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Use of Nanoparticles In Refrigeration Systems: A Literature Review Paper

Amey Majgaonkar
Kirloskar Pneumatic Co. Ltd, India, amey.majgaonkar@gmail.com

Use of Nanoparticles In Refrigeration Systems: A Literature Review Paper

Amey Sharad Majgaonkar [1]*

[1] Kirloskar Pneumatic Co. Ltd,
Air Conditioning & Refrigeration Division,
Pune, Maharashtra, India
Contact Information (Phone +919881498975, +91-(0)20-26870514, majgaonkaras@kpcl.net)

* Corresponding Author

ABSTRACT

Researchers are trying to use new generation heat transfer fluids called nanofluids in refrigeration systems. This paper presents a literature review of the research in this field. This paper briefs about basics, historical developments, nanoparticle production techniques, nanofluids & its preparation methods and limitations of using nanofluids. The paper discusses about limitations of literature reviewed and also informs about future research directions required in this field. A checklist to be used while publishing papers related to nanoparticles is also proposed. Though research with nanofluids is in primitive stage, it will not be a surprise if just like any other refrigerant; nanorefrigerants will be commercially available in future.

1. INTRODUCTION

Monetary savings from energy efficient systems & responsibility felt to contribute to save environment are encouraging researchers to use different technologies & advancements in science to make their equipments & systems more & more energy efficient. Refrigeration systems are no exceptions. This paper presents a literature review of the research with nanofluids relevant for refrigeration systems.

Reviewed literature is classified in two sections. First section evaluates basic properties of nanofluids like thermal conductivity, viscosity, heat transfer coefficient, friction factor and second section analyses application of nanofluids in refrigeration system. From literature reviewed it can be said that, for the use of nanofluids in refrigeration more research is needed in both fundamental science & in direct application. Heat transfer depends on thermal conductivity of nanofluid, and compressor energy efficiency depends upon viscosity & friction factor. Therefore, focus for fundamental research should be on determining these thermo-physical properties, mechanism of thermal transport & tribological behavior. An application related research is also equally important. It needs to be carried out simultaneously with the basic research so that basic research can be more focused on obtaining desirable properties, and developing nanofluids. An applied research must focus on stability of nanorefrigerants. The use of nanofluids appears promising, but has several challenges. Nanofluids stability and its production cost are major hurdles in using nanofluids. Since research about nanofluids is only in primitive stage large amount of research is possible in this field. This presents a big challenge to find suitable nanofluids of desirable properties for refrigeration application.

While evaluating performance of refrigeration system, effect of nanofluid preparation method, effect of various types of nanoparticle materials, variation of sizes of nanoparticles, variation of concentration of nanoparticles, variation of suspension concentration in refrigerant needs to be investigated. Available nanoparticle materials are limited, however there are too many combinations of base fluid (refrigerants & oils) with nanoparticles and too many variables (sizes, concentration) & alternatives to explore & research. Development of nanoparticle production & dispersion technique will further enhance nanofluid research possibilities. Any new development of nanoparticle material shall also go through all production, research, & experimentation steps. Public concern about nanoparticles safety both in production and in use shall also be required to be considered. Possibility of using non-toxic or biodegradable nanoparticles can also be explored. Low cost, high volume production of stable green nanofluids suitable for refrigeration application is one of the most challenging objectives.

2. HISTORICAL DEVELOPMENTS

More than a century ago, Maxwell initiated the efforts to enhance inherently poor thermal conductivity of liquids by adding solid particles in base fluids. Earlier studies used millimeter or micrometer solid particles, which led to problems such as rapid settling of solid particles, clogging, surface abrasion & high-pressure drop, limiting their practical applications. Nanofluids have good potential to overcome these problems.

Choi (1995) conceived the novel concept of nanofluids by making use of particles sizes in the order of 1 to 100 nm. Research on heat transfer enhancement by adding nanoparticles has had mixed results since then. Gains & losses of heat transfer have been reported. Main factors, which influence the results, are nanoparticle material, nanoparticle concentration, nanofluid preparation methods & testing consistency. In last decade, the number of published articles mentioning nanoparticles has increased significantly in refrigeration field.

3. NANOPARTICLES

In nanotechnology, a particle is defined as a small object that behaves as a whole unit with respect to its transport properties. Nanoparticles are between 1 and 100 nanometers (1×10^{-9} and 1×10^{-7} m) in size. Tubes and fibers with only two dimensions below 100 nm are also nanoparticles. Novel properties that differentiate particles from bulk material typically develop at a critical length scale of 100 nm. They are made from ceramics, metals & metal oxides.

