CHAPTER 2

LITERATURE SURVEY

Retrofitting of existing R134a in the domestic refrigeration system with alternative refrigerants would be an area of interest to the domestic refrigeration developers. Various alternative refrigerants are available to retrofit the conventional system, but each one has its own merits and limitations. In this context, a new environmental friendly alternative refrigerant mixture is considered to be of much use to the refrigeration sector.

Many experimental and theoretical studies have been reported regarding the performance of various alternative refrigerants and their mixtures. In this chapter a comprehensive survey of the existing literature on the performance of alternative refrigerants and their mixtures in refrigeration system has presented. The need for and scope of this research work has been outlined at the end of the chapter.

2.1 ALTERNATIVE REFRIGERANTS TO R12 SYSTEM

The role of chlorofluorocarbons (CFCs) in the process of ozone depletion is now widely accepted, though in other respects CFCs have proved to be ideal refrigerants. The search for alternatives has been focused on chemically similar compounds which could be used as direct substitutes. Notable amongst these is the R134a as a replacement for R12. While this can now attain efficiencies comparable with that of R12, it is considerably more expensive and has a relatively high GWP. Hydrocarbon refrigerants have the advantages of low cost,
local availability and environmental acceptability when compared to CFCs and HCFC substitutes. The absence of chlorine results in zero ODP and has a negligible GWP.

R Jakobs et. al. [20], demonstrated that zeotropic refrigerant mixtures of R12 and R114 provide considerable advantages for heat pump application with mixture R12/R114. The maximum value of the COP, at a concentration about 60% of R12, is about 16% higher than the COP of pure R12.

D.S Jung et. al. [6] has carried out experiments to identify drop in replacement for R12 on a single evaporator domestic refrigerator. The simulation was performed with 15 pure refrigerants and 21 mixed refrigerants. The results indicate that pure refrigerants are not suitable for drop in replacement for R12, it requires compressor change. R152a and R134a had 7 to 30% lower capacity than R12 and might be good candidates for future refrigerators requiring a lower capacity. Only a few fluids such as R22, R32, R152a and R142b have COPs comparable to R12. Binary mixtures of R32/R142b and R22/R142b yield an increase in COP of up to 3% with the same capacity as that of R12. These mixtures may act as substitutes for R12 in the short run, thus helping to solve the ODP problem without affecting the energy efficiency.

Shamsul Hoda Khan et. al. [1] has studied that R12 is the major contributor to ozone depletion. The new refrigerant, R134a, which is
leading candidate to replace R12 in RAC applications, has been chosen for investigation. To calculate the properties of R134a, a computer program is written, which can be used as a reference for analysis. The results reveal that R12 may be replaced by R134a without any significant loss in the overall performance. It is found that for the same capacity compressor, cooling capacity of R134a is less than that of R12 under the similar operating conditions. Thus, a larger compressor will be required for the same refrigeration capacity with R134a.

Besides the values of the ODP and GWP, energy consumption is another important index to be considered in developing a refrigeration system using CFC substitutes. Many researchers have indicated that unless the original refrigeration system is correspondingly adjusted when using CFC substitutes, the energy efficiency ratio (EER) of the system will decrease. Y.Wu et. al. [21] has reported the reasons for a decrease in EER which have been analysed theoretically, and proposals were made to improve EER. These proposals are used to develop a domestic refrigerator charged with a zeotropic mixture of RC22/R152a as the substitute for the R12. The results show that the energy efficiency ratio of the refrigerator charged with this refrigerant mixture is increased by 6.5% when compared with that of the same refrigerator charged with R12.

Hydrocarbons such as R290, R600a and R600 were used as refrigerants before the advent of CFCs, although in the open systems flammability was a drawback However, in a modern hermetically sealed
system, problems of flammability are reduced to some extent. R.N.Richardson et. al. [16], reported that if the system is designed such that the saturation pressure is always greater than atmospheric, the risk of a potentially flammable mixture forming within the circuit should not arise. The author investigated the performance of hydrocarbon refrigerant mixture of R290/R600a in a VCR system. It is shown that the 56%/44% mixture has a COP greater than that of R12 throughout the range of temperatures which have been investigated. Mixture of 50%R290 and 50%R600a has very similar saturation characteristics to R12 but COP which would seem to improve with the proportion of R290.

Zhijing Liu et. al. [22], noticed a drop-in substitute for R12 in a 20 cubic-feet, single evaporator, top mount, auto defrost, conventional domestic refrigerator with the binary mixtures of R290/nc5, R290/R600 and a ternary mixture R290/R600/nc5. In his experimentation all the hardware remained the same, only the capillary tube was lengthened to achieve the optimum performance. The best result with an optimized R290/R600 blend was 6% savings compared to the baseline test with R12. Further investigation was carried out at 18.0 cubic-feet, top mount, auto defrost, domestic refrigerator. Having tested for the single evaporator baseline performance, the unit was converted to a two evaporator modified Lorenz Meutzner cycle. The optimum performance of the modified unit yielded 16.7% and 14.6% energy savings with binary mixtures R290/R600R and 290/nc5
respectively. Further ternary mixture R290/R600/n-c5 with 17.3 % energy savings proved to be better than the binary mixtures.

I.W.Eames et. al. [23], have developed alternative refrigerants to R12 with the ternary mixture of 88%R134a/9%R218/3%R600a called ISCEON 49. The author has developed a computer program to determine cooling capacity, pressure ratio, system pressure and temperature, compressor power and COP. The experimental result shows that ISCEON 49 is a drop in replacement and has comparative performance with that of R12. The COP of ISCEON 49 was found to be 8 to 10% lower than that of R12 and 5 to 7% lower than that of R134a.

