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Research Article

Simultaneous Compression and Cooling in Vapor Compression Refrigeration System

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Abstract

Vapor compression refrigeration systems are employed in almost all commercial, industrial and home refrigeration and HVAC systems. The compressor work represents a major part of the total energy consumption of this system. This compressor work is increased substantially by the heating of refrigerant gas during compression. This paper suggests a modification to reduce the work input to compressor thereby increasing the efficiency and Coefficient of Performance (COP) of the system. The modification consists of simultaneous cooling and compression of refrigerant to reduce pressure of gas and thus work rate required of compressor.

Keywords: *Vapor Compression Refrigeration, Heat exchanger, compressor, COP, Simultaneous Compression and Cooling*

1. Introduction

Currently vapor compression refrigeration is the most popular refrigeration cycle in use. Most of the commercial refrigeration plants, HVAC plants, home air-conditioners and refrigerators, etc. are based on the vapor compression refrigeration cycle.

Globally residential, commercial and industrial air-conditioning consumes well over one trillion kilowatt-hours of electricity globally[1]. This doesn't even include the tremendous amount of energy used in commercial refrigeration plants and home refrigerators. Thus this represents an extraordinarily high expenditure in terms of power and resources as well as tremendous environmental damage due to the heat and emissions released during the generation of this energy.

Apart from the already very high amount of energy consumption for air-conditioning and refrigeration, this consumption is expected to explode as incomes and standards of living rise around the world.

Thus increasing the efficiency of refrigeration and air-conditioning systems can lead to substantial economic savings as well as a major reduction in the environmental damage caused by refrigeration systems.

The vapor compression refrigeration system consists mainly of a refrigerant compressor, condenser, refrigerant control valve or expansion valve and an evaporator. The refrigerant is compressed to high pressure and temperature in compressor, rejects heat in condenser and absorbs heat in evaporator to produce cooling effect.

The work of compression accounts for the bulk of the energy consumption of refrigeration systems. The process of compression increases the pressure of refrigerant thereby increasing energy consumption of the compressor.

This paper describes a method to reduce the power required to drive compressor by cooling the refrigerant during compression. The reduction in power required to drive the compressor can increase the energy efficiency and coefficient of performance of the refrigeration system.

2. Conventional Vapor Compression Refrigeration Cycle[3]

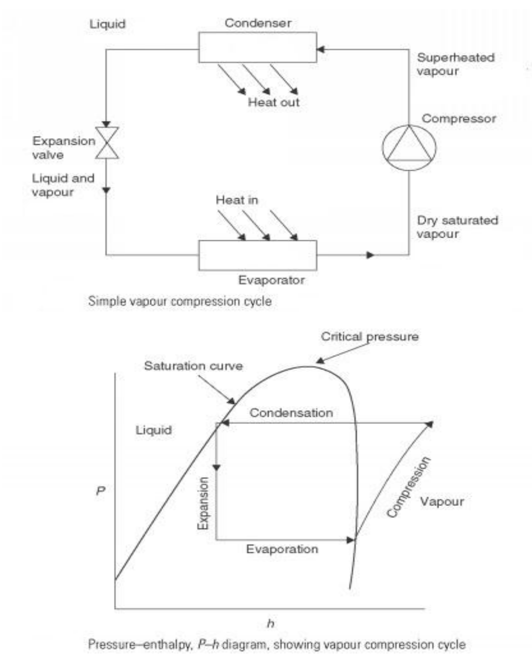

Fig.1 Vapor Compression Cycle on P-h graph, Courtesy[2]

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An ideal VCR cycle consists of four major processes:

Basic Processes in Conventional VCR Cycle

1- Compression of dry saturated refrigerant vapor. Isentropic Compression

2- Condensation of the superheated vapor by removing its latent heat. Isothermal Condensation

3- Expansion of the liquid refrigerant in throttle valve. Isenthalpic Expansion.

4- Evaporation of the refrigerant.

Expansion and evaporation of refrigerant causes drop in it's temperature. Heat is absorbed from the refrigerated space in this process.

