

Thermodynamic cycle and machinery of

Vapor-compression

Heat pump and refrigerator

Engineering Thermodynamics 2

Lab Report

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March 15, 2006

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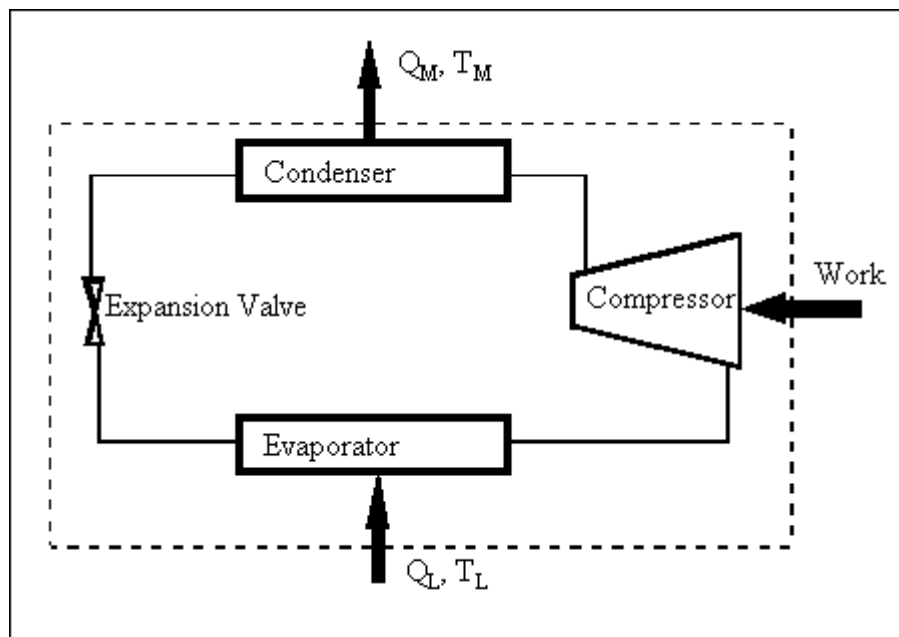
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A heat pump is a device that transfers heat for heating, cooling or dehumidification. Heat naturally flows from a high to a lower temperature. Heat pumps however are able to force the heat flow in the other direction using a small amount of high quality drive energy. A heat pump is therefore sometimes depicted as a heat engine in reverse. While a heat engine delivers work, a heat pump requires work to operate. This lab experiment was on the vapor compression cycle heat pump. Vapor compression cycle's principle of operation is relatively simple. A working fluid (i.e. ammonia) is boiled in an evaporator at a pressure and hence temperature, T_L , low enough to provide cooling. A work driven compressor (usually electrical work) then increases the pressure of the working fluid vapor allowing it to condense and reject heat at a temperature that of the surroundings, T_M . Having rejected its heat of condensation and condensed the working fluid liquid is then expanded (via an expansion valve) back into the evaporator where it can again provide cooling at a low temperature.

