Performance Enhancement of Refrigeration Cycle by Employing a Heat Exchanger

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Abstract

Refrigeration system works on the second law of thermodynamics specifically on the Clausius statement which summarizes that the refrigerator is nothing but a reversed heat engine which consumes energy in the form of work to transfer heat from Low temperature body to high temperature body.

Refrigeration system mainly works on Vapour Compression Refrigeration cycle (VCR), in simple VCR cycle the refrigerant after condensation enters into the region of interest after throttling i.e. from where the heat is to be removed. Greater the extent of condensation that ensures the low temperature vapour in cooling region. To enhance the performance means to enhance the cooling capacity but with adjustment of the consequences of doing so. The heat exchanger is installed between the suction line and the discharge line which transfer the heat from low temp low pressure suction line to the high temperature high pressure discharge line also known as Liquid Suction Heat Exchanger. The liquid in the discharge line gets sub cooled and the vapour gets superheated due to which the compressor works increases due to increase in specific volume. In this experimentation various parameters change. This paper identifies the ways of installing the heat exchanger and to find the best suitable way and to analyze the impacts of experimentation on various operating parameters.

Key Words: *Clausius statement, VCR, Cooling capacity, Subcooling.*

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1. INTRODUCTION

Refrigeration system takes energy in the form of work and transfer heat from low temperature to high temperature to get the desired cooling therefore it consumes a large amount of electrical energy to do so, as a result many methods have been developed by researchers to improve the system performance [2].The commercial refrigeration systems (freezer and air conditioner) consume approximately 50- 60% of energy total. Installed heat exchanger (HX) uses an internal heat exchanging technique to subcool the discharge liquid, which transfers heat from the condenser outlet to the compressor suction, may lead to an increase in the cooling capacity produced by the evaporator. This method is called subcooling using liquid suction heat exchanger (LSHX). The most important effect of the use of LSHX is the increase in cooling capacity because of the lower quality of refrigerant entering the evaporator, consequently the evaporator absorb more heat from the ambient. On the other hand due to the liquid suction heat exchanger (LSHX) the vapour to the suction of compressor get superheated.

The positive effect of this superheating is that if the degree of superheating eliminates liquid refrigerant entering to the compressor, because wet intake can cause damage to the compressor [1]. The negative effect if the degree of superheating is too high, as a result an increase in the compressor discharge temperature (K). The increase in the compressor discharge temperature results in an increase in the power consumption. Consequently, the subcooling using LSHX does not always increase the COP.

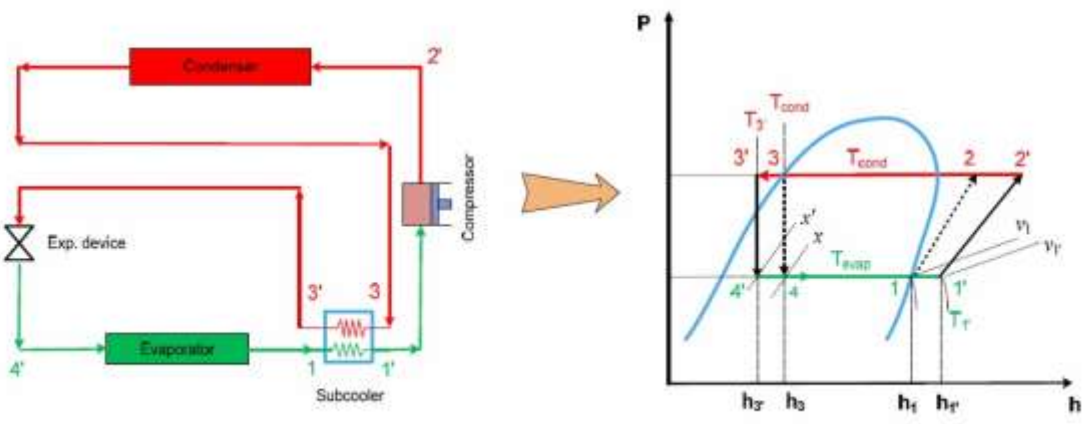

Figure1.1: LSHX Subcooler Schematics and P-h Plot

In employment of the LSHX to enhance the performance the factors which dominate mainly are the proper selection of the refrigerant and the operating ambient temperature. Some of the famous refrigerant which suit to this design are R22, R290, R134a etc. because R22 has a high global warming potential (GWP), the near future this refrigerant shall be phased out and R290 (propane) is recommended as a substitute refrigerant for R22. The R290 is a natural refrigerant, abundant and relatively cheaper than that of R22. Many studies reported that replacement of R22 with R290 in freezer resulted in COP improvement. The discharge temperature of R290 at an ambient temperature greater than 40 ^{0}C is above 110 ^{0}C hence this puts limitation to the use of this refrigerant [5].

