Industrial Applications of Nano Fluids: A Review

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Abstract— Nanotechnology has a huge impact on modern industry where nanomaterials are applied for numerous application and thus increasing the efficiency of any system to maximum possibilities. Nanofluids, which are prepared by dispersing nanoparticle into a base fluid, have huge potential in industrial application. Low cost additives like nanoparticle play a vital role in modern industry. This review on nanofluids consisting nanoparticle made of titanium, copper, aluminum, silver, Iron, Single Wall Nanotube (SWNT), Multi Wall Nanotube (MWNT) and many more as base elements .These are currently in application for lubrication, Refrigeration, automobile, coating, heat transfer, machining of various materials and electronics. Researches have substituted conventional fluid with nanofluids and briefly mention about various Industrial application and potential scope for contribution of nanofluid technology in research centers, academics centers, and industrial sectors. This study will also mention the challenges for implementation of nanofluid in various applications.

Key words: Nanofluid; Heat Transfer; Lubrication; Machining; Nanocoating

I. INTRODUCTION

Nanotechnology came into light with the discovery of fullerene in 1985 where nanotechnology beginning with the 1986 publication of the book Creation. Since then there has been numerous development and the transformative applications by the field. A Nano-lubrication is introduced where it is defined as the art and science necessary to control adhesion, stiction friction and wear of surface coming inter contact at the micro/nano scale[4]. Heat flow plays a significant role in heat transfer but it is difficult to apply this concept in microprocessor and micro electro-mechanical devices (MEMs) which will have high potential application in aerospace and automotive system. Hence nanofluid will be used to achieve the desirable result. Coating technology flourish by the development of nanofluid where high resistance coating is developed for various industrial, automotive and aerospace application. Machining technology also has huge scope for use of nanofluid to obtain high quality product with minimum consumption of energy[16]. Despite of this promising application the main concern is to develop a stable product where other nonconventional nanomaterial is being tested. Disposal of this nanomaterial also matters to environment and health issue and thus various techniques like Minimum quantity lubrication (MQL) are opted for minimum consumptions[12].

II. METHODOLOGY

Different preparation methodology has been developed for different type of materials to obtain higher feasibility rate. For preparation of nanofluid careful knowledge of nanomaterial with base fluid must be through so that stable mixture can be obtained. There are two types of method used for preparation of nano fluid [19].

A. *One-Step Method*

One step method consists of preparing and dispersing the nanoparticle in the base fluid at the same time as shown in "Fig 1". The following steps like drying, storage, transportation and dispersion of nanoparticles are neglected in this process. This results in reduced agglomeration considerably and enhances the stability of nanofluid. This method is highly successful in preparation of nanofluid in big scale and production cost is also low. One step method is being adapted for industrially feasible and phase transformation method is one of them. Nanoparticles like graphene oxide which has high stability and homogeneity is prepared through phase method.

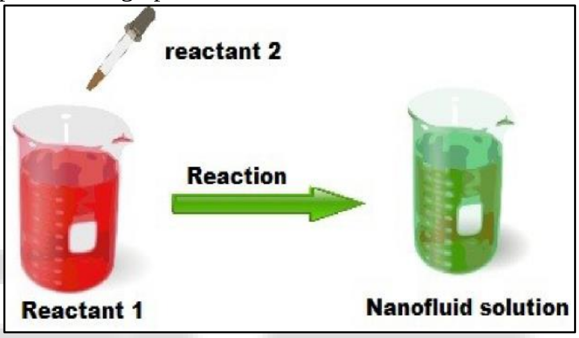

Fig. 1: One step method

B. *Two-Step Method*

This method is widely used for preparation of nanofluid where nanomaterials are made into dry powder using physical or chemical means. Then nano size powder is dispersed into base fluid using various techniques like magnetic agitation, ultrasonic agitation, high shear mixing and homogenizing as shown in "Fig 2". This is most simple and economical method for nanofluid preparation. As nanoparticles has tendency to get agglomerated subjected to large surface area and surface activity, Surfactant are used for this issue as fluid remain stable at high temperature as well. But still there are limitation in preparation of nanofluid using two step method that is where one step method is adapted.

