International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 871-877 www.ijaem.net ISSN: 2395-5252

Experimental Investigations of Vapour Compression Refrigeration System Using R600a and Analysis of Preparation of R600a Agglomerated With CNT Refrigerant

M.Ravi Kumar, Dr.R.Satya Meher, Dr.A.Swarna Kumari,
Assistant Professor, MVSR Engineering College, Nadergul, Hyderabad, Telangana
Prof-MED, Sree Vidyanikethan Engineering College, Tirupati, Andhra Pradesh
Prof-MED, JNTUK, Kakinada, Andhra Pradesh,

Date of Submission: 20-06-2023 Date of Acceptance: 29-06-2023

ABSTRACT: The quest for new refrigerants had made sustainable development and advances in refrigeration industry in switching over to alternative refrigerants of carbon family compounds such as Butane (R600a) , which can be used as a fuel and refrigerant. The present paper focus on preparation of R600a Refrigerant agglomerated with Carbon nano tubes (CNT) for enhancement of COP in a simple vapour compression refrigeration system test rig. The test rig is specifically designed to compare performance of two refrigerants working on hermetically sealed compressors.R600a is a hydrocarbon that is increasing in demand due to its low environmental impact and excellent thermodynamic performance.CNT have excellent thermal conductivity (2000W/Mk- 3000W/Mk) and high electrical conductivity due to the strength of bond between them and because of their high thermal conductivity and strength, they help in enhancing the performance of the system. Preparation methodology and performance characteristics at 1.5 TR capacity of the VCR system is discussed and presented.
Keywords: Carbon Nano Tubes (CNT), Coefficient of Performance (COP)

I. INTRODUCTION

Simple vapour compression refrigeration system is used universally to meet the growing demandof human comfort conditions and industry 4.0, which looks at clean spaces for commercial and industrial applications. The refrigerant of Halo-carbon families were not recommended after Kyoto protocol, due to presence of chlorine which is depleting the ozone layer, when situations of refrigerant leakages are observed. Most of the VCR systems earlier were working on R-22 due to its lowest freezing point, lowest boiling point and highest latent heat of vaporization after R 717. But substantial developments were made in the refrigeration industry, and it has looked for various alternatives for R-22, such as R 134a ,R-40 and R600. The major issue associated with these refrigerants was that thermal conductivity of the refrigerant is of the order of 0.01~0.02 w/mk. It is learnt from the fundamentals of transport phenomenon that thermal conductivity of liquid metal is higher than liquids and by mixing a solid particle of Carbon corresponding to Nano scale (particle size <100 Nm) the liquid refrigerant can be a liquid metal and it has higher thermal conductivity. Higher thermal conductivity of R600a is of the order of 0.017 w/mk and enhancing its thermal conductivity by mixing with carbon nano tubes (CNT) will drastically improve its heat transfer coefficient. It is known fact that in liquid heat transfer is due to convection and conductivity at fluid-fluid interface will enhance the Nusselt number and thereby heat transfer rate increases. An attempt is made in this paper to add CNTs to existing Isobutane (R600a) , such that its thermal conductivity will increase. Thermal conductivity of CNTs for a single tube varies between 2800 w/mk ~ 6000 w/mk , and distribution of this CNT in the R600a medium will get the thermal conductivity in the range of $K_{liquids} \sim K_{solids}$. This will drastically reduce the volume of evaporator for same quantity of refrigerant or otherwise, require less amount of refrigerant for same size of evaporator, with less work input. This will increase the COP of VCR system, for same operating pressure of condenser & evaporator. The other reason for using R600a , which is simplest alkane with a tertiary carbon, have high impact on the environment in domestic refrigerators. It has zero ozone depletion potential (ODP) and a negligible global warming potential (GWP).