4. NANOPARTICLE PRODUCTION TECHNIQUES

Nanoparticles can be produced from mechanical attrition, pyrolysis, gas condensation, chemical precipitation. Methods like dc plasma jet, dc arc plasma, radio frequency induction plasmas, chemical synthesis, gamma rays and laser ablation are used. Inert-gas condensation is frequently used to make nanoparticles from metals with low melting points. Depending upon application (properties) & cost, specific manufacturing technologies are chosen.

5. NANOFLUIDS

Nanofluids are engineered colloidal suspensions of nanoparticles in base fluids at modest concentrations showing significant enhancement of their properties. Compared to normal solid liquid suspensions nanofluids have 1) higher heat transfer between particles & fluids due to high nanoparticles surface area 2) better dispersion stability with predominant Brownian motion 3) reduced particle clogging & 4) reduced pumping power compared to base fluid.

Nanoparticles can be added to the lubricant (compressor oil) and the lubricant nanoparticles mixture is known as nanolubricant. Similarly nanoparticles can be added to the refrigerant and the refrigerant nanoparticles mixture is known as nanorefrigerant. Nanolubricant-refrigerant can be prepared by mixing pure refrigerant with nanolubricant. Nanolubricant, nanorefrigerant & nanolubricant-refrigerant are type of nanofluids. In refrigeration systems, nanolubricant improves tribological characteristics improving compressor performance; nanorefrigerant improves thermo-physical properties, improving refrigerating effect. Presence of nanoparticles enhances solubility between oil & refrigerant and returns more oil back to the compressor.

6. PREPARATION OF NANOFLUIDS

Nanofluid can be produced by one-step and two-step techniques. One-step technique, combines production & dispersion of nanoparticles in the base fluid into a single step & in two-step technique, these two steps are separate. Nanofluids preparation is a key step in experimentation requiring four guidelines 1) Dispersability of nanoparticles 2) Stability of nanoparticles 3) Chemical compatibility of nanoparticles 4) Thermal stability of nanofluids.

In refrigeration systems, preparation of nanolubricant is comparatively easier than direct preparation of nanorefrigerant, as only few refrigerants are available in liquid state at atmospheric pressure. Nanoparticles of required type & size are dispersed in base fluid after precise weighing on electronic balance. Stirring is done in a mechanical stirrer for some period followed by ultra sonic vibration technique to form a stable nanofluid. Surface-active agents and/or dispersants are generally not used. Nanoparticles increase the surface area; improve mixing, turbulence & temperature distribution in nanofluids. Suspension of highly thermally conductive materials is not always effective to improve the thermal transport properties of nanofluids. Refer Table 1 below. CNT has highest thermal conductivity. Aligned CNTs are easier to disperse. However it is most expensive option. Natural Diamond has second highest thermal conductivity with no significant health risks but is second most expensive option. CuO & ZnO can be dangerous for health. Al_2O_3 reacts with water & heat is generated. Oil has low thermal conductivity whereas refrigerant has very low thermal conductivity. For other nanoparticles study is limited.

Table 1: Thermal conductivity of different materials

Material	CNT	Diamond	Cu	Al	Ni	Ni	Si	CuO	ZuO	Al_2O_3	TiO_2	Oil	Refrigerants
Thermal Conductivity (W/mK)	1800 to 6600	2200 to 2300	350 to 400	200 to 250	90 to 240	100 to 150	100 to 150	20 to 40	10 to 50	30 to 40	0.4 to 11.8	0.1 to 0.2	0.01 to 0.09

7. LIMITATION OF USING NANOFLUIDS

The use of nanofluids seems attractive but its application is hindered by many factors like poor long term stability, high pressure drop, high pumping power, low specific heat, particle settling, fouling and high production cost.