1.2 Important Definitions

In this section a few important terms commonly used in heat transfer and refrigeration are defined.

1) **Coefficient of Performance (COP)**

   It is defined as the ratio of the desired cooling effect to the work input given to the system.

$$COP = \frac{Desired\ effect}{Work\ input}$$

2) **Log Mean Temperature Difference (LMTD)**

This term takes into account the varying temperature difference along the length of the heat exchanger and is defined as the temperature difference which if remains constant would give the same heat transfer as given by the varying temperature difference.

3) **Nusselt Number (Nu)**

The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h ($W.m^{-2}.k^{-1}$) is the convective heat transfer coefficient, d is the Diameter of the tube and k ($W.m^{-1}.k^{-1}$) is the thermal conductivity.

As can be seen from the Pressure (bar)-Enthalpy (kJ/kg) (P-h) plot Fig.1.1 that

In the simple VCR cycle without LSHX:

Refrigerating effect = h_1-h_4 (kJ/kg)

Compressor work = h_2-h_1 (kJ/kg)

Hence,

COP = R.E/C.W

= (h_1-h_4)/ (h_2-h_1)

In the simple VCR cycle with LSHX:

Refrigerating effect = h_1-$h_{4'}$ (kJ/kg)

Compressor work = h_2-$h_{1'}$ (kJ/kg)

The refrigerating effect is increased and the compressor work also increases but to certain extent hence the overall COP Increases.

COP = R.E/C.W

= (h_1-$h_{4'}$)/ (h_2-$h_{1'}$)

1.3 Effect of LSHX on Operating Parameters

Above introductory part explains that the employment of the heat exchanger for subcooling affects various operating parameters. The table shows that the use of heat exchanger subcooler is always followed by increasing cooling capacity but also the compressor work and superheating. As the COP is the ratio of the cooling capacity to compressor power, as a result the increase in the COP depends on the extent of subcooling and results are relative. Most of the refrigerant gives COP improvement on the system when the LSHX is installed, and only few refrigerants don't because their specific volume increases to greater extent comparatively [6].

Table1.1. Effect of LSHX on operating parameters

Quantity	Effect
Mass flow rate	Vary*
Subcooling	Increases
Superheating	Increases
Condensation pressure	Constant*
Compressor work	Increases
COP	Increases*

*Depending upon the Refrigerant used and degree of subcooling.

2. REVIEW OF THE BACKGROUND

All over the world researchers have been performing research and experimentation on LSHX since 1980s. Stoecker and Walukas (1981) [3] focused on the influence of liquid-suction heat exchangers systems utilizing refrigerant mixtures. Their analysis indicated that liquid-suction heat exchangers yielded greater performance improvements when Refrigerant is chosen carefully. McLinden (1990) [10] used the principle of corresponding states to evaluate the anticipated effects of new refrigerants. He showed that the performance of a system using a liquid-suction heat exchanger increases with the specific heat of the refrigerant.

Domanski and Didion [9] (1993) evaluated the performance of nine alternatives to R22 including the impact of liquid-suction heat exchangers. The analysis was extended by Domanski et al. [9] (1994) by evaluating the influence of liquid-suction heat exchangers installed in vapour compression refrigeration systems considering 29 different refrigerants in a theoretical analysis. Bivens et al. (1994) their analysis indicated a 6-7% improvement for the alternative refrigerant system when system modifications included a liquid-suction heat exchanger and counter flow system heat exchangers (evaporator and condenser). Bittle et al. (1995a) conducted an experimental evaluation of a Liquid-suction heat exchanger applied in a domestic refrigerator using R152a. The authors compared the system performance with that of a traditional R12-based system.

This paper analyzes the liquid-suction heat exchanger to quantify its impact on system capacity and performance (expressed in terms of a system coefficient of performance, COP). The influence of liquid-suction heat exchanger size over a range of operating conditions (evaporating and condensing) is illustrated and quantified using a number of alternative refrigerants. Refrigerants included in the present analysis are R22, R290, and R134a. This paper extends the results presented in previous studies in that it considers new refrigerants, it specifically considers the effects of the pressure drops, and it presents general relations for estimating the effect of liquid-suction heat exchangers for any refrigerant.

3. DIFFERENT WAYS OF INSTALLING LSHX AND THEIR PROS. AND CONS.

Following are the main ways of installing the LSHX in the VCR cycle.

