2ND ANNUAL REFRIGERATION CONFERENCE 2018

Detailed Study of Pressure Enthalpy Chart

DETAILED STUDY OF PRESSURE ENTHALPY CHART

Complete and detailed study of the pressure enthalpy chart

1- Introduction and definitions

- **1.4.1- stored energy**
  - **1.4.1.1- Thermal (Internal) energy**
  - **1.4.1.2- Potential energy (PE)**
  - **1.4.1.3- Kinetic energy (KE)**
  - **1.4.1.4- Chemical energy**
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- **1.4.2- Transient energy**
  - **1.4.2.1- Heat (Q)**
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  - **1.4.2.2.a- Mechanical or shaft work**
  - **1.4.2.2.b- Flow work**

1.4.1- stored energy

1.4.1.1- Thermal (Internal) energy:- It is the energy possessed by a system caused by the motion of the molecules and or intermolecular forces.

1.4.1.2- Potential energy (PE):- It is the energy possessed by a system caused by the attractive forces existing between molecules, or the elevation of a system. ($PE = m*g*z$), where: m = mass, g = local acceleration of gravity, z = elevation above horizontal referenced plane.

1.4.1.3- Kinetic energy (KE):- It is the energy possessed by a system caused by the velocity of the molecules and is expressed as (KE = mV2\2), where "V" is the velocity of a fluid stream crossing the system boundary.

1.4.1.4- Chemical energy:- It is the energy possessed by the system caused by the arrangement of atoms composing the molecules.

1.4.1.5-Nuclear (Atomic) energy:- It is the energy possessed by the system from the cohesive forces holding protons and neutrons together as the atom's nucleus

1.4.2- Transient energy

1.4.2.1- Heat (Q):- It is the mechanism that transfers energy across the boundary of systems with differing temperatures, always towards the lower temp.

1.4.2.2- Work:- It is the mechanism that transfers energy across the boundary of systems with differing pressures (Or force of any kind), always towards the lower pressure. If the total effect produced in the system can be reduced to the raising of a weight, then nothing but work has crossed the boundary.

1.4.2.2.a- Mechanical or shaft work;- It is the energy delivered or absorbed by a mechanism, such as turbine, air compressor, or internal combustion engine.

1.4.2.2.b- Flow work:- It is the energy carried into or transmitted across the system boundary because a pumping process occurs somewhere outside the system, causing fluid to enter the system. It can be more easily understood as the work done by the fluid just outside the system on the adjacent fluid entering the system to force or push it into the system. Flow work also occurs as fluid leaves the system.

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Flow work (per unit mass) = pv . where "p" is the pressure & "v" is the specific volume, or the volume displaced per unit mass

1.5-Property of a system:

It can be defined as any observable characteristic of the system. The most common thermodynamic properties are:

-Temperature "T".

-Pressure "P".

-Specific volume "v" or density "p".

-Entropy (BTU/Lb.R or J/Kg. K) = Stored forms of energy

-Enthalpy "h" = (BTU/Lb or Kj/Kg), which is a result of combining properties. (h = u + pv).

Where: "u" is internal energy of unit mass.

Conclusion

<u>Each property in a given state has only one value, and any property always has the same value for a given state, regardless of how the substance arrived at the state.</u>

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1.6- State of a system: It is defined by listing system properties. Example: R- 22 when at 65psig pressure, and 30 f temperature, it will be liquid having h = x, v = y, and density = z.

1.7-Process: It is a change in state that can be defined as any change in the properties of a system. A process is defined by:- 1) specifying the initial and final equilibrium states, 2) the path (if identifiable), and 3) the interactions that take place across system boundaries during the process.

Process Example:

R-22 at the suction port of the compressor is at state one, then it arrives at the inlet of the condenser at state two after it is compressed by the compressor and passes through the discharge pipes till it reaches the condenser.

This is called a process because

a) we have two defined states,

b) a path

c) the interactions with the boundaries.

1.8-A cycle: It is a process or series of processes wherein the initial and final states of the system are identical. Therefore, at the conclusion of a cycle, all the properties have the same value they had at the beginning.

Example: R-22 at the suction port of the compressor is at state one, then it arrives at the inlet of the condenser at state two after it is compressed by the compressor and passes through the discharge pipes till it reaches the condenser, then it is liquid when it leaves the condenser and arrives at the inlet of the expansion valve (state three), then it is expanded in the expansion valve and changes state, i.e. evaporates at the evaporator and enters the compressor suction valve at the same original state one.

1.9-A pure substance: A pure substance has a homogenous and invariable chemical composition. It can exist in more than one phase, but the chemical composition is the same in all phases.

Example: water is in liquid state, vaporizes to be in gas state, freezes to be in solid state but the chemical composition stays the same in all cases (Hydrogen and Oxygen).

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1.10-Saturated & sub-cooled liquid, saturated & superheated vapor, quality: If a substance exists as liquid at the saturation temp & press, it is called the saturated liquid. If the temp of the liquid is lower than the saturation temp for the existing press, it is called either a sub-cooled liquid or a compressed liquid (the press is greater than the saturation press for the given temp).

- When a substance exists as part liquid and part vapor at the saturation temp, its quality is defined as the ratio of the mass of vapor to the total mass.
- Quality has meaning only when the substance is in a saturated state.

- If a substance exists as vapor at the saturation temp, it is called saturated vapor. (Sometimes called dry saturated vapor to emphasize that the quality is 100%
- When a substance exists as part liquid and part vapor at the saturation temp, its quality is defined as the ratio of the mass of vapor to the total mass. Quality has meaning only when the substance is in a saturated state.
- When the vapor is at a temp greater than the saturation temp, it is superheated vapor. The press & temp of superheated vapor are independent properties, since the temp can increase while the press remains constant. Gases are highly superheated vapors.

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1.11-First law of thermodynamics: The first law of thermodynamics is often called the law of the conversion of energy. The following form of the first law equation is valid only in the absence of a Nuclear or chemical reaction.

Based on the first law or the law of conservation of energy for any system, open or closed, there is an energy balance as: Net amount of energy added to system = Net increase in stored energy of system.

1.12-Second law of thermodynamics: The second law of thermodynamics differentiates and quantifies processes that only proceed in a certain direction. (irreversible) from those that are reversible. The second law may be described in several ways. One method uses the concept of entropy flow in an open system and the irreversibility associated with the process. The concept of the irreversibility provides added insight into the operation of cycles. For example, the larger the irreversibility in a refrigeration cycle operating with a given refrigeration load between two fixed temperature levels, the larger the amount required to operate the cycle.

<u>Irreversibilities include pressure drops in lines & heat exchangers, heat transfer between fluids of different temp, & mechanical friction. Reducing total irreversibility in a cycle improves the cycle performance</u>

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Further details on First & Second laws of thermodynamics

A. The First Law of Thermodynamics:

A.1. The first law of Thermodynamics can be stated formally as follows:

"The amount of work done by any system in going from one state to another does not depend on the course of states passed through by the system nor on the manner of work interaction, so long as the system and surroundings are equal in temperature at each step of the process". Forming it into an equation it will read:

$E_1 - E_2 = (W_{e.t}) \; 1-2$ Where:

E_1 = System State No. "1" (System Condition One).

E_2 = System State No. "2" (System Condition Two).

$W_{(e.t.)} \; _{1} \; _{2}$ = Work done by the system in going from state one to state two during an equal temperature process.

<u>An equal temperature process means that the system and the surroundings are equal in temperature at each step of the process.</u> "E" is called the "Internal Energy" of the system.

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Further details on First & Second laws of thermodynamics

A. The First Law of Thermodynamics:

A.2. Equality of Temperature:

It is well known that when two substances, one "feels hot", the other "feels cold" are brought together, some type of interaction occurs, where after some time, both will have equal temperature and the interaction stops. Such interaction is called "Heat Interaction". Formally we can state that no interaction occurs between two substances when brought together if equality of temperature exists between the two.

A.3. Heat:

Referring equation: - E1 - E_2= $(W_{e.t})$ 1 – 2. And assuming that equality of temperature does not prevail between the System State and surroundings during process of system going from state one to state two, this means that heat interaction will also occur while work (energy) interaction takes place. The amount of heat is measured by the difference between the work done during the equal temperature process and the work done during the non-equal temperature process.

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Translating above into formal equation will give: $Q = W - W_{e.t.}$,

Where Q = The heat received. W = Work done during actual process. $W_{e.t}$ = Work done during equal temperature process.

A.4. Conclusion: Using two equations: E1 - E2 = $(W_{e.t.})_{1-2}$ &Q = W $W_{e.t.}$ Will result in :- $Q = E_2 - E_1 + W$ _____1_____

This equation is called the first law of Thermodynamics.