II. LITERATURE REVIEW

An experimental study was conducted by Mohanraj et al. [1] using a hydrocarbon mixture consisting propane and isobutane with a ratio of 45.2:54.8 by weight as a replacement for R134a indomestic refrigerator. Latent heat of hydrocarbons is considerably higher than that of R134a, the amount of refrigerant charge can be reduced. A study was carried out with a mixture of propane and iso-butane with a ratio of 50:50 by weight in a domestic refrigerator [2] which worked with 150 g of R134a. The outcomes showed that hydrocarbon mixture reduces the energy consumption by 4.4% and the weight of the refrigerant used was reduced by 40% compared to R134a. By using a hydrocarbon mixture [3], the temperature variations in refrigerator cabin occurs faster and the ON time ratio is less than of R134a.Ghorbaniet al.[4] performed the analysis POE/CuO Nano refrigerant in R600a and compared it to POE oil with R600a in a refrigeration system. Three different various POE/CuO mass percentage samples of R600a with POE/CuO of 0.5, 1 and 1.5% were considered for the experiment and compared with pure R600a with POE oil. The result displayed that presence of Nanoparticles in POE lubricant oil increases condensing heat transfer of 4.1%, 8.11%, and 13.7% respectively compared to base fluid. Srinivas [5] performed experimental investigation with LPG as refrigerant and found that energy consumption is drastically decreases with LPG as refrigerant. Elcock [6], TiO_2 nanoparticles were used as additives to enhance the solubility of mineral oil with the hydrofluorocarbon (HFC) refrigerant. It was observed that refrigeration systems using a mixture of HFC134a and mineral oil with TiO_2 nanoparticles appear to give betterperformance by returning more lubricant oil to the compressor with similar performance to systems using HFC134a. An experimental study on the performance of a domestic refrigerator using Al_2O_3-R134a Nano refrigerant as working fluid was carried out in the work of Senthilkumar and Elansezhian [7]; It was observed that Al_2O_3-R134a system performance was better than pure lubricating oil with R134a working fluid with 10.30% less energy used with 0.2%vol of the concentration used and also heat transfer coefficient increases with the usage of Nano Al_2O_3.Ali JarrarJaffri [8] conducted experiment with CuO nano refrigerant and found that density and thermal conductivity is increasing gradually with increase in concentration of CuO. Whereas, when the concentration percentage of R-600a decreases, the density and thermal conductivity decreases. It was observed from the specific heat calculations that as the volume concentration percentage of nanoparticles increases, the specific heat is decreasing eventually. The results indicated that TiO_2-R600a function normally and efficiently in refrigerator. Shengshan Bi [9] studied with refrigerator using pure R600a as working fluids, 0.1 and 0.5 g/L concentrations of TiO_2 -R600a saves 5.94% and 9.60% energy consumption respectively and the freezing rate of nano refrigerant system was faster than pure R600a system. S. A. Fadhilah experimented with nanoparticle suspended into the conventional refrigerant with 1% volume fraction which causes a growth in thermal conductivity about 3121% enhancement from 0.0139 to 0.4477 W m-1K-1. In the previous work, the Nair [10] investigated the basic characteristics of the TiO_2-R134a nano-refrigerants. Bi SS [11-15] studies dispersion behavior, thermal conductivity and flow boiling heat transfer TiO_2 with HFC134a. Saurabh Gupta and Srinivas pendyala [16-19] used hydrocarbon refrigerants and observed enhancement of performance of VCR system. Ravi Kumar MR [20] experimentally evaluated performance enhancement of refrigeration system by 115% with nanomaterial added to lubricating oil.

III. MATERIALS & METHODS

The experimental set up at thermal engineering lab of MVSR Engineering college consist of a vapour compression refrigeration system, with thermostatic expansion valve and variable capillary tube arrangement as shown in figure 1. The Refrigeration system is design to test the performance of two refrigerants simultaneously. It consists of hermetically sealed compressors, air cooled condenser, series of capillary tubes for variable static thermal load and a evaporator, which is computer controlled. In built naïve software will provide the necessary salient point operation data to estimate the performance of the refrigerant. Experiments were conducted with R600a and preparation of R600a with CNT are discussed in this part. The vapour compression refrigeration can work in dual refrigerant mode, hence in the first part of the experimental set up, R 600a is charged

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 871-877 www.ijaem.net ISSN: 2395-5252

with operating temperature range of atmospheric conditions to -40^{0}C. Initially check the valves whether they are in closed condition or not. Fix the capillary tube of desired length(8feet) and Evacuate the circuit by using vacuum pump (shown in figure2), it removes any moisture content and other gas particles in the refrigeration circuit. Now charge the Refrigerant R-600a into the Circuit and check the refrigerant charge. switch on the apparatus and open the valve of the capillary tube. Keep the thermostat valve to maximum condition and choose the evaporator temperature and start the timer. Note the readings in the digital indicator and the time taken for every one-degree drop of temperature. Repeat the experiment until we get the required temperature.