1) Shell and tube type
2) Tube in tube Annulus type (Parallel and Counter flow)

3.1 Shell and Tube Type LSHX

Shell and Tube Heat Exchangers are one of the most popular types of exchanger due to the flexibility the designer has to allow for a wide range of pressures and temperatures. A shell and tube exchanger consists of a number of tubes mounted inside a cylindrical shell. Fig.3.1 illustrates a typical unit of shell and tube type LSHX. Two fluids can exchange heat, one fluid flows over the outside of the tubes while the second fluid flows through the tubes. The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement.

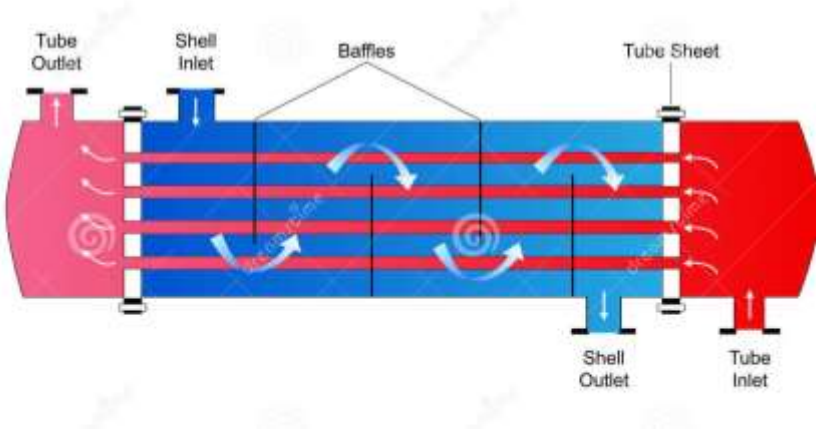

Figure 3.1: Shell and Tubes Heat Exchanger

In shell and tube heat exchanger the vapour flows outside the tubes in a shell and the discharge liquid flows in the tubes due to that sudden expansion the sp. Volume of the vapour increases and the superheating adds to that and hence the work of compression increases and the inlet and outlet of the section faces energy losses and due to that the compressor works roughly and heat exchanger also incur jerks and vibrations, Hence that puts limitation to the use of this type.

3.2 Tube in Tube Annulus type (Parallel and Counter flow)

Tube-in-tube heat exchangers consist of two tubes, an inner and an outer coiled together. This unique, compact design prevents thermal fatigue, increases efficiency and reduces the overall size. It is ideal for high temperature, high pressure and low flow applications.

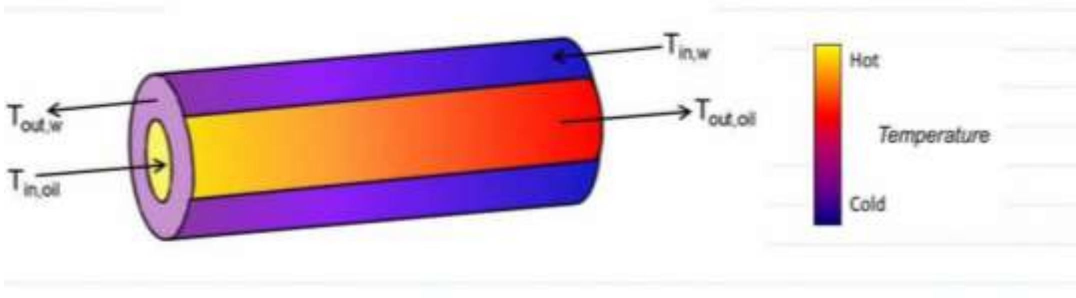

Figure 3.2: Tube in Tube Heat Exchanger

As shown in Fig. 3.2 in tube in tube HX two concentric tubes are used with not large difference in diameter hence when the vapour in the outer tube opens up they don't expands to the considerable extent and therefore the Sp. Volume of the gas don't increase to considerable extent and the work of compression don't rise considerably compared to earlier.

3.2.1 Operational Procedure

The tube in tube type counter flow heat exchanger is most suitable type for the proposed design hence, to design that the following operational procedure is to be considered first.