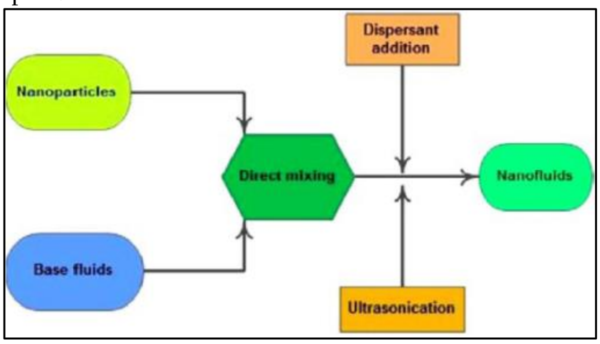

Fig. 2: Two step method

III. RESULTS AND DISCUSSION

A. Heat Transfer and Lubrication

Performance of automobile radiator was studies using pure water mixed with nanoparticle Al_2O_3 in 0.02, 0.05 and 0.1 vol%[1]. The selection of nanofluid was based on suitability, proportioning, cost & stability of both components. Different way has been mention to produce nanoparticles e.g. - Au, Ag, Cu, Fe of oxides like CuO, Al_2O_3, CeO_2 and single & Multiwall carbon nanotube. Nanofluid made of H_2O/Al_2O_3 powder mixture under turbulent condition was used for forced convection heat transfer in automobile radiator. It was found that out let temperature of the radiator with different volume flow rate and nanofluid concentration increased with increasing in the volume flow rate and decreasing in nanofluid by volume concentration. It was also found that heat transfer increased with increase of inlet temperature too. Performance analysis of TiO_2 nanoparticle as additive with mineral oil as lubricant was carried out on sealed compressor in a refrigeration system. Power consumption was studied[2]. Here it was found out that use of nanoparticle obtain higher heat transfer rate compared to use of conventional mineral oil lubrication. Nanoparticles used were 21 nm. By performing experiment it was found that lubrication effect increases with increase in viscosity of lubricant with change in temperature. The increased in viscosity of the nanofluid in predominant under lower temperature range. There was increased of 5.17% of average heat transfer in the evaporator cabin. COP was increased by 16.08% due to reduction of compressor work and enhanced heat transfer. As nanofluid obeys Newtonian law of cooling given by

$Q = h * A * t$

Q = rate of heat transfer

h = coefficient of convective heat transfer

A = surface area

t = temperature difference

Q is maximize with help of nanofluid by increasing the value of 'h' for constant of A & T., Conductivity of nanofluid can be controlled by varying particle size. Conductivity increases with reduction of particle size. As pharmaceuticals application is concerned nanofluid can be used in drugs delivery system where infected cell can be directly targeted and monitored. Iron based nanoparticles can be used during radiation which is administrated to the cancer patient. Nanofluid can be used as biomed due to magnetic properties which will help in delivery of anticancer drug to the target all without causing damage to health like tumor[3]. There are many limitation of nanofluid in this application. Few of them are long term stability; homogeneity and boiling characteristic are poor. Nano lubrication need to be taken into account for Micro electro machine (MEMs) devices, micro system, Nano-electro machine devices(NEMs) in electrical and telecommunication industries. Nanofluid can be deposited in the form of nanometer thick films to enhanced mechanical and electrical properties concept is being used in magnetic hard disk where perfluoropolyeter (PFPE) is used[4]. Thickness for air bearing was 10-15 nm which records magnetic signal. This prevent surface from oxidation resistance, low volatility, adhesion and withstand centrifugal forces from disk rotation. Nanolubrication helps in achieving control over adhesion, friction, stiction, and wear at nanoscale. Gap between head and disk is less than 20nm. Lower the molecular weight of PEPF(which is between 2000 to 4000)longer the durability of lubrication film. With appropriate stickiness and oxidation stability PEPF make optimum material for ideal lubrication of magnetic hard disk.PEPF make optimum material for ideal lubrication of magnetic hard disk. Studies about various nano particles like CuO, SiO_2, Hg, Fulleren, MWCNT with base fluid like DI water, ethylene glycol, oil, silicon oil and poly-a-olefin oil (PAO) is done for better thermal conductivity and lubricating properties[5]. Thermal conductivity can be measured using transient hot-wire method. One of the important lubrication properties of nanofluid is the extreme pressure properties. Nanofluid can also be used to increase the dielectric strength of transformer oil by using nanodiamonds particles [16]. The thermal conductivity of coolant (ethylene glycol) can be increased by 40% using 0.3% vol of Cu nanoparticles having diameter <10 nm. It has been found that heat transfer coefficient has been increased by using CuO and Fe_2O_3 nanoparticle added in water varying concentration from 0.15% - 0.65% vol. A CFD simulation result indicated Cu-water Nanofluid gave the best result when the concentration reached 5% the heat dissipation capacity increased by 44.1%.As lubrication properties of nanofluid contributes to reduction of friction and wear, reducing parasitic losses which lead to more than 6% of saving fuel[6]."Table. I" shows the Thermal performance of nanofluid of different type.