3. Modification of Conventional Cycle by Cooling o Refrigerant during Compression

In the conventional VCR cycle as given above, the work required to be done by the compressor is increased substantially due to heating of gas during compression.

The work of compression can thus be reduced by cooling the refrigerant during compression. This can be achieved by either of the following methods:

1- Forced convection air cooling with fins on outer surface of compressor- This method would be relatively more economical to design and produce but less effective on account of the low thermal conductivity and specific heat of air.

2-Forced convection cooling using a liquid coolant and a heat exchanger built into the wall of the compressor. This method would be substantially more effective than air cooling due to the high specific heat and thermal conductivity of liquid coolants. However it would increase capital cost of the system due to the need for a pump and heat exchangers.

Graphical Representation of Modified Cycle

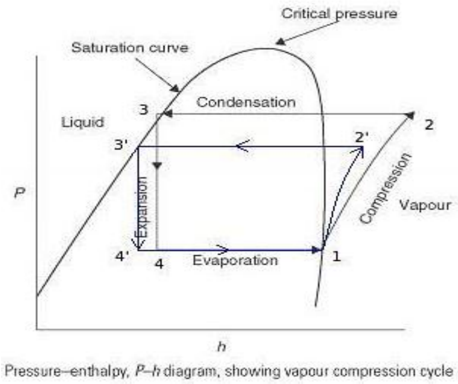

Fig. 2 Modified Vapor Compression Refrigeration Cycle
Cycle 1-2-3-4: Conventional VCR Cycle
Cycle 1-2'-3'-4': Modified VCR Cycle

Thermodynamic Analysis of Modified VCR Cycle[4]

Refer Fig. 2

Tn = Temperature at point 'n'
Pn = Pressure at point 'n'
γ = Heat Capacity Ratio (C_p/C_v)
x = Ratio of difference between inlet and discharge temperatures in modified and conventional VCR cycles

Let

T2'- T1 = x.(T2 - T1)

$$\frac{P2}{P1} = \left(\frac{T2}{T1}\right) \wedge \left(\frac{\gamma}{\gamma-1}\right)$$

Similarly,

$$\frac{P2'}{P1} = \left(\frac{T2'}{T1}\right) \wedge \left(\frac{\gamma}{\gamma-1}\right)$$

$$\therefore P_2' = P_1\left(1 + \frac{x(T2-T1)}{T1}\right) \wedge \left(\frac{\gamma}{\gamma-1}\right)$$

The compressor may be assumed to be a hollow cylinder with

R_2 = Outer radius

R_1 = Inner radius

∴ Heat transfer from the compressor to surroundings is:

$$Q = \frac{\Delta T}{\frac{ln\left(\frac{R2}{R1}\right)}{2\pi kL}}$$

Denoting the Heat Exchanger efficiency as η

$\therefore \eta Q = mC_p\Delta T$

$\therefore \Delta T = \frac{\eta Q}{mCp} = T_2'-T_1$

$\therefore T_2' = T_2 - \frac{\eta Q}{mCp}$

The values of m and C_p depend upon operating conditions like temperature, pressure, compressor specifications, refrigerant used, *et cetera*

The improvement in the value of Coefficient of Performance (COP) is shown below :

$COP_{before} = \frac{H1-H4}{H2-H1}$

$COP_{after} = \frac{H1-H4'}{H2'-H1}$

$H_1 – H_4' > H_1 – H_4$ and

$H_2' - H_1 < H_2 – H_1$

$\therefore COP_{after} > COP_{before}$

Conclusions

1) Simultaneous cooling and compression of refrigerant increases the efficiency of the refrigeration system.
2) The increase in efficiency also increases the coefficient of performance of the system
3) As illustrated the savings in energy consumption of the system over the existing would in typical situations be high enough to justify the additional cost of the system.
4) The increased efficiency of the system can reduce to a degree the environmental damage caused by refrigeration systems.

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Image Courtesy: www.ref-wiki.com

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