Figure 1-1: The Vapor-Compression Cycle



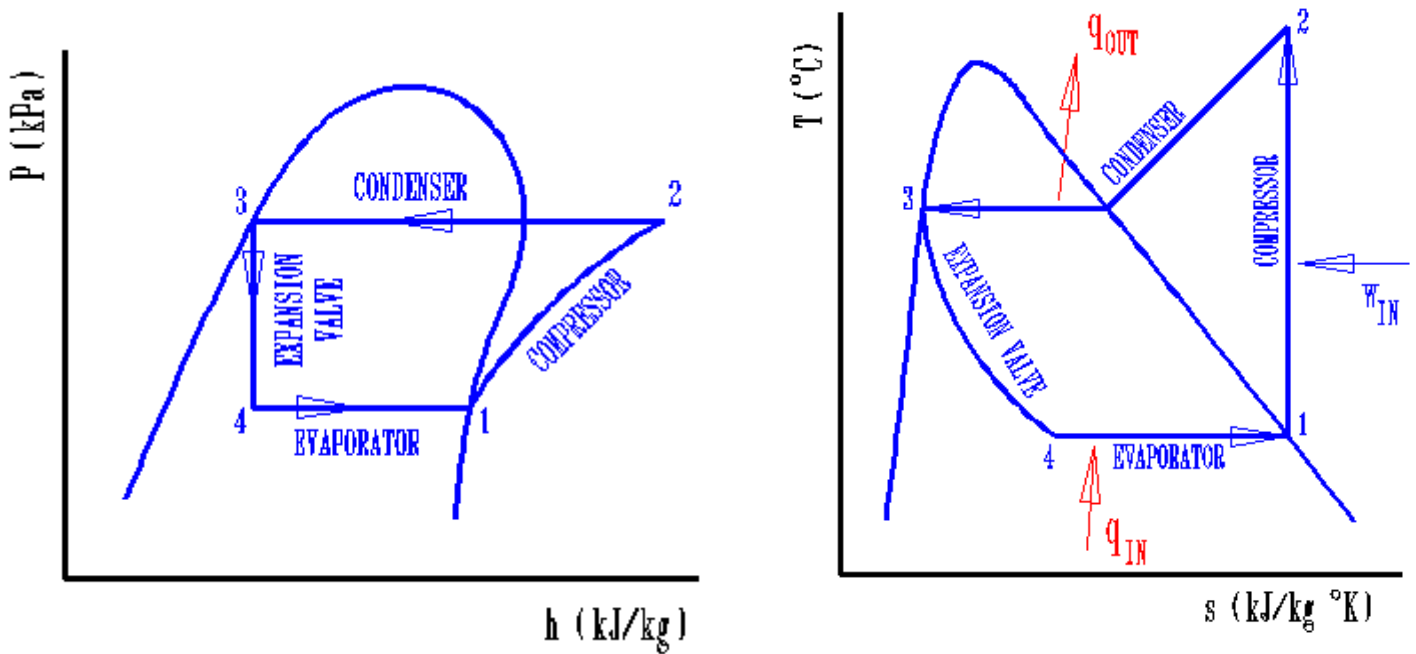
Flow passes through a cycle of four distinct processes:

- a) evaporation at low pressure and temperature absorbing heat from the cold space;
- b) compression to a high pressure by work input
- c) cooling and condensation at high pressure and temperature delivering heat to the hot space
- d) expansion by throttling through a valve from the high pressure to the low pressure .

Theory

Ideal Vapor-Compression Cycle

- for refrigeration air conditioning and heat pumps Processes:
- 1-2 (compressor) Isentropic compression
- 1-3 (condenser) Constant pressure heat rejection
- 3-4 (expansion valve) throttling, isenthalpic
- 4-1 (evaporator) constant pressure and temperature heat addition



ANALYSIS of the CYCLE:

$$s_1 = s_2$$

state 1 is saturated vapor

state 3 is saturated liquid

pressure in the condenser is constant ($P_2 = P_3$)

pressure and temperature in the evaporator are constant ($P_4 = P_1$ and $T_4 = T_1$)

Compressor: $w_{IN} = h_2 - h_1$ use: $h_1 = h_g @ P_1$

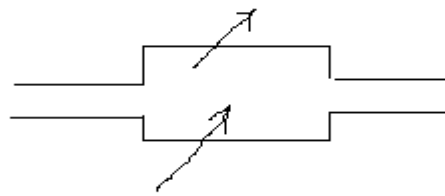
Condenser: $q_{OUT} = h_2 - h_3$ use: $h_3 = h_f @ P_3$

Expansion Valve: $h_3 = h_4$ use: h_4 to find x_4

$q_{IN} = h_1 - h_4$

Evaporator:

In order to use the steady flow energy equation , it was assumed that the refrigerant flowrate and the property values were steady . Assumed that Kinetic and Potential energy changes were negligible . Thus the Bernoullie equation was derived as follows :

