Experimental Studies and Comparison of Various Mechanical and Thermal Properties of Lubricants by Adding Nano Additives of Al2o3 and Sio2

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Abstract. In industrial and domestic applications conventional fluids are used such as lubricating oils, air, water and other coolants for cooling and heating purposes in case of automobiles engines and other parts in automobiles, refrigeration, cotton industries, manufacturing industries and other applications. It observed that by using some of such fluids there is hindrance and curb in heat transfer capacity due to low thermal conductivity possessed by fluids. Recent technology projected on nano fluids shows, nano materials occupies an important place in changing the properties of elements in basic structure. Various advanced researches revealed that heat transfer rate dependent on the conductivity of particles of material as well as particle size, diameter and volume concentration of nano material. The advanced nano fluids are using to increase thermal conductivity in heat transfer applications by using equipment such as radiators, heat exchangers, boilers, economizers etc. This experimental work studies and investigates thermal conductivity for nano fluids by adding additives of Al_2O_3 and SiO_2 about 60nm size. The thermal and mechanical properties evaluated based on experimental data by using a counter flow pipe in pipe heat exchanger at laminar flow conditions and by using a forced convection mode operation. The nano fluid consists of different concentrations of nano materials as 0.2%,0.4%,0.6%,0.8%,1.0% and 1.2% with SAE0W-20 engine oil as base fluid. Images taken to measure size of nano particles and also other characteristics by using Electron microscope scanning (SEM).

Key words: Heat transfer coefficient, Thermal conductivity, Nanofluids, Nano materials, Tribology, Reynolds number, SEM.

1. Introduction

The major role of the lubricants is to reduce the friction by absorbing the heat and transferring that heat as soon as possible to the surroundings, such that the components protected from overheating, so that efficiency increases as well the life of the components increases. Several investigations made by researchers to minimize the heat exchangers size to reduce the cost and increasing the performance. Heat exchanger used to transfer of thermal energy between fluids different temperatures like heating and cooling processes, process industries, power plants, transportation field, petroleum plants, airconditioning, cryogenic, refrigeration purposes and others. In addition, the concept of heat transfer has excellent role in metal cutting, lubrication and other manufacturing and production industries. The OHTC and LMTD are most effecting parameters in the performance and design a heat exchanger analysis to find the mean equivalent temperature difference for two fluids in given point in given conditions.

Kakaç et al [1] considered a typical pipe in pipe heat exchangers placed in various parallel and series arrangements to acquire the required mean temperature difference and pressure drop requirements. Pipe in pipe heat exchangers most suitable in heating or cooling process when both fluids at high temperature and pressure. However, drawback for this type of exchangers is they are bulky and expensive per unit surface area. Frass et al [2] designed a heat exchanger with the help of calculations for special cases to deal individual problems. John R [3] did experiments on shell side coefficients and concluded tube clearance, tube size and fluid flow characteristics. Mansoor et al [4] have done an Experimental analysis on heat transfer for turbulent and single-phase flow for micro-finned tube. Wen et al [5] studied to characterize heat transfer in pipe in pipe type heat exchangers by vertical and horizontal oval cross section alternately numerically. Akpinar et al [6] investigated experimentally heat transfer capacity in a counter flow heat exchanger pipe in pipe with swirl elements. The heat transfer capacity increased by 130% by using engine lubricating oil, ethylene glycol and Water as coolants. However, several techniques used like change of designs in heat exchanger for better heat transfer, however due to some issues and challenges in designing, researchers moving towards thermal conductivity for fluids by adding solid particles as additive into the base fluid becoming an advanced technique for better heat transfer capacity. Thus adding additives to fluids is key idea for thermal conductivity improvement. Solid(metallic) particles possesses good thermal conductivity compared fluids (conventional fluid), Choi [7] started first experimentation on nano fluids by mixing solid particles in liquids such as engine oils and water. Results showed that, this suspension has better in thermal conductivity compared with conventional fluid, but there is comprise with some draw back such as sedimentation, friction, pressure drop and others. Sandesh et al [8] said that nano fluids are solid-liquid combination contains metallic nano particles of 1 to 100 nm size suspended in conventional fluid. Apart from that, it has some issues, as they are robust, scalable, stability and cost effective methods not yet developed in industrial level. [9-11] discussed effects on thermal and physical properties for EG based fluid when suspended with nano particles of Al2O3. Similarly [12] discussed on CuO, and [13, 14] ZnO. However, Vajjha et al. [15-17] done experiments on thermo-physical properties forSiO2, ZnO, Al2O3 and CuO nano fluids. Kulkarni et al. [18] evaluated rheological properties for the nano fluid of CuO. Similarly, Kulkarni et al. [19] undertook experimentation to determine viscosity of SiO2 nano fluids. Sahoo et al. [20, 21] worked on SiO2 and proposed an innovative correlation for evaluation of thermal conductivity and the obtained results have good agreement with deviation less than 3.35% with experimental values. Sundar et al [22] studied enhancements of thermal properties for nano fluid by suspending nano-diamond and they determined various properties at different temperatures and concentrations. Vajjha et al [23] conducted experiments and evaluated HTC in turbulent range for CuO, SiO2 and Al2O3 in between temperature of 20-90ºC with 20-100nm particle diameters for volume concentration of 0-10%.