8. LITERATURE REVIEW

In literature review, Table 2 summarizes basic research & Table 3 summarizes applied research in refrigeration

Table 2: Summary of basic research

Year	Researcher	NP	Size, nm NPC	Nanofluids	Key Results & Remarks
2014	Anoop, K., et al	SiO_2	20 1, 2 NPVFL	MO+SiO_2	Viscosity ~ NPC, Viscosity ~ Pressure, at high temp. Viscosity of nanolubricant is less affected by pressure. Viscosity ~ (1/Temperature), below 100 deg C viscosity remains almost same. At high pressure & temp. viscosity of nanofluid is unexpectedly affected.
2008	Bartelt, K., et al	CuO	30 -	R134a + POE (RL68) + CuO	At 4 % NPVFL, flow boiling experiment showed 0.5 % NLMF has no effect on flow HTC. 1 % NLMF increases HTC 42 to 84 %. 2% NLMF increases HTC 50 to 101 %. Presence of NP has insignificant effect on system pressure drop.
2015	Behabadi, M., et al	CuO	40 0.5,1,1.5 NPMFL	R600a + (POE RL68H + CuO)	At 1.5 NPMFL & 1 NLMFR, HTC increases 83 % compared with pure refrigerant.
2013	Dhindsa G, Lalkundan, R.	Al_2O_3	20 0.01-0.05 NPVF	R11 + Al_2O_3	Viscosity increases linear with respect to NPVF up to 0.03 then sharp increases. Small NPVF useful for refrigeration

Table 2 (Continued): Summary of basic research

Year	Researcher	NP	Size, nm	NPC	Nanofluids	Key Results & Remarks
2009	Ding, G., et al	CuO	40	Variable	R113+ RB68EP +CuO	Migrated mass of NP in pool boiling increases with increase in initial mass of NP & mass of nanorefrigerant. (MR) ~ (1/ NPVF)
2010	Fedele, L., et al	TiO_2	21	Many values of NPC for each NP	R134a & (TiO_2 + POE /MO) / (SWCNH+ POE)	No improvement in rotary compressor efficiency or heat transfer.
		SWC NH	100			
2011	Hadi, et al	CuO	15 -70	0.1 to 1 NPMFL	R134a + (Oil + CuO)	For all heat flux values, evaporating HTC increases with 1. NPC from 0.1 to 0.55 % & then decreases 2. NP size from 15 to 25 & then decreases
2006	Hays, A., et al	Al_2O_3	47	2 NPMF	de-ionized water + NP	Nanofluid preparation method affects resultant thermal conductivity. NP size in dry state may be different than in effective NP size in nanofluid. This is to be remembered while matching experiment with theory.
2010	Henderson	CuO	-	0.5,1,2	R134a & (POE oil + CuO)	Flow boiling HTC increases with increase in NPC. Increase in HTC up to 100 % compared with R134a & POE Oil. Excellent dispersion of CuO NP with R134a & POE oil having insignificant effect on flow pressure drop
2010	Henderson	SiO_2	-	.05,.08,.5 NPVF	R134a + SiO_2	NP decreases flow boiling HTC. Inverse result compared to other studies. Dispersion method influences results.
2009	Jiang, W., et al	Cu	25		R113 + NP	Thermal Conductivity ~ NPVF. Thermal Conductivity of nanorefrigerants with various kinds of NPs is close to one another if NPVF is same.
		Al	18			
		Ni	20			
		CuO	40			
		Al_2O_3	20			
2009	Kedzierki, M. & Gong M.	CuO	30	1 NPVFL	R134a + POE + CuO	Nucleate pool boiling HTC increases between 50 to 275 %.
2009	Kedzierki, M.	CuO	30	4, 2 NPVFL	R134a + POE + CuO	No improvement or degradation in boiling HTC at 2 % NPVFL with respect to R134a & POE without NP.
2006	Lee, J., et al	CNP	-		R22 & (MO + CNP)	Increase in breaking pressure of oil film up to 225 %. Friction coefficient 0.015. It is lower than 0.023 of pure oil. Thus, enhancement in anti-wear characteristics at the thrust slide-bearing of scroll compressor.
					MO + 0.1 % CNP wt.	Higher suspension stability. Viscosity of oil increases in proportion to volume fraction.
					MO + 0.1 % CNP wt.	Better lubrication properties & better polishing of friction plates than pure oil.
2013	Mahbubul, I., et al	Al_2O_3	30	1 to 5 NPVF	R134a + Al_2O_3	Thermal Conductivity ~ NPVF Thermal Conductivity ~ temperature Thermal Conductivity ~ (1/ Particle size) NPVF ~ pressure drop ~ pumping power ~ viscosity
2011 2012	Mahbubul, I., et al	TiO_2	-	Up to 2 NPVF	R123 + TiO_2	Theoretical study shows viscosity increases with increase in particle volume fraction.