Figure 1: Vapour compression refrigeration system


Figure 2: Vacuum pump

The CNTs is grinded to Nano size particles by CVD process and mixed to R600a in the laboratory. The uniform mixing of the CNT in R600a is ensured with continuous magnetic stirrer for 72 hours and uniform solution (approximately) is obtained. The CNT powder is mixed with lubricating oil of the compressor and then the VCR system is charged with R600a. This will ensure proper mixing of the CNT with R600a in dynamic condition of VCR system. Different proportions of CNT is mixed with compressor lubricating oil (Zcol mineral oil) of 0.01%, 0.1% and 0.2% to 350ml of lubricating oil. Fig-3, Fig-4 and Fig-5 indicate the composition and mixing apparatus to obtain the required solution. As the compressor is hermetically sealed, the lubricating oil is in contact with the R600a during operation, hence the CNTs associated with lube oil will mix with refrigerant and enhance the refrigeration effect of the VCR system. The lubricating oil (Synthetic oils)such as glycols, esters and alkylbenzenes (AB) have been used in the refrigeration applications for some time without any problem. CFC refrigerants such as R12, R13, R113, R114 and R115 are using mineral oil or alkylbenzene as their lubricants. Similarly, HCFC refrigerants such as R22, R123, R401A and R409A are also using these lubricants in their design. In recent years CFC and HCFC refrigerants usage began to dwindle due to their ozone-unfriendly properties. Usage of new HFC refrigerants such as R23, R32, R134a, R407A, R407C and R410A have been increasing in HVAC equipment. These new refrigerants use Polyol esters or POE as lubricant. One setback of POE is that it absorbs moisture many times more compared to mineral based oils. Hence proper procedures must be used when handling this oil to reduce the contact of this oil with the atmosphere. Metal containers are used instead of plastic containers to prevent moisture from entering the containers.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 871-877 www.ijaem.net ISSN: 2395-5252

Figure 3: 0.01% CNT with lube oil of 350 ml

Figure 4: 0.1% CNT with lube oil of 350 ml

Figure 5:0.2% of CNT with 350 ml of Lube oil

IV. EXPERIMENTAL RESULTS& DISCUSSIONS

Experiments were conducted on simple vapour compression refrigeration system test rig at three condenser temperatures of 27^{o}C, 33^{0}C and 37^{0}C.and three varying lengths of capillary tube 8,10 and 14 feet. The experiment is again repeated with R600a agglomerated with CNT powder of 0.01 %, 0.1% and 0.2 % in 350 ml of lubricating oil. At 27 ^{0}C, for a capillary length of 8 feet, the temperature at inlet of compressor (T_1), Temperature at outlet of compressor (T_2), temperature at outlet of condenser (T_3), temperature at outlet of evaporator (T_4) , temperature of thermal load in evaporator (T_5) , with delivery pressure (condenser pressure P_d) , suction pressure (evaporator pressure p_s) and work input to the compressor are estimated. The same procedure is adopted for 10 feet and 14 feet length

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 871-877 www.ijaem.net ISSN: 2395-5252

capillary tube, at various ambient temperatures of 33^0 C and 37^0 C was performed.

