© 2019 IJSRSET | Volume 6 | Issue 1 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET196191

Study and Analysis of Capillary Tube and Thermostatic Expansion valve in Domestic Refrigerator using Eco friendly Refrigerant : A Review

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ABSTRACT

The current review is concerned with the study of the effect of different expansion devices (capillary tube and Thermostatic expansion valve) on the alternative refrigerants used in the domestic refrigerators to have better performance with minimum losses. This paper give the summary and range of various refrigerants used in the refrigeration cycle of global warming which affect the environment by the use of refrigerant, and our aim is to reduce the effect of global warming as well as optimize the performance of domestic refrigerators by using the latest refrigerants and appropriate expansion devices like capillary tube and Thermostatic expansion valve. R134a is used in vapor compression refrigeration system having zero ozone depletion potential (ODP) and almost good thermodynamic properties, but it has a high Global Warming Potential (GWP) of 1300.So many researchers identifying new refrigerants and their blend which are environmental friendly and having low GWP and low ODP. Hydrocarbon refrigerants mainly propane, butane and isobutene are proposed as an environment friendly refrigerants. After reviewing the various literatures on the various expansion devices and hydrocarbons refrigerants and their mixture gives good performance in small capacity domestic refrigerator.

Keywords : Capillary tube, Thermostatic expansion valve GWP, ODP, Alternative refrigerants, , Propane (R290), Isobutene (R600a) and Refrigerant Blends.

I. INTRODUCTION

A refrigerator or a water cooler is nothing but a heat pump whose job is to reject heat from higher temperature sink to surrounding and absorb heat from a lower temperature source. In 1834 the first mechanically produced cooling system was developed in England which later known as vapor compression cycle. The vapor refrigeration cycle is the process that cools an enclosed space to a temperature lower than the surrounding temperature. Since the invention of vapor compression refrigeration system, the application of refrigeration has entered many fields which include preservation of medicine, food, air-conditioning for comfort and industrial applications. Refrigerant is a working fluid used to transfer heat from lower temperature reservoir to higher temperature reservoir.

1.1 History of Refrigerants -

1.1.1 **Chlorofluorocarbon:** They are molecules composed of carbon, chlorine and fluorine. It contributes to the damage of the ozone layer. These are R11, R12, R113, R500, R502 etc.

1.1.2 Hydro chlorofluorocarbon: They are molecules composed of carbon, chlorine, fluorine & hydrogen. They are less stable than CFCs, destroy ozone and to a lesser extent. These are R22, R123, R124, R401a etc.

1.1.3 Hydro fluorocarbon: They are molecules composed of carbon, fluorine and hydrogen. They don't contain chlorine and therefore do not participate in the destruction of the ozone layer. But it has a high Global Warming Potential (GWP).

1.1.4 Hydrocarbons: This is primarily propane (R290), butane (R600) and isobutene (R600a). These fluids have good thermodynamic properties, but they are dangerous because of their flammability.

In the process of searching new substitute, instead of using single refrigerant we can achieve better performance characteristics through the combination of two or more than two refrigerants to get a innovative working fluid with the desired characteristics which are known as refrigerant blends. Refrigerant blends are mixtures of refrigerants containing 2, 3 or 4 components that have been formulated to provide an equivalent property of the refrigerants originally used. We can observe the various refrigerants using in various generations and the type of importance are shown in table1.1

Importance	Generation	Type of Refrigerants
What ever Worked	1st Generation	CO_2, NH_3, H_2O, CCL_4,etc.
Safety and Permanence	2nd Generation	CFC, HCFC's, NH_3,H_2O, etc.
Ozone depletion Potential	3rd Generation	HCFC's, HFC's, CO_2,NH_3,etc.
Global Warming Potential	4th Generation	HC, Refrigerant Blends

Table : 1.1 Generation of refrigerants [1]

1.2 Need for Alternatives of R134a

1.2.1 Montreal protocol [2]

In the year 1987 Montreal protocol established the requirements that began the world – wide phase out of Chlorofluorocarbon (CFCs.). Production of CFCs was phased out by the Montreal Protocol in developed countries from 1st of January, 1996 and for developing countries was phased out in 2010. In year 1992 Montreal protocol established the requirements that began the world – wide phase out of HCFCs and complete production of HCFCs will be phased out by Montreal protocol in 2030.

1.2.2 Kyoto protocol [2]

Kyoto protocol aims to phasing out of substances that will lead to global warming. R134a is used in domestic refrigerator and other vapor compression refrigeration systems it was identified as a replacement of R-12, keeping in view its zero ozone depleting potential. R134a has 1300 GWP per 100 year, which is very high. The sailing of R134a reported to AFEAS 1970-2003 is significantly increasing during the past two decades. The increased emission of R134a into the atmosphere are steadily increasing the concentration of greenhouse gases via leaks and mostly, in an indirect way, via energetic performance of refrigeration plant. This will lead to adverse climatic difficulty. Hence, R134a is one of the six chemicals in the "basket" that are to be phased away in the near future under Kyoto protocol.

1.2.3 Environmental concern [2]

The first most important concern is depletion of ozone layer. Ozone layer is a layer which protects the earth from ultraviolet rays coming from sun. Ozone depletion potential is evaluated on a scale that uses R-11 as a benchmark. All the other components are based on how damaging to the ozone they are in relation to R-11.The second major concern is global warming. Global warming is increase the earth surface temperature due to the absorption of infrared emission on earth surface. Global warming potential (GWP) is evaluated on a scale that uses CO_2 as the bench mark i.e. CO_2 is assigned a value and other components are compared to CO_2.

1.2.4 Expansion devices

Expansion devices are very important parts of vapour compression refrigeration system. According to selection of cooling facility and size of compressor, the expansion device is selected or adjusted. Main purpose of expansion device is The refrigerant has to overcome the frictional resistance offered by tube walls hence this leads some pressure drop which is necessary between condenser and evaporator and control the mass flow rate,

1.3 Classification of Expansion Devices

1. Capillary Tube
2. Thermostatic expansion valve (TXV)
3. Hand operated expansion valves
4. Orifice
5. Constant pressure or automatic expansion devices (AEV)
6. Float type expansion valve
7. Electronic expansion valve

1.3.1 Capillary tube

A capillary tube having long length approximately from 1.0 m to 6.0 m and narrow tube of constant diameter. Typical tube diameters of refrigerant capillary tubes range from 0.5 mm to 3 mm.

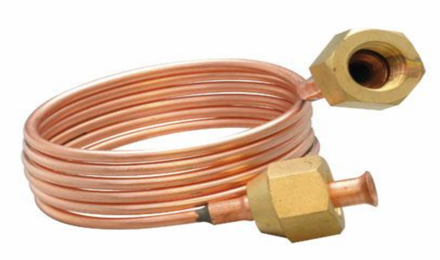

Fig. 1.1 Capillary Tube [3]

1.3.2 Thermostatic expansion valve

Thermostatic expansion valve (TXV) is the most versatile expansion valve and is most commonly used in refrigeration systems. It is variable opening type expansion device. A thermostatic expansion valve are maintains a constant degree of superheat at the exit of evaporator; hence it is most effective for dry evaporators in preventing the slugging of the compressors since it doesn't allow the liquid refrigerant to enter the compressor. This consists of a feeler bulb that is attached to the evaporator exit tube so that it senses the temperature at the outlet of evaporator. The feeler bulb is linked to the top of the bellows by a capillary tube. The feeler bulb and the narrow tube contain some fluid that is called power fluid.

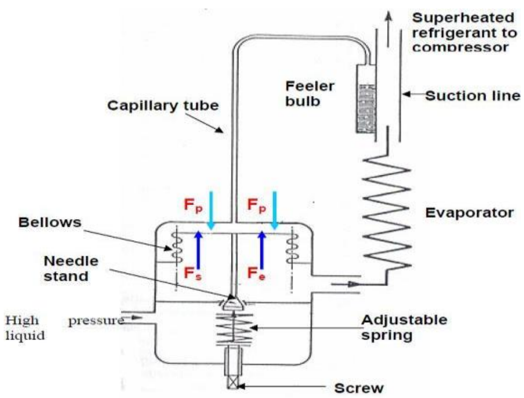

Fig. 1.2 Thermostatic Expansion Valve [3]

II. LITERATURE REVIEW

Rao et al. [**4**] his paper illustrate that the energy consumption of the thermostatic expansion valve system was found to be lower than that of the capillary tube system at higher cooling loads and at lower cooling capacities. They observed that the value of Carnot COP > theoretical COP > actual COP which is accordance to the theory.

Joshi et al. [**5**] In This Study the Coefficient of performance of vapour compression refrigeration system is calculated for Thermostatic expansion valve, constant expansion valve and capillary. Carnot, theoretical and actual COP of thermostatic expansion valve is more than constant expansion & capillary tube Thermostatic expansion valve provides maximum efficiency over a wide temperature and load range., it gives improved refrigerant return to the compressor hence assures better cooling at high temperatures and reduces the possibility of liquid slugging which can be destroy the compressor.

Chavan et al.[5] They have used domestic refrigerator working on vapour compression refrigeration for optimization capillary tube with various diameter and performance analysis with refrigerant R 134a and R 600a. R 600a exhibited higher compressor work than R 134a, but R600a exhibited significantly high refrigerating effect. R 600a has the higher COP all most 23% compare to R 134a.They found that the capillary tube with 0.031 inch inner tube diameter offer best desirable requirements; it has low compressor work with high refrigerating effect. It results in higher COP compare to other studied diameter capillary tube. They analyze that in morning, refrigerating effect were more and compressor work were less as compared to whole day time. As per their result Compressor work and power consumption was more for same refrigerating effect in afternoon.