	particles	Base fluid	Average particle size (nm)	Volume Fraction (%)	Thermal conductivity enhancement
Metallic Nanofluid	Cu	Ethylene	10	0.3	40%
	Cu	Glycol water	100	7.5	40%
	Fe	Glycol water	100	7.5	78%
	Au	Ethylene	20-Oct	0.55	21%
	Ag	Glycol water	60-80	0.001	21%
	Ag	Water	60-80	0.001	17%
Non-Metallic Nanofluid	Al_2O_3	Water	13	4.3	30%
	Al_2O_3	Water	33	4.3	15%
	Al_2O_3	Water	68	5	21%
	CuO	Water	36	3.4	12%
	CuO	Water	50	0.4	17%
	SiC	Water	26	4.2	16%
	TiO_2	Water	15	5	30%
	MWCNT	Synthetic Oil	25	1	150%
	MWCNT	ethylene/glycol	100	1	20%/13%/7%
	MWCNT	water	100	0.6	38%

Table 1: Thermal Performance Of Nanofluid

A test was conducted where erosion was determined by weight loss measurement using the velocity as high as 9 m/s and at 90^o-30^o impact angle. It was observed that copper nanofluid produce higher wear rate that the base fluid and this is due to oxidation of copper nanoparticles. A lower wear rate and friction rate was seen for aluminum nanofluid. More stable nanofluid was studied like sodium dodecyl sulfate (SDS), cetyl Trimethyl ammonium bromide (CTAB), sodium hexa meta phosphate (SHMP) as dispersant water. It was used as lubricant in steel on steel studying contact influence friction[8]. An experiment was conducted on pin on disc arrangement having 50 HRC hardness. It was found that large agglomeration in water suspension resulted in high friction but stable surfactant dispersion particle help in controlling the friction. Due to interaction between steel and sulfur least coefficient of friction was observed. Still further research is done to understand the functionality with these particles. For application of lubrication in real engine various nanofluid like TiO_2, CuO, PbS, ZnS and many more are used to study lubrication effect in wear reduction. A low concentration of range from 0.05%–2.97% is well enough to improve the tribological properties. Mostly nanoparticles ranging from 2-120 nm are used to reduce friction and increased anti-wear ability. For lubricant content 90% oil and 10% additive solution, it was found that engine oil with TiO_2 nanofluid is not successful with ethylene glycol as dispersant[9]. Paraffin oil was used to replace glycol. Same test condition was set and gelation problem from ethylene glycol was solved. Study suggested that lubrication with C60 fullerene molecule and IF-SW2 increase the weld load and seizure resistance and the mix form was more stable dispersion hydrocarbon than that on conventional nanofluid. Nanodiamonds lubricant was studies on Pin on disk test doped with 50-150 ppm. Hence nanodiamonds in engine oil improve surface finish of certain component after running. Boric acid as nanofluid shows promising result in metalworking fluid (MWF) which drastically lowers friction and wear in wide range of industrial application. As boron is not compatible with many lubricating fluid which are widely used in engine oil causes slugged problem and led to corrosion engine[18]. PTFE shows promising footsteps in lubrication engineering but risk of instability of PTFE in engine oil and oil filter clogging led to difficulties with recycling[5].