R.S.Agawal et. al. [24], have developed retrofit refrigerant to existing R12 with MP-39(R22/R124 and R152a) and mixtures of R290 and R600a of equal composition (50%/50%). Theoretical and experimental studies were carried out by varying the composition of the mixtures. The researcher selected the alternative refrigerants based on their vapour pressures. For the drop in tests with the HC mixture (R290 and R600a), the condenser and evaporator lengths were adequate. With the cut and try procedure, capillary length was optimized and it requires double the length of R12 capillary for the HC mixture to get a better performance. The researcher carried out the experiments with base line tests with R12 refrigerant. To test the drop in tests with the HC mixture experiments were carried out at different capillary lengths, and optimum performance was obtained at double the length of capillary. HFC mixture consumes more power than R12 and HC mixture consumes slightly less power than R12. In conclusion
the performance of the retrofitted refrigerator is more or less similar to that of R12.

Sukumar Devotta et. al. [25], has compared the performance of the two door direct cooled refrigerator with the R12 and Care30 (HC blend) by varying two grades of the lubricating oil of ISO VG 15 and ISO VG 22. Energy consumption was very sensitive to over charged and under charged condition. The energy consumption was found to be much higher for under charging and over charging of refrigerant. The optimum charge is only about 40% of the original R12 charge by weight. The performance of the HC mixture is matches with the R12.

R.S.Agarwal et. al. [26], has discussed the salient features of R600a and mixtures of 50%R290/50%R600a for domestic and small capacity commercial refrigerators working with R12. The performance of the refrigerator with the alternative refrigerants R600a and mixtures of R290/R600a was compared with R12. Hydrocarbons have a zero ODP and negligible GWP, compatible with most of the materials and commonly used lubricating oils. HC refrigerants in comparison with R12 have high latent heat of vaporisation and low value of density which makes the refrigerant attractive inspite of their flammability because of low charge and circulation rate. The charge levels are approximately 40% that of R12. Compressor discharge temperature in case of HC refrigerants is lower than R12. Based on the thermodynamic and heat transfer considerations for HC technology the following conclusions were made.
• Heat rejected in the condenser is almost the same as in case of R12. The size of condenser remains same as overall heat transfer coefficient is governed mainly by the air side heat transfer coefficient. Thus no change is required in the condenser.

• The cooling capacity required is the same, the overall heat transfer coefficient in case of evaporator is also mainly governed by outside heat transfer coefficient. Thus no change is required in the evaporator.

• In case of HC systems the mass flow rate is quite lower than R12 system and also pressure ratio is slightly higher. Therefore, increased capillary length of the same diameter is needed.

• In case of isobutane saturation pressure which does not match with R12, hence it is not suitable for drop in replacement, it demands compressor change.

R.S. Agarwal [27], has conducted experiments to evaluate the substitute for R12 with the HC mixture of R290/R600a (50%/50%) and R134a/R600a. Thermodynamic properties of these mixtures needed for the analysis have been computed using REFPROP. The HC blend consumes 12% less energy than R134a/R600a. Pull down time for R134a/R600a (88%/12%) is 11 hours 50 minutes and it is 13 hours 15 minutes for HC blend. COP of the R134a/R600a is 1.7938 and it is 1.9445 for the R12. Up to a certain extent energy consumption decreases with the increase in capillary length.
M.A.Hammad et al. [14], has experimentally investigated the performance parameters of a domestic refrigerator with four proportions of R290, R600 and R600a are used as possible alternative replacements to the R12. The proposed alternative refrigerants have the advantage of being locally available, economical and of an environmentally friendly nature. An unmodified R12 domestic refrigerator was charged and tested with each of the four hydrocarbon mixtures that consist of 100% R290, 75%R290/19.1%R600/5.9%R600a, 50%R290/38.3%R600/11.7%R600a and 25%R290/57.5%R600/17.5%R600a. The investigated parameters are the refrigeration effect and energy consumption. The results show that the hydrocarbon mixture with 50%R290/38.3%R600/11.7%R600a is the most suitable alternative refrigerant which has COP which is 2.7% higher than the R12.

Qiyu Chen et. al. [9], has experimentally compared the performance of R12 and R134a. Simulation models were developed for R134a and R12 on the basis of fluid properties and thermo-hydraulic characteristics obtained from available experimental data and/or correlations. With the developed simulation model system performance was analysed. A comparison of the performance of R134a and R12 is presented. Results indicate that for the same cooling load, COP for R134a is 3% lower than that for a R12 system. This means that the power requirement for a R134a system is higher than that for CFC12 system for an identical cooling requirement.
V. Havelsky [28], noticed the influence of substitutes for R12 on energy efficiency and global warming expressed by values of COP and Total Equivalent Warming Impact (TEWI). Experimental investigations are presented which relate the use of refrigerants R134a, R409A, R401A, R22 and the mixture of R12 with R134a to the values of COP and TEWI of refrigerating system in comparison with R12 application. It is shown that the use of R134a, R409A and R401A refrigerants enables the increase of COP and significantly reduces the value of TEWI in comparison with R12 application.

B. Tashtoush et al. [10], has experimentally investigated the drop in substitutes for R12 in domestic refrigerators by new HC/HFC (butane/propane/R134a) refrigerant mixture. The tests were performed in a range of evaporator duty from 100 to 350 W and found that domestic refrigerator originally designed to work with R12, can be replaced successfully by the BPR80 mixture without changing the lubricating oil or replacing the evaporator and condenser. In addition, it was found that the BPR80 (31.25% R600/31.25% R290/37.5% R134a) mixture gives performance characteristics very close to R12. The COP of BPR80 at a 100 W evaporator duty is 5.4% less than that of R12 and 0.8% less at a 350 W evaporator duty. These differences are due to the slightly higher compression power requirements of BPR80, and are considered too small to affect retrofitting.

Y. S. Lee et al. [29], has conducted performance tests of a domestic VCR system with R600a as the refrigerant. The tests were
carried out by varying the input power of the compressor between 230 and 300 W, while the amount of the charged refrigerant was about 150g. The refrigeration temperatures were set at about 4 and −10°C. The COP of the system lies between 0.8 and 3.5 in the freezing application, which is comparable with those of the system with R12 and R22 as the refrigerant and the refrigeration capacity increases with the refrigeration loads.

