Performance Enhancement of Refrigeration Systems Using Nanomaterials- A study

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ABSTRACT

Application of nanomaterials in refrigeration system is relatively new concept for performance enhancement due to improved thermal properties and tribologicalbehavior of nano-refrigerants and nano-lubricants respectively. Thermal performance of the mixture of refrigerants (such as R-113, R134a, R-123) andnano materials e.g. CNT, TiO_2, Al_2O_3 and CuO in refrigeration and air conditioning systems have been studied by many researchers experimentally worldwide.On the basis of available literature on the subject performance improvement of refrigeration systems has been thoroughly studied and reviewed in this paper.

I INTRODUCTION

Molecules and structures with at least one characteristic dimension measured from 1 to 100 nanometers are called "nanoparticles". Now a day's many commonly used nano materials in engineering applications are:Al_2O_3, Carbon Nano Tubes,Single-Walled carbon Nano Tubes(SWCNT),Multi-Walled carbon Nano Tubes(MWCNT), TiO_2, CuO , Carbon nano horn, Fullerene, Deldriners,Quantum dots, Nano gold, Nanosilver, Nanocopper etc.

These are conventional fluids (e.g. water, ethylene glycol, Oils, Acetone glycol, Refrigerants, Lubricants and Mineral Oils) in which nano materials are mixed in order to get nano fluids and thus, nanometer (10^{-9} m) sized particles are suspended in nanofluids. Properties of nanofluid depend on the nano material used, its size and shape, mass / volume concentration and method of preparation.Preparation of nano fluids is the first step in applying nano phase particles to changing the performance of base fluid. The nano fluid does not simply refer to a liquid-solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles and no chemical change of the fluid. In general these are effective method used for preparation of suspension:(i) changing the pH value of suspension, (ii) using surface activators and / or dispersants, (iii) using ultrasonic vibration. These methods can change the surface properties of the suspended particles and can be used to suppress the formation of particle clusters in order to obtain stable homogeneous suspension. Use of these techniques depends on the required application of the nano fluid. (Visinee et al.[6])

Nano materials can be used to improve the performance of refrigeration system due to their special properties. Nano fluid has the superior heat transfer capability because of improved thermal conductivity, convective heat transfer coefficient and phase change properties. However, nanofluids can enhance or reduce the boiling performance and degradation of systemperformance increased with increase in nmconcentration (Sergio et. al. (2010) [5]). Many researchers (Ki-Jung et. al., 2010 [1], Hao et. al.[3], Weiting et. al.[2]) have tried nanomaterials with different refrigerants in refrigeration and air conditioning systems.

II KEY FINDINGS ONNANO MATERIAL-REFRIGERANT MIXTURES

Multiwalled CNT's were mixed with R123 and R134a and experiment were performed (Ki-Jung et. al., 2010)at 20 and 60 kW/m^2 heat fluxes at the evaporator of building chillers. It was found that CNT's help enhance nucleate boiling heat transfer greatly at low heat fluxes. Important observation was that there was no fouling on the evaporator surfaces and efficient energy removal capability associated with CNT's in the evaporators of large building chillers will help reduce the energy consumption of the devices used and in turn will result in lowering green house warming.

R113 refrigerant and CuOnano particles of 40 nm were mixed (Hao et. al., 2009) at 78.25 kPapressure.Study was carried out at mass flux varying from 100 to 200 kg $m^{-2}s^{-1}$, heat flux from 3.08 to 6.16 kW m^{-2}, inlet vapor quality from evaporator 0.2 to 0.7 and mass fraction of nano particles from 0 to 0.5 wt %. The experimental results show that the heat transfer coefficient of refrigerant – based nano fluid is larger than that of pure refrigerant, and the maximum enhancement of heat transfer coefficient is 29.7%.

Mineral oil with TiO_2 nanoparticles mixtures were used as the lubricant instead of polyol-ester (POE) oil in the 1,1,1,2-tetrafluoroethane (HFC134a)(Sheng-shan et. al., 2008).The result indicate that the refrigerator performance was better than the HFC134a and POE oil system, with 26.1 % less energy consumption with 1% mass fraction of TiO_2 nanoparticles compared to the HFC134a and POE oil system.

Single wall carbon nanohorns (SWCNH) and TiO_2were mixed with commercial POE oil together with R133a refrigerant at different temperatures (Sergio et. al., 2010). Results showed that the tribological behavior of the base lubricant can be either improved or worsen, depending on the property of nano lubricant (anti-wear or extreme-pressure behavior), by adding small amount of nanoparticles. On the other hand nanoparticles dispersion in the base oil did not affect significantly the solubility.

