

Eff. = isentropic work / actual work

0.9 = (429-420)/(x-420)

x=430kJ/kg

Step 9: The refrigeration cycle drawn



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Pressure–Enthalpy Diagram for Refrigerant 134a

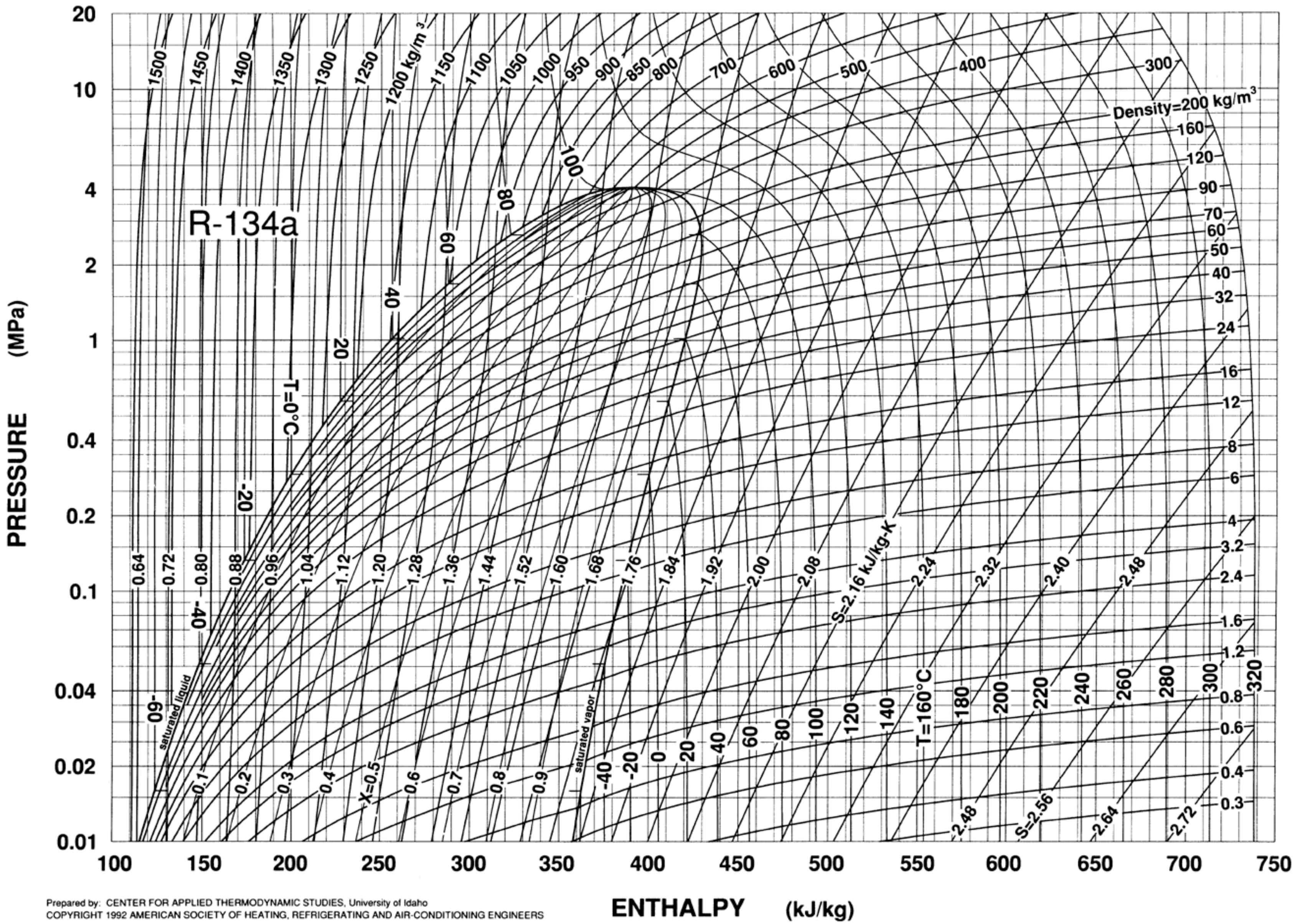
- The refrigeration effect is determined

  = (1-0.109)(410-239) = 152.4kJ/kg
- The work done by the compressor

  = (1-0.109)(421-410)+(430-420)

  = 19.8kJ/kg
- The COP

  = 152.4 / 19.8 = 7.7



Pressure-enthalpy diagram for Refrigerant R-134a