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Review on CNT Based Hybrid Nanofluids Performance in the Nano Lubricant Application

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Abstract: The advanced hybrid nanofluids are the important outcome of the nanotