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Experimental Investigation on Performance of Vapor Compression Refrigeration System using Nanorefrigerant (R134a+Al_2O_3) with Evaporative Condenser

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Abstract **-In traditional refrigeration system the focus of researchers is always to improve its performance by reducing work of compression & enhancing the heat transfer rate in different heat exchangers and this can be achieved by adopting suitable technique. In this research work experiment is carried out on vapor compression refrigeration test rig using nanorefrigerant of R134a as base refrigerant and nanoparticles of aluminium oxide Al_2O_3 in different concentration so that variation in heat transfer rate can be observed. The different concentration of Al_2O_3 (gm/litre) in R134a were prepared, studied, and tested experimentally in VCR test rig. The test rig consists of evaporative condenser as conventional air-cooled condenser does not perform well in hot and dry climatic conditions. This evaporative air cooling offers desired heat rejection rate in condenser at high pressure and enhances system performance. The investigations show that nano refrigerant (R134a+ Al_2O_3 0.5gm/L Concentration & 50-60nm size) with evaporative condenser recorded the highest coefficient of performance among all other combination of nanorefrigerant. This indicates that nanorefrigerant can be safely experimented without any blockage or difficulty. The conventional VCR system operated with evaporative condenser without nanorefrigerant also shows improvement in performance compared to simple VCR with air cooled condenser. This system is suitable for hot and dry climate conditions.**
Keywords: **VCR System, Nanorefrigerant, Evaporative cooling, COP.**

I. INTRODUCTION

Every research in the field of heating, ventilation and air conditioning (HVAC) system focuses on producing desired effect at minimum & economical investment with no hazardous effect on environment. It is expected that system power consumption should be less, and heat transfer rate should enhance significantly by implementing suitable technique. This makes researchers more curious to work in direction of either modification in existing HVAC system or to try different refrigerant, their blends, and additives. Researchers are adopting new refrigerant as replacement of existing hydrocarbon-based refrigerant which possesses better thermodynamic, physical and chemical properties than conventional hydrocarbon-based refrigerant. As per UNEP's emission gap report-2015 it is reported that the global average temperature is increasing by 1.5-2^{0}C. This is because the available conventional classes of refrigerants are responsible for ozone layer depletion and global warming effect. Thus, environment friendly refrigerants must be introduced which can replace the conventional refrigerants.

The R134a is most popular traditional refrigerant widely used in different HVAC applications like domestic refrigerator, automobile air conditioners, cold storage units, chilling plant etc. The main concern in using this refrigerant is utilization of power consumption for producing the desired effect. There must be optimum utilization of electric power for required heat transfer rate. This can improve the capacity and performance of the system. In any cooling or heating application thermo-physical of working fluid plays an important role which decides the coefficient of performance of the system.

The conventional refrigerants have limited thermal properties which limits the performance of system. Due to this the nano particles of certain materials can be used & mixed with base refrigerant in different concentration which significantly improves the heat transfer properties. The Proper size and quantity of nanoparticles of Al_2O_3 can enhance the thermal properties of working fluid. In this work, performance of vapor compression refrigeration system is examined with nanorefrigerant of R134a & Al_2O_3 particles in different concentration and compared it with conventional experimental set up.

II. LITERATURE SURVEY

In previous work, researchers have investigated the effect of different types of nanoparticles in refrigeration system. The nanoparticles mixed either with lubricating oil (nanolubricants) or base refrigerant (nanorefrigerant) and examined their behavior & characteristics so that desired concentration of nanoparticle can be chosen to obtain the desired performance of system.

M. A. Onakade *et.al* [1] had used nanoparticles of Al_2O_3 in different concentration (0.2, 0.4 & 0.6g/L) with lubricating oil in slightly modified domestic refrigerator filled with

LPG as refrigerant. The trial was conducted for 180min of duration and performance characteristics like power consumption, coefficient of performance, cooling capacity, discharge temperature and pressure ratio were calculated. It is observed that least power consumption was found at 0.6g/L concentration of Al_2O_3 in lubricating oil with lowest cabinet temperature of -8.7^{o}C. This represents that nanolubricant in system can produce lower cabinet temperature than conventional system with pure lubricating oil.

