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Experimental Investigation of Sub Cooling Effect on Simple Vapour Compression System by Domestic Refrigerator

KEYWORDS: Thermoelectric module; Domestic refrigerator; Sub cooling

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ABSTRACT *Refrigerator has become an essential part of a house hold. The primary function of refrigerator is to provide food storage space maintained at low temperature for the preservation of food & secondary function is to manufacture of ice. Performance of this system becomes main issue and many researches are still ongoing to evaluate and improve efficiency of the system. This paper gives an understanding of basic vapour-compression refrigeration system & performance of refrigeration system can be determined using refrigerator test rig. In domestic refrigerator have been conducted sub cooling parameter take in order to analyze performance of the refrigerator. Using of thermoelectric module in domestic refrigerator for sub cooling, the effect on COP and refrigerating effect is investigated. The performance of the refrigerator test rig analyze by the using the actual pressure-enthalpy diagram of actual refrigeration cycle and by using the equation.*

1. INTRODUCTION

Refrigeration systems transfer heat from a low-temperature medium to a high-temperature medium. It is also define as a process of heat removal [1]. Refrigeration systems are cyclic processes that employ refrigerants to absorb heat from one place and move it to another. Mainly, a refrigeration system consists of a condenser, an evaporator, a compressor, and an expansion valve as shown in figure -1.1 [2].

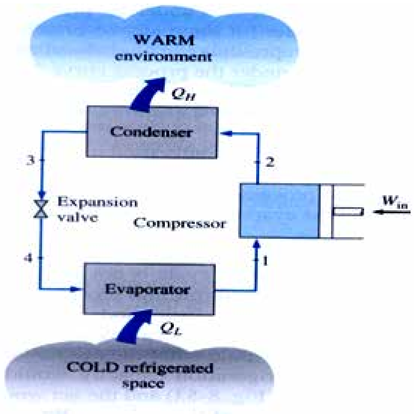

Figure -1.1 Simple vapour compression system

Vapour compression systems use the latent heat of vaporization of the working fluid in order to transfer large amounts of heat per unit mass, at a fixed temperature level. The liquid refrigerant evaporates in the evaporator, absorbing heat. The superheated vapours are compressed by the compressor and the vapours turn to liquid state in the condenser.

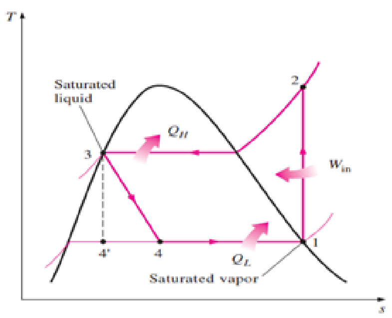

Figure-1.2 T-S diagram for vapour compression system

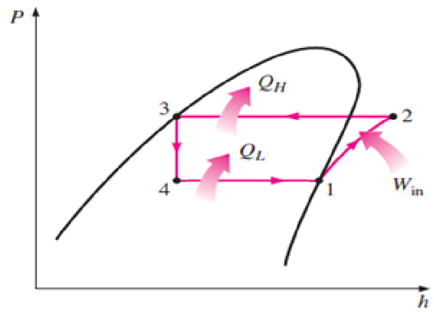

Figure- 1.3 P-S diagram for vapour compression system

The coefficient of performance (COP) of the refrigeration system is defined as the ratio between the useful heat and the absorbed mechanical. Cooling of condensed liquid leaving the condenser (subcooling), using thermoelectric module, allow the increase of the amount of extracted heat without increasing the power input to the compressor.

Attaching a thermoelectric cooling device at the condenser outlet allows the subcooling of the refrigerant without any modification of the circuit; in the meantime, by subcooling the working fluid the high side pressure can be reduced, increasing compression efficiency and cooling capacity without adding moving parts [3].

2. Effect of subcooling in vapour compression system

When the liquid is subcooled before it reaches the expansion valve, the refrigerating effect per unit mass is increased. Because of the greater refrigerating effect per unit mass, the mass flow rate of refrigerant per unit capacity is less for the subcooled cycle than for the saturated cycle. It should be noted that the refrigerant vapour entering the suction inlet of the compressor is the same for both cycles. For this reason, the specific volume of the vapour entering the compressor will be the same for both the saturated and subcooled cycles and, since the mass flow rate per unit capacity is less for the subcooled cycle than for the saturated cycle, it follows that the volume of vapour that the compressor must handle per unit capacity will also be less for the subcooled cycle than for the saturated cycle. Because the volume of vapour compressed per unit capacity is less for the subcooled cycle, the compressor displacement required for the subcooled cycle is smaller than that required for the saturated cycle. It should also be noted that the heat of compression per unit mass is the same for both the saturated and subcooled cycles [2].