Table 1: Experimental Observations at various ambient temperatures and Different length of capillary tubes

L	Ambient	T1	T2	T3	T4	T5	Pd	Ps	W
8	27 ^{0}C	32.22	42.82	38.22	3.57	27.00	4.18	0.65	195.55
8	33 ^{0}C	34.70	51.50	46.46	5.64	25.00	4.88	1.14	195.55
8	37 ^{0}C	36.15	53.47	48.63	8.53	25.00	5.20	1.28	200.73
10	27 ^{0}C	30.75	42.76	38.76	2.79	23.00	4.26	0.52	190.00
10	33 ^{0}C	34.49	51.71	46.45	4.43	24.00	5.03	1.03	193.00
10	37 ^{0}C	36.39	52.02	47.69	8.76	25.00	5.37	1.06	201.09
14	27 ^{0}C	31.51	42.06	38.26	1.80	26.00	4.27	0.42	191.09
14	33 ^{0}C	34.83	50.69	45.75	4.65	26.00	5.01	0.94	188.00
14	37 ^{0}C	35.75	53.79	48.41	5.62	26.00	5.32	1.12	188.82

The length L of capillary tube is expressed in foot, Temperatures in degrees centigrade, pressure in kg/cm^2 and work input to the compressor in watts. The evaporator is dry evaporator with a thermal load of 7 liters of water kept at prescribed evaporator temperature T_5. The coefficient of performance is calculated for various observations with R600a as refrigerant.

Table 2: COP at various ambient conditions for 8 feet long capillary tube

T	Refrigeration effect	Power consumption	COP
27°C	222 W	195 W	1.13
33°C	271.3 W	195 W	1.3
37°C	183.3 W	200.7 W	0.91

From the table 2 it is observed that, at the condenser temperature 27°C the refrigeration effect was found to be 222W and the power consumed was 195 W. The Co-efficient of Performance was found to be 1.13. At the condenser temperature 33°C the refrigeration effect was found to be 271.3W and the power consumed was 195 W. The Co-efficient of Performance was found to be 1.3. At the condenser temperature 37°C the refrigeration effect was found to be 183.3Wand the power consumed was 200.7 W. The Co-efficient of Performance was found to be 0.91.

Table 3: COP at various ambient conditions for 10 feet long capillary tube

T	Refrigeration effect	Power consumption	COP
27°C	195.3 W	190 W	1.02
33°C	250 W	193 W	1.2
37°C	287 W	201 W	1.42

From the table 3 it is observed that, at the condenser temperature 27°C the refrigeration effect was found to be 195.3W and the power consumed was 190 W. The Co-efficient of Performance was found to be 1.02. At the condenser temperature 33°C the refrigeration effect was found to be 250W and the power consumed was 193 W. The Co-efficient of Performance was found to be 1.2. At the condenser temperature 37°C the refrigeration effect was found to be 287W and the power consumed was 201 W. The Co-efficient of Performance was found to be 1.42.

Table 4: COP at various ambient conditions for 14 feet long capillary tube

T	Refrigeration effect	Power consumption	COP
27°C	180 W	191 W	0.94
33°C	244 W	188 W	1.2
37°C	232 W	206 W	1.12

From the table 4, it is observed that, at the condenser temperature 27℃ the refrigeration effect was found to be 180W and the power consumed was 191 W. The Co-efficient of Performance was found to be 0.94. At the condenser temperature 33℃ the refrigeration effect was found to be 244W and the power consumed was 188 W. The Co-efficient of Performance was found to be 1.2. At the condenser temperature 37℃ the refrigeration effect was found to be 232W and the power consumed was 206 W. The Co-efficient of Performance was found to be 1.12.

Regression analysis is performed using MS excel and residual plots are indicated for outlet temperature of capillary tube and work input to the compressor.As per the regression analysis between the evaporator inlet temperature and work input to the compressor, the linear equation obtained is

W= 186.1745 + 1.4907 * T_4-------(1)

The work input to the compressor is a function of evaporator inlet temperature and it is estimated for working temperatures of -20 to 10 ^{0}C as shown in the figure-6 .