The nanoparticles can also be used in refrigeration system by mixing it with base refrigerant in proper proportion and can be termed as nanorefrigerant. Pravesh Kumar Kushwaha *et.al* [4] attempted a trial with nanorefrigerant (Al_2O_3+R134a) in conventional vapor compression refrigeration system and his findings revealed that system filled with nanorefrigerant produces more temperature drop across condenser compared to R134a refrigerant system. Similarly, there is gain in evaporator temperature by 5-10% with the use of nanorefrigerant of suitable concentration.

At the same time power consumption is significantly reduced with the use of nanorefrigerant compared to pure refrigerant. Apart from R134a few researchers worked on other refrigerant and suitable nanoparticles in refrigeration or air conditioning system. G Senthilkumar *et.al*[2]used nanorefrigerantof R22 base refrigerant and CuO nanoparticles in air conditioning test rig and observed that thermo-physical properties of nanorefrigerant slightly improved and correspondingly heat transfer rate also enhances significantly. A blend of R22 with 0.05% volume of CuO reduces compressor work which led to reduction in power consumption; ultimately the performance of air conditioning system is improved.

This also shows the compatibility alternative refrigerant and nanoparticle with any HVAC system. M. Anish *et.al*[3] investigated the use of nanorefrigerant CuO/Al2O3 with R-22 in domestic refrigerator without any modification in the system. An experimental result indicates that CuO-R22 nanorefrigerant work normally & safely in a refrigerator and produces enhanced heat transfer rates at minimum power consumption.

At the same time, required air temperature and humidity monitored perfectly for obtaining desired air conditioning. The use of nanorefrigerant is not just limited to conventional refrigeration or air conditioning system but it can also be used in other HVAC applications with additional auxiliaries. Amrat Kumar Dhamneya [5], had used TiO_2 nanoparticles in R134a refrigerant filled in ice plant test rig with evaporative condenser for hot and dry climatic conditions.

This evaporative cooling system enables more drops in temperature across condenser and enhances the performance of ice plant test rig for variety of nanoparticle concentration in base refrigerant. This also concludes that use of evaporative condenser is preferable than use of nanorefrigerant in hot and dry climate. D.S Adeleken [6], conducted an experiment using nanorefrigerant consisting of nanoparticles of TiO_2 15nm size in R600a refrigerant and observed that nanorefrigerant worked efficiently and safely in vapor compression refrigeration system. Also, it is found that the performance of system improved with nanorefrigerant compared to pure R600a system. 0.1gm of TiO_2 in 40gm of R600a nanorefrigerant shows highest refrigerating effect and COP with least specific compressor work. Damola S. Adelekan [7], conducted a trial on domestic refrigerator using variable masses of LPG refrigerant with nanolubricants of mineral oil + TiO_2 nanoparticles in different concentration.

His findings revealed that nanolubricants can be safely worked in domestic refrigerator, and it is able to require evaporator temperature at minimum power consumption compared to pure mineral oil.

With the perspective of more reduction in compressor work B. PitchiaKrishnan [8] experimented blend of R290 and R600a as base refrigerant with addition Al_2O_3 nanoparticles in domestic refrigerator. Its performance analysis is carried out and shows that COP of the system improved when nanorefrigerant Al_2O_3/R290/R600a (0.03/0.9/0.1) has significantly reduces the compressor work compared to R290/R600a (0.9/0.1) refrigerant blend. It is also concluded that increase in evaporator temperature increases the coefficient of performance, where power consumption and work of compression slightly decreases.

On the basis of above mentioned literature survey, it is observed that addition of nanoparticle in base refrigerant or lubricating oil can enhance thermo-physical properties of working fluid which further improves heat transfer rates and thus significantly improves performance of the HVAC system. However limited experimentation had been done on VCR system by employing evaporative condenser. Hence in this work focus is given not only use of nanorefrigerant but also on use of evaporative cooling system, and their effects on performance of VCR system.

III.EXPERIMENTAL SETUP

The experimental set up consist of conventional vapor compression refrigeration test rig comprises of hermetically sealed compressor, condenser, expansion device and evaporator. The existing test rig is having evaporative condenser as air cooled condenser does not perform well in hot and dry climatic conditions. The evaporative condenser consists of water circulating pump, khus cooling pad, water sprinkle nozzle and water tank as shown in figure 1 & figure 2. The evaporative air-cooling condensing unit fabricated separately using duct type arrangement attached to condenser of existing vapor compression refrigeration set up. The detailed specification of system components, controls & instrumentation are given in table 1 as below.

