Effect of Liquid Suction Heat Exchanger in Existing Refrigeration System: Review

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Abstract: In this paper theoretical analysis has been carried out on the effect of liquid suction heat exchanger on the cooling performance of vapour compression Refrigeration system, a liquid suction heat exchanger has been introduced in existing refrigerator, and theoretical effects of introducing LSHX has been carried out to explain its impact on overall performance of refrigerator. It is found that heat exchange between high pressure and high-temperature refrigerant liquid coming from the condenser and low pressure and low-temperature refrigerant vapour coming from the evaporator is having a significant effect on its COP. Which may be reported to be 20-30% higher.

Keywords: VCR System, LSHX, R-134a, COP, Sub-cooling.

1. INTRODUCTION

In the existing VCR system, COP is less and power consumption is comparatively higher which results in excess energy consumption. The use of heat exchanger has the potential to increase the COP of the VCR system higher than existing (11). In the VCR system, there are two heat exchangers. One is evaporator which absorbs the heat and another is condenser where heat rejection takes place. A theoretical study has been done to improve the COP of the VCR system. A liquid suction heat exchanger has a significant effect on COP and is a type of counter-flow heat exchanger which sub cools saturated liquid refrigerant coming from the condenser and superheats the saturated vapour coming from evaporator.

2. LIQUID SUCTION HEAT EXCHANGER

Liquid Suction Heat Exchanger is introduced in the refrigeration system to improve the performance of the refrigeration system.

The superheated vapour from the compressor goes into the condenser where a phase change occurs & it converts into the saturated liquid. Then this saturated liquid goes into the heat exchanger where it rejects heat to the liquid-vapour mixture coming from the evaporator & gets sub-cooled. Now, this sub-cooled liquid goes into the expansion device where it converts into the low pressure & low-temperature liquid-vapour mixture. Then this liquid-vapour mixture goes into the evaporator where heat addition takes place at constant pressure & refrigeration effect is obtained. The low pressure & low-temperature liquid-vapour mixture after coming out of the evaporator goes into the heat exchanger where it gains the heat from the sub-cooling of the saturated liquid. After that, it becomes saturated vapour& then enters into the compressor & the cycle continues. The schematic Diagram of VCR System with LSHX is shown in fig. 1 and representation of sub-cooling on T-S coordinate is shown in fig. 2.

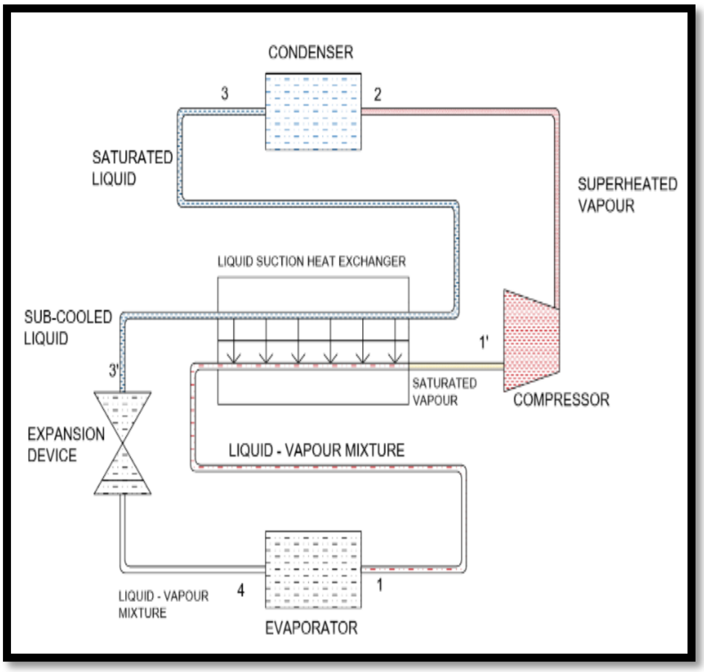

Fig. 1: Schematic of the VCR System with LSHX [10]

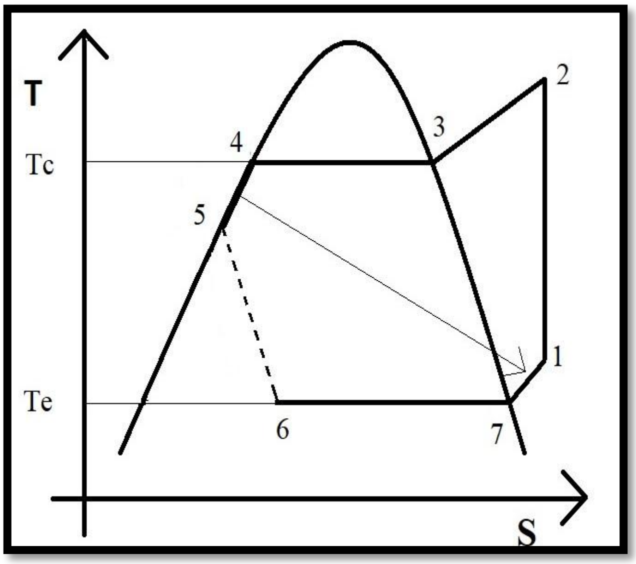

Fig. 2: Representation of Sub-Cooling on T-S Coordinate [11]