Dhumal et al. [**6**] studied the effect of R407C refrigerant which is HFC refrigerant on vapour compression refrigeration system with different expansion devices. Thermostatic expansion valve, Capillary tube of diameter 0.50" with length 1.5m and 0.55" with length 1.75m. Experimental setup of 1234W capacity was used for analysis purpose. Thermostatic expansion valve requires 50% more work input at all loads compare to the capillary tube but the average increase in compressor work with increase in load is 14%. which is much lesser than the capillary tube where it is 75%. The Thermostatic expansion valve shows 43% low refrigerant flow rate as compared to capillary tubes and it decreases with increase of load on the system. The capillary with dia. 0.50" shows higher mass flow rate of refrigerant and it increases with increase of load on the system.

Gawali et al.[7] has investigated and performed the experiment on vapour compression refrigeration system of 0.33 TR and refrigerant used was R-12. and used both expansion valve thermostatic expansion valve and Capillary tube for analysis with R-12. The analysis focuses on Coefficient of Performance (COP) for both expansion devices (Capillary tube and Thermostatic expansion valve). The Carnot, Theoretical and Actual Coefficient of Performance of system is increase while using Thermostatic expansion valve compare to capillary tube. With Thermostatic Expansion, the returning of refrigerant into compressor is improved so possibility of liquid slugging is avoided with better cooling at high temperature.

Chavhan et al. [**8**] had presented the study on vapour compression refrigeration system by using refrigerant R-134a. R-134a is having zero ozone depletion potential (ODP) and almost same thermodynamic properties as compare to R-12, but it has a high Global Warming Potential (GWP) of 1300.Hence an alternative for this refrigerant is to be identified. Paper reviews the performance of different environmental friendly refrigerants and their mixtures in different proportions and also observed the effect of working parameters like dimensions of capillary tube, thermostatic expansion valve working pressures and working temperatures, which affect the coefficient of performance (COP) of vapor compression refrigeration system.

Joybari et al. [9] had investigated the performance of a domestic refrigerator system which is originally design to use 145 g of R134a. It was create that the highest exergy destruction occurred in the compressor followed by the condenser, capillary tube, evaporator, and superheating coil. Taguchi process was applied to design experiments to minimize exergy destruction while using R-600a.Taguchi parameters were selected by the obtained results from R134a and an experiment using 60 g of R-600a, which show similar results as compare to R-134a. Based on the outcome, R-600a charge amount, condenser fan rotational velocity and compressor coefficient of performance (COP) were selected for the design. The investigation of variance results indicated that R-600a charge amount was the most effective parameter.

Rasti et al. [10] had performed on domestic refrigerator and study of substitution of two hydrocarbon refrigerants instead of R-134a in a domestic refrigerator. The result of parameters including refrigerant type, refrigerant charge and compressor type are investigated for this system. This research is performed by using R-436A (mixture of 46% iso-butane and 54% propane) and R600a (pure iso-butane) as HC refrigerants, HFC type compressor (designed for R-134a) and HC type compressor (designed for R-600a).

Tiwari et al. [11] performed an investigation on vapour compression refrigeration system by using HFC refrigerants R-125, R-134a, R-143a and R-152a four ozone friendly refrigerants to replace R-12. The experiment was done to calculate the coefficient of performance (COP), refrigerating capacity (RC) and compressor work at various evaporating and condensing temperature. Among all the tested refrigerants R-152 has higher coefficient of performance (COP), higher refrigerating capacity compare to R-12, while R-134a has a slightly lower COP and higher refrigerating capacity than R-12.

Austin et al. [12] had performed on domestic refrigerator using blend refrigerants. The Mixed Refrigerants (hydrocarbons mixtures propane, and isobutene) and compared with the performance of refrigerator with R-134a was used as refrigerant. The effect of condenser temperature and evaporator temperature on coefficient of performance (COP), refrigerating effect (RC) was investigated. The energy consumption of the refrigerator during experiment with blend refrigerants is less compare to R-134a.

Rashid et al. [13] In This paper they presents a comparable evaluation of R-600a, R-290, R-134a, R-22,for R-410A, and R-32 an optimized finned-tube evaporator, and study the evaporator effect on the system coefficient of performance (COP). The Results concerning response of refrigeration system simulation software to an increase in the amount of oil flowing with the refrigerant are presented. It is shown that there are optima of the apparent overheat value, for which either the exchanged heat or the refrigeration coefficient of performance is maximized: consequently, it is not possible to optimize both the refrigeration COP and the evaporator effect on the system. The obtained evaporator optimization results were incorporated in a conventional analysis of the VCRS system.