Table 2 (Continued): Summary of basic research

Year	Researcher	NP	Size, nm / NPC	Nanofluids	Key Results & Remarks
2007	Park, K., & Jung, D.	CNT	20 nm x 1 µm / 1% vol.	(R22/R123 /R134a) + CNT	Pool boiling HTC increases about 36.6 % at low heat fluxes less than 30 kW/m^2.
2009 a	Peng, H., et al	CuO	40 / NPMFR 0.1, 0.2,0.5	R113 + CuO	Flow boiling HTC (CuO + R113) is higher than pure R113 up to 29.7 %. Useful heat transfer correlation is proposed.
2010 b	Peng, H., et al	Diamond	10 / NPCRL 0.05,0.1, 0.15,0.25 ,0.3,0.45, 0.5,0.75	R113 & (VG68 oil + Diamond)	Nucleate pool boiling HTC increased by 63.4%. The enhancement increases with increase of NPC in the nanoparticles/oil suspension and decreases with the increase of nanoparticles/oil suspension concentration. Useful heat transfer correlation is proposed.
2011 c	Peng, H., et al	Cu	20, 50, 80 / NPCRL 0.1,0.2,0.3,0.6,1.0	R113 + (Oil VG68 + Cu)	Nucleate pool boiling HTC increased up to maximum 23.8 % with decrease in nanoparticles size at fixed NPC. The enhancement increases with increase of NPC in the nanoparticles/oil suspension and increases with the decrease of nanoparticles/oil suspension concentration. Useful heat transfer correlation is proposed.
2011 d	Peng, H., et al	Cu	20, 50, 80	R113, R141b, n-Pentane + Oil RB68EP + NP	MR ~ (1/NP Density) MR ~ (1/NP size) MR ~ (1/Dynamic Viscosity) MR ~ (1/NLMF) MR ~ (1/heat flux) MR ~ (Liquid density of refrigerant) MR ~ (Initial liquid level height) MR : (Al > Al_2O_3 > Cu) at 20 nm size.
		Al	20		
		CuO	40		
		Al_2O_3	20		
			Variable		
2009	Trisaksli, V. & Won--gwises, S.	TiO_2	21 / 0.01,0.03 ,0.05 NPVF	R141b + TiO_2	Nucleate pool boiling HTC decreases with increase in NPC at high heat flux. At higher NPC, the effect of pressure on boiling HTC is less than that at lower NPC.
2008	Wu, X., et al	TiO_2	-	R11 + TiO_2	Pool boiling HTC increases with low NPC & decreases with high NPC.
2014	Zhang, F., Jacobi, A.	Al_2O_3	40 / .01,0.1,1 NPMF	Water+NP	Higher the NPC higher the wetting of surface. Surface roughness increases with NPC.

Table 3: Summary of applied research in refrigeration systems

Year	Researcher	NP	Size, nm / NPC	Nanofluids	Key Results & Remarks
2013	Abbas, M., et al	CNT	- / 0.01, 0.05,0.1 NPMFL	R134a + (POE + CNT)	Nanorefrigerant improves COP by 4.2 % at 0.1 % of CNT.
2011a	Bi, S., et al	TiO_2	50 / 0.1 & 0.5 g/L	R600a + TiO_2	Reduction in energy consumption (5.9 % & 9.6%) & improvement in freezing capacity compared with pure R600a. TiO_2-R600a system worked normally & efficiently