Processes:

1) Process 1-2: Isentropic Compression
2) Process 2-3: De-superheating
3) Process 3-4: Heat rejection at constant pressure
4) Process 4-5: Sub-cooling
5) Process 5-6: Isenthalpic process
6) Process 6-7: Heat addition at constant pressure
7) Process 7-1: Superheating

3. ABBREVIATIONS AND ACRONYMS

ΔT	Degree of sub-cooling = $T_4 - T_5$ (°C)
ΔT_s	Degree of sub-cooling (°C)
T_1	Superheated Temperature (°C)
T_7	Evaporator Temperature (°C)
T_3	Condenser Temperature (°C)
T2	Condenser Discharge Temperature (°C)
C_{pl2}	Specific heat capacity of saturated liquid (KJ/kg-K)
C_{pv1}	Specific heat capacity of saturated vapour (KJ/kg-K)
C_{pv2}	Specific heat capacity of saturated vapour(KJ/kg-K)
s_7	Entropy of saturated vapour(KJ/kg-K)
s_1	Entropy of superheated vapour(KJ/kg-K)
s_3	Entropy of saturated vapour(KJ/kg-K)
h_7	Enthalpy of saturated vapour(KJ/kg)
h_4	Enthalpy of saturated liquid (KJ/kg)
h_1	Enthalpy of Super- heated vapor (KJ/kg)
h_2	Enthalpy at end of compression process (KJ/kg)
h_3	Enthalpy of saturated vapour at (KJ/kg)
h5 = h6	(Throttling process) (KJ/kg)
V7	Specific volume of saturated vapour (m^3/kg)

4. LITERATURE REVIEW

1) P.A Domanski, D.A. Didion and J.P. Doyle (1992) targeted the assessment of the liquid line heat exchanger in the refrigeration cycle. The study observed the advantages of the liquid suction heat exchanger that rely upon different conditions and properties of the fluid. The fluids whose behaviour in the primary cycle is fine are hardly concerned by the use of LSHX, and its effect on the coefficient of performance and volumetric capacity can be either positive or negative. Fluids whose behaviour in the primary cycle is below par, are largely helped by the installation of LSHX which results in the improvement of the coefficient of performance and volumetric capacity.[1]

2) S. A. Klein, D. T. Reindl, and K. Brownell (2000) investigated by assessing the effect of LSHX in simple vapour compression refrigeration system and concluded that by installing liquid suction heat exchanger it leads to the performance improvements for any refrigerant by ignoring the decrement in the mass flow rate of refrigerant. When assessing closely, the LSHX results in the rise in temperature of refrigerant and results in the decrement of the pressure of the refrigerant which is going into the entering the compressor which leads to decrement in the density and volumetric efficiency of the compressor, and suggested that the choice of the heat exchanger must be on the basis of refrigerant properties. [2]

3) R. Mastrullo, A.W. Mauro, S. Tino, G.P. Vanoli (2007) observed the outcomes by introducing a liquid suction heat exchanger in a vapour compression refrigeration cycle. They indicated that by introducing a liquid suction heat exchanger, the performance of the vapour compression refrigeration system can enhance or it can be diminished based on operating parameters. They come to a point that by introducing a liquid suction heat exchanger the system performance can be enhanced since it stops the formation of gases at the entry of the expansion valve and also leads to the elimination of liquid at the entry of the compressor.[3]

4) G. Maruthi Prasad Yadav, P. Rajendra Prasad, G. Veeresh (2011) conducted a study on how capillary tubes can be used with VCR System with LSHX. Capillary tubes are cheap and its design is comparatively simple therefore, they are widely used in refrigeration systems.[4]

5) G.Edision, A. Suresh & K. Narayan Rao (2012) conducted a study by employing the R-12 refrigerant in the VCR system and they came to a point that with increment in the liquid's density there is an increase in volumetric efficiency and as a result mass flow increases due to which cooling effect increases. [5]

6) Shoeb J. Inamdar, H.S. Farkade (November 2016) calculated the effects of heat exchanger in simple VCRS with R-134a varying length and concluded that if the length of heat exchanger increases then heat rejection rate per TR decreased, and the cooling effect increased.[6]