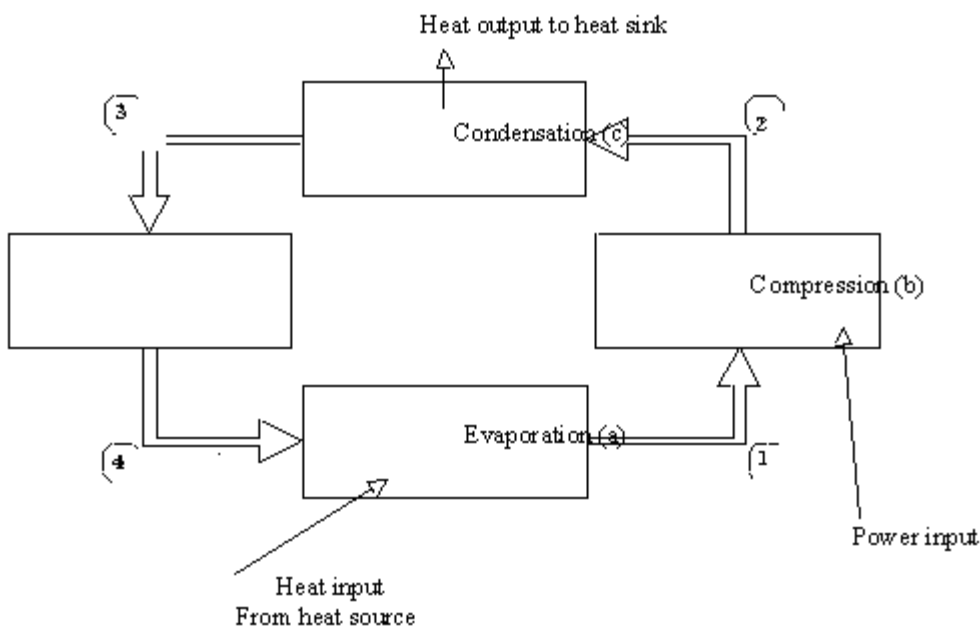


$$Q + m (h_i + \quad + gz_i) = w + m (h_e + \quad + gze)$$

SFEE for the evaporator stage became $Q + m \times h_4 = m \times h_1$. In adiabatic process ,there is no heat transfer in compressor , therefore SFEE for compressor was written as $w + m \times h_1 = Q + m \times h_2$ and $w + m \times h_1 = m \times h_2$.

It was assumed that w and Q in expansion valve cycle were zero and due to the small size of the surface area of valve the velocities were small enough to neglect kinetic energy . Therefore , SFEE for the condenser cycle becomes $m \times h_2 = Q + m \times h_3$ and for the expansion valve : $m \times h_3 = m \times h_4$.

Moreover , in expansion valve cycle due throttling, the enthalpy was kept constant .



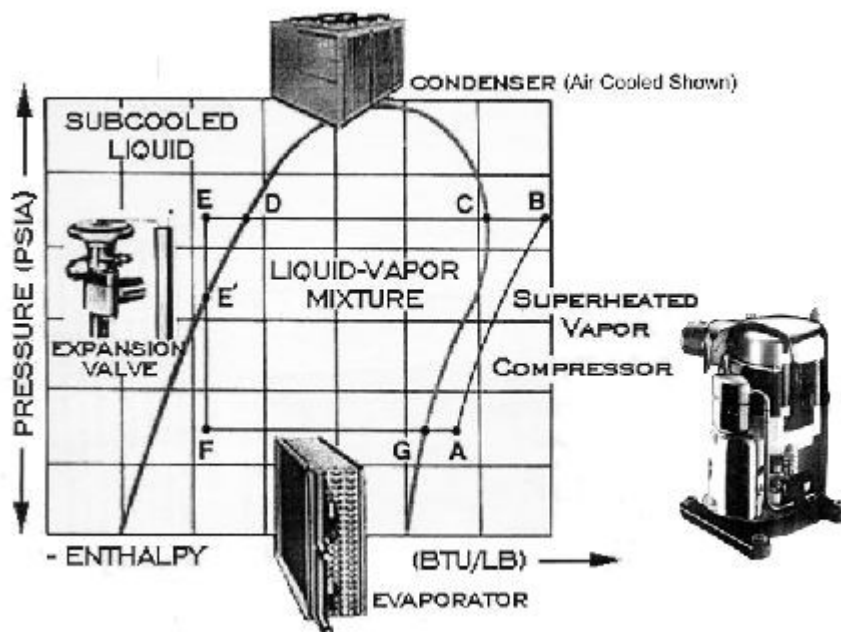
The four processes of the vapour-compression cycle