This means that the increase in refrigerating effect per unit mass resulting from the subcooling is accomplished without increasing the energy input to the compressor [4]. Any change in the refrigerating cycle that increases the quantity of heat absorbed in the refrigerated space without causing an increase in the energy input to the compressor will increase the COP of the cycle and reduce the power required per unit capacity [5].

3. Thermoelectric module

A thermoelectric module is a small heat pump which has the advantage of no moving parts. TEM are used in various applications where space limitations and reliability are paramount. The coolers operate on direct current and may be used for heating or cooling by reversing the direction of current flow. This is achieved by moving heat from one side of the module to the other with current flow and the laws of thermodynamics. A typical single stage module (Figure-3.1) consists of two ceramic plates with p- and n-type semiconductor material (bismuth telluride) between the plates. The elements of semiconductor material are connected electrically in series and thermally in parallel [3].

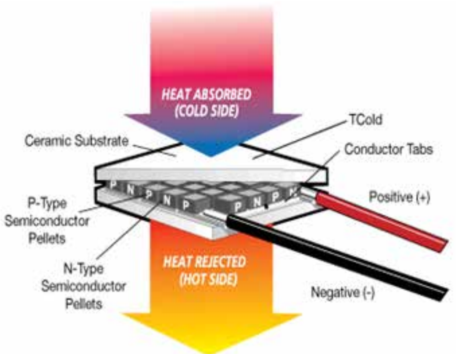

Figure-3.1 Thermoelectric module

When dc voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. The surface where heat energy is absorbed become cold, the surface where heat energy is released becomes hot. Using this simple approach to "heat pumping", thermoelectric technology is applied to many widely-varied application- small laser diode coolers, portable refrigerators, scientific thermal conditioning, and liquid coolers etc. Here it is use for sub cooling in the vapour compression system in domestic refrigerator. The coefficient of performance (COP) of the domestic refrigerator system was calculated with the relation:

$$COP = \frac{R.E}{W} \qquad (1)$$

Where, R.E is the cooling capacity and P is the compressor power input. When a thermoelectric device is used for sub-cooling, its power consumption must be accounted for and the relation for COP becomes:

$$COP = \frac{R.E}{W+W*} = \frac{R.E}{W+\frac{R.E*}{C.O.P*}} \qquad (2)$$

Where, W is the power input to the thermoelectric device, COP   is the efficiency of the thermoelectric device and R.E is the cooling capacity required for subcooling.

TEC1-12708T125 thermoelectric cooler was considered as subcooling device; the following expressions were used to calculate the fundamental TEC parameters form the set of data given by the manufacturer.

Seebeck coefficient: $\alpha = \frac{U_{max}}{T_H}$ [V/K], (3)

Electrical resistance: $R = \frac{U_{max}}{I_{max}} = \frac{T_H - \Delta T_{MAX}}{T_H}$ [Ω], (4)

Thermal resistance: $\theta = \frac{\Delta T_{MAX}}{I_{max} \cdot U_{max}} \cdot \frac{2 \cdot T_H}{T_H - \Delta T_{MAX}}$ (5)

Where, Umax is the maximum DC voltage [V] that will deliver the maximum possible temperature drop ΔTmax [K] at the supplied current Imax [A] and at the temperature TH of the hot junction [K].

The figure of merit of the thermoelectric module was determined with the relation:

$$Z = \frac{\alpha^2 . \theta}{R} \text{ [k-1]} \qquad (6)$$

Coefficient of performance of the TEC module was evaluated with the relation:

$$COP^* = \frac{T_C}{T_H - T_C} \cdot \frac{\sqrt{1+z \cdot \frac{T_H+T_C}{2}} - \frac{T_H}{T_C}}{\sqrt{1+z \cdot \frac{T_H+T_C}{2}}+1} \qquad (7)$$

Where, TH is the hot plate temperature and TC is the cold plate temperature.

Item	Value
No. of thermocouple	71
Imax [A]	8
U_{max} [V]	8.5
Δ Tmax [^{0}C]	67
Z [k^{-1}]	79.1

Table no - 3.1 Characteristic of TEC1-12708T125 TEM

The cooling capacity required for subcooling was calculated using the relation:

R.E = m . cP . Δ TTEM (8)

Where, m is the refrigerant mass flow [kg/s], cP is the specific heat of the refrigerant [J/kg*K] and Δ TTEM is the degree of subcooling [K][6].