7) M. Krishna Prasanna (2014) concluded that by introducing a heat exchanger in the existing VCR system there is an increment in refrigeration effect of 16%. There is also an increment in COP (coefficient of performance) of the VCR system by 16% when a heat exchanger is introduced. There is a decrement in refrigerant's mass flow rate by 14% when a heat exchanger is introduced with the VCR system. Also, there is a decrement in power input to the compressor by14% when a heat exchanger is employed with VCR system. [7]

8) Ms Priyanka V. Desai, Mr Umang M. Satute, Mr Suraj N. Salunke, Mr Rushikesh A. Taware, Mr Akshay B. Ransing (April 2017) work on the performance of refrigeration system by increasing the C.O.P. of the system by employing liquid suction heat exchanger, with any refrigerant. Due to this addition there is variation in the system parameters such that sub-cooling, superheating, C.O.P. increases and the compressor work is also increased in small amount due to change in state of refrigerant entering in the compressor as a result of which the mass flow rate also increases as the temperature and pressure increases by the use of heat exchanger.[8]

In this study, by using a liquid suction heat exchanger, the performance of a vapour compression refrigeration system is theoretically analysed. To increase the performance of VCR, the refrigeration effect should increase and work input to the compressor should decrease.

5. METHODOLOGY & CONCLUSION

Taking R-134A as heat transfer media, Refrigerant Capacity of the VCR system is 1 TR i.e. 3.5 KW, Condenser Temperature is 40° C, Evaporator Temperature is -16° C and mass flow rate is constant.

- Formulas Used [10]:

1. $T_1 = T_7 + \frac{C_{pl2}}{C_{pv1}}(\Delta T)$ -----(1)
2. $s_1 = s_7 + c_{pv1} * \ln\frac{T_1}{T_7}$------(2)
3. $s_2 = s_3 + c_{pv2} * \ln\frac{T_2}{T_3}$ -----(3)
4. $h_1 = h_7 + c_{pv1} * \Delta T_s$-----(4)
5. $h_2 = h_3 + c_{pv2}(T_2 - T_3)$-----(5)
6. $h_6 = h_5 = h_4 - c_{pl2}(\Delta T)$----(6)
7. $R.E. = (h_7 - h_6)$-----(7)
8. $W.D. = (h_2 - h_1)$ -----(8)
9. $C.O.P. = \frac{R.E.}{W.D.} = \frac{(h_7 - h_6)}{(h_2 - h_1)}$-----(9)

Table No. 1: Values from psychometric chat [9]:

1	h_3	419.58	KJ/kg
2	h_4	256.35	KJ/kg
3	h_7	389.11	KJ/kg
4	C_{pl1}	1.5	KJ/kg-K
5	C_{pv1}	0.82	KJ/kg-K
6	C_{pv2}	1.12	KJ/kg-K
7	T_3=T_4	313	K
8	T_7	257	K
9	s_3	1.7115	KJ/kg-K
10	s_7	1.7383	KJ/kg-K
11	p_2	10.165	Bar
12	p_7	1.5721	Bar
13	v_7	0.1256	m^3/kg

Table No. 2: Degree of sub-cooling without considering volumetric efficiency

S. No.	Degree of sub-cooling	R.E.	W.D.	C.O.P.
	°C	KJ/kg	KJ/kg	
1	0	132.76	38.95	3.40
2	0.5	133.51	39.14	3.41
3	1	134.26	39.32	3.413
4	1.5	135.01	39.51	3.416
5	2	135.76	39.69	3.42
6	2.5	136.51	39.87	3.423
7	3	137.26	40.05	3.426
8	3.5	138.01	40.23	3.429
9	4	138.76	40.41	3.433
10	4.5	139.51	40.59	3.436

Table No. 3: Degree of sub-cooling considering volumetric efficiency

S. No.	Degree of sub-cooling	Volumetric efficiency	R.E.	W.D.	C.O.P.
	°C		KJ/kg	KJ/kg	
1	0	1	132.76	38.95	3.40
2	0.5	0.996	133.51	39.28	3.39
3	1	0.992	134.26	39.60	3.389
4	1.5	0.989	135.01	39.93	3.38
5	2	0.985	135.76	40.25	3.37
6	2.5	0.982	136.51	40.58	3.36
7	3	0.979	137.26	40.91	3.35
8	3.5	0.975	138.01	41.23	3.34
9	4	0.972	138.76	41.56	3.338
10	4.5	0.968	139.51	41.89	3.33

6. RESULTS

Table No. 4: Degree of sub-cooling vs Percentage increase in C.O.P.

Degree of sub-cooling	Percentage increase in C.O.P.
0	0
0.5	0.35
1	0.70
1.5	1.05
2	1.40
2.5	1.74
3	2.09
3.5	2.43
4	2.76
4.5	3.10

Table No. 5: Percentage increase in degree of sub-cooling vs Percentage Increase in C.O.P.