Refrigerant

A refrigerant is a fluid used for heat transfer in a refrigeration system. Most refrigerants absorb heat during evaporation at low temperature and low pressure and reject heat during condensation at a higher temperature and higher pressure. Some refrigerants produce a refrigeration effect when they throttle and expand in the refrigeration cycle. 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. 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. 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. 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. 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. The system without subcooling must evaporate substantially more refrigerant within a larger coil to produce the same capacity as the system with subcooling.

Pressure-Enthalpy chart

Pressure-enthalpy diagram defines the thermodynamic properties for the refrigerant in use and the performance of equipment.

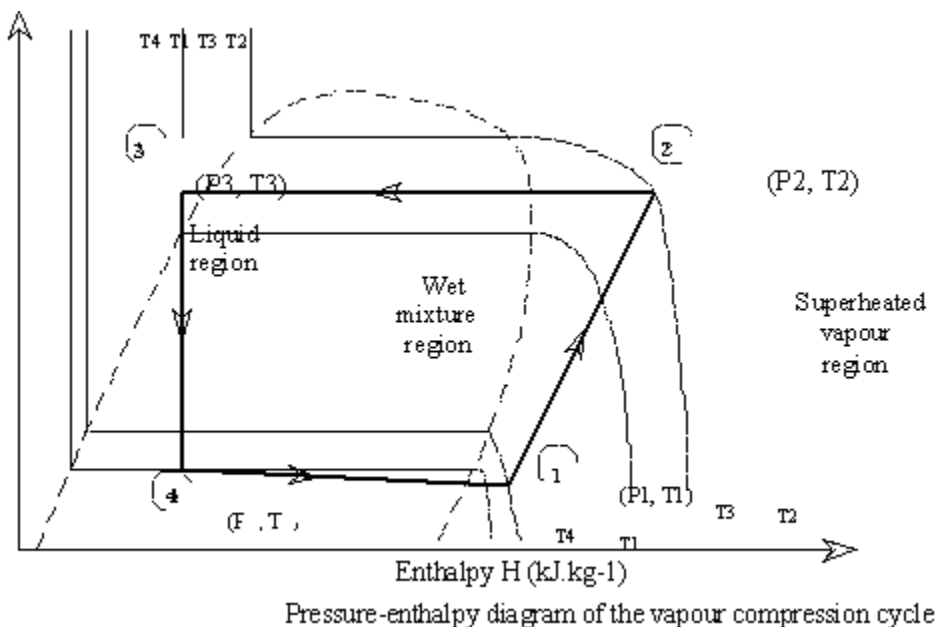


The region on the left is subcooled liquid; basically refrigerant liquid at a temperature cooler than the equivalent boiling point for the pressure noted. The region inside the "dome" is a liquid-vapor mixture. If the liquid is at the boiling point, but just hasn't begun to boil, it is defined as saturated liquid. Adding any heat to this liquid will vaporize a portion of it. Adding more heat to the liquid-vapor mixture eventually evaporates all of the liquid. At that precise point (G), the vapor is fully saturated. Adding any more heat to the vapor will cause it to rise in temperature further; this is referred to as superheated vapor. The term superheat does not associate with being "hot." Superheated vapors can be cold. They are simply above their corresponding saturated vapor point. Similarly, subcooled liquid can be fairly warm. It just means that the liquid is cooler than the saturation line for that pressure.

Procedure

In this experiment synthetic chemical refrigerant known as Freon 12/Arcton 12 was used; thus, the pressure – enthalpy chart for this substance was studied.