Table 1 Important finding of different refrigerant-nano material mixtures for refrigeration systems

S. No	Refrigerant/ Lubricant	Nano Material	Application	Findings				Reference
				Heat transfer coefficient	Thermal conductivity	Energy consumption	Stability	
1	R-123	Carbon Nano Tubes (CNT), 1.0 vol %, 20 nm dia and 1μm length	Building chiller	Increased upto 36.6%	Increases	Reduced substantially	Stable	Ki-Jung et. al., 2010 [1]
	R-134a							
2	R-113	CuO, Upto 0.5 wt %, 40 nm,	Refrigeration	Increase upto 29.7%	Increases by 3%	Reduced substantially	Stable	Hao et. al.[3]Weiting et. al.[2]
3	HFC134a	TiO_2, 0.1 mass %	Domestic Refrigerator	Improve	—	26.1 % decrease	Highly Stable (>50 days)	Sheng-shan et. al.[4]
	HFC134a	$Al_2O_3$0.1 mass %	Domestic Refrigerator					
4	R-134a/ POE	SWCNH, Up to 0.6043 mass fraction, 100 nm dia.	Refrigeration and air conditioning	—	—	Reduced substantially	Stable	Sergio et. Al. [5]
		TiO_2, Up to 0.684 mass fraction, 21 nm dia.	Refrigeration and air conditioning					
5	R-113	No. 1 CNT, Upto 1.0 vol %, 15 nm dia. 1.5 μm Length	Refrigeration systems	—	Increase upto 82%	—	—	Weiting et. al.[2]
	R-113	No. 2 CNT, Upto 1.0 vol %, 15 nm dia. 10 μm Length	Refrigeration systems	—	Increase upto 104%	—	—	
	R-113	No. 3 CNT, Upto 1.0 vol %, 80 nm dia. 1.5 μm Length	Refrigeration systems	—	Increase upto 43%	—	—	
	R-113	No. 4 CNT, Upto 1.0 vol %, 80 nm dia. 10 μm Length	Refrigeration systems	—	Increase upto 50%	—	—	

III RESULT AND DISCUSSION

3.1 Heat transfer coefficient

Table 2 lists the heat transfer enhancement with nano material. Test results show that the nucleate boiling of refrigerates were increased with addition of nano materials.

Table 2 Enhancement in heat transfer coefficients with the use of nanomaterials

S. No	Refrigerent	Nanomaterial	Concentration	Heatflux (kW/m^2)	Evaporation Pressure (kPa)	Heat Transfer coefficient (kW/m^2k)		Enhancement(%)	Reference
						without NM	with NM		
1	R123	CNT	1.0 vol %	20.0	44.50	1136	1461	28.6	[1]
2	R123	CNT	1.0 vol %	60.0	44.50	2747	3493	27.1	[1]
3	R134a	CNT	1.0 vol %	20.0	374.6	3184	4349	36..6	[1]
4	R134a	CNT	1.0 vol %	60.0	374.6	7421	8888	19.8	[1]
5	R113	CuO	0.1 wt %	3.08	78.25	933	1130	21.11	[3]
6	R113	CuO	0.1 wt %	4.62	78.25	1640	1655	0.90	[3]
7	R113	CuO	0.1 wt %	6.16	78.25	1756	1890	7.63	[3]
8	R113	CuO	0.2 wt %	3.08	78.25	933	1144	22.61	[3]
9	R113	CuO	0.2 wt %	4.62	78.25	1640	1666	1.58	[3]
10	R113	CuO	0.2 wt %	6.16	78.25	1756	2257	28.53	[3]
11	R113	CuO	0.3 wt %	3.08	78.25	933	1248	33.76	[3]
12	R113	CuO	0.3 wt %	4.62	78.25	1640	1723	5.06	[3]
13	R113	CuO	0.3 wt %	6.16	78.25	1756	1965	11.90	[3]

Experimental data of the local heat transfer coefficient of CuO/R113 nanofluid versus the vapor quality at three mass fluxes of100, 150, and 200 kgm_2 s_1 are shown in Fig. 5 (a)–(c). It canbeseen that the heat transfer coefficient of CuO/R113 nanofluidis higher than that of pure R113 refrigerant. The presence ofnanoparticles enhances the heat transfer of refrigerant-basednanofluid flow boiling inside tube. From Fig. 5 (a)–(c), it canalso be seen that the heat transfer coefficient increases withthe increase of vapor quality of CuO/R113 nanofluidcontaininggiven mass fractions of nanoparticles (Hao et. al.[3])

