INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.4 Issue 1,

January 2016

Pgs: 86-95

Experimental Investigation of Refrigeration System Using Al_2O_3/Water Nanofluids as Cooling Medium

Kedarnath B. Kolhapure [1], U.S. Patil [2]

[1] *PG Student Mechanical Engineering Department, Deogiri Institute of Engineering. & Management Studies, Aurangabad.*

[2] *Assistant Professor, Mechanical Engineering Department, Deogiri Institute of Engineering & Management Studies, Aurangabad.*

Abstract

Downscaling or miniaturization has been a recent major trend in modern science and technology Confronted with limited energy and material resources and undesirable manmade climate changes, science is searching for new and innovative strategies to save, transfer and store thermal energy. In the face of imminent energy resource crunch there is need for developing thermal systems which are energy efficient. Thermal systems like refrigerators and air conditioners consume large amount of electric power. So avenues of developing energy efficient refrigeration and air conditioning systems with nature friendly. The traditional method for increasing heat dissipation is to increase the area available for exchanging heat, However, this approach involves an undesirable increase in the size of a thermal management system; therefore, there is an urgent need for new and novel coolants with improved performance. The innovative concept of 'nanofluids' heat transfer fluids consisting of suspended of nanoparticles has been proposed as a prospect for these challenges. In this work experimental investigation is carried out using Al_2O_3/H_2O nanofluids with 0.1% to 0.3% wt concentration as a cooling medium in condenser of refrigeration system. From experimental the results it is found that amount heat absorbed in condenser from refrigerant found more as Compared to Base fluid Water as the concentration increased so that size of Condenser can be reduced due to more Heat Transfer. Actual compression work required gets reduced & Actual COP gets increased.

1. Introduction

Recent Technological development in the fields of electronics, Transportation Medical, HVAC&R systems and mechanical system have resulted pressing a need for performance enhanced cooling system. Heat transfer through a fluid medium finds many applications such as heat Exchangers, Automobiles, Heating and cooling system and Power Plants. Heat transfer through in fluids is essentially through convection. However the heats transfer coefficient depends upon the thermal conductivity of the fluid. To improve the thermal conductivity of the fluids Suspensions of solid particles is an effective strategy as the thermal conductivity of solids is greater than that of fluids. Nano fluids are a new class of heat transfer fluids which are engineered by dispersing nanometer-sized metallic or non-metallic solid particles or tubes in conventional heat transfer fluids such as water, ethylene glycol, and engine oil. This is a rapidly emerging interdisciplinary field where Nano science, nanotechnology, and thermal engineering meet. In the field of heat transfer, all liquid coolants currently used at low and moderate Temperatures exhibit very poor thermal conductivity and heat storage capacity resulting in their poor convective heat transfer performance. Although thermal conductivity of a fluid plays a vital role in the development of energy-efficient heat transfer equipment's and other cooling technologies, the traditional heat transfer fluids possess orders-of-magnitude smaller thermal conductivity than metallic or nonmetallic particles. Therefore, the thermal conductivities of fluids that contain suspended metallic or nonmetallic particles or tubes are expected to be significantly higher than those of traditional heat transfer fluids. With this classical idea and applying nanotechnology to thermal fluids, Steve Choi from Argonne National Laboratory of USA coined the term "Nano fluids" to designate a new class of heat transfer fluids (Choi, 1995). From the investigations performed thereafter, Nano fluids were found to show considerably higher conductive, boiling, and convective heat transfer performances compared to their base fluids (Murshed et al., 2005, 2006, 2008a, 2008b & 2011; Das et al., 2006, Murshed, 2007; Yu et al., 2008). These Nano particles suspensions are stable and Newtonian and they are considered as next generation heat transfer fluids which can respond more efficiently to the challenges of great heat loads, higher power engines, brighter optical devices, and micro-electromechanical systems. (Das et al., 2006; Murshed et al., 2008).The Fig 1. shows the comparison of thermal conductivity of different conventional heat transfer fluids and solids. Addition of nanoparticles changes the boiling characteristics of the base fluids. Nanoparticles can be used in refrigeration systems because of its