Note: When change of state is minor, a differential form can be used for above equation as follows: ♎Q = ♎E + ♎W _____2_____

B. The First Law for a Cycle:

If a system starts from one and goes through series of states ending again at state one forming a cycle, the net change in "E" being internal energy is exactly zero. Applying this to equation __2__ will give Q = W Where: Q = Algebraic net heat received by the system during a cycle. W = Algebraic net work done by the system during the same cycle.

C. Adiabatic Process :If heat insulators (barriers) are placed between a system having a certain temp & surroundings with different temp, the heat (Q) transferred between the system and surroundings becomes very small. Assuming insulation to be very effective to the extent that "Q" becomes zero. Applying same on equation: $Q = E_2 - E_1 + W$, Will result in $E_1 - E_2 = W$

which is the same equation of first law of thermodynamics for an equal temperature process. We conclude from above that :

<u>An Adiabatic Process is same as Equal Temperature Process.</u>

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D. The Second Law of Thermodynamics:

To understand the second law of thermodynamics easily and well let us study how a steam turbine operates:

1- The steam turbine receives high temp, high press steam from an outside source (boiler).

2- The boiler receives water, burns fuel and generates steam. When fuel is burnt, it puts heat (energy) on water to change it into high press, high temp steam.

3- When the high pressure, high temperature steam passes through the turbine, it generates work (drives the turbine which produces electricity), then finally the steam is released to atmosphere.

4- The temperature (energy) of the steam when released to atmosphere is lower than the temperature (energy) it has when it enters the turbine, but at the same time its (energy) is higher than that of the water when it enters the boiler.

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D. The Second Law of Thermodynamics:

5- We will now call the water when entering the boiler to be at state one (E_1). Then the steam entering the turbine to be at state two (E_2), the steam when released to atmosphere after it drives the turbine to be at state three (E_3).

6- For the steam at state (E_3) released to atmosphere to return back to water as it entered the boiler with state one (E_1), it has to give away its heat "energy" to the air, cool down and fall on ground as rain.

From above we conclude the following: $E_2 - E_3 = E_1$. Assuming no heat loss during the three processes, then $E_2 - E_F = E_1$____a____. Where E_F = Fuel Energy and E = W (Work generated by the turbine) + E_3 _b_.

Using a & b results in: $E_1 + E_F = W + E_3$ _c_.

But state three has to release heat (energy) to surroundings to return to state one i.e.

$E_3 = E_x + E_1$ _d_. Where E_x = Extra energy released to atmosphere.

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But state three has to release heat (energy) to surroundings to return to state one i.e. $E_3 = E_x + E_1$ _d_.

Where E_x = Extra energy released to atmosphere.

Using equations "C" & "D": $E_1 + E_F = W + E_x + E_1$. i.e. $E_F = W + E_x$.

In an adiabatic or equal temp process, the system goes through different states without exchanging heat with surroundings.

Since E_F and E_x represent heat exchanged between system and surroundings (fuel gives heat to water and steam looses heat to atmosphere), and if those become zero as in equal temp process, then "W" work will also become zero.

<u>From above we conclude that there is no way for a system to generate work while passing a complete cycle without exchanging heat with surroundings.</u>

D. The Second Law of Thermodynamics:

Now we can define the Second Law of Thermo dynamics formally as follows:

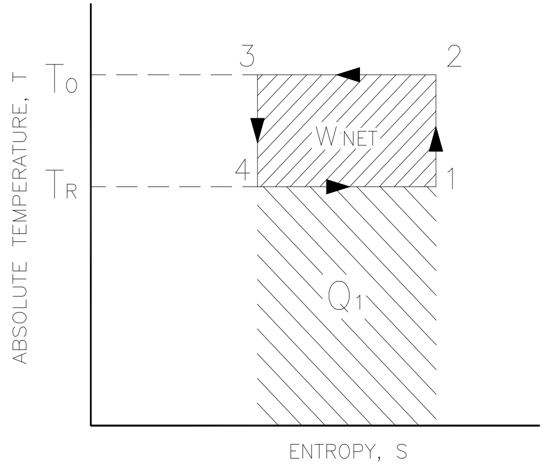
- No system can pass through a complete cycle of states and deliver positive work to the surroundings while exchanging heat with only a single source of heat at uniform temperature.

CARNOT COMPRESSION REFRIGERATION CYCLE

- **The Carnot cycle, which is completely reversible, is a perfect model for a refrigeration cycle operating between two fixed temps, or between two fluids at different temps and each with infinite heat capacity. Reversible cycles have two important properties:**

  1)-No refrigerating cycle may have a coefficient of performance higher than that for a reversible cycle operated between the same temp limits

  2)-All reversible cycles, when operated between the same temp limits, have the same coefficient of performance.