B. Machining

Machining is one of the essential and challenging tasks in manufacturing which involves a controlled removal of material from work piece using a cutting tool. friction between tool and work piece result in high amount of heat if not controlled can led to wear and deformation of tool hence reducing the tool life and machining quality of work piece. Minimum quality lubrication(MQL) technique is opted giving good result with only small consumption of resources(power, cutting fluid)[7]. The flow rate of cutting fluid is in range of 50-500 ml/h which is directly applied to cutting zone. This technique solved fluid disposal problem as it takes very small quantity for machining. It was observed that MQL provided surface lubrication but insufficient work piece cooling with convective abrasive wheel. Thermal conductivity of ethylene glycol was improved 40% though dispersion of 0.3%vol Cu nanoparticles. Carbon nanotube yield up to 150% increase in conductivity by 1% vol. heat transfer coefficient and increased by 47% for a water based nanofluid containing 1.6 vol% of Al_2O_3 nano particle. Results in term of G-ratio were obtained for various nanofluids. Higher the G-ratio indicates low wheel wear rate ranging from 16-33.for Al2O3 nanofluid the G-ratio increased with increased in volume fraction whereas G-ratio of other nanofluid was relatively low[10]. Result in term of g ratio is were obtain using various nanofluid is given in "Fig. 3".

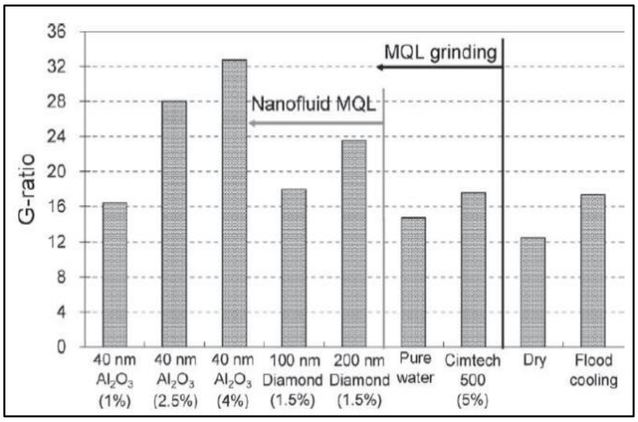

Fig. 3: G ratio of various nanofluid

Nanodiamond nanofluid obtains even better result. Use of base fluid as water, mineral oil or any chemical fluid can create toxic fumes during process and its disposal systems quit hazardous and complicated to environment, an alternative base fluid is being researched in which vegetable oil one of the promising choice[11]. It was concluded that the formulation with vegetable oil let to higher tool life and smoother surface finish compared to other synthetic based fluid. Over 117% increase in tool life was reported. Study was conducted on soybean oil concluded that soybean form a stable mixture with emulsifier and water conveniently used in machining[18]. Many more technique was performed using palm oil, coconut oil, sunflower oil, karanja oil, neem oil, and conventional fluid. Better surface finished was observed[12]. **"**Fig.4" shows the colloidal stability of nanofluid

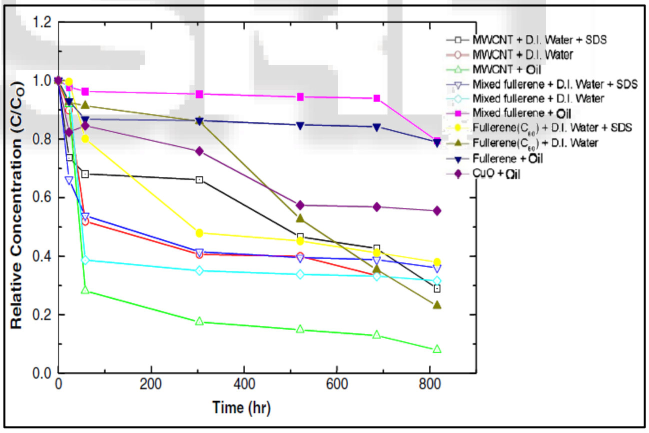

Fig. 4: colloidal stability of nanofluid

Method like fuzzy logic, artificial neural network, simulation annealing, genetic algorithms, etc. are being popular. This method helps in achieving better surface finish of by minimizing machine force and chip thickness[13].