Bilal A. Akash et. al. [3], has conducted performance tests on the performance of liquefied petroleum gas (LPG) as a possible substitute for R12 in domestic refrigerators. LPG is obtained from the local market with the composition of about 30% propane, 55% n-butane and 15% isobutane by mass fraction. The refrigerator which is initially designed to work with R12 is used to conduct the experiment for LPG. Various mass charges of 50, 80 and 100g of LPG were used during the experimentation. The results show that LPG compares very well to R12. The COP was higher for all mass charges at evaporator temperatures lower than −15°C. Overall, it was found that at 80g charge, LPG had the best results when used in this refrigerator. The condenser was kept at a constant temperature of 47°C. Cooling capacities were obtained and they were in the order of about three to fourfold higher for LPG than those for R12.

E. Halimic et. al. [30], has compared experimentally the operating performance of R290 and R134a for use in a VCR cycle. The cooling capacity of R290 was the largest of the refrigerants tested, and higher
than the R12. The performance of R290 was found to be very similar to that of R12. Thus it can be said that it represents an effective alternative to existing CFCs in small domestic refrigerators, but due to mismatch in saturation characteristics it would require a smaller capacity compressor than R12. The refrigerant R401a displayed a level of performance for both capacity and COP that was very similar to R12 thus confirming that it can be considered to be a drop in replacement for R12. R134a is not miscible with lubricant oil used in R12 compressor. So, it demands change of lubricating oil and also compressor to have the same cooling capacity.

S.Joseph Sekhar et. al. [4], has developed drop in substitutes for R12 with R134a and HC blends. HC refrigerants have inherent problems in respect of flammability. R134a is neither flammable nor toxic. But HFCs are not compatible with mineral oil and the oil change is a major issue while retrofitting. The experimental analysis has been carried out in a 165 liter R12 domestic refrigerator retrofitted with the ternary mixture of 91%R134a/4.032%R290/4.968%R600a without changing the mineral oil. Its COP as well as energy consumption is compared with the conventional one. It has been found that the new mixture could reduce the energy consumption by 4 to 11% and improve the actual COP by 3 to 8% of R12.

S.Joseph Sekhar et. al. [7], carried out the experiments with the same mixture in a walk in cooler, operating with an open type compressor with a mineral oil as lubricant. Tests were conducted with the alternative mixture as well as with R12 for the realistic comparison.
It is observed that the mixture has better performance, resulting in 28.6% less energy consumption than R12. The enhancement in COP was 6 to 10%. With the same mixture S. Joseph Sekhar et. al. [17], tests were extended to low temperature and medium temperature systems of deep freezer and visi cooler respectively. The oil miscibility of the investigated mixture with mineral oil was also studied and found to be good. The R134a/HC mixture that contains 9% HC blend (by weight) has better performance resulting in 10 to 30% and 5 to 15% less energy consumption than R12 in medium and low temperature system, respectively.

Gurumurthy Vijayan Iyer et. al. [31], has experimentally investigated drop in replacement for R12 refrigerant with the ternary mixture of R290/R600/R600a with the mass fraction of 50%/38.3%/11.7%. To conduct experiments on ternary mixture same unmodified R12 refrigerator was used. With similar operating conditions ternary mixture shows an improvement in COP by 2.7%. After 5000 hours of continuous running of the refrigerator with the ternary mixture no problems have been encountered with the condenser, compressor and evaporator. In addition, no degradation of lubricating oil could be detected.

At the advent of the Montreal protocol, R134a has been recommended as an alternate refrigerant to R12. R134a is also a high global warming potential gas and needs to be controlled as per the Kyoto protocol(1997). It is reported that there is no single refrigerant or blends available to satisfy both the ozone depletion potential and global
warming issues. In this context K. Senthil Kumar et. al. [5], developed an eco-friendly refrigerant mixture with negligible ODP and GWP values that is nearly equivalent to R12 in its performance. R123 is a potential refrigerant with very low GWP and ODP values, but due to its high boiling point and suction specific volume, it has not been considered as substitute for R12. In his work, to overcome the above said problems, R290 has been identified as suitable for combination with R123 in a refrigerant mixture. Theoretical analysis was carried out by using REFPROP software. At 70%R123 and 30%R290 mixture gives the performance parameters were near matching with R12. And the same was confirmed experimentally by conducting a base line test with R12 and tests with the new mixture, made the following conclusions.

- The actual COP of Mixture is higher than that of R12 for calorimeter temperature ranging from 1 to 25°C.
- The compressor discharge temperature of Mixture is 5 to 22°C which is less than R12
- Saturation pressures of the mixture are similar to that of R12, hence no need modify R12 system

Rafael Quintero Ricardo [32], has developed a drop in replacement for R12 with zeotropic mixture of R290/R600/R600a with the mass fraction of 65%/25%/10%. Theoretical analysis was carried out with REFPROP software. Experiments were conducted on 220 liters capacity, single evaporator domestic refrigerator. The energy
consumption of the alternative refrigerant was 9.6% greater than R12 and ice making time was increased by 10% than R12.

Man-Hoe Kim [33], has assessed the performance of a hydrocarbon refrigerant, R600a, as an alternative to R12 in a 215 liters domestic refrigerator. A theoretical analysis was performed with REFPROP and tests were conducted with R600a. All the tests were performed in a temperature controlled room at 30±1°C. The test results showed that the energy efficiencies and the cooling speeds with R600a were improved by 1 to 11% and 3 to 10%, respectively, when compared to R12.