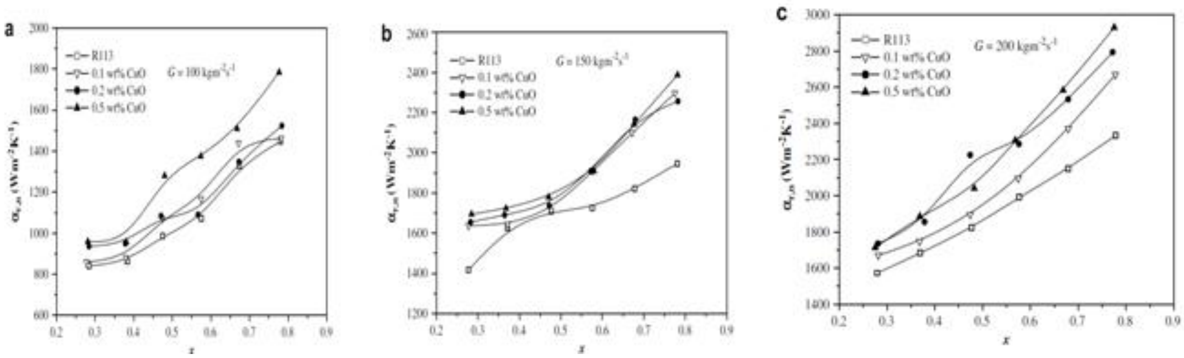

Figure 1. Heat transfer coefficient of CuO\R113 nanofluid versus local vapor quality at different mass fluxes: (a)G=100kgm^{-2}s^{-1};(b)G=150kgm^{-2}s^{-1};(c)G=200kgm^{-2}s^{-1}

3.2 Thermal conductivity

Thermal conductivity characteristics of refrigerants improve by nano materials. Improvement in thermal conductivity can be measured by the ratio of thermal conductivities of nano refrigerants and pure refrigerates (k_{nf}/k_f) [2]. Table 3 lists value of $k_{nf}/k_f$for different refrigerants and different nanomaterials.

Table 3 Thermal conductivity for different composition of nanorefrigerant (Weiting et. al.[2])

S.No.	Base fluid	Nano materials	Concentration (vol %)	K_{nf}/k_f
	R113	No.1 CNT	0.2	1.35
	R113	No.1 CNT	0.4	1.41
1	R113	No.1 CNT	0.6	1.52
	R113	No.1 CNT	0.8	1.54
	R113	No.1 CNT	1.0	1.82
	R113	No.2 CNT	0.2	1.16
	R113	No.2 CNT	0.4	1.58
2	R113	No.2 CNT	0.6	1.67
	R113	No.2 CNT	0.8	1.88
	R113	No.2 CNT	1.0	2.04
	R113	No.3 CNT	0.2	1.06
4	R113	No.3 CNT	0.4	1.12
	R113	No.3 CNT	0.6	1.20

	R113	No.3 CNT	0.8	1.41
	R113	No.3 CNT	1.0	1.43
5	Water	No.1 CNT	0.2	1.10
6	Water	No.2 CNT	0.2	1.13
7	Water	No.3 CNT	0.2	1.08
8	Water	No.4 CNT	0.2	1.05
9	R113	Cu	0.2	1.05
10	R113	Al	0.2	1.03
11	R113	Ni	0.2	1.04
12	R113	CuO	0.2	1.03
13	R113	Al2O3	0.2	1.04

3.3 Energy Consumption

Table 4 lists the energy consumption of the refrigeration system with nano materials was lower than that of the refrigerant without nano materials. The energy consumption of 0.796 kWh/day was least at a nanoparticle mass fraction of 0.1%, which is 26.1% less than the POE oil system.

Table 4 Energy consumption and oil return ratiofor different nano refrigerants

Mass fraction %	POE	0.06 TiO_2	0.1 TiO_2	0.1 TiO_2(50 days later)	MO
Energy Consumption (kWh/day)	1.07	0.849	0.796	0.849	0.796
Energy savings %		21.2	26.1	25.7	16.67
Oil return ratio %		92	-	-	84

IV CONCLUSION

Application of nanomaterials in refrigeration system is relatively new concept for performance enhancement due to improved thermal and tribological properties of nano-refrigerants and nano-lubricants. Available literature on the application of nanomaterial in refrigeration and air conditioning systems has been thoroughly studied and compiled in this paper. The main findings are as follows:

I. The heat transfer coefficients of nano refrigerant (flow boiling inside tube) are larger than that of pure refrigerant. Especially at low heat flux (20kw/m^2) the enhancement was up to 36.6%. As the heat flux further increased the enhancement decreased due to vigorous bubble generation.

II. The thermal conductivities of nano refrigerants increase significantly with the increase of the nano particle volume fraction and maximum increment up to104% has been observedwithCNT volume fraction of1.0 % in R-113.

III. The energy consumption of the refrigeration system has been reducedby 26.6% using mineral oil and nano particle mixture as lubricant. The mineral oil is the main effect for the energy saving for this technology. However, the nanoparticles enhanced the solubility of the refrigerants and the mineral oil as indicated by the higher oil return ratio. In addition, the nanoparticles enhanced the refrigerator performance.

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