C. Nano Coating

Emerging coating technology provide wide range of its application. In general Nanocoating can be anti-graffiti, anti-static, and anti-glare or can be presented from UV light most used in medical application. High resistance to corrosion, dirt and good erosive properties are being focused for the future application. Material like CuO, ZnO and TiO_2 for anti-microbial. SiO_2 and Al_2O_3 for mechanical properties.CeO, Iridium/antimony oxides, TiO2 for UV/IR absorptivity. FeO for magnetism. TiO2 has potential for decreased fogging, but technique only work in existence of (UV) light. Silica nano particle are being studied to create a surface_ that never fog. It can be applied on bathroom mirrors, eyeglass, camera lenses, ski goggles etc[14]. Experiment was conducted for TiO_2 on heat box which was sealed using glass window remain at 27.3ºC and other box without coated glass. Non-coated set show rise inside temperature as it could not reflect UV/IR radiation from sun. Anti-graffiti coating is mostly used in preventing paints from sticking to surface.it is used in maintenance of historic structure, walls and other surface. Nanocoating was studied using solar system both theoretically and experimentally. The performance of liquid flat plate collector coated with mono material was studied for absorbtance and low emmitance. Normally Al, Cu, Fe, Zn, Cr, based high performance Nanocoating are used. Nano chromium paint were earlier applied to collector resulted in increased in efficiency by 4.5% and thermal performance improved by 11%[15]. Similarly nickel aluminum coating for thermal solar absorber reached solar absorbtance of 0.93 and a thermal emmitance of 0.04. Various nanomaterial like SiO_2, ZnO, NiO, and TiO2 showed much better performance. **"**Table.II" below is the Thermal properties of various type of coating

Optical properties of selective coating	Absorptivity (α)	Emissivity (ε)	α/ ε
Black chrome	0.93	0.1	9.3
Black nickel on polished nickel	0.92	0.11	8.4
Black Nickel on Galvanized Iron	0.89	0.12	7.4
CuO on Nickel	0.81	0.17	4.7
Co_3O_4 on Silver	0.9	0.27	3.3
CuO on Aluminum	0.93	0.11	8.5
CuO on Anodized Aluminum	0.85	0.11	7.7
Sol chrome	0.96	0.12	8
Black Paint	0.96	0.88	1.09

Table 2: Thermal Properties Of Various Type Of Coating

Corrosion in open to air and at room temperature for up to 30 days in 3.5% NaCl solution was tested. It was observed that most common problem in sol gel coating was poor adhesion to surface. Hence environmental acceptance salts such as silica, ceria, vanadia and molybdate can be used with sol gel which provides covalent bonding for stronger coating adhesion. Such process was applied to aluminum and its alloy successfully. With salt mixed in sol gel showed higher corrosive resistance [17]. The pitting and crevic corrosion resistance were improved by nanocoating based on ceria, zirconia and Stamata and Mg alloys. In "Fig.4" it was seen no pitting or crevice corrosion was observed while silica and ceria treatment showed micro-cracked film and vanadia was uniformly distributed along the surface while dots are the oxide layer formed which up to minimum extent.

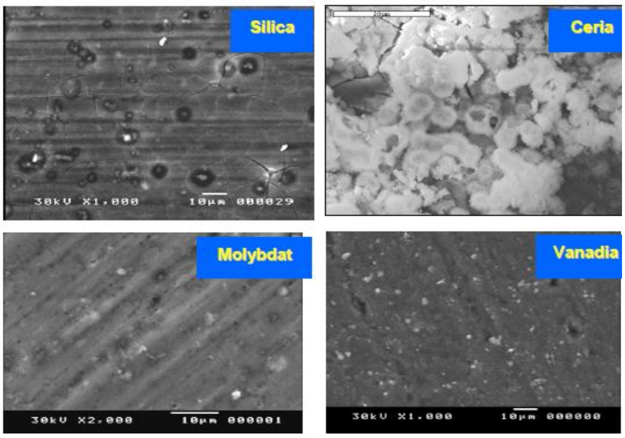

Fig. 4: Pitting or Crevice corrosion

"Fig.5" and "Fig.6" shows the pitting and crevic corrosion resistance which is improved by nano coating based on ceria,zirconia and stamate on Mg alloys. It was found that formation of tin oxide rich magnesium hydroxide layer that act as barrer to oxygen diffusion to to metal surface. Hence the higher resistance obtain from sample coated with dilute stamate conversion coating (25g/L), so the optimum economical aspect and industrial application were determined. The surface resistance abtaind was five time higher than the surface sesistance in polish sample.