Jwo, et al. [14] was investigated and perform through the mixture of hydrocarbon refrigerants, R-290 and R-600a with each 50% component ratio, instead of the refrigerant R-134a for domestic refrigerators. During test the official R-134a refrigerant was replaced by varied mass hydrocarbon refrigerant, which was mixed by 50% each ratio of R-290 and R-600a. And they found refrigerating effect is improved by using hydrocarbon blend refrigerant. Moreover, the applied mass of refrigerant is reduced 40% and total power consumed is saved 4.4%.

Lee, et al. [15] has investigate the performance of a small refrigerator is used for evaluated by using the mixture of R290 and R600a with mass fraction of 55:45 as an alternative of R134a. The compressor displacement volume of the alternative system with blend refrigerant R290/R600a (55/45) was modified from that of the original system with R134a to match the refrigeration capacity. Both systems with blend refrigerant R290/R600a (55/45) and R134awere tested, and then optimized by varying the refrigerant charge and capillary tube length The power consumption of the optimized system R134a was 12.3% higher than that of the optimized system R290/R600a. The cooling speed of the optimized R290/R600a (55/45) system was improved by 28.8% over that of the optimized R134a system.

Sattar et al. [16] designed a domestic refrigerator system to work with R-134a and was used as test unit to determine the possibility of using hydrocarbons and their blends as refrigerants. Pure R-600, R-600a and mixture of R-290, R-600 and R-600a were used as refrigerants. The performance of refrigerator using hydrocarbons as refrigerants was investigated and compared with the performance of refrigerator when R-134a was used as a refrigerant. They also investigated effect of condenser temperature and evaporator temperature on COP, refrigerating effect, condenser duty, work of compression and heat rejection ratio in this experiment. After successful investigation on the performance of hydrocarbon and blends of hydrocarbon refrigerants it is found that COP of the system and energy consumption is similar to R-134a and suggests that blends of hydrocarbon refrigerant can be used as an alternative to R-134a.

Wongwises et al. [17] performed the theoretical study on conventional vapor compression refrigeration system with refrigerant mixtures based on R-134a, R-152a, R-32, R-290, R-1270, R-600 and R-600a for various ratios and their results are compared with R-12, R-22 and R-134a as possible alternative replacement. considering the comparison of coefficient of performance (COP) and pressure ratio of tested refrigerants and also the main environmental impacts of ozone layer depletion (ODP) and global warming, refrigerant blends of R-290 (40%) + R-600a (60%) and R-290 (20%) + R-1270 (80%) are found to be the most appropriate alternatives among refrigerants tested for R-12 and R-22 respectively. The coefficient of performance (COP) and refrigeration efficiency of the system is increases with increasing evaporating temperature for a constant condensing temperature. Similarly R-22a can be tested for R-134a.

III. CONCLUSIONS

From the above literature review it is found that, the several refrigerants are expelled due to their environmental collision, are expected to be replaced. Few researchers have reported on combination of different refrigerants and expansion devices in refrigeration system. Hence it is clear that there is wide scope to do the research in the study on different types of refrigerants as well as different types of expansion devices used to improve performance of domestic refrigerator. The Following conclusions were observed from this review paper.

- R-134a is a HFC refrigerant and it contributes to global warming because of fluorine content in it. Ozone depletion and total climate change depends on both global warming potential (GWP) and ozone depletion potential (ODP). So, there is a need to find out alternatives of R-134a under Kyoto protocol and Montreal protocol.
- From literature survey and properties of refrigerant R-32, R-152a, R-125, R-413A identified mixture of 90% R-134a, 10%R-290 and R-290/R-600a (68/32 by weight. %), R-290/R - 600a (40/60 by weight. %) and R-123/R290 (70/30 by weight. %) are identified as alternatives of R-134a.
- According to Montreal and Kyoto protocols R-600a, R-290 and blends of R-290 with R-134a are the better option for the replacement of R-134a in domestic refrigerator, due to their low global worming potential (GWP) and zero ozone depletion potential(ODP).
- There is a need of further research to be done on the different mixtures of HFCs and HCs, and check the performance of expansion devices on blends mixture
- The use of electronic expansion devices provides steady operation than thermostatic expansion valve.

- Thermostatic expansion valve performs well than capillary tube for variable load conditions.
- For serpentine coil capillary tube pitch as well as the coil diameter affects the performance of system.

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Cite this article as :

Yudhveer Kumar Verma, Dr. Ajay Singh, Prof. Ashish Verma, "Study and Analysis of Capillary Tube and Thermostatic Expansion valve in Domestic Refrigerator using Eco friendly Refrigerant : A Review", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), ISSN : 2456-3307, Volume 6 Issue 1, pp. 480-487, January-February 2019.
Available at doi :
https://doi.org/10.32628/IJSRSET196191
Journal URL : http://ijsrset.com/IJSRSET196191