Percentage increase in degree of sub-cooling	Percentage Increase in C.O.P.
0	0
1.25	0.35
2.5	0.70
3.75	1.05
5	1.40
6.25	1.74
7.5	2.09
8.75	2.43
10	2.76
11.25	3.10

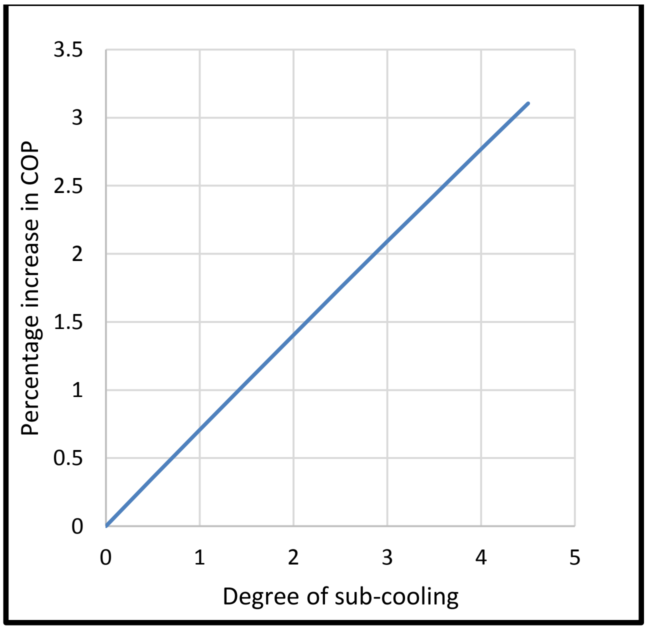

Fig. 4: Relation between COP & Degree of sub-Cooling

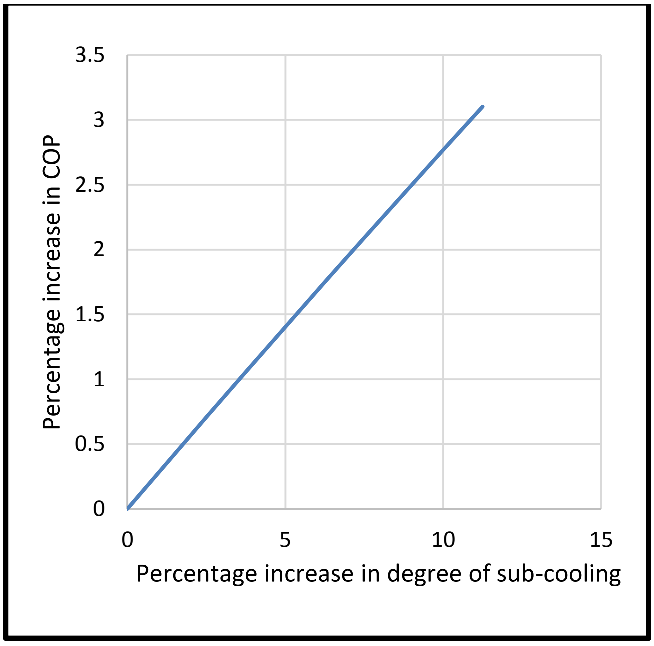

Fig. 5: Relation between Percentage increases in COP VS Percentage increase in degree of sub-cooling

According to our calculation, the results are shown in table no. 4 & 5 and the corresponding graphs have been plotted in fig. no. 4 & 5 respectively between the degree of sub-cooling VS percentage increase in COP and percentage increase in Degree of Sub-cooling VS percentage increase in COP respectively and it is found out that COP of the VCR System increases by installing a liquid suction heat exchanger.

7. CONCLUSIONs

- From the theoretical analysis, it can be summarised that increase in sub-cooling of refrigerant before entering to expansion device has a positive impact on COP of the system.
- Installation of Liquid Suction Heat exchanger with existing Refrigeration is a very easy process. And costing is very less comparing to improvement in the refrigeration effect.
- Sub-cooling of Refrigerant also increases superheating of refrigerant entering to compressor hence it is not one way.
- Due to the superheating process, the mass flow rate of refrigerant going into the compressor decreases. But if we assume that the mass flow rate is constant then according to our study, we concluded that on increasing the degree of sub-cooling, the COP of the VCR system is increased by installing a liquid suction heat exchanger in case of R-134a refrigerant.
- Therefore, installing a liquid suction heat exchanger improves the performance of the VCR system since the refrigeration effect increases.
- But COP does not always increase with the increase in the amount of sub-cooling because a point comes when it attains a maximum value & after that, it decreases due to increase in compressor work but Refrigerating effect continued to be on improving if refrigerant entering condition is maintained the saturated liquid at the entry to the expansion device.

8. REFRENCES

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