Table 3 (Continued): Summary of applied research in refrigeration systems

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">Researcher</th><th rowspan="2">NP</th><th>Size, nm</th><th rowspan="2">Nanofluids</th><th colspan="4" rowspan="2">Key Results & Remarks</th></tr>
<tr><th>NPC</th></tr>
<tr><td>2008 b</td><td>Bi, S., et al</td><td>TiO_2
Al_2O_3</td><td>50
0.01, 0.06, 0.1 NPMFL</td><td>R134a & (MO+TiO_2)
R134a & (MO+ Al_2O_3)</td><td colspan="4">Reduced energy consumption (>20 %) & improved freezing capacity with (MO + NP) compared with (R134a + POE) in domestic refrigerator. MO is main factor for energy saving with additional 5-10 % energy saving achieved by use of NP. Oil return improved with NP. Studied two NP have little effect on performance.</td></tr>
<tr><td>2014</td><td>Coumaressin, T., Paladiradja, K</td><td>CuO</td><td>10 to 70
0.05 to 1</td><td>R134a + CuO</td><td colspan="4">Refrigeration system performance is better with nanorefrigerant. Details of oil used are not mentioned.</td></tr>
<tr><td>2014</td><td>Hussen, H.</td><td>TiO_2</td><td>20
-</td><td>R22 + (MO+ TiO_2)</td><td colspan="4">Refrigeration system performance is better with nanorefrigerant. Compressor work reduction 13.3 % & 12 % increase in COP.</td></tr>
<tr><td>2009</td><td>Jwo, C. et al</td><td>Al_2O_3</td><td>-
0.05,0.1, & 0.2 NPMFL</td><td>Hydrocarbon + MO + Al_2O_3</td><td colspan="4">Replacing R134a refrigerant with hydrocarbon refrigerant and adding Al_2O_3 nanoparticles to the lubricant effectively reduced power consumption.</td></tr>
<tr><td>2012</td><td>Kumar, D., Elansezhian, R.</td><td>Al_2O_3</td><td>40-50
0.2 NPCLR</td><td>R134a + (PAG Oil + Al_2O_3)</td><td colspan="4">Refrigeration system performance is better with nanorefrigerant than pure lubricant & R134a.</td></tr>
<tr><td>2014</td><td>Kumar, D., Elansezhian, R.</td><td>ZnO</td><td>50
0.1, 0.3,05 NPVF</td><td>ZnO + R152a</td><td colspan="4">Performance of refrigeration system improved with reduction in energy consumption.</td></tr>
<tr><td rowspan="4">2013</td><td rowspan="4">Kumar, R., et al</td><td rowspan="4">Al_2O_3</td><td>< 50</td><td rowspan="4">R600a + (MO + Al_2O_3)</td><td>Fluid</td><td>MO +NP</td><td>MO</td><td>POE</td></tr>
<tr><td rowspan="3">0.06 NPMFL</td><td>Energy input (kWh)</td><td>0.572</td><td>0.614</td><td>0.635</td></tr>
<tr><td>COP</td><td>3.51</td><td>3.4</td><td>3.2</td></tr>
<tr><td>TP (min)</td><td>60</td><td>70</td><td>85</td></tr>
<tr><td rowspan="4">2013</td><td rowspan="4">Kotu, T., Kumar, R.</td><td rowspan="4">Al_2O_3</td><td><50</td><td rowspan="4">R134a + (MO + Al_2O_3)</td><td>Case</td><td>R134a +MO+ DPHE</td><td>R134a+ MO+NP</td><td>R134a+ MO</td></tr>
<tr><td rowspan="3">0.06 NPMFL</td><td>Energy input (kWh)</td><td>0.445</td><td>0.470</td><td>0.635</td></tr>
<tr><td>COP</td><td>3.05</td><td>2.88</td><td>2.7</td></tr>
<tr><td>TP (min)</td><td>80</td><td>90</td><td>100</td></tr>
<tr><td>2013</td><td>Sajumon, K., et al</td><td>TiO_2</td><td>21
0.2 NPMFL</td><td>(MO+TiO_2)</td><td colspan="4">Nanolubicants shows higher viscosity, smaller friction coefficient. Less power consumption, high heat transfer rate & high COP with nanorefrigerant.</td></tr>
<tr><td rowspan="4">2013</td><td rowspan="4">Subramani, N., et al</td><td rowspan="4">Al_2O_3, CuO, TiO_2</td><td>50</td><td rowspan="4">R134a & (Suniso 3GS MO + NP).</td><td>nanofluid with</td><td>TiO_2</td><td>CuO</td><td>Al_2O_3</td></tr>
<tr><td rowspan="3">0.06 NPMFL</td><td>Power (kW)</td><td>0.432</td><td>0.45</td><td>0.468</td></tr>
<tr><td>COP</td><td>2.40</td><td>2.34</td><td>2.31</td></tr>
<tr><td>TP (min)</td><td>75</td><td>80</td><td>85</td></tr>
<tr><td rowspan="4">2013</td><td rowspan="4">Subramani, N., Prakash, M.</td><td rowspan="4">Al_2O_3</td><td>< 50</td><td rowspan="4">R134a & (Suniso 3GS MO + NP)</td><td>Fluid</td><td>R134a + MO + Al_2O_3</td><td>R134a + MO</td><td>R134a + POE</td></tr>
<tr><td rowspan="3">0.06 NPMFL</td><td>Power (kW)</td><td>0.469</td><td>0.511</td><td>0.625</td></tr>
<tr><td>COP</td><td>1.78</td><td>1.6</td><td>1.34</td></tr>
<tr><td>TP (min)</td><td>80</td><td>95</td><td>110</td></tr>
</table>