CARNOT REFRIGERATION CYCLE

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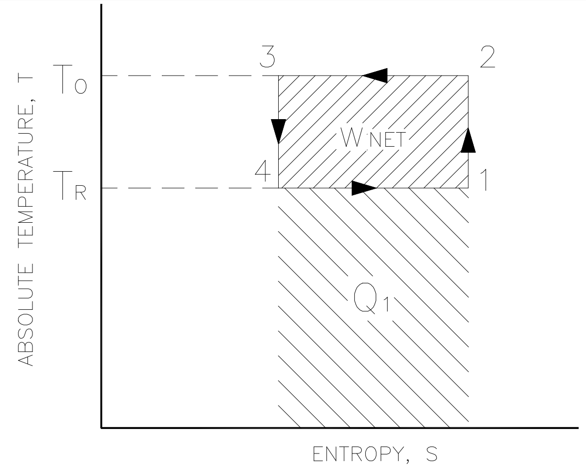
CARNOT COMPRESSION REFRIGERATION CYCLE

- The figure shows the Carnot cycle on temp-entropy coordinates. Heat is withdrawn at the constant temp T_R from the region to be refrigerated. Heat is rejected at the constant ambient temp T_o The cycle is completed by an isentropic expansion & an isentropic compression. The energy transfers are given by:

$Q_O = T_O(S_2 - S_3)$ & $Q_I = T_R(S_1 - S_4) = T_R(S_2 - S_3)$ &

$W_{net} = Q_o - Q_I$. And $COP = T_R \backslash (T_o - T_R)$.



CARNOT REFRIGERATION CYCLE

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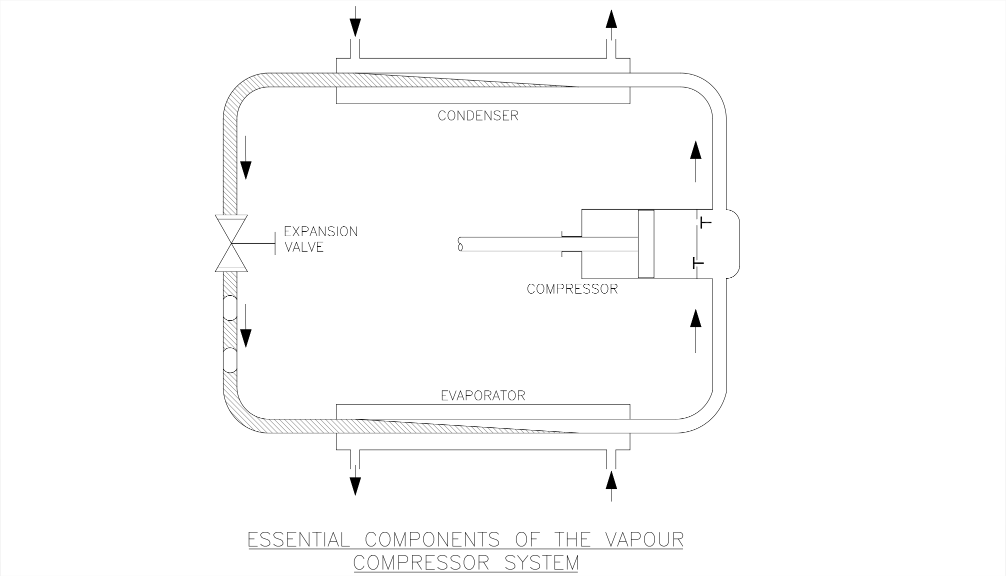
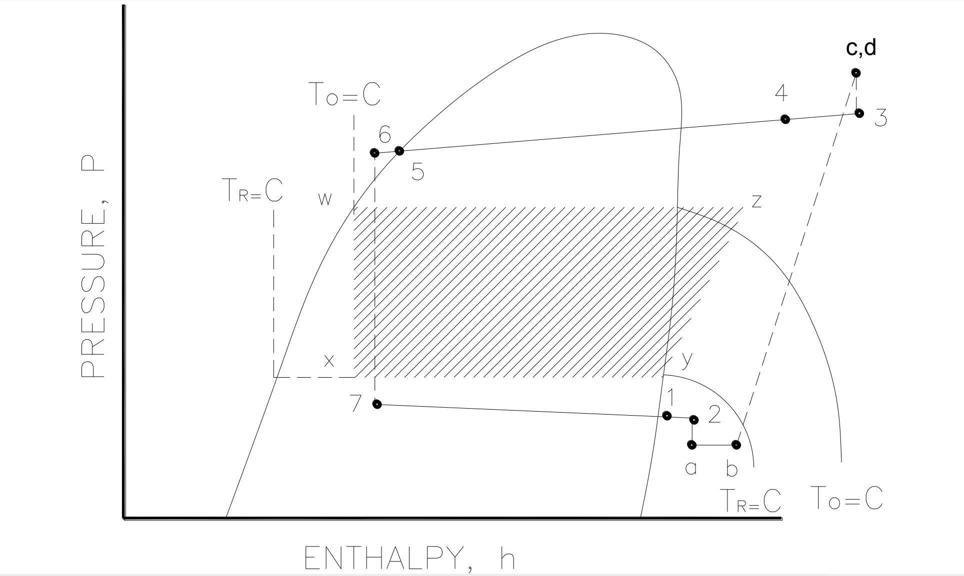
ACTUAL VAPOR COMPRESSION CYCLE