T.S.Ravikumar et. al. [34], reported that R134a can be used in place of R12. However, to avoid synthetic oil they used the conventional mineral oil as lubricant, R134a is mixed with the commercially available hydrocarbon blend, (45.2% R290 and 56.8% R600a) in the proportion of 91% and 9%, respectively by mass. The mass of hydrocarbons used is well below the safe limit of 150 grams. This new mixture R134a/R290/R600a is tested in the air-conditioning system of a passenger car ‘on road’ in the true running conditions and the performance was compared with the results of R12. The cool down performance was better than R12 under varying speed and varying ambient conditions, system performance under severe accelerating conditions and bumper-to-bumper traffic conditions. The test results show that the new blend can be a promising substitute for the existing R12 systems and overcomes the issue of change of lubricating oil.
It is clear from the above studies that various researchers have tried for a suitable alternative for R12. It is quite evident that identifying a suitable alternative for R12 is attempted from various quarters at different angles. The R134a has been identified as a substitute in the context of retrofitting R12 systems issues of change of lubricating oil and lower COP values for the same cooling capacity. Also global warming is quite serious, as per the Kyoto protocol there is a necessity to decrease the greenhouse gases including R134a. Pure hydrocarbons are not drop in replacements for R12 refrigerators due to mismatch in saturation characteristics. A zeotropic mixture of hydrocarbons of 50%R290/ 50%R600a was identified as drop in replacement for R12 with little modification of changing the length of capillary by cut and try procedure. The only draw back of the hydrocarbon mixture is that it is inflammable. Hence R12 phase out demands a better alternative refrigerant.

2.2 ALTERNATIVE REFRIGERANTS TO R134a SYSTEM

The reduction in CFCs and HCFCs production and the scheduled phase out of these ozone depleting substances requires the development of environmentally safe refrigerants for use in refrigerators, heat pumps, water chillers and air conditioners.

M.S.Kim et. al. [18], has experimentally investigated the performance of a heat pump with two azeotropic refrigerant mixtures of R290/R134a and R134a/R600a with the mass fractions of 45%/55%
and 80%/20%. The performance parameters of the azeotropes were compared with pure R12, R134a, R290 and R22 at the both heating and cooling conditions with suction-liquid heat exchanger. The COP of R134a/R290 was lower than that of R22 and R290, and R600a/R134a shows higher COP than R12 and R134a. The capacity for R134a/R290a was higher than that for R290 and R22, and R600a/R134a exhibits higher system capacity than R12 and R134a. Experimental results show that the compressor discharge temperatures of the considered azeotropic mixtures are lesser than those of the pure refrigerants i.e., R22 and R12

Dongsoo Jung et. al. [35], has assessed the performance of a binary mixture R290/R600a mixture for domestic refrigerator. Theoretical analysis indicated that at 0.2 to 0.6 mass fraction of R290 of the considered mixture yields an increase in the COP of up to 2.3% as compared to R12. For the actual tests, two commercial refrigerators of 465 and 295 liters capacity were used. For the tests wit the alternative refrigerants, the hardware remains same, except the length of the capillary and quantity of charge. For each unit, both energy consumption test and pull-down test were conducted under the similar operating condition. The experimental results indicated that the R290/R600a mixture at 0.6 mass fraction of R290 has 3 to 4% higher energy efficiency and more off time due to faster cooling rate than R12. In conclusion, the proposed HC mixture seems to be a suitable long term applicant to replace R12/R134a from the viewpoint of minimum
energy consumption requiring minimal changes in the existing refrigerator.

Suresh Bhakta Shrestha et al. [36], has studied the performance of R290 and R600a mixtures in VCR systems for heating, and simultaneous heating and cooling applications in comparison with R134a, R114 and R236ea. R290 offers a large pressure difference usually more than 18 bar, an allowable limit for reciprocating compressors. It offers discharge temperature comparable with that of R134a. R290 is not suitable for high temperature heat pumps because of its lower critical temperature. R290 is not suitable to retrofit into systems designed for R134a and R236ea. Pure R600a is also not suitable for retrofit condition due to its high pressure ratios. At 50%R290/50%R600a has favourable pressure chromatistics can be used as drop in replacement for R134a.

Somchai Wongwises et al. [12], has conducted experiments to substitute R134a in a domestic refrigerator with hydrocarbon mixtures of R290, R600 and R600a. A 239 litre capacity refrigerator initially designed to work with R134a was chosen in the experiment. The pressure and temperature at the entry and exit of the compressor and compressor power readings were taken for the analysis. The alternative refrigerant mixtures used are divided into three groups: the mixture of three hydrocarbons, the mixture of two hydrocarbons along with R134a and the mixture of two hydrocarbons. The experiments are conducted with the refrigerants under the same no load condition at a
surrounding temperature of 25°C. The results show that 60% R290/40% R600 is the most suitable alternative refrigerant to R134a.

Somchai Wongwises et. al. [37], has experimentally investigated the performance of hydrocarbon mixtures to replace R134a in automotive air conditioners. The hydrocarbons investigated are R290, R600 and R600a. The air conditioner, with a capacity of 3.5 kW driven by a Diesel engine, is charged and tested with four different mass fractions of HC mixtures. The experiments are conducted at the same ambient conditions. The temperature and pressure of the refrigerant at every major position in the refrigerant loop, humidity of air and refrigerant mass flow rate, engine speed and torque are recorded and analyzed. The parameters investigated are the refrigeration capacity, the compressor power and the COP. The results show that 50% R290/40% R600/10% R600a is the better substitute for R134a among the considered HC mixtures.

M. Fatouh et. al. [13], have studied the possibility of using hydrocarbon mixtures as working fluids to replace R134a in domestic refrigerators has been evaluated through a simulation analysis. The performance parameters COP, cooling capacity, compressor power, discharge temperature, pressure ratio and mass flow rate of the refrigerant were studied over a wide range of evaporator and condenser temperatures −35 to −10°C and 40 to 60°C respectively for various
working fluids such as R134a, propane, commercial butane and R290/R600a/R600 mixtures with various propane mass fractions.

The results showed that pure R290 could not be used as a drop in replacement for R134a due to mismatch in saturation characteristics, which in turn leads to high operating pressures and low COP. R600 yields many desirable characteristics but requires a compressor change. The COP of the domestic refrigerator using a ternary hydrocarbon mixture with propane mass fractions from 0.5 to 0.7 is higher than that of R134a. Comparison among the selected working fluids confirmed that the average refrigerant mass flow rate of the R290/R600 mixture is 50% lower than that of R134a. Also, the results indicated that R134a and the R290/R600 mixture with 60% R290 mass fraction have approximately the same values of saturation pressure, compressor discharge temperature, condenser heat load, input power and cooling capacity. However, the pressure ratio of the hydrocarbon mixture with 60% propane is lower than that of R134a by about 11.1%. Finally, the reported results confirmed that the R290/R600a/R600 mixture with 60% propane is the best drop in replacement for R134a.