Table 3 (Continued): Summary of applied research in refrigeration systems

Year	Researcher	NP	Size, nm / NPC	Nanofluids	Key Results & Remarks
2015	Vandaarkuzhali S., Elansezhian, R.	CuO, ZnO, Al_2O_3	50 / 0.1 NPMF	R22+ (de-ionized water+NP)	Air conditioning system with CuO nanorefrigerant is found to be more energy efficient than ZnO & Al_2O_3 nanorefrigerants.
2010	Zhu, Y., et al	Proprietary	-	R22+ (Oil NM56EP+ NP)	NP improve anti wear , friction conditions, reduce power conditions and increase cooling capacity and COP.

In many studies, where nanoparticles are directly mixed with refrigerants following terminology shall be useful NPMFR = Nanoparticle mass fraction in refrigerant = Ratio of mass of NP to mass of NP-refrigerant mixture. In many studies nanolubricant is first prepared by mixing nanoparticles with lubricant. Nanolubricant is then mixed with pure refrigerant, thereby making nanorefrigerant. In such cases following terminology & equations shall be useful. NPMFL = Nanoparticle mass fraction in lubricant = Ratio of mass of NP to mass of NP-lubricant mixture. NPMFL = $w_n = m_n/(m_n+m_o)$,where m_n is mass of nanoparticles in Kg, m_o is mass of lubricant in Kg. NLMFR = Nanolubricant mass fraction in refrigerant = Ratio of mass of nanolubicants to mass of nanolubricant and refrigerant mixture = $X_{n,o} = m_{n,o}/(m_{n,o}+m_r)$, where $m_{n,o}$ is mass of nanolubricant in Kg, m_r is refrigerant mass in Kg. NPCRL = Nanoparticle concentration in refrigerant & nanolubricants mixture = $y_n = w_n \times X_{n,o}$. In cases where volume of lubricant & nanoparticles is considered while preparing nanolubricant following terminology shall be useful NPVFL = Nanoparticles volume fraction in lubricant = Ratio of volume of NP to volume of NP-lubricant mixture.

9. LIMITATIONS IN LITERATURE REVIEW & FUTURE RESEARCH DIRECTIONS

Nanofluids are prepared by dispersing nanoparticles in base fluid. Dispersion stability affects thermo-physical properties of nanofluids. Dispersions can remain stable for some amount of time without coagulation, clustering & deposition. Many researchers have done the experiments within this stability time & produced the results. In real life, the refrigeration system can be continuously operated or intermittently operated, the pressure & temperatures of refrigerant change as it passes through different components in system. Therefore, if nanorefrigerant is to be used in actual refrigeration system then it needs to be stable continuously & in all practical pressure temperature conditions.

Nanofluid preparation methods influence its thermo-physical properties. Property like thermal conductivity depends upon sonication time. In many papers, it is not specifically mentioned that the same preparation method & same sonication time is used for all the cases studied. Therefore the comparison of thermo-physical properties with different nanoparticle material, size & concentrations may not be on the same platform. Similarly thermo-physical property results of one paper cannot be accurately compared with another paper if different nanofluid preparation methods are used or different sonication time durations are employed.

Nanoparticles travel along with refrigerant in refrigeration cycle. In condenser and evaporator of refrigeration systems, the refrigerant changes its phase. Similar to boiling studies, migration characteristics studies in condensation process also needs equal importance. Peng et al (2011d) & Ding et al (2009) studied the migration characteristic of nanoparticles in pool boiling experiment. Such studies shall be useful in refrigeration systems with flooded evaporators. However, the effect of compressor suction pulling force also needs to be considered in such studies to make it applicable to real cases. A large amount of study is still needed to investigate the mechanism of migration. To the author's knowledge no study is yet published with application of nanoparticles in refrigeration systems having flooded evaporators. Density of nanorefrigerant needs to be investigated as depth of the pool of boiling refrigerant in a flooded evaporator exerts a liquid pressure on lower part of heat transfer surface. Therefore, saturation temperature at this surface is higher than that in suction line, which is not affected by the liquid pressure. This temperature gradient must be considered when designing the flooded evaporator. Also oil return ports needs to be located on flooded evaporator shell considering miscibility & relative density of nanolubricant/refrigerant.