TABLE I DETAILED SPECIFICATION OF EXPERIMENTAL TEST RIG

SL.No.	Equipment	Range/ Capacity	Accuracy
1	Compressor Hermetically Sealed, Reciprocating type, Godrej company	410BTU/ hr, 120 watt 230V AC, 50Hz	-
2	Evaporative condenser (Tubes-Copper, Fins-Al&Fan Motor) with cooling pas and water pump	09″*09″*02 row, Diameter of tubes- 9mm, Length of tubes- 40 ft., Fan diameter – 10 ft, 1/10 HP	-
3	Capillary tube (Material–copper)	Length- 2meter	-
4	Evaporator coil & shell Capacity- 10 lit	Coil dia- 10”, Tube dia. -12mm, Tube length-40ft, Shell dia- 250 mm	-
5	Digital Temp. Indicator	0 to 9999^{0}C,	+- 1^{0}C
6	Thermocouple (Cr-Al) K type	0 to 900^{0}C, 06 Nos.	+- 1^{0}C
7	Pressure Gauge, Connection 1/806 NPT	0 - 500 psi, 0 - 35kg/cm^2	+- 0.1

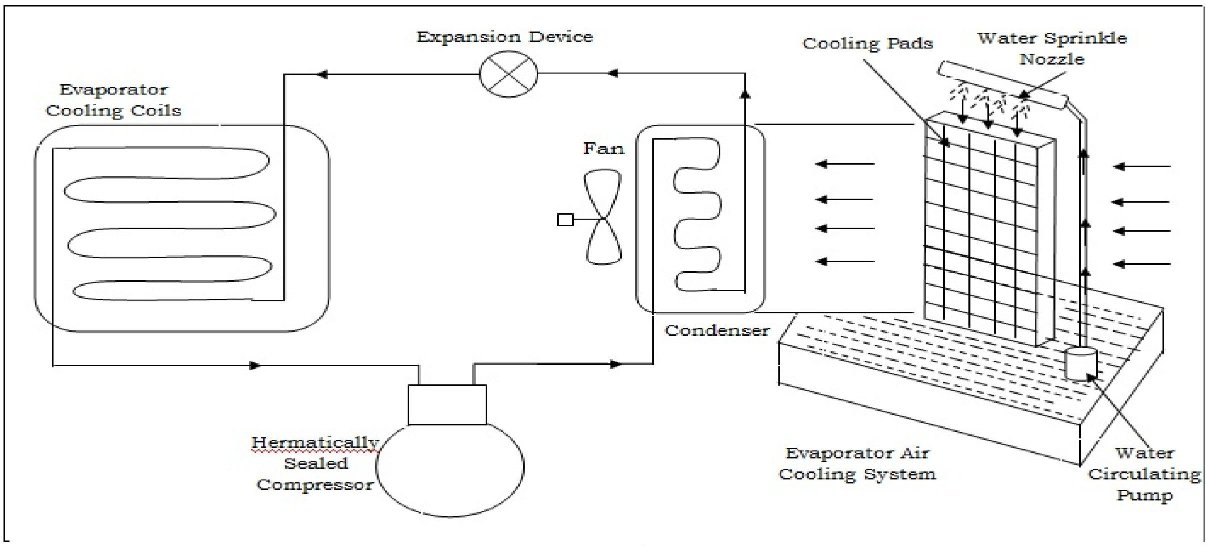

Fig.1 Schematic View of Experimental Test Set Up

IV. EXPERIMENTAL METHODOLOGY

The nano refrigerant is prepared by mixing nano particles of Al_2O_3 in different concentration (gram per litre) with R134a as base refrigerant. The experiments are carried out with different concentration of nano refrigerant to examine the performance of test setup. The nanoparticles of Al_2O_3 are in the range of 50-60nm & having 99% purity. Initially nano particles are mixed with base refrigerant in magnetic stirrer for 2-3 hours and then mixture is allowed to vibrate in ultrasonic homogenizer up to 1 hour in order have proper stability and homogeneity. This ensures uniform distribution of nano particles in base refrigerant. The test set up is thoroughly evacuated using a vacuum pump before performing each trial and using vacuum pump it is ensures that there is no leakage. Each trial is carried for 150minutes of steady state conditions and repeated twice for getting more accurate readings. For every trial mass of nano refrigerant is filled with digital charging system. During experimentation, refrigerant pressures & temperatures were recorded and their corresponding value of enthalpies such as saturated vapor enthalpy at compressor inlet (h_1), superheated vapor enthalpy at entry of condenser (h_2) and saturated liquid enthalpy at entry of expansion device (h_3) using MS Excel which had imported thermodynamic property table from NIST RefProp fluid property software version 9.1 and also peace software is used for verifying thermodynamic properties.

TABLE II DETAILED SPECIFICATION OF WORKING FLUID USED IN EXPERIMENT

SL.No.	Working Fluid Parameters	Detail Specification
1	Base refrigerant used	R134a
2	Nano Particle used	Al_2O_3
3	Size of Nano particle	40-60nm
4	Concentration of nanoparticles	0.25g/L, 0.50g/L & 0.75g/L
5	Nano refrigerant Mass	100gm

After recording the observation during each trial, thermodynamic analysis of vapor compression refrigerationcycle can be done in order to calculate the coefficient of performance.

Theoretical work of Compression

$W_{th}= m(h_2 - h_1)$

Actual compressor work (W_{at}) input can be calculated as

W_{act} = (3600 x No.of pulses of Energy meter) / (Time for said pulses x Energy meter constant)

Heat rejection in condenser (Qc) can be calculated as

$Qc = m(h_2 – h_3)$

Expansion of refrigerant in capillary tube can be expressed as

$h_3 = h_4$

Heat absorption in evaporator (Qe) can be calculated as

$Qc = m(h_1 – h_4)$

Where, h_1 is enthalpy of the refrigerant at compressor inlet, h_2 is enthalpy of the refrigerant at compressor outlet, h_3 is enthalpy of the refrigerant at condenser outlet and h_4 is enthalpy of the refrigerant at evaporator inlet. T_1 is the suction temperature at compressor inlet, T_2 is discharge temperature at compressor outlet, T_3 is the temperature of refrigerant at condenser and T4 is the temperature of evaporator inlet. Ps and Pd are suction and discharge pressure of compressor.

Coefficient of performance of refrigeration system as defined as [18]

C O P = Refrigeration effect / Work Input

V. RESULTS AND DISCUSSION

In present work, nano particles of Al_2O_3 in different concentration mixes with R134a base refrigerant and were used in vapor compression refrigeration experimental setup. The objective of this work is to analyze the performance of exiting set up with use of different concentration of nano refrigerant and evaporative type condenser. From observations & computed results it is concluded that the coefficient of performance of system is significantly higher in case of nano refrigerant than conventional pure refrigerant vapor compression refrigeration system. The nano refrigerant with 0.50g/L of Al_2O_3 in R134a shows the improved heat transfer and reduction in work of compression. The maximum possible lowest temperature of evaporator was observed when 0.50g/L concentration is used in experiment. This represents the overall improvement in the cooling capacity of the system. The addition of nano particles in required concentration facilitates the improvement in system cooling capacity. The performance parameters of the system such as Evaporator temperature & coefficient of performance are plotted on graphs.

Also, it is observed that if experiment is perform with pure R134a refrigerant using evaporative type condenser the readings are very closer to the readings obtained for 0.5g/L concentration of Al_2O_3 in R134a. This reveals that if existing experiment setup is coupled with evaporative condenser then its effect on performance of system is almost same as that of required nano particle in base refrigerant.

It can be suggested that use evaporative condenser is more feasible than use of nano refrigerant in suitable concentration. Use of nano refrigerant can be expensive and complex over use of evaporative condenser which only require one-time installation and circulation of cooling water.

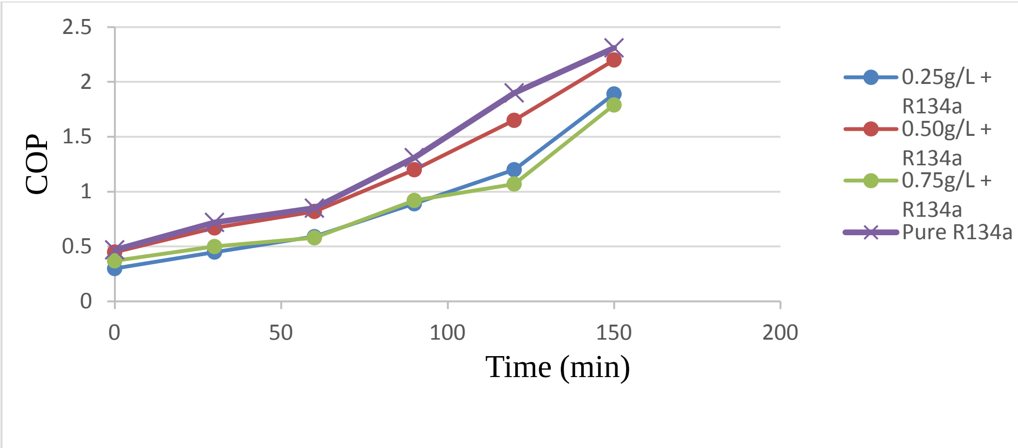

Fig.2 Variation of COP vs. Time for Different Concentration of Nano Particles in R134a

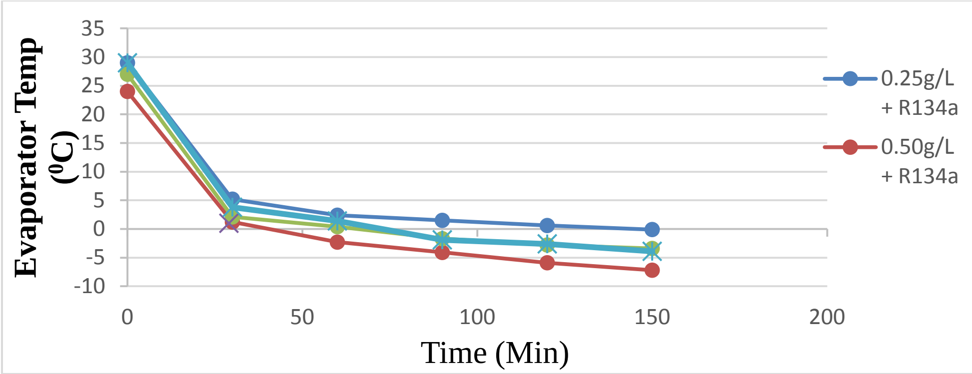

Fig.3 Variation of Evaporator Temp vs. Time for different concentration of nano particles in R134a

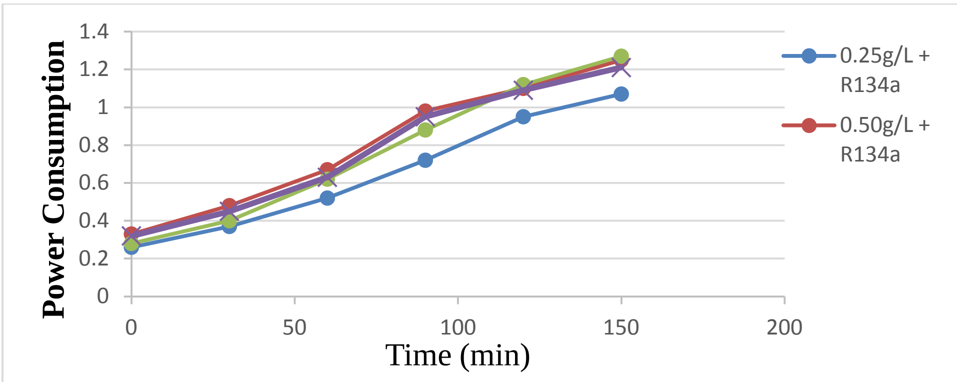

Fig.4 Variation of COP vs Time for different concentration of nano particles in R13

VI. CONCLUSION

From the above experimental investigation, it is concluded that all the trials using R134a+Al_2O_3 nanorefrigerants, in different concentration, were conducted safely in vapor compression refrigeration system. It is found that addition of Al_2O_3 nanoparticles in base refrigerant results in improvement in thermo-physical properties of refrigerant. The use of nanorefrigerant with 0.5g/L Al_2O_3 in R134a shows significant improvement (4% to18%) in coefficient of performance and reduction in power consumption (3% to 15%) compared to conventional R134a system. Also, the lowest evaporator temperature and more temperature drop across condenser are obtained at this concentration.It is also concluded that use of evaporative condenser employed with pure R134a VCR system can produce approximately similar evaporator temperature and COP that of n 0.5g/L Al_2O_3+R134a nanorefrigerant. Incorporating evaporative condenser in conventional VCR system is more feasible and economical than use of nanorefrigerant as it less expensive and simple.

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