4. Experimental setup

The experimental test rig has a vapour compression refrigeration cycle working with the refrigerant R 134a. It consists of a compressor, evaporator, air-cooled condenser, receiver, expansion valve & thermoelectric module.

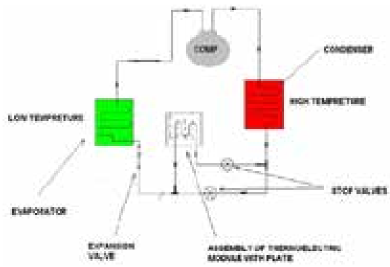

Figure -4.1 Experimental diagram of vapour compression system of domestic refrigerator with thermoelectric module

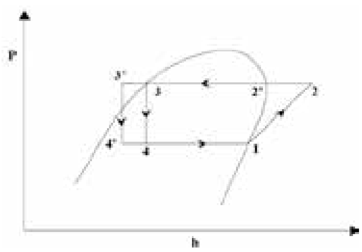

Figure -4.2 P-H diagram for experimental test rig.

1-2 Isentropic compression
2-3 Heat rejected in condenser
3-3' Subcooling

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3'-4' Isentropic expansion
4'-1 heat absorbed in evaporator

Figure -4.3 Experimental test rig

As shown in figure 4.4, thermoelectric module place between condenser & expansion valve for the sub cooling effect in domestic refrigeration. The liquid refrigerant subcooled by passing it through cooling surface of thermoelectric module. The performance measures considered in experimental test rig are coefficient of performance, refrigerating effect, compression work & degree of subcooling.

Figure -4.4 Experimental test rig with module

5. Results & Discussions

Vapour compression refrigeration system with thermoelectric module achieves high coefficient of performance. Table no – 5.1 & 5.2 represents the reading taken from experiment respectively without module & with module respectively.

$T_{EVP.}$ [° c]	$T_{CON.}$ [° c]	$P_{EVP.\,[kpa]}$	$P_{CON.\,[kpa]}$	Compressor work	Refrigerating effect	cop
-6	40	234.4	1017	24.36	138.6	5.69
-6.5	38.9	230	987.5	24.17	140	5.79
-6.3	41.2	231.8	1050	25.05	136.7	5.45
-6.9	39.3	226.5	998.2	24.59	139.2	5.66
-6.8	38.8	227.4	984.8	24.31	140	5.75

Table no - 5.1 Domestic refrigerator without module [without subcooling]

$T_{EVP.}$ [° c]	$T_{CON.}$ [° c]	$P_{EVP.\,[kpa]}$	$P_{CON.[kpa]}$	Compressor work	Refrigerating effect	cop
-6	20	234.4	1017	25.27	167.6	6.63
-6.5	18.9	230	987.5	25.13	167.3	6.65
-6.3	21.2	231.8	1050	26.03	167.9	6.45
-6.9	19.3	226.5	998.2	25.59	167.3	6.53
-6.8	18.8	227.4	984.8	25.24	166.9	6.61

Table no - 5.2 Domestic refrigerator with module [with subcooling]