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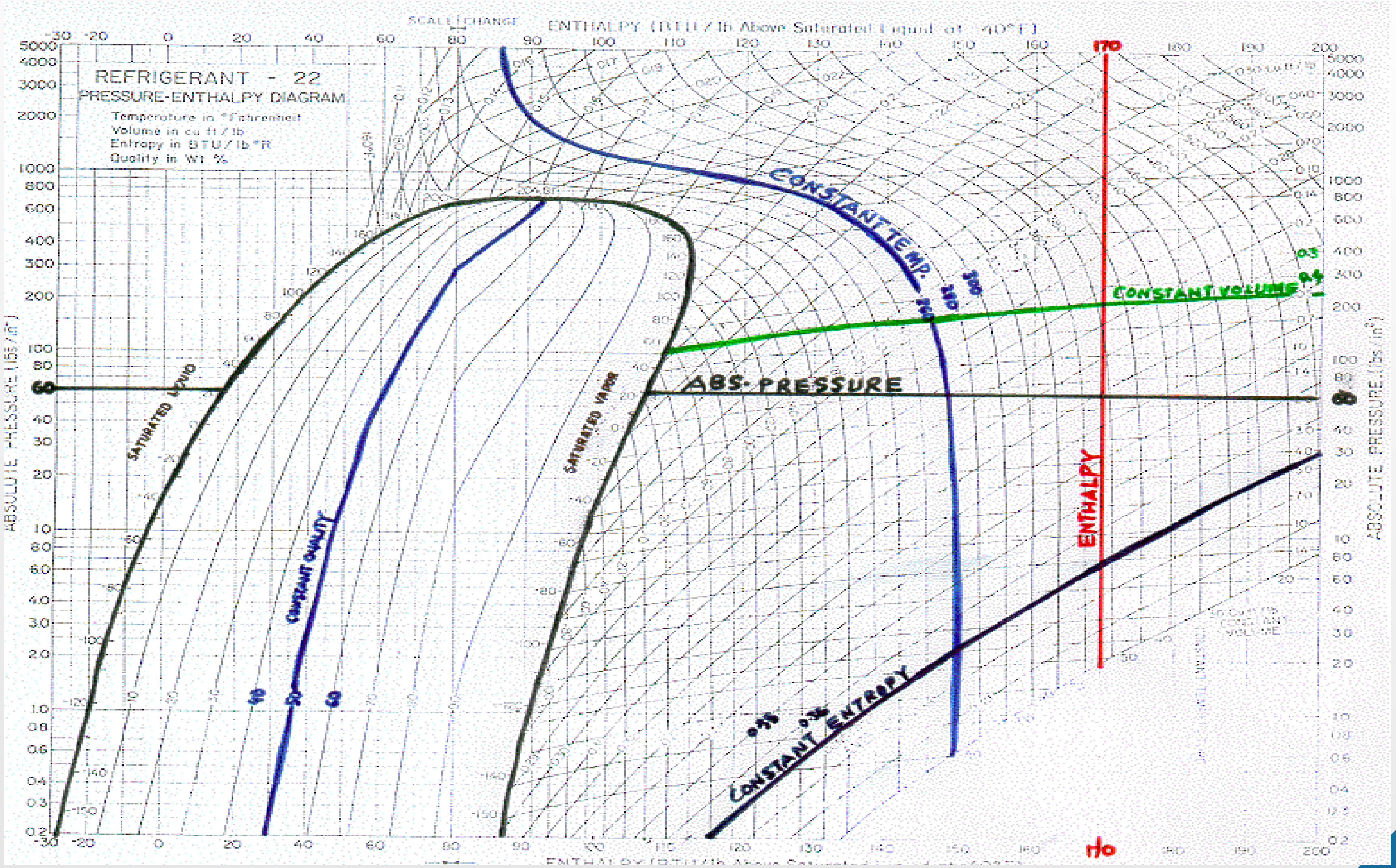