2. EXPERIMENTAL SET UP and PARAMETERS:

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Figure 1: The experimental set up

The major components of experimental set-up is test section which contains horizontal pipe in pipe copper pipes, cold-water tank, hot lubricating oil tank Rota meters, pumps, sensors. These instruments selected according to the requirement based on measuring range, accuracy and availability in the market. The test section fabricated from copper tubes, which possesses higher thermal conductivity. To achieve any particular engineering problem, we need to follow set of principles for proper product development economically. This economic is important for the design and selection of good heat transfer equipment. The various heat exchangers fabricated in different types, but the simplest form consists of concentric pipes contains different diameters known as pipe in pipe heat exchanger. In addition, one fluid flows in inner pipe and another fluid flows through annulus space between both the pipes. Out of these fluids, one called hot fluid other called cold fluid. If flow is in same direction called parallel flow and opposite direction called counter flow. The counter flow heat exchanger is much effective than parallel flow for the given surface area, hence considered for present study. For the design purpose, several parametric values assumed to calculate the length and diameter for both pipes. Moreover, various iterations made to optimize these values.

Let

Di= pipe inner diameter in m; mhot=hot fluid flow rate in LPM; mcold=cold fluid flow rate in LPM; L = length of the inner pipe in m; Vfluid =volume of fluid in ml; U= overall heat transfer coefficient in kW/m2C; Cpc = specific heat of cold fluid in KJ/kg K; Cph =specific heat of hot fluid in KJ/kg K; Th,in= hot fluid inlet temperature in °C; Tc,in= cold fluid inlet temperature in °C; mc =cold fluid in kg/sec; mh=hot fluid in kg/sec; As = Surface Area in m²; Cc =Heat capacity of cold fluid in kW; Ch =Heat capacity of hot fluid in kW; Cmin= Minimum heat capacity in kW; Cmax= Maximum heat capacity in kW; C =Capacity Ratio = Cmin/Cmax; Qmax = maximum heat transfer in kW; Q actual= actual heat transfer in kW; NTU= number of transfer units; ε = Effectiveness; Th,out= hot fluid outlet temperature in °C; Tc,out= cold fluid outlet temperature in °C; Thi-Tho= hot fluid temperature difference in °C; Tco-Tci= cold fluid temperature difference in °C; LMTD= log mean temperature difference; $_\varrho$=density of oil, kg/m3; $_v$=kinematic viscosity, m2/s; Q= discharge, m3/s; Ac=cross sectional area, m2; V=velocity, m/s; Re=reynolds number; f=friction factor; hf=pressure drop due to friction, bar.