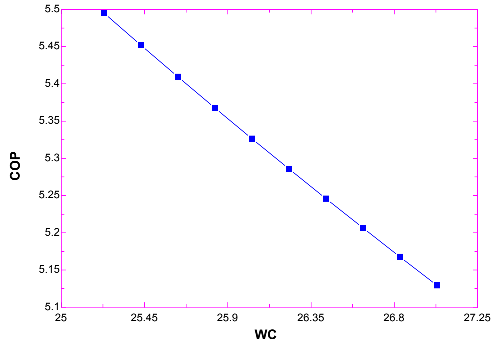

Figure -5.1 Cop vs compression work for VCR system without module

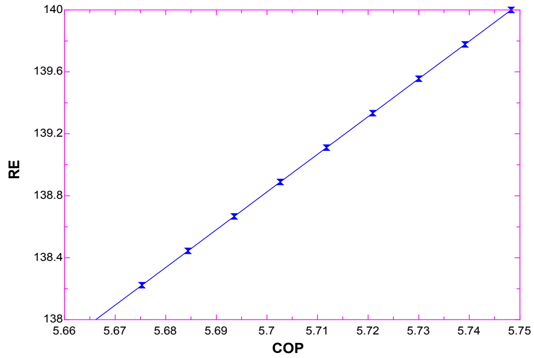

Figure -5.2 Refrigerating effect vs cop for VCR system without module

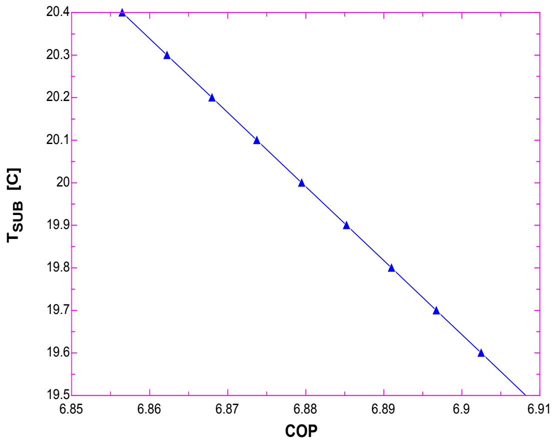

Figure -5.3 Subcooling temp. vs cop for VCR system with module

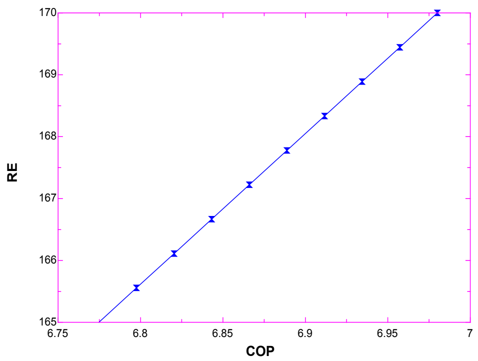

Figure -5.4 Refrigerating effct vs cop for VCR system with module

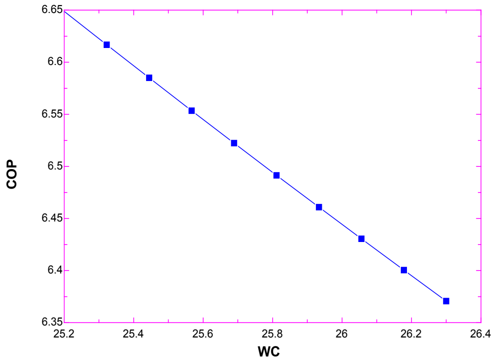

Figure -5.1 Cop vs compression work for VCR system with module

5. CONCLUSIONS

Vapour compression refrigeration systems are used widely in refrigeration applications. In refrigeration systems, system performance increases with subcooling. A thermoelectric cooling device, placed at the outlet of the condenser to subcool the liquid refrigerant in a vapour compression refrigeration system. It increases of cop of vapour compression system in domestic refrigerator.

The result obtained showed that cop of vapour compression system with thermoelectric module is higher than vapour compression system without module. An increase in sub-cooling reduces the compressor work input and increases the system refrigeration capacity. Thermoelectric module are not position dependent & required lower space so easily applicable in domestic refrigerator for sub cooling purpose.

REFERENCE [1] Orhan Ekren, Banu Y. Ekren " Experimental design and regression analysis for performance of a chiller system" , Journal of Thermal Science and Technology, May 2010, pp. 59-65. | [2] Resat Selbas, Onder Kızılkan, Arzu Sencan "Thermoeconomic optimization of subcooled and superheated vapor compression refrigeration cycle", Energy 31 (2006), pp. 2108–2128. | [3] Jonathan Schoenfeld, Jan Muehlbauer, Yunho Hwang, Reinhard Radermacher "Integration of a Thermoelectric Sub cooler Into a Carbon Dioxide Transcritical Vapour Compression Cycle Refrigeration System" , International Refrigeration and Air Conditioning Conference at purdue, July 2008. | [4] J. Benouali, Y. S. Chang, D. Clodic "Analysis of the Sub-Cooling on Refrigerating Systems Using R-410A or R-404A" International Refrigeration and Air Conditioning Conference at purdue, July 2000. | [5] Bukola Olalekan Bolaji " Effects of Sub-Cooling on the Performance of R12 Alternatives in a Domestic Refrigeration System " , Thammasat International Journal of Science & Techlogy, March 2010, vol. 15. | [6] R. Rosca, I. Tenu, P. Carlescu, E. Rakpsi, Gh. Manolache "Assessment of the subcooling capabilities of a thermoelectric device in a vapour compression refrigeration system", University of Agricultural Sciences and Veterinary Medicine, 2007. | [7] Ramadan Bassiouny," Evaluating the effect of the space surrounding the condenser of a household refrigerator", International journal of refrigeration, April 2009, pp. 1645-1656.