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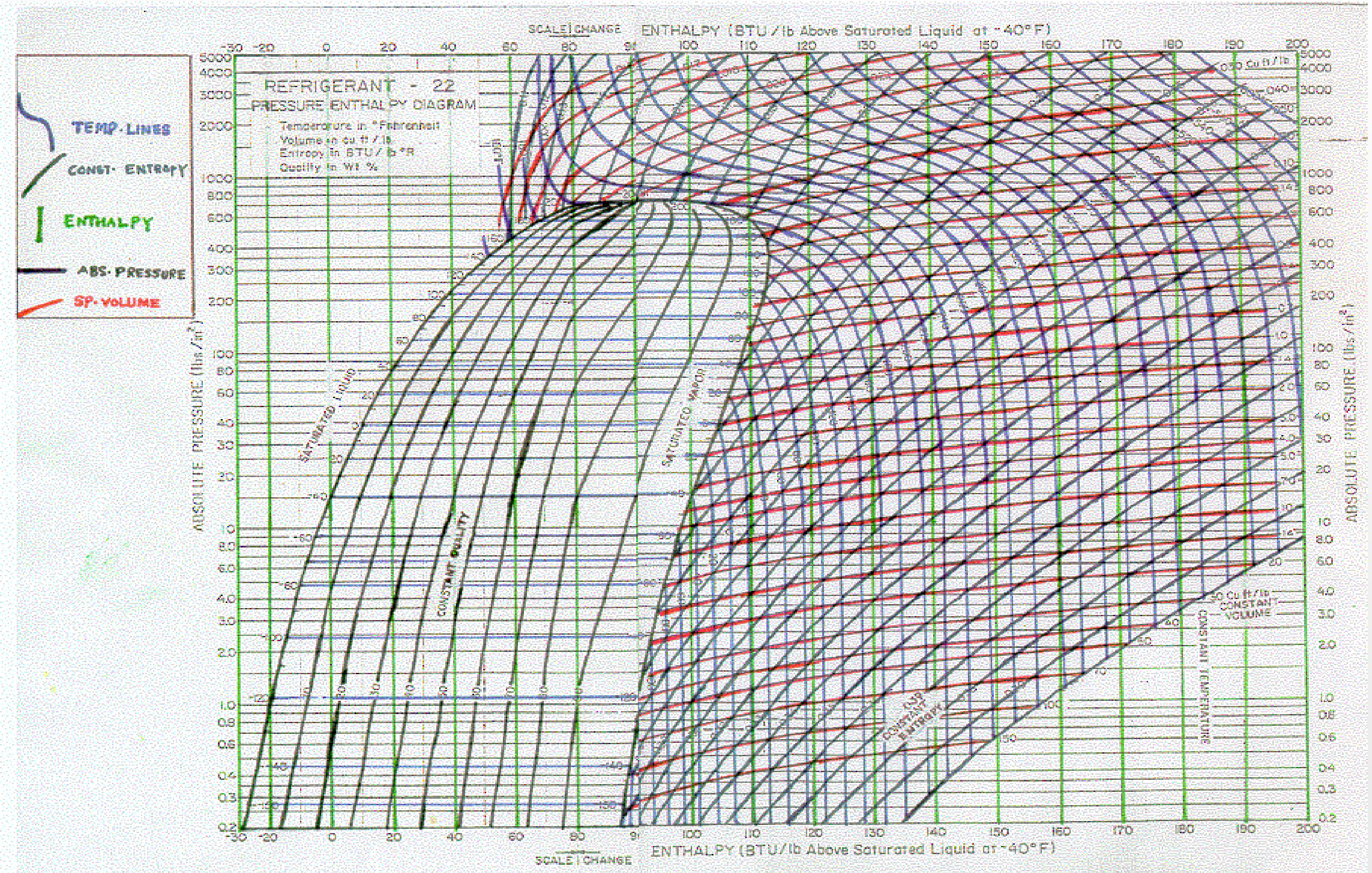

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FIG. 4....PRESSURE-ENTHALPY DIAGRAM FOR REFRIGERANT 22