S. NO	Constant parameters	values
1	D_i	0.008
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2
5	Cpc	4.178
6	Cph	2.219
7	Th,in	100
8	Tc,in	30
9	mc	0.0333
10	mh	0.042
11	Cc	0.1393
12	Ch	0.0932
13	Cmin	0.0932
14	Cmax	0.1393
15	C	0.6692
16	Qmax	6.5239

S. No	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	V_{fluid}	50.2400	75.3600	100.480	125.60
3	As	0.0251	0.0377	0.0502	0.0628
4	Q actual	0.3365	0.4941	0.6452	0.7902
5	NTU	0.0539	0.0809	0.1078	0.1348
6	ε	0.0516	0.0757	0.0989	0.1211
7	Th,out	96.3891	94.6979	93.0768	91.521
8	Tc,out	32.4164	33.5482	34.6331	35.673
9	Re	398.0891			
10	h_f	0.0836	0.1254	0.1672	0.2090

Table 1: selection of parameters and values

S.No	Constant Parameters	Values		S No	Parameters	1	2	3	4
1									
2									
3									
4									
5									
6									
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9									
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14									
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16									

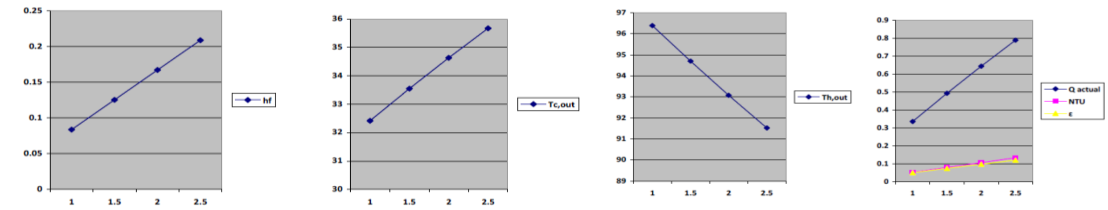


Fig:Variation of h_f along the length Fig:Variation of $Tc_{,out}$ along the length Fig:Variation of $Th_{,out}$ along the length Fig:Variation of Qactual,NTU and ε along the length

Fig 2: variation of hf, Tc_{out}, Th_{out}, NTU and effectiveness along the length

From the above fig2, at constant diameter of pipe 8mm as the length increases the pressure drop, heat transfer, NTU, effectiveness increases. The gain in temperature of cold fluid increases, whereas the heat loss of hot fluid decreases.

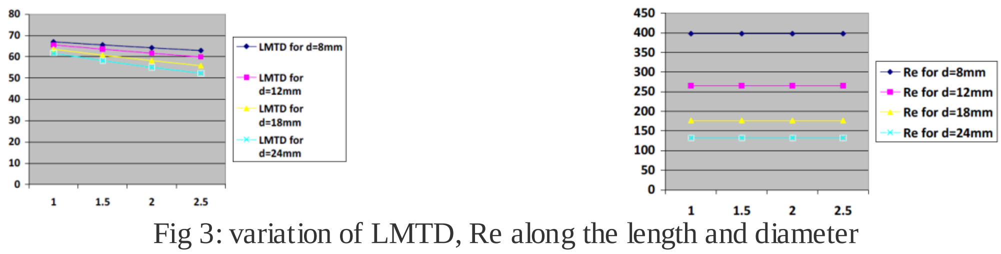


Fig 3: variation of LMTD, Re along the length and diameter

From the above fig3, we can understand that the smaller diameter of pipe tends to high logarithmic mean temperature difference. Hence, there will be higher heat transfer rate. Whereas larger the diameter of pipe will tends to lower the Reynolds number indicates the flow in the pipe may cause flow obstruction. Hence, from above diagram we can conclude that the preferable diameter of the pipe can is 8mm or 12mm and the length 2m.

CONCLUSION: from above diagrams and discussion even though there is more pressure drop, more temperature difference exists between fluids, it is very important to have flow as high as possible to sustain flow in the pipe. Hence, by compromising other parameters, we concluded the dimensions of inner pipe is diameter=8mm and length 2m.

3. DATA COLLECTION AND CALCULATION OF PARAMETERS

The various properties of the lubricants measured are as follows:

1) Viscosity (μ)
2) Flash and fire points
3) Specific gravity (SG)
4) Specific heat (Cp)
5) Thermal conductivity (k)
6) Coefficient of friction (Cf)
7) Heat transfer coefficient (h)

A sample calculation for various parameters viz., Viscosity (μ), Flash and fire points, Specific gravity (SG), Coefficient of friction (Cf), Specific heat (Cp), Heat transfer coefficient (h), Thermal conductivity (k)are presented for Al2O3 at 0.6% from table 2 to 4.

S.NO		Temperature of oil	Time of collecting 50ml of oil	weight of measuring jar	weight of measuring jar + 50cc of oil	mass of oil	volume of oil	density of oil	kinematic viscosity	Dynamic Viscosity
	symbol	T	t	W1	W2	m	v	ρoil	$V x10^{-6}$	μ
	units	℃	sec	gms	gms	gms	cc	kg/m3	m2/s	N-s/m² or Pa-s
	relation					[W2-W1]		[m/v]	[At-(B/t)]	[=ρ*V]
1		40	924	17.17	58.91	**41.74**	50.1	**833**	**228.1577**	**0.1901**
2		60	625	17.17	58.91	**41.74**	50.7	**823**	**154.2710**	**0.1270**
3		80	302	17.17	58.91	**41.74**	51.5	**810**	**74.3788**	**0.0603**
4		100	133	17.17	58.91	**41.74**	51.6	**809**	**32.3623**	**0.0262**
5		120	83	17.17	58.91	**41.74**	53.5	**780**	**19.7179**	**0.0154**
6		140	56	17.17	58.91	**41.74**	54.2	**770**	**11.3911**	**0.0088**

Table 2: Estimation of density and viscosity for 0.6% of Al2O3

Fig 4: Density and Viscosity for Al2O3 at different concentrations

The above table 2 shows calculation of viscosity and density for Al2O3 at 0.6% for addition of nano material. The experimental data collected by using redwood viscometer1. Fig 4 represents comparison values for Viscosity and density for Al2O3 at different concentrations.

S.NO		Material	%	Flash point	Fire point
	symbol			T	T
	units			℃	℃
1			0	200	215
2			0.2	210	220
3			0.4	210	222
4		Al2O3	0.6	215	225
5			0.8	217	223
6			1	220	225
7			1.2	223	227

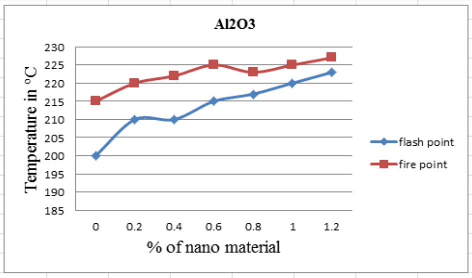


Fig 5: Flash and Fire points for Al2O3 at different concentrations

The above Fig 5 represents the data collection for flash and fire point for Al2O3 at different concentrations and graph shows the comparison values. The data collected by using Cleveland's flash and fire point apparatus.

S.NO		Temperature of oil	density of oil	density of water	specific gravity
	symbol	T	ρ_{oil}	ρ_w	SG
	units	℃	kg/m3	kg/m3	
	relation				ρ_{oil}/ρ_w
1		40	**833**	**1000**	0.8331
2		60	**823**	**1000**	0.8233
3		80	**810**	**1000**	0.8105
4		100	**809**	**1000**	0.8089
5		120	**780**	**1000**	0.7802
6		140	**770**	**1000**	0.7701

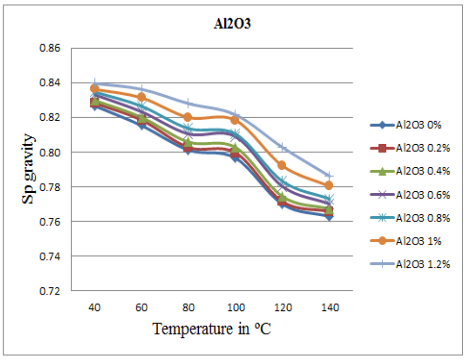


Fig 6: Specific gravity for Al2O3 at different concentrations

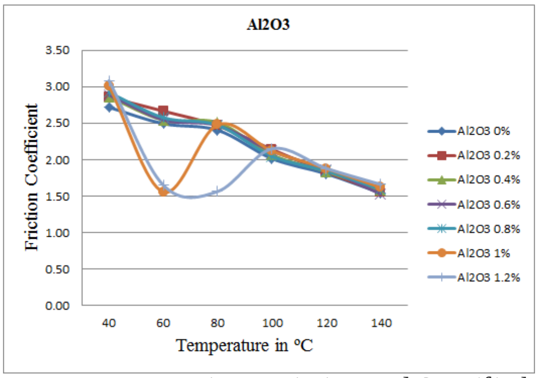
The Fig 6 represents the calculation of specific gravity for Al2O3 at 0.6% of nano material addition as a sample calculation and comparison of specific gravity for Al2O3 at different concentrations.

The table 3 represents the estimation of Friction and Specific heat for Al2O3 at 0.6% of nano material addition as a sample calculation. Fig 7 represents comparison for Friction and Specific heat for Al2O3 at different concentrations.

S.NO		Temperature of oil	manometer reading	density of mercury	pressure drop	volume flow of oil	Velocity of oil	density of oil	Darcy friction factor	friction coefficient
	symbol	T	h	ρ_{mer}	ΔP	Qoil	Voil	ρoil	f	Cf
	units	℃	m	kg/m3	N/m2	m3/s	m/s	kg/m3		
	relation				ρgh		Qoil/A		(2*d*ΔP)/(L*ρoil*V²)	f/4
1		40	0.0225	13500	2979.7875	**0.0000025**	**0.0498**	**833.1337**	**11.5599**	**2.8900**
2		60	0.0196	13500	2595.7260	**0.0000025**	**0.0498**	**823.2742**	**10.1905**	**2.5476**
3		80	0.0187	13500	2476.5345	**0.0000025**	**0.0498**	**810.4854**	**9.8760**	**2.4690**
4		100	0.0160	13500	2118.9600	**0.0000025**	**0.0498**	**808.9147**	**8.4665**	**2.1166**
5		120	0.0136	13500	1801.1160	**0.0000025**	**0.0498**	**780.1869**	**7.4615**	**1.8654**
6		140	0.0110	13500	1456.7850	**0.0000025**	**0.0498**	**770.1107**	**6.1140**	**1.5285**

S.NO		Temperature of oil	hot fluid inlet temp	hot fluid outlet temp	cold fluid inlet temperature	cold fluid outlet temperature	hot fluid flow rate	cold fluid flow rate	specific heat of water	heat transfer rate	specific heat of oil
	symbol	T	Thi	Tho	Tci	Tco	mh	mc	Cpw	Q	Cp oil
	units	℃	℃	℃	℃	℃	kg/s	kg/s	J/kgK	W	J/kgK
	relation									mc*Cpw*(Tco-Tci)	Q/(mh*(Thi-Tho)
1		40	38.7	33.9	33.1	34.3	**0.0021**	**0.0042**	**4178**	**20.89**	**2089.5005**
2		60	58.7	36.3	34.2	39.7	**0.0021**	**0.0042**	**4178**	**95.75**	**2076.7651**
3		80	76.6	40.6	34.3	42.9	**0.0020**	**0.0042**	**4178**	**149.71**	**2052.4279**
4		100	95.5	49.8	34.8	45.8	**0.0020**	**0.0042**	**4178**	**191.49**	**2072.0056**
5		120	114.6	55.3	34.7	48.7	**0.0020**	**0.0042**	**4178**	**243.72**	**2107.1326**
6		140	134.8	63.2	34.4	51.2	**0.0019**	**0.0042**	**4178**	**292.46**	**2121.5843**