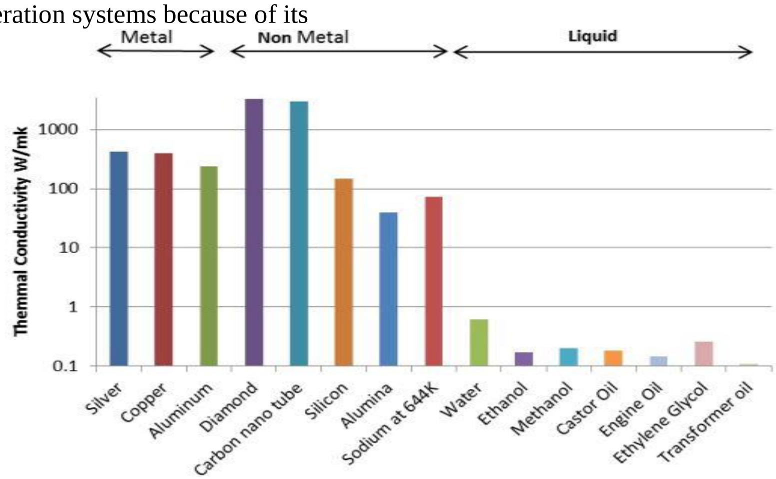


Fig: 1 - Comparison of Thermal Conductivities of Different Materials

Remarkable improvement in thermo physical and heat transfer capabilities to enhance the performance of refrigeration systems. In a VCRs the nanoparticles can be added to the lubricant (compressor oil) & the lubricant nanoparticles mixture is known as nanolubricant. Therefore, researches about convective heat transfer in nanofluids have been increasing for various applications such as electronics, air conditioning & refrigeration system.

2. Literature review

In literature several applications of nanofluids in HVAC&R have been studied, both as primary or secondary fluids. For refrigeration applications, scientists usually investigated the use of NPs as additives with conventional refrigerants & oils in order to make refrigeration systems more efficient. Recently, some investigators have conducted studies on vapour compression refrigeration systems, to study the effect of nanoparticles in the refrigerant/lubricant on its performance. Wang et al. (2003)[3], they studied a refrigeration system working with R134a & mineral oil added with TiO2 nanoparticles; better performances than using Polyolester (POE) oil. Shengshan et.al (2007) [4], Bi et al. (2008) [5], conducted studies on a domestic refrigerator using mixture of mineral oil TiO2 was used as the lubricant with R134a They found that the refrigeration system with the nanorefrigerant worked normally & efficiently & the energy consumption reduced & refrigerator performance improved when compared with R134a/POE oil system. Similar results were found by Subramani & Prakash (2011)[9], they employed Al_2O_3 nanoparticles at 0.06% by weight in mineral oil instead of POE in the cycle compressor & they found about 25% reduction of power consumption. Jwo et.al (2009) [6], conducted studies on a refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant & Al2O3 mineral lubricant. Their studies show that the 60% R-134a & 0.1 wt % Al2O3 nanoparticles were optimal. & the power consumption was reduced by about 2.4%, & the COP was increased by 4.4%. Kristen Henderson et.al (2010) [7], conducted an experimental analysis on the flow boiling heat transfer of R134a based nanofluids in a horizontal tube. They found excellent dispersion of CuO nanoparticles with R134a & POE oil & the heat transfer coefficient increases more than 100% over baseline R134a/POE oil results. K.P. Kumar et.al [2013] [1], studied the heat transfer Properties of Nano fluids (volume fraction 0.1 % to 0.5%), sisal & silicon Nano particles in Shell & coil Heat Exchanger & concluded that Heat Transfer Rate Enhanced by Using Nano fluids as Compared to base Fluid. Dr. Nimai Mukhopadhyay et.al (2013) [8], they summarized the nanofluid preparation methods reported by different investigators in an attempt to find a suitable method for preparing stable nanofluids. Moreover, challenges and future directions of applications of nanofluids have been reviewed. R. Reji Kumar et.al (2013) [11], Investigated heat transfer enhancement numerically using Al2O3 Nanolubricant & R600a/mineral oil/nano-Al2O3 as working fluid in domestic refrigerator they found that Freezing capacity higher & the power consumption reduces by 11.5 % & the COP increases by 19.6 %. Subramani et al. (2013) [17], investigated performance of a VCRs using nano-lubricant with mineral oil and mineral oil with different nanoparticles added to it. They concluded nanolubricant works normally and safely. It is found that power consumption reduces by 15.4% & the COP increases by 20% when TiO2 nanolubricant is used instead of SUNISO 3GS. T. Coumaressin and K. Palaniradja (2014) [12], carried out Performance Analysis Using CuO-R134a Nanofluids in the VCRs with concentrations ranged from 0.05 to 1% with using FLUENT Heat transfer coefficients were evaluated for heat flux ranged from 10 to 40 KW/m2. & found evaporator heat transfer coefficient increases with the usage of nano CuO. Laura et.al (2014) [13], Several Nanolubricants, formed by Polyolester (POE) or mineral oil as base fluid, & TiO2 or SWCNH as nanoparticles, were studied in a dedicated test rig. In contrast with the published literature, no improvement was detected using nanofluids instead of commercial oil. Fatou Toutie Ndoye et.al (2014) [15], studied numerically energy performance secondary loops of refrigeration Systems using nanofluids for various types of nanoparticles (Al2O3, Co, CuO, Fe, SiO2 and TiO2) and a wide range of volume fraction they found that heat transfer coefficients significantly & pumping power also increased with the increase of nanoparticles concentration whatever the flow regime Prof (Dr) R S Mishra (2014) [16], described thermal modeling of VCRs using R134a in primary circuit & Al2O3-Water based nanofluids in secondary circuit. The model uses information of the secondary fluids input conditions geometric characteristics of the system, size of nanoparticles and the compressor speed to predict the secondary fluids output temperatures, the operating pressures, the compressor power consumption and the system overall energy performance. Simulation results have shown that for the same geometric characteristics of the system performance increased from 17% to 20% by application of nanofluid as a secondary fluid in VCS.