The state of the refrigerant was fixed in the chart, by knowing two independent thermodynamic properties such as P and T. Noted that the enthalpy at point (3) was not dependent on the assumption that $P_3 = P_2$, because according to the definition $h = PV + u$, enthalpy would not change for an incompressible liquid.



Coefficient of Performance of the experimental plant was achieved by the following equations:

$$COP_R = \frac{q_L}{w_{IN}} = \frac{q_{IN}}{w_{IN}} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{q_H}{w_{IN}} = \frac{q_{OUT}}{w_{IN}} = \frac{h_2 - h_3}{h_2 - h_1}$$

$Q_2 = Q_H$ for the condenser as a function of the refrigerant enthalpy $Q_2 = mh_2 - mh_3$

W for the compressor as a function of the refrigerant enthalpy $w = mh_2 - mh_1$

Where $Q_2 = Q_H$ and $Q_1 = Q_L$

Hilton Heat Pump or Refrigerator

The components of the heat pump and its instrumentation were mounted on a gloss finish glass reinforced plastic panel. The heat pump consisted of a hermetic compressor, an insulated coiled concentric tube water cooled condenser, a liquid receiver, a thermostatically controlled expansion valve and air heated evaporator. The components were clearly but compactly arranged in a manner similar to that used for many domestic air-water heat pumps and all were visible from the front of the unit.



The operating cycle is as follows:

Slightly superheated refrigerant vapor enters the compressor from the evaporator and its pressure is increased. This brings about a rise in temperature and the hot vapor enters the water cooled condenser. Heat is given up to the cooling water and the refrigerant condenses to a liquid before passing to the liquid receiver and then the expansion valve. On passing through the expansion valve the pressure of the liquid refrigerant is reduced, causing the saturation temperature to fall to below that of the atmosphere. Thus, as it flows energy meter recording power input to the compressor and a digital electronic thermometer recording all relevant temperature, allow an interesting range of experiments to be conducted.

The heat transfer and to these water flows can be calculated from the water flowrates and temperature changes using the following formula where C_p is specific heat capacity.

$$Q = mC_p \Delta T$$

After starting the plant, reading of T , P and flowrate was taken until it settled to steady state conditions. Data were recorded in tables of refrigerant conditions, work/heat input and output and the tables of refrigerant properties and energy balances were completed.

Conclusion

● In the above experiment, the thermodynamic cycle of vapor – compression heat pump and refrigerator were studied . The heat pump worked on a vapor-compression cycle in which the refrigerant flew through four processes:

- a) Evaporation at low pressure and temperature .
- b) Compression to high pressure .
- c) Condensation at high pressure and temperature.
- d) Expansion by throttling from high pressure to low pressure.

● By knowing two variables it was possible to obtain the value of the third unknown and for this purpose the pressure-enthalpy diagram was used .

● The experiment was made upon three assumptions: 1-It was assumed that the refrigerant flowrate and the property values were steady, so SFEE was valid.

2- Reasonably it was assumed that KE and PE were negligible and equal to zero.

3- Assumed that heat transfer in compressor was zero and negligible.

● Discrepancy at about 181.0 was calculated from table 3. That indicated the difference of energy input and output was not zero . The apparatus gave energy out , since the energy output had a bigger value.

● Discrepancy was calculated for individual processes and listed in table 4 :

for evaporator = 297.84 , for condenser = 72.27 , for compressor = 91.6

These results should have been found zero specially for the compressor ;however , the equipment was open to air and therefore it did not meet the ideal conditions.

● Coefficient of performance was calculated to be 1.954 ; however the theoretical COP was 2 , according to the fact that $w=Q_1$, $2w=Q_2$. This indicated that the equipment was not 100% efficient.

● Errors raised from instruments used in the experiment .The error bounds for temperature from thermometers was ± 0.1 ° C , for pressures from the pressure gauge = ± 0.25 bar, and using the P-H chart, the effect of the above errors on the enthalpy values for the superheated vapor = ± 1 kJ.kg⁻¹ . Therefore, the enthalpy values determined in the experiment were correct to within ± 1 .

As well ,human error in reading the measurements contributed to the other source of errors .

Appendix

References

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