Table 3: Estimation of Friction coefficient and specific heat for 0.6% of Al2O3



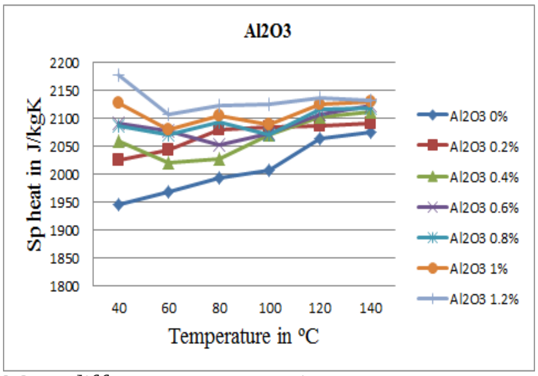


Fig 7: Friction and Specific heat for Al2O3 at different concentrations

The table 4 represents the calculation of HTC and thermal conductivity for Al2O3 at 0.4% of nano material addition as a sample calculation. Fig 8 represents comparison of HTC and thermal conductivity for Al2O3 at different concentrations.

S.NO		Temperature of oil	hot fluid inlet temp	hot fluid outlet temp	cold fluid inlet temperature	cold fluid outlet temperature	temp diff between hot fluid inlet & hot fluid outlet	temp diff between cold fluid inlet & cold fluid outlet	heat transfer rate	convective heat transfer coefficient
	symbol	T	Thi	Tho	Tci	Tco	ΔTh	ΔTc	Q	hi
	units	℃	℃	℃	℃	℃	℃	℃	W	W/m2K
	relation						Thi-Tho	Tco-Tci	mc*Cpw*(Tci-Tco)	Q/(ΔTh*Ai)
1		40	38.7	33.9	33.1	34.3	4.8	**1.2**	**20.8900**	**86.6259**
2		60	58.7	36.3	34.2	39.7	22.4	**5.5**	**95.7458**	**85.0790**
3		80	76.6	40.6	34.3	42.9	36	**8.6**	**149.7117**	**82.7758**
4		100	95.5	49.8	34.8	45.8	45.7	**11**	**191.4917**	**83.4035**
5		120	114.6	55.3	34.7	48.7	59.3	**14**	**243.7167**	**81.8052**
6		140	134.8	63.2	34.4	51.2	71.6	**16.8**	**292.4600**	**81.3025**

S.NO		Temperature of oil	Nusselt number	heat transfer coefficient	thermal conductivity of fluid
	symbol	T	Nu	hi	k_{nf}
	units	℃		W/m2K	W/mK
	relation		constant heat flux		(hi*d)/Nu
1		40	4.36	86.6259	0.1589
2		60	4.36	85.0790	0.1561
3		80	4.36	82.7758	0.1519
4		100	4.36	83.4035	0.1530
5		120	4.36	81.8052	0.1501
6		140	4.36	81.3025	0.1492

Table 4: Estimation of heat transfer coefficient and thermal conductivity for 0.6% of Al2O3

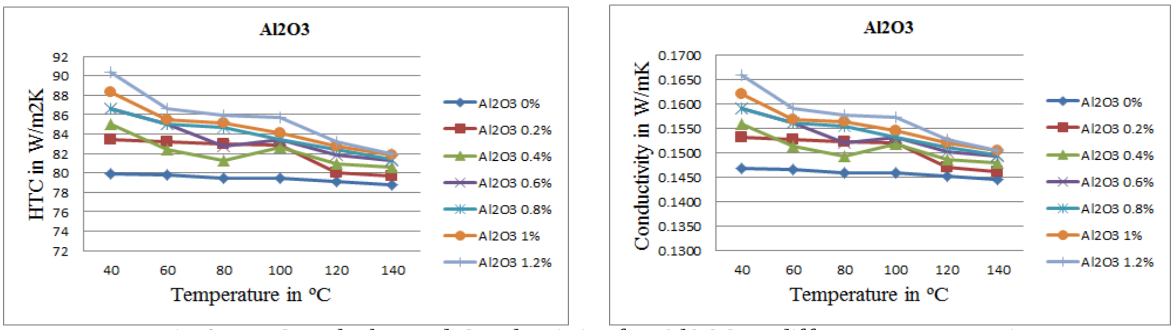


Fig 8: HTC and Thermal Conductivity for Al2O3 at different concentrations

4. RESULTS AND DISCUSSIONS

From the above data, the following results obtained and compared at nano particles for 0.2% and 1% for Al2O3 and SiO2:

1) Comparison of viscosity:

From the diagrams, it is clear that the viscosity of SiO2 is more than that of the Al2O3 at any given temperature ranges from 40ºC to 140ºC at the concentration 0.2% and 1%. Hence, from the viscosity point of view the addition of Al2O3 is preferable than the SiO2. Because, the increase in viscosity decreases Reynolds number (by keeping the other parameters constant) causes the difficulty in flow of the fluid.