Most of the literature reports that only one type of nanoparticle is studied to make a particular type of nanofluid. To the author's knowledge, a mixture of different types of nanoparticles dispersed in a base fluid to make nanofluid containing different types of nanoparticles is not published yet. Also many studies also do not publish nanoparticle size in dry & in suspension states.

Refrigeration systems studied are mostly domestic refrigerator, home air conditioners & refrigeration test rigs employing small scroll & reciprocating type compressors. Industrial refrigeration systems are not yet studied, which contain screw & centrifugal compressors, shell & tube and plate type heat exchangers. Studied systems are mainly with halocarbon or hydrocarbon refrigerants. However natural refrigerants like ammonia are not yet studied. Studied systems are mainly dry expansion type refrigeration systems; flooded refrigeration systems are not yet studied. Most of the basic studies are related to single phase or nucleate pool boiling. More focus also needs to be given on flow boiling with and without lubricants. Most studies focus on thermal conductivity & viscosity. Basic studies are also required to focus on properties like latent heat, specific heat, density, surface tension, dielectric strength, miscibility, & solubility. Nanoparticles which improve lubrication to reduce compressor wear & tear, enhance HTC, & able to travel in refrigeration system without accumulation or settling needs to be discovered.

Data base with large number of investigations needs to be created, for knowing the trends and deciding future research direction. Since this field is in its infancy stage, it is therefore necessary to create a checklist for parameters, which should be used while publishing research. One such checklist is attempted here and investigators are welcome to update it as required. Checklist: 1) nanoparticle/s 2) size (dry & in fluid) 3) base fluid (refrigerant/ lubricating oil/ other) 4) nanofluid preparation method 5) dispersion stability duration 6) were the experimental tests performed within dispersion stability duration (when dispersion is stable)? 7) details (name, type, quantity) of surfactants/ dispersants if used 8) NPMF, NPMFR, NPMFL, NLMFR, NPCRL, NPVF, NPVFL whichever is applicable 9) details of sonication time and dispersion method used 10) experimental/test conditions. To ensure traceability and repeatability nanoparticle make and production technique may also be added in checklist if possible.

It is important to understand the physical mechanisms of heat transfer & flow behavior of nanofluids. Many investigators have provided correlations for predicting thermo-physical properties for nanofluids. However they are suitable only for narrow range with limited use in practical applications. Interdisciplinary study approach may help to develop better prediction methods useful for basic research. In application related research, experimental facility must be capable to allow understanding of the effect of change of one variable while keeping all other variables constant. Refrigeration system performance is affected too many variables like evaporating & condensing pressure-temperature, cooling & chilling medium temperature, their flow rates, speed, fouling, pressure drops, refrigerant & oil charge, subcooling/superheating, input electric supply (voltage, current, power factor, and frequency), ambient temperature causing insulation gains/losses. Simultaneously logging all parameters by automatic instrumentation can help to monitor real time performance & keep minimum measurement uncertainties.

10. CONCLUSION

From the review, it is clear that use of nanofluids is attractive but its application is hindered by many factors like poor long term stability, high pressure drop, high pumping power, low specific heat and high production cost. For use of nanofluids in refrigeration more research is needed. A checklist to be used while publishing papers related to nanoparticles is proposed. Future research directions are discussed along with the limitations of literature reviewed.

NOMENCLATURE

NP	Nanoparticles	NPMF	Nanoparticles mass fraction (%)
NPC	Nanoparticles concentration	NPMFR	Nanoparticle mass fraction in refrigerant (%)
CNP	Carbon nanoparticles	NPMFL	Nanoparticle mass fraction in lubricant (%)
MO	Mineral Oil	NLMFR	Nanolubricant mass fraction in refrigerant (%)
CNT	Carbon nanotubes	NPCRL	NPC in refrigerant & nanolubricants mixture (%)
MR	Migration Ratio	NPVF	Nanoparticles volume fraction (%)
HTC	Heat transfer coefficient	NPVFL	Nanoparticles volume fraction in lubricant (%)
COP	Coefficient of performance	DPHE	Double pipe heat exchanger (liquid/suction)
SWCNH	Single wall carbon nanohorns	TP	Time to pull down temp. from 28 to 1 deg C
POE	Polyester oil	PAG	Polyalkylene glycol oil

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