M. Fatouh et. al. [38], investigated a drop in substitute for R134a in a single evaporator domestic refrigerator with a total volume of 0.283 m$^3$ with Liquefied petroleum gas (LPG) of 60% propane and 40% commercial butane. To optimize the performance of the refrigerator, tests were conducted with different capillary lengths and different charges of R134a and LPG. Experimental results of the refrigerator
using LPG of 60g and capillary tube length of 5 m were compared with those using R134a of 100g and capillary tube length of 4 m. Pull-down time, pressure ratio and power consumption of LPG refrigerator were lower than those of R134a by about 7.6%, 5.5% and 4.3%, respectively. COP of LPG refrigerator was 7.6% higher than that of R134a. Lower on-time ratio and energy consumption of LPG refrigerator was lower than 14.3% and 10.8%, respectively, compared to those of R134a refrigerator were obtained. In conclusion, the proposed LPG is drop in replacement for R134a, to have the better performance, optimization of capillary length and refrigerant charge was needed.

M.Mohanraj et. al. [39], have studied experimentally the drop in substitute for R134a with the environment friendly, energy efficient hydrocarbon (HC) mixture which consists of 45% HC290 and 55% R600a at various mass charges of 50g, 70g and 90g in domestic refrigerator. The experiments were carried out in 165 liters domestic refrigerator using R134a with POE oil as lubricant. The performance characteristics such as COP, energy consumption, pull down time and compressor discharge temperature of HC mixture are measured and compared with R134a. During the experimentation the ambient temperature is maintained at 30 ± 2°C. The results showed that the higher COP of 8.82%, 11.42% and 12.67% respectively for -15°C evaporator temperature and 45°C condensing temperature.

The discharge temperatures of HC mixtures are found to be lower than R134a by 13.76%, 6.42% and 3.66% for 50g, 70g and 90g respectively. The power consumption of HC mixture at 50g and 70g are
lower by 10.2% and 5.1% respectively and 90g shows higher power consumption by 1.01%. The percentage reduction in pull down time is 18.36%, 21.76% and 28.57% for 50, 70 and 90g mass charges respectively when compared to R134a. The HC mixture because of its high energy efficiency will also reduce the indirect global warming. In conclusion HC mixture of 70g is found to be an effective alternative to R134a in 165 liters domestic refrigerator.

M.A. Sattar et. al. [11], investigated and compared the performance of the refrigerator using R600a, R600 and a ternary mixture of mixture of R290/R600a/R600 as refrigerants with the R134a. The effects of evaporator and condenser temperatures on COP, refrigerating effect, compressor power and heat rejection ratio were investigated. The results show that the compressor consumed 3% and 2% less energy than that of R134a at 28°C ambient temperature when R600a and R600 was used as refrigerants respectively. The compressor power and COP of hydrocarbons and their blends shows that hydrocarbons can be used as refrigerants in the domestic refrigerator. The COP and other results obtained from the experiments show a positive indication of using HC as refrigerants in a domestic refrigerator.

Moo-Yeon Lee et. al. [40], have studied the performance of a small capacity directly cooled refrigerator by using the mixture of R600a/R290 with mass fraction of 45:55 as an alternative to R134a. The compressor displacement volume of the alternative system with R600a/R290 (45/55) has modified from that of the original system with
R134a to match the refrigeration capacity. System design was optimized by varying the refrigerant charge and length of the capillary under experimental conditions for both the pull-down test and the compressor energy consumption test. The refrigerant charge of the optimized R600a/R290 system was approximately 50% of that of the optimized R134a system. The capillary tube lengths for each evaporator in the optimized R600a/R290 system were 500 mm longer than those in the optimized R134a system. The power consumption of the optimized R134a system was 12.3% higher than that of the optimized R600a/R290 system. The cooling speed of the optimized R600a/R290 (45/55) system at evaporator temperature of −15°C was improved by 28.8% over that of the optimized R134a system.

K. Mani et al. [41], has conducted tests on a VCR system with HC mixture of R290/R600a as drop in replacement for R12 and R134a. Base line tests were carried out with R12 and R134a. Experimental results showed that the refrigerant R290/R600a had 19.9% to 50.1% higher cooling capacity than R12 and 28.6% to 87.2% higher than R134a. The refrigerant R134a showed slightly lower cooling capacity than R12. The mixture R290/R600a consumed 6.8% to 17.4% more energy than R12. At higher evaporating temperatures R12 consumed slightly more energy than R134a. The COP of R290/R600a mixture increases from 3.9% to 25.1% than R12 at lower evaporating temperatures and 11.8% to 17.6% at higher evaporating temperatures. R134a showed slightly lower COP than R12. The discharge temperature and discharge pressure of the R600a/R290 mixture was very close to
R12. The R290/R600a with the mass fraction of 68%/32% has been considered as a drop in replacement refrigerant for R12 and R134a.

M.Mohanraj et. al. [8], carried out the theoretical investigation of the possibility of using R152a and hydrocarbon refrigerants (such as R290, R600a, R1270 and R600) as alternatives to R134a in domestic refrigerators. The performance parameters such as pressure ratio, compressor discharge temperature, energy consumption of power and COP were taken for the analysis. The results shows that pure HC refrigerants are not suitable for drop in replacement for R134a due to its mismatch in saturation properties, it demands compressor change. R152a saturation properties are close to R134a, hence no need to change the compressor. R152a has 9% higher COP, less compressor input power due to lower values of operating pressures. The compressor discharge temperature of R152a is 14 to 26 K higher than that of R134a.

M.Mohanraj et. al. [42], also carried experimental investigation to find out a drop in replacement for R134a with the binary mixture of 45.2%R290/54.8%R600a in a 200 liter single evaporator domestic refrigerator. Tests were carried out at different ambient temperatures (24, 28, 32, 38 and 43°C); cycle ON/OFF tests were carried out at 32°C ambient temperature. The results showed that the HC mixture has lower energy consumption; pull down time and ON time ratio by about 11.1%, 11.6% and 13.2% respectively, with 3.25 to 3.6% higher COP. The discharge temperature of HC mixture was found to be 8.5 to 13.4 K lower than that of R134a. The overall result has proved that the above
hydrocarbon refrigerant mixture could be the best long term alternative to R134a.

Ching-Song Jwo et. al. [43], have investigated the substitute for R134a with the zeotropic mixture of 50%R290/50%R600a. The experiments used a 440 liters capacity domestic refrigerator as test facility, which originally works with 150g of R134a refrigerant. Tests were conducted by varying masses of hydrocarbon mixture. The results show that refrigerating effect is improved by using 50%R290/50%R600a. Moreover, the total consumed energy is saved to 4.4% and the applied mass of refrigerant is reduced by 40%.

It is clear from the above discussion that various researchers have tried for a suitable alternative for R134a. It has been observed that the energy consumption of R12 appliances tend to increase while they are retrofitted with R134a. These days, the concern for the global warming has never been greater. In 1997 the Kyoto protocol was agreed by many nations calling for the reduction in emissions of greenhouse gases including HFCs (R134a). Pure hydrocarbons are not drop in replacements for R134a refrigerators due to mismatch in saturation characteristics. Zeotropic mixture of 50%R290/50%R600a can be used as drop in replacements for R134a refrigerator by adjusting the capillary length and optimizing the refrigerant charge, but the hydrocarbons have the flammability factor.
### 2.3 EFFECT OF MASS OF THE REFRIGERANT

Compared with CFCs, HCFCs and HFCs, hydrocarbon refrigerants offer zero ODP and extremely low GWP in regard to their performance. They offer reduced charge levels, high efficiency and lower compressor discharge temperatures. From the technological point of view, they also offer good miscibility with conventional and synthetic lubricating oils and show more compatibility with the materials like metals and elastomers, which are traditionally employed in refrigeration equipment.

The development of highly efficient and minimum charge units is then one of the crucial challenges for the future success of HC based RAC equipment. The appropriate refrigerant charge into the system is an important subject in the design of refrigerating machines, since it is directly linked to its system performance.

V.I. Dmitriyev et. al. [44], had assessed the optimum refrigerant (R12) charge quantity for domestic refrigerators employing a capillary tube expansion device. The amount of refrigerant charge was found to depend mostly on the volumes of the evaporator and condenser. Experimental measurements were made with different charge quantity and it was concluded that ambient air temperature was not a significant factor. The COP was shown to be more sensitive to overfilling than under filling.

Naer Vjacheslav et. al. [45], has proposed a rationally based algorithm to evaluate the optimal mass charge into refrigerating
machines. The calculated results indicate that the system performance is strongly related to the refrigerant mass charge and a sharp rise in COP is observed during the early stage of refrigerant charge. The COP reaches maximum value for a specified refrigerant charge and shows a slight drop for a further increase of refrigerant charge. Calculated results reveal similar trends to those of experimental data.

J.M.Choi et. al. [46], investigated the effects of refrigerant charge on the performance of a water-to-water heat pump by varying refrigerant charge amount from −20% to +20% of full charge in a steady state, along with cooling mode operation with expansion devices of capillary tube and electronic expansion valve(EEV). The characteristics of the heat pump with an EEV are compared with those with a capillary tube. The capillary tube system is more sensitive to charge as compared with the EEV system. For a wide range of operating conditions the performance of the EEV system was superior to the capillary tube system. The performance of the EEV system can be optimized by adjusting the EEV opening to maintain a constant superheat at all test conditions.

Erik Bjork et. al. [47], found that the lowest energy consumption was obtained with optimum charge and selection of suitable expansion device capacity. For undercharged condition the evaporator superheat is increased, the suction line becomes cold with overcharged condition. Both cases lead to increased energy consumption of the compressor.
Jose M. Corberan et. al. [48], developed an optimized R290 heat pump unit providing the highest COP with the minimum necessary charge. The experimental study was carried out to compare the effect of replacing R407C with propane without any other change in the unit. The heating capacity of R290 was lower, being in the range of 9 to 13%, while in the cooling mode, the capacity decreased slightly by 3%. Heating COP with R290 was higher, being in the range of 9 to 15%, while the cooling COP increased by 27% as compared to R407C. The reason for COP differences was the result of the better thermodynamic performance of R290. Capacity differences between the two refrigerants are mainly due to the much lower density of R290.

From the above studies it was observed that the system performance is increased with the refrigerant charge and peaks at a specific refrigerant charge. Further refrigerant charge quantity after this optimal point may decrease the system performance thereafter. Hence to obtain the better results with new refrigerant mixtures, charge optimization were needed.

2.4 HYDROCARBON REFRIGERANTS AND ZEOTROPIC REFRIGERANT MIXTURES

The refrigerant R134a has zero ODP, but its high global warming potential (GWP) seems to be an obstacle for more use. Fluids with lower energy efficiency would not solve the global warming issues. This leads to the new search for environmental friendly alternatives. Hydrocarbon refrigerants could be considered as viable substitute for R12 and R134a refrigerators because of their low global warming potential.
W.F Stoecker et. al. [50], have proved the advantages of zeotropic mixture over pure refrigerants. The irreversibility of the cycle decreases by using zeotropic mixtures due to temperature glide. The analysis was carried out with pure R12 and mixture of R12/R114 with equal mass fraction. The results show that zeotropic mixture consumes 12% lower energy consumption than pure R12.

David A. Didion et. al. [51], suggested that zeotropic blends would influence the refrigeration sector, these are the future long term alternative refrigerants in terms of ODP, GWP and energy efficiency. A zeotrope refrigerant is a mixture of two or more refrigerants. Blending of refrigerants allow the tuning of the most desirable properties of the mixture by varying the mass fraction of the selected components.

He.X. et. al. [52], experimentally investigated the performance of a zeotropic mixture of R22 and R142b as an alternative to R12 in a domestic refrigerator/freezer. Energy consumption was measured for 24 hours while the refrigerator was maintained at an average temperature between -15°C and 3.3°C in the freezer and food compartments. To obtain the best performance with the zeotropic mixture, the evaporator and condenser were modified to achieve a cross-counter-current heat transfer, thereby utilizing the advantages of the nonazeotropic mixture. Testing of all alternative mixtures was conducted without changing the compressor. Results show a 3% increase in performance for a mixture containing 52% R22 and 48% R142b. Analysis indicated that an additional 5% increase in
performance was possible by optimizing the motor and compressor design for the refrigerant mixture.

A capillary tube is a key component of a small VCR system, such as the household freezer and refrigerator. It is commonly used as the expansion and refrigerant controlling device because of the advantages of simplicity and low cost. It is a long (between 2 to 6 m) drawn copper tube with a very small bore diameter, often less than 1 mm, which connects the exit of the condenser to the inlet of the evaporator. It allows the pressures between the condenser and evaporator to balance during the off cycle, thus reducing the compressor starting torque requirements. The capillary tube size and system charge must be determined to have a compatibility with the compressor to meet the required design conditions with alternative refrigerants. A.Meyer [53], has discussed the advantages of HC refrigerants over R12 and R134a. Due to difference in saturation properties, pure hydrocarbons are not suitable for drop in replacement for R12 and R134a. A zeotropic mixture of 50%R290 and 50%R600a saturation properties are close to the properties of R12 and R134a. So, the mixture can be use as drop in replacement with little modification of the capillary length. To get similar pressure difference between condenser and evaporator as R12/R134a, the throttle resistance can be increased by doubling the length of the capillary tube using the same bore.

J.D.Douglas et. al. [19], proposed that flammable refrigerants can be mixed with non-flammable refrigerants to produce a non-flammable mixture. He investigated the alternative refrigerants to R22 with the
blends of HFCs and propane (R290). Flammable refrigerants are not cost competitive with non-flammable refrigerants. Results show that the optimal cost of pure propane is about 5% less than that of R22. Propane could be used as a viable alternative if a manufacturer could design a system with a flammability cost of less than about 5%.

H.M.Hughes et. al. [54], has addressed the issues by blending the components of zeotropic mixtures and subsequent packing. Assessment was carried out with the blend of R32, R125 and R134a with the mass fraction of 23%, 25% and 52% respectively. He focused on the issues related to blending equipment and techniques, the number and quantity of components and the temperature of the blend. While preparing the blends in the cylinder, introduce the individual components of the mixture serially starting with the lowest vapour pressure component and progressing to the highest.

Mark O.McLinden et. al. [55], has described the revised version of the software for refrigerant properties REFPROP 6.0. This software is based on the most accurate pure fluid and mixture models presently available. It implements three models for the thermodynamic properties of pure fluids: the modified Benedict-Webb-Rubin and Helmholtz equations of state, and the extended corresponding states model. Mixture calculations employ a new model which applies mixing rules to the pure fluid Helmholtz energies. Viscosity and thermal conductivity are modeled with either fluid specific correlations or a new variation on the ECS method. These models are implemented in a suite of subroutines written in standard FORTRAN. A separate graphical user
interface provides a convenient means of accessing the models. It will generate tables and/or plots for any user specified mixture. This user interface provides numerous options to customize the outputs and also to copy and paste capabilities to and from other applications.

R.S. Agarwal [15], has provided the information about HFC and HC refrigerants, servicing and retrofit procedures and the tools needed. Manual provides the information of retrofitting of R134a/R12 with HC blend, charging procedure and safe handling of HC cylinders. He also provided the information of lower and upper flammability of HC mixtures. In a space which is 3m by 3m by 2.5m high the practical limit of an HC charge is 180g. If the total charge of 180g is released into the space, it will not be enough to produce a flammable mixture.

Lambert Kuijpers [56], discussed the assessment of the impact of the Montreal and Kyoto Protocol on the developments in the RAC sector related to the use of certain refrigerants or methods. Most of the developed countries have agreed to decrease the gases causing global warming for the commitment period 2008-2012 which varies from 5 to 8%.

D. Colbourne [57], discussed the various safety considerations with respect to the application of flammable refrigerants (hydrocarbons). As per British Standard (BS 4434:1995) differentiation between refrigerant charge sizes and areas of human occupancy as described in the Table 2.1
Table 2.1 Summary of maximum allowable flammable refrigerant charges (per circuit) for specific occupancy

<table>
<thead>
<tr>
<th>Category</th>
<th>Category Definition</th>
<th>Max charge</th>
<th>Specific cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Where people sleep, restricted in movements, an uncontrolled number of people not familiar with safety precautions.</td>
<td>1.5kg</td>
<td>Systems using up to 0.25kg can be located anywhere. 5.0kg for indirect system with primary circuit in special machinery room or open air.</td>
</tr>
<tr>
<td>B</td>
<td>Where rooms, parts of buildings contain certain limited number of people, some familiar with safety precautions.</td>
<td>2.5kg</td>
<td>10.0kg for indirect system with primary circuit in special machinery room or open air.</td>
</tr>
<tr>
<td>C</td>
<td>Where only authorized persons have access to rooms, parts of buildings or buildings</td>
<td>10.0kg</td>
<td>25.0kg for indirect system with high pressure side in special machinery room or open air. No charge restriction provided that all of the primary circuit is in special machinery room or open air.</td>
</tr>
</tbody>
</table>
Eric Granryd [59], has discussed the possibilities and problems of using hydrocarbons as working fluids in refrigerating equipment and also given an overview of safety standards. Different HC alternatives and characteristics are listed in terms of thermodynamic cycles as well as heat transfer. The general conclusion is that HCs can be used as better refrigerant alternatives for environmental friendly and energy efficient refrigerating equipment and heat pumps. This is cost effective as it can be included with in the installation cost.

ACRIB [60], has discussed the maximum allowable HC refrigerant charge. The limiting factor associated with the use of hydrocarbon refrigerants is the refrigerant charge size, the occupancy category and the room size. Systems with charge sizes of 150g or less can be installed in any size of room. Systems with charge size of more than 0.15kg room size should be such that a sudden loss of refrigerant shall not raise the mean concentration in the room above the practical limit (approximately 8g/m³).

Westra and Douglas G [61], discussed the dilemma that industry is facing regarding CFC phase out and the problems associated with CFC alternatives presently under development. The COP and characteristics benefits of zeotropic refrigerant mixtures have been explained using thermodynamic principles and also discussed the disadvantages and Limitations of zeotropic mixtures.

S.Srinivasa Murthy [62], has discussed the importance of zeotrope and azeotrope mixtures to provide alternative solutions to the problem of the limited availability of pure fluids with suitable properties
to replace CFCs, HCFCs and other mixtures. Mixing of refrigerants allows the adjustment of the undesirable properties of the individual components such as flammability of pure refrigerants which can be reduced by adding non-flammable components.

D.B. Jabaraj et. al. [63], experimentally investigated a drop in replacement for R22 in a window air conditioner with the ternary mixture of HFC/HC (R407C/R290/R600a). Performance tests were carried out without changing the lubricant mineral oil. The results show an alternative mixture with the mass fraction of 80% R407C/10.96% R600a/9.04% R290 which will be giving better performance than R22 and R407. The ternary mixture produces 9.54 to 12.76% faster cooling rate than R22, while the actual COP was found to be 11.91 to 13.24% better than that of R22. The overall performance has proved that the HFC/HC blend refrigerant mixture could be an eco-friendly substitute to phase out R22 for window air conditioner.

Bjorn Palm [64], investigated the properties of the hydrocarbons like propane, propane and isobutane and compared them to R22, R134a and ammonia in small-size heat pump and refrigeration systems (<20 kW cooling). The results show that using hydrocarbons will result in COPs equal to, or higher than, those of similar HFC systems. The flammability risk can be overcome by decreasing the amount of refrigerant in the system.

In developing country like India, most of the vapor compression based air conditioning, refrigeration and heat pump systems continue
to run on halogenated refrigerants due to their excellent thermo-physical properties apart from the low cost. However, the halogenated refrigerants have adverse environmental impacts such as ODP and GWP. Hence, there is a need to search for alternative refrigerants to full fill the objectives of the international protocols like (Montreal and Kyoto) and to satisfy the growing demand worldwide. M.Mohanraj et. al. [65], has carried out the experimental and theoretical studies with environment friendly alternatives such as hydrocarbons, hydrofluorocarbons and their blends, which are going to be the promising as long-term substitutes.

From the above discussion it can be observed that zeotropic refrigerant blends of HCs with the proper mass fractions would increase the performance of the refrigeration system. The hydrocarbon mixture of 50%R290/50%R600a is a better drop in replacement refrigerant for R134a. The HC refrigerants have lower density and lower viscosity values than the R134a and so it needs nearly double the length of the capillary. For the drop in tests with the HC refrigerants there is a necessity to optimize the capillary length and refrigerant charge. The only draw back of using HC refrigerants is their inflammability. From the literature it was observed that as the quantity of the HC refrigerant charge is less than 150grams no need to take any safety measures, refrigerator can be placed any where. Mixing of refrigerants allows the adjustment of the undesirable properties of the individual components such as inflammability of the hydrocarbon refrigerants can be reduced by adding non-flammable components.
2.5 DESIGN OF EXPERIMENTS

Improvement can be achieved in one or more of the many characteristics of any given system or process. In most situations, improvement primarily implies that performance is enhanced. Experimental design is one technique that can be learned and applied to determine system or process design for improved performance. An effective way to improve performance is to optimize the processes by experimental means. DOE is a statistical technique introduced by Ronald A. Fisher in England [68] to conduct projects whose output performance depends on many input parameters. In the 1950’s, Genichi Taguchi of Japan proposed a much-standardized version of the technique for engineering applications. His proposed methodology for experiment designs to incorporate the effects of uncontrollable factors and ability to quantify the performance improvement by the use of a loss function, made the DOE technique much more useful to the practicing engineers and scientists in all kinds of industries [69, 70].

2.6 SCOPE OF THE PRESENT WORK

From the review of the literature, R134a is the leading refrigerant in India which is used to substitute R12 due to its high ODP value. Even though R134a is non toxic, non-flammable and has a zero ODP, it is one of the green house gases. It has to be decreased as per the Kyoto Protocol. It is seen that most of the available alternative refrigerants are not matching with the R134a in various aspects such as saturation properties, energy efficiency and safety.
On the other hand Hydrocarbon blend has better energy efficiency but is inflammable issues, which restrict the usage in existing systems. However, they can be made less flammable by blending flammable refrigerant with non flammable refrigerant such as HC refrigerants with HFC refrigerants. It is possible to mix hydrocarbon refrigerants with other alternatives such as HFC refrigerants. The miscibility of HFC/HC mixtures with POE oil has been reported to be good. The GWP of HFC/HC mixtures is less than one third of HFC, when it is used alone.

The safety issues pertaining to the flammability of HC blend does not arise due to total quantity of the hydro carbon in the mixture of HFC/HC mixture is coming less than 150 grams which is the safe range it doesn’t require any special attention as per the literature.

Optimization was done for capillary tube length and mass of the refrigerant. The proposed mixture is expected to work with the existing components of conventional R134a systems with an improvement in the system performance. This can solve the issues faced by refrigeration sector in the near future due to phase out of R12 and reduction of green house effect with the decrease of R134a quantity in the proposed mixture.

The need for research to identify a suitable HC and its composition with R134a to retrofit the R134a systems is realized. This is obvious that the resultant mixture is expected to be energy efficient also.