- When the refrigerant leaves evaporator at that time refrigerant have low temperature.
- Condenser is used for the purpose of removing heat from refrigerant to the atmosphere, to reduce temperature of refrigerant and make phase change of refrigerant.
- Super heating is done at the inlet of compressor and subcooling is done at exit of condenser.
- Both evaporator and condenser heat to make subcooling and superheating are being used at the same time and in same device.
- Heat exchanger is used to make this heat exchange between hot and cold refrigerant.
- From the outer tube evaporator outlet refrigerant (low temp refrigerant) flowing and from inner tube condenser outlet refrigerant (High Temp refrigerant) flowing.
- Heat exchange between both refrigerant produces the superheating at entry of compressor and subcooling at exit of condenser.
- Hence refrigeration effect considerably increased with same amount of work supplied
- and Hence overall COP of system increases

3.2.2 Proposed Numerical Analysis for Design

As it can be seen from the above procedure that at the exit of the LSHX we get the saturated vapour converted into the superheated state and due to that the specific volume of the vapour get increased and due to that the compressor work gets increased that may reduce the COP.

Hence the design should be made such that the optimum value of superheating should be there so associated with the subcooling and that can be done by the proper choice of the refrigerant and the proper HE design.

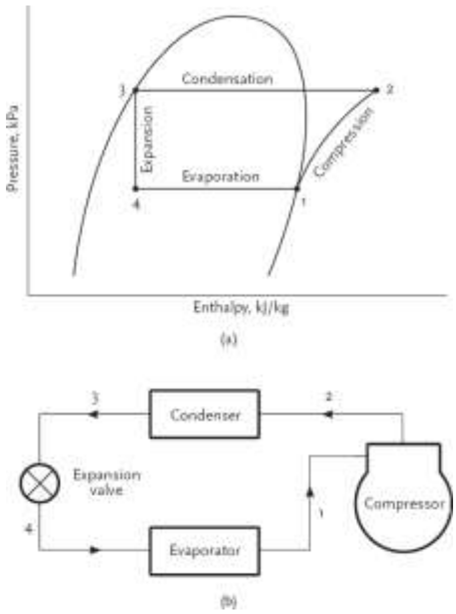

Figure 3.2.1: Simple VCR cycle with P-h Plot

As can be seen from above figure,

In the experimental setup we can get the following data.

Suction and discharge pressure - P_1 and P_2 (bar)

From the temp. Sensors

We can get,

Temp. At entry to compressor – T_1 (K)

Temp. At exit to compressor – T_2 (K)

Temp. At exit to condenser – T_3 (K)

Temp. After expansion – T_4 (K)

From Energy meter

We get work of compression in the form of power for time t (sec),

$P = m (h_2-h_1)$ kilowatt (KW).

Where m- mass flow rate (kg/sec) is found from above

Now,

From P-h chart

R.E is found and finally COP

R.E = m (h_1-h_4) KW.

COP = (R.E)/ (P)

The Design of HX

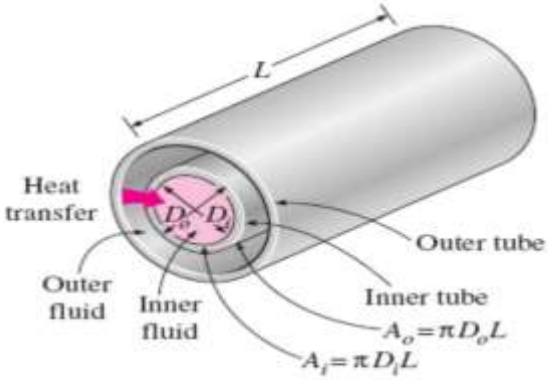

Figure 3.2.2: Schematics of tube in tube HX

From Forced convection Analysis;

For tube in tube counter flow heat exchanger.

- For defined degree of subcooling we can find degree of superheating.
- Then finding varied mass flow rate by maintaining the superheating condition.
- Apply analysis **Nu = 0.023 $(Re)^{0.8}(Pr)^n$**

  n = 0.4 for heating of fluid

  = 0.3 for cooling of fluid.
- We have **Nu=hD/k**

  We get h_i and h_o – heat transfer co-efficient for inner and outer flow respectively.
- Then finding overall heat transfer coefficient U.
- Then calculating the desired dimensions of HX from heat transfer equation for HX.

4. CONCLUSION

Superheating causes variation in the mass flow rate of the gas, if we neglect that variation as it varies to very small extent and can further be minimized by the proper selection of the refrigerant. We can conclude that liquid-suction heat exchangers lead to performance improvements for any refrigerant. The compressor power is only slightly affected by the change in state of the refrigerant entering the compressor, which causes the reduction in refrigerant mass flow rate because liquid-suction heat exchangers increase the temperature and reduce the pressure of the refrigerant entering the compressor causing a decrease in the refrigerant density and compressor volumetric efficiency.

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