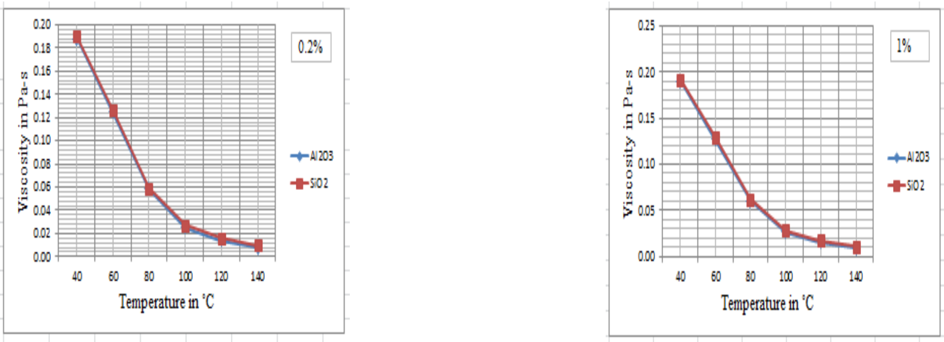


Fig 9: Comparison of viscosity for Al2O3 at 0.2% and 1% concentrations

2) Comparison of Flash and Fire Points:

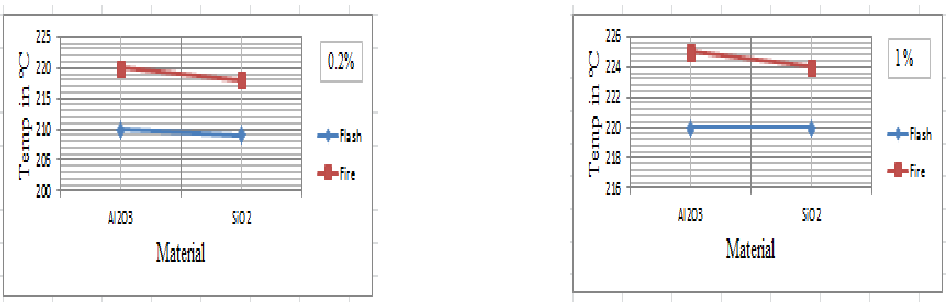


Fig 10: Comparison of Flash and Fire Points for Al2O3 at 0.2% and 1% concentrations

From the above diagrams, it is clear that the flash and fire points of SiO2 is much higher than that of the Al2O3 for the concentration 0.2% and 1%. Hence, from the flash and fire points point of view the addition of $SiO_2$is preferable than the Al_2O_3. Because, the increase in flash and fire points is reliable for the lubricants and increases the operating temperatures of fluids.

3) Comparison of Dynamic Friction:

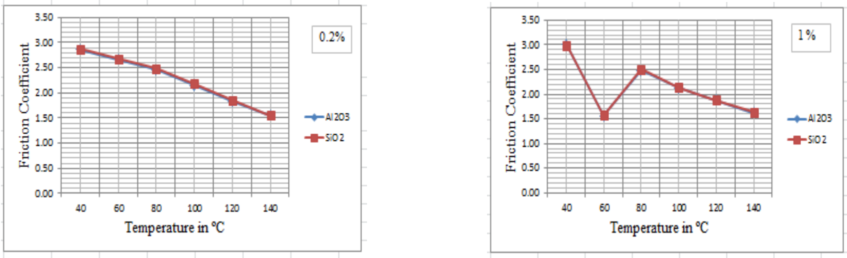


Fig 11: Comparison of Dynamic Friction for Al_2O_3 at 0.2% and 1% concentrations

From the above diagrams, it is clear that the Dynamic Friction of SiO_2 is more than that of the Al_2O_3 at any given temperature ranges from 40℃ to 140℃ at the concentration 0.2% and 1%. Dynamic Friction is very low at 60℃ for the concentration of 1%. Even, it is very low for the all other concentrations. In the Friction point of view, addition of Al_2O_3 is preferable than the SiO_2.