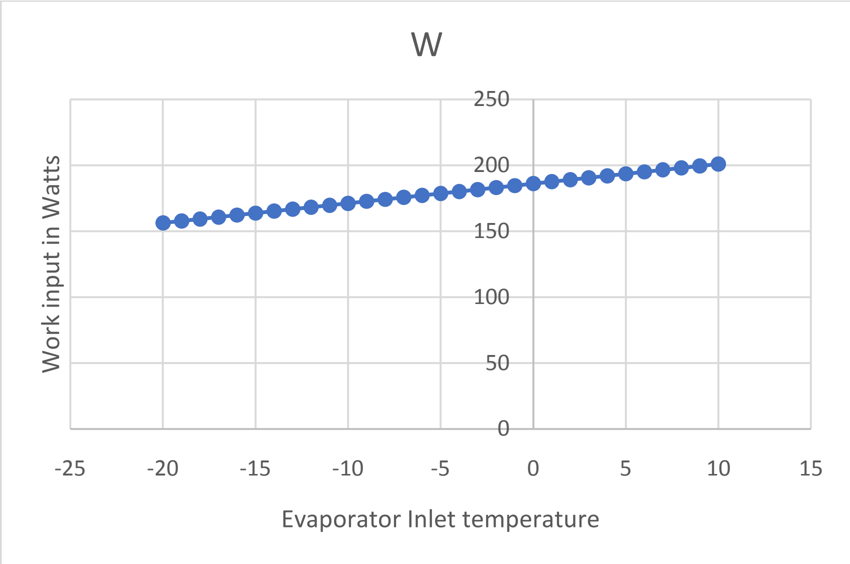

Figure 6: Work input as a function of evaporator inlet temperature

The linear regression analysis is performed between T_4 and COP, and the relation is obtained as

COP= 1.002266 - 0.026635 * T_4 ------------(2)

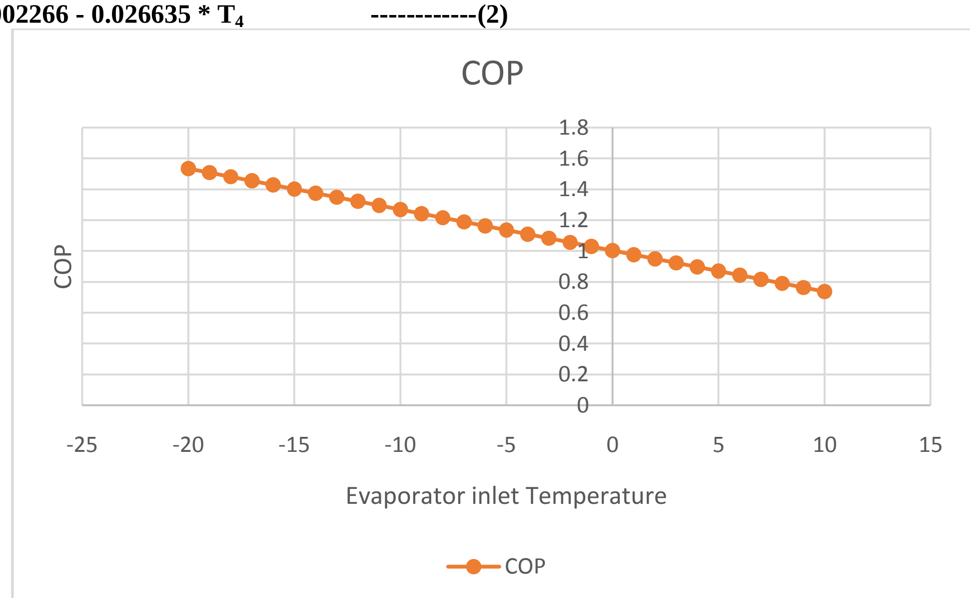

Figure 7: COP as a linear function of Evaporator inlet temperature

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 871-877 www.ijaem.net ISSN: 2395-5252

V. CONCLUSIONS

The experiments with R600a were performed and preparation of R600a with CNTs are prepared for further experimentation. The experimental values of R600a are reference values for improvement of COP of VCR system.

REFERENCE

[1]. M. Mohanraj, S. Jayaraj, C. Muraleedharan, P. Chandrasekar, Experimental investigation of R290/R600a mixture as an alternative to R134a in a domestic refrigerator, Int. J. Therm. Sci. 48 (2009) 1036e1042.