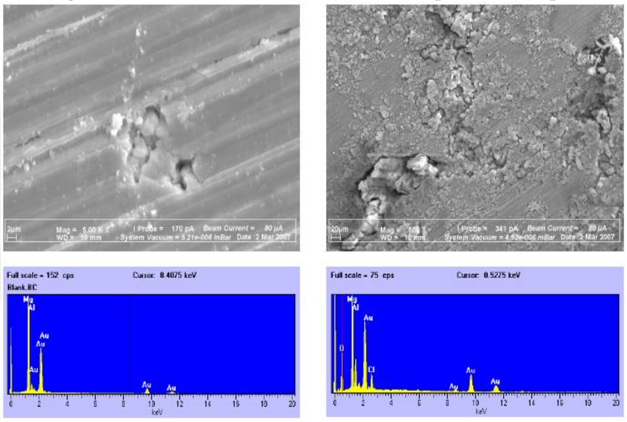
Fig. 5: Pitting or Crevice corrosion

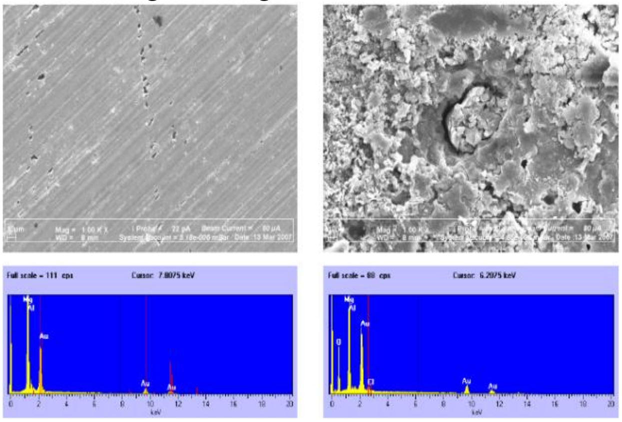
Fig. 6: Pitting or Crevice corrosion

Most of corrosion applications are found in maritime component such as ship and marine platform as well as offshore jet rings and jetties under the constant influence of marine environment. Nano particle such as ZnO, SiO_2 were selected and real maritime environment is produce to test the same[18]. It was observed that most of the sample showed anti-fouling properties and presence of algae or other organism deposit in the surface was eliminated. Sample without coating demonstrated corrosion pits and addition defects. Hence it was concluded that epoxy coating based on nano particle of maritime component due to synergistic effect created by different nanoparticle. A computer model was developed to improve the Nanocoating technology for surface on problem with corrosion [13]. Computer simulation indicates that the Nano coated passivation alloy composition has superior corrosion resistance. It verifies that the imperfective intensity of grain boundary led to metal dissolution. If aluminum dissolves fast inside the grain boundary, it produce stable thin layer and oxide layer in Nanocoating which give better corrosion response. "Table. 3 shows the material removal properties of coated and non-coated material.

Time(days)	Nanocoated sample weight change (mg/cm2)	Conventional coating sample weight change (mg/cm2)
30	0	-0.958
60	0	-6.888
90	0	-48.338
120	0	-78.365
150	0	>>-85.000
180	0	>>-85.000
210	0	>>-85.000
240	-0.02	>>-85.000
270	-0.05	>>-85.000
300	-0.08	>>-85.000
330	-0.11	>>-85.000
360	-0.14	>>-85.000
390	-0.17	>>-85.000
420	-0.2	>>-85.000
450	-0.25	>>-85.000
480	-0.29	>>-85.000
510	-0.35	>>-85.000

Table 3: Material Removal Properties

IV. CONCLUSION

Future of nanomaterial and nanofluid found promising in most type of industrial sector other than conventional nanofluids. Other material was studied for their potential application based on experimentation and result analysis. Nanofluids are seen as key technology for wide range of application specially in thermal, lubrication and coating for industrial, aerospace and automotive engineering. Despite its development, there are some obstacles to a superior impact of nanotechnology in industry. Challenges in the nanofluid development were identified and encountered where alternative solution was proposed. Issues like environmental impact and health were studied by the application of these fluid and alternative were devised for the same using biodegradable vegetable oil. A summary review of nanofluids used in major industrial sectors has been address providing examples of practical applications, security issues and market.

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