4) Comparison of Heat transfer coefficients:

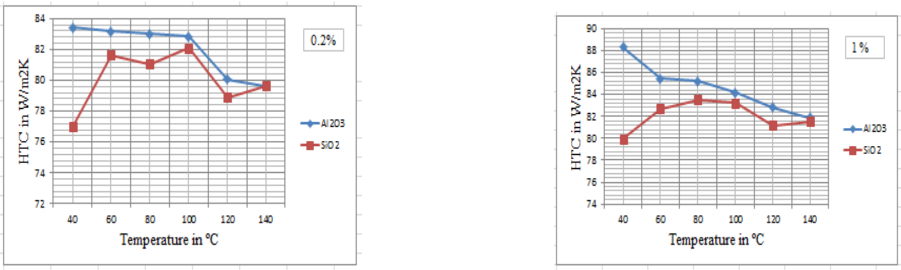


Fig 12: Comparison of Heat transfer coefficient for Al_2O_3 at 0.2% and 1% concentrations

From the above diagrams, we can understand that the HTC (h) of Al_2O_3 is more than that of the SiO_2 at any given temperature ranges from 40℃ to 140℃ at the concentration 0.2% and 1%. Heat transfer coefficient is high at 80-100℃ for SiO_2 and at 40℃ Al_2O_3. It is very important to note that, as the temperature increases HTC decreases for Al_2O_3, whereas SiO_2 showing multiple values. However, from the Heat transfer coefficient point of view the addition of Al_2O_3 as additive is preferable than the SiO_2.

5) Comparison of Thermal Conductivity:

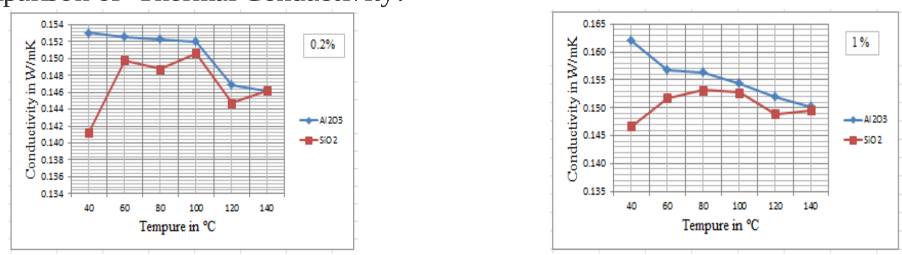


Fig 13: Comparison of Thermal Conductivity for Al_2O_3 at 0.2% and 1% concentrations

From the above diagrams, it is clear that the Thermal Conductivity (k) of Al2O3 is more than that of the SiO2 at any given temperature ranges from 40ºC to 140ºC at the concentration 0.2% and 1%. Thermal Conductivity is very high at 100ºC for SiO2 and at 40ºC Al2O3. It is very interesting to know that thermal conductivity decreases with temperature increase for Al2O3, whereas SiO2 showing multiple values. However, from the Thermal Conductivity point of view the addition of Al2O3 as additive is preferable than the SiO2.

CONCLUSIONS:

The contribution of present study is to review the current state of research and analysis in lubricants area, properties of lubricants and applications with reference to suspension of nano particles of Al2O3 and SiO2 in fluids and comparing the results obtained for various properties in order to improve the life of the machines and increase the performance in heat exchange. From the experimental studies it is observed that Al2O3 having an excellent thermal conductivity and higher heat transfer capacity with low friction compared to SiO2about 6-11% by AL_2O_3 and -1-10% by SiO_2 with base fluid.

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