[2]. J. Ching-Song, T. Chen-Ching, W. Wei-Ru, Efficiency analysis of home refrigerators by replacing hydrocarbon refrigerants, Measurement 42 (2009) 697e701.

[3]. K. Mani, V. Selladurai. Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a, Int. J. Therm. Sci. 47 (2008) 1490e1495.

[4]. B. Ghorbani, M. A. Akhavan-behabadi, S. Ebrahimi, and K. Vijayaraghavan, "Experimental investigation of condensation heat transfer of R600a / POE / CuO nano-refrigerant in flattened tubes," Int. Commun. Heat Mass Transf., vol. 88, no. October, pp. 236–244, 2017.

[5]. P Srinivas, RP Chandra, M Ravi Kumar, N Reddy Experimental Investigation of LPG as Refrigerant in a Domestic Refrigerator" International conference on recent advances in engineering sciences- ICRAES -2014, MSRIT, Bangalore, NOV, pp 470-476

[6]. Elcock D., Potential impacts of nanotechnology on energy transmission applications and needs: Environmental Science Division, Argonne National Laboratory (2007).

[7]. Sendil-kumar D., and Elansezhian R., Experimental Study on Al_2O_3-R134a nano Refrigerant in Refrigeration System. IJMER. 2(5) (2012) 3927-3929.

[8]. Ali JarrarJaffri, Raja Sekhar Dondapati, Mohd Waheed Bhat, Gaurav Vyas study on Investigation on Thermo-Physical Properties of Mixed Nano Refrigerant with CuO based nanoparticles, ICCMMEMS_2018. 5 (2018) 27795–27800

[9]. Shengshan Bi, Kai Guo, Zhigang Liu, Jiangtao Wu, Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as a working fluid, Energy Conversion and Management 52 (2011) 733–737.

[10]. Nair, Vipin & Parekh, A. & Tailor, P. (2018). Water-based Al_2O_3, CuO and TiO_2 nanofluids as secondary fluid for refrigeration system: a thermal conductivity study. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 40. 10.1007/s40430-018-1177-6.

[11]. Bi SS, Wu JT, Shi L, The thermal conductivity of the nanoparticles TiO_2 and R134a mixtures. J Eng Thermophys 2008; 29:205–7.

[12]. Bi SS, Shi L. Flow boiling heat transfer nano-refrigerant TiO_2 and HFC134a mixtures in a horizontal tube. J Chem Indus Engg. 2009; 59:104–8.

[13]. Bi SS, Shi L, Zhang LL, application of nanoparticles in domestic refrigerators. Appl Therm Eng 2008; 28:1834–43.

[14]. Bi SS, Shi L. Experimental investigation of a refrigerator with a nanorefrigerant. J Tsinghua Univ (Sci Tech) 2007; 47:1999–2002.

[15]. GB/T 8059.1–3-1995, China refrigeration and air-conditioning standard, Standards Press of China; 2002.

[16]. Saurabh Gupta, Srinivas Pendyala, Optimization in Window Air conditioner with Commercial LPG (Hydrocarbon Blend), International Journal of Air-Conditioning and Refrigeration, Vol. 29, No. 2 (2021) 2150020.

[17]. Saurabh Gupta, Srinivas Pendyala, "Flammability issue of hydrocarbons in air conditioning industry", Materials Today: Proceedings, 28 (2020), pp 2247-2250

[18]. Srinivas Pendyala, Ravi Prattipati, "Optimization process of a visi-cooler using ternary mixtures of R134a and hydrocarbons", International Journal of Air-conditioning and Refrigeration, 25(2), 1750019-1 to 1750019-10 (2017).

[19]. Srinivas, K Narayana Rao, A V SitaRama Raju, "Optimization of Visi Cooler with the Low Global Warming Potential Refrigerant Mixture as an Alternative to R134a and HC blend", International Journal of Global Warming, 2(4), Inder Science Publications, pp 316-329 (2010).

[20]. Kumar MR, Meher RS, Swarna Kumari AS. 2022. Experimental Investigations of Effect of Nano Composites on Performance of VCR System at Variable Capillary Tube Lengths. NanoWorld J 8(1): 28-35