3. Methodology

3.1 Experimental test rig

A vapour compression test rig is a table mounted unit which uses water as a heat sources & sink for both cooling and heating purposes. The apparatus consists of, the compressor is mounted centrally and both evaporator and condenser are mounted on either sides of compressor.

Fig: 3.1- Experimental Test Rig

Specifications:

01. Compressor. Hermetic Reciprocating Type; 02. Condenser. Water Cooled," O. Copper Tube, Shell & Coil type; 03. Evaporator. Water cooled 3/8" O copper tube Shell and Coil type; 04. Expansion Device. Thermostatic, Danfoss make; 05. Pressure Gauges. i). 0-300 PSIG. Wika make. ii). -30" of Hg to 150 PSIG. Wika make; 06. Refrigerant R-134a (Non – CFC); 07. Rota meter for liquid Refrigerant flow measurement.CVG Make Range – 6.6 to 66 LPH; 08. Energy meter for compressor input power measurement; 09. Temperature indicator Multichannel, Digital. Range up to 10000C with PT100 type thermocouples.

3.2 Preparation of nanofluids

The preparation of nanofluids is that the first key step in experimental studies with nanofluids. There are commonly two methods for the preparation of nanofluid that is single step and two step method. In these study two step methods is employed for preparation of nanofluids. The Nanoparticles of Aluminum Oxide purchased directly from Intelligent Materials Pvt Ltd. the Aluminum Oxide nanopowder with 0.1, 0.2, 0.3 wt% was added in to the pure distilled water act as base fluids then, composition dispersed by magnetic stirring followed by sonication & total solution Agitated using Agitator. No surfactant was used in aluminum oxide water suspensions.

Properties of nanoparticles:- Chemical Formula- Al_2O_3; Color- White; Morphology- Spherical; Density-3.950 g/cm3; Phase- Alpha phase; Average particle Size- Less than 100 nm; Surface area-15-20 m^2/gm

Fig 3.2: - Magnetic Stirring

Fig 3.3: - After 8 hours Magnetic Stirring

Fig: 3.4 Agitation

Fig: 3.5 - Nanofluid suspension After 24 Hrs

Following Mathematical Models used Calculate the properties of Nanofluids

Specific Heat of nanofluid kJ/Kgk = $Cp,_{nf} = \dfrac{\phi\,(\rho s\ Cp,\ s) + (1-\phi)\,\rho w\ Cpw}{\rho_{nf}}$ (1)

Where

1). The Nanoparticles Volume Fraction (ϕ) = $\dfrac{\text{The Nanoparticles Volume in Nanofluid Suspension}}{\text{Total Volume of Nanofluid}}$ (2)

$$= \frac{Vs}{Vt} = \frac{(\rho_s / ms)}{Vt}$$

2). Density of nanofluids $\rho nf = \phi\,\rho s + (1-\phi)\,\rho_w$ (3)

3). Specific Heat of Aluminum Oxide = $C_{p,\,Al2O3} = 22.08 + 0.008971T - \left(\frac{522500}{T^2}\right)$ (4)

4). Thermal conductivity of nanofluid (Maxwell Equation) $K_{nf} = \frac{(K_s + 2K_f) - 2\phi(K_s - K_f)}{(K_s + 2K_f) + \phi(K_s + K_f)} \times K_f$ (5)

S. N.	Cooling Medium	Specific Heat Kj/Kgk	Density kg/m3	Thermal conductivity w/mk
1	Pure water	4.18475	998	0.613
2	0.1 wt% Al2O3/H2O Nanofluids	4.1875	998.194	0.613
3	0.2 wt% Al2O3/H2O Nanofluids	4.1874	998.231	0.61301
4	0.3 wt% Al2O3/H2O Nanofluids	4.1874	998.266	0.61303

Table 3.1 Properties Summary of nanofluids

3.3 Experimentation and calculations

Experimentation is carried firstly with hard water as cooling medium in water cooled condenser refrigeration system. The readings are taken with hard water 9-10 times & with Distilled Water (pure Water) 5-6 Times, from the readings it is found that the Experimental set up was better precise. Then the experimentation is carried out with Aluminum oxide/Water nanofluids as cooling medium in condenser with 0.1, 0.2, & 0.3 wt% concentrations.

S. N.	DESCRIPTIONS & SYMBOLS	Readings			
		Pure water	0.1wt% Al2O3 /H2O	0.2wt% Al2O3 /H2O	0.3wt% Al2O3 /H2O
1	Cond. water initial Temp (Tci) 00 C	30	31	31	31
2	Cond. water/Nanofluid Temp after 10 min (Tci) 00 C	42	45	49	54
3	Time Required for 25 blinks on Compressor Energy Meter In sec (Tc)	51	53	54	57

Table 3.2: - Observations with Distilled water & nanofluids

6). Condenser Heat output = Mcw.Cpw. ΔTc / t (6)

7).Actual Compressor work = $\frac{25 \times 3600}{Tc \times EMC}$ (7)

Where EMC= energy meter constant = 3200 imp/Kwhr

8). Actual COP = $\frac{\text{Heat absorbed in evaporator from water.}}{\text{Compressor work}}$ (8)

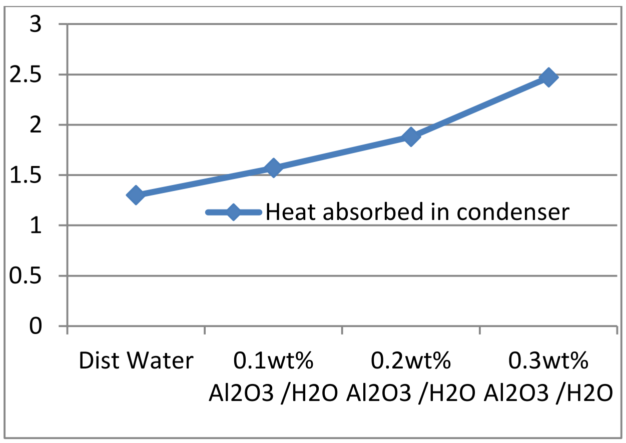
Using equations 6, 7 & 8 the results obtained are presented in following table

Cooling Medium	Heat absorbed in condenser	Actual Compression Work	Actual COP
Dist Water	1.3	0.551	2.08
0.1wt% Al2O3 /H2O	1.57	0.530	2.37
0.2wt% Al2O3 /H2O	1.88	0.520	3.01
0.3wt% Al2O3 /H2O	2.47	0.494	3.39

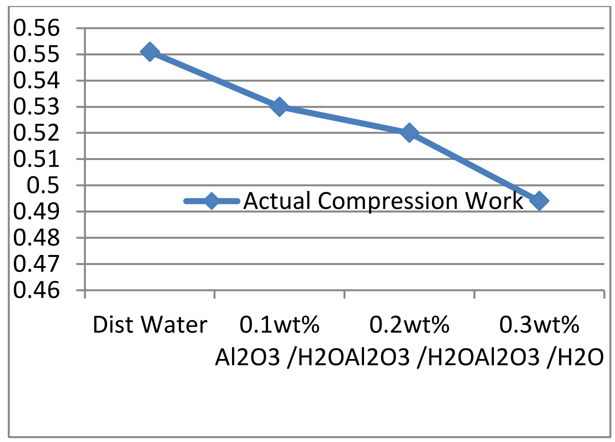
Table 3.3: Experimental Results Summary

4. Results and discussions

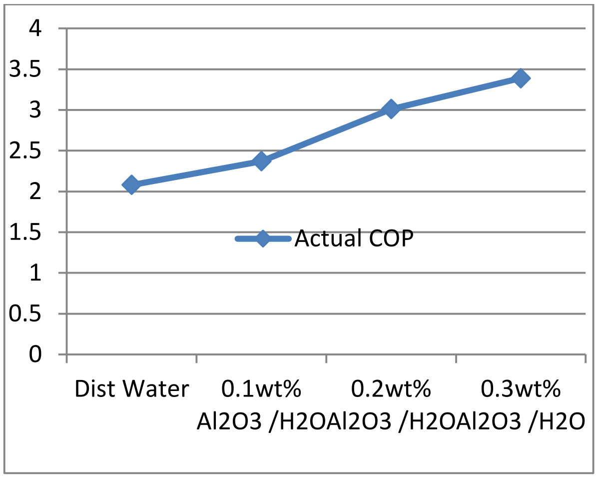
Experimental Investigation is carried out by using hard water (9-10 Times) Distilled water (5-6 Times), & Al2O3/water Nanofluids with 0.1 to 0.3 wt% Concentration (Three Times for each Concentrations) as cooling medium in water cooled condenser refrigeration system. Also Regression Analysis is carried out for Nanofluid Concentration versus heat Absorbed in Condenser Actual Compression, Work COPact etc.



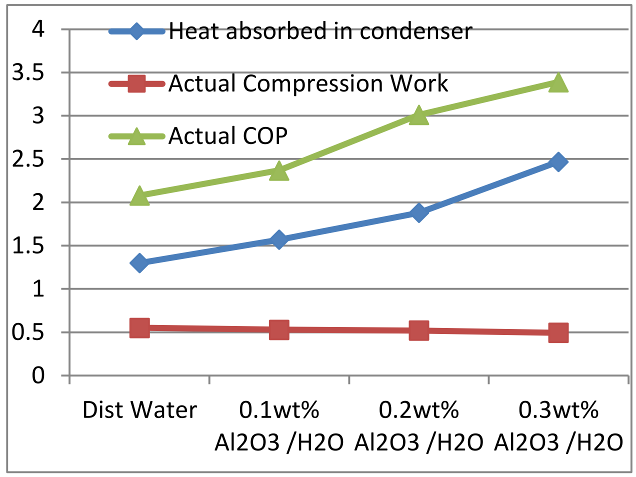
4.1. Exp. Results Plot for CONC. Vs Habs in condenser.



4.2. Exp. Results Plot for CONC. Vs W_{ACT}



4.3. Exp. Results Plot for CONC. Vs Actual COP



4.4. CONC. Vs Habs in condenser WACT, Actual COP.

From the experimental results it is found that as the concentration of Al_2O_3 nanoparticles in Condenser Water increased from 0 to 0.3 %. The amount heat absorbed in condenser increased as compared to pure water and compression Work get decreased, hence results increase in actual coefficient performance of the system. Thermal properties of pure water will be enhanced due to addition of nanoparticles in pure water hence more amount heat absorbed in condenser increased due to addition of nanoparticles in pure water.

1. Maximum percentage increase in amount heat absorbed in condenser by 37.40% & actual coefficient performance of system by 87% of refrigeration system, found at the Concentration of nanoparticles 0. 3%.
2. The power consumption of Vapour Compression refrigeration system decreased by Maximum 1.2% found at the Concentration of nanoparticles 0. 3%,
3. Also from the regression result Analysis it is found that nanoparticles concentration in condenser water has Great influence on amount heat absorbed in condenser Actual Compression Work etc of refrigeration system for Concentration from 0-0.3%. The results obtained with regression analysis fit with experimental results.

5. Conclusions

Amount heat absorbed in condenser increased so size of condenser can be increased due to more amount of heat transfer. Actual coefficient performance of refrigeration system increased as the concentration of nanoparticles increased from of 0 % to 0.3%. The power consumption of vapour compression refrigeration system decreased as the Concentration of nanoparticles increases from of 0.1% to 0.3%. The use of nanofluid as cooling medium will be the best method for enhancing the performance of refrigeration system. Using this method there is no need to modify the current system or to add the extra components in the system. Maintaining the uniform suspension of nanoparticles in water cooled condenser is the big Challenge.

6. Future scope and challenges

Experimentation is carried out for Time 10 minutes only also the flow rate of water & Nanofluid in Evaporator and Condenser are Kept Constant or fixed. Experimentation can carry out with varying the flow rate of water/Nanofluid in Evaporator & Condenser for different time intervals, with different types of nanoparticles, by adding Surfactants in nanofluid which will results increase in stability of Nanofluids also with different types Condenser configurations.

Preparation and maintaining the uniform/Homogenous suspension of nanoparticles water is the big challenge because it is found that nanoparticles settle down at the bottom of condenser after some time.

Acknowledgement: We are Very much Thankful to Head of the Mechanical Engineering Department of DIEMS A'BAD, Head of the Nano-Technology Department Dr. BAMU University Aurangabad for Supporting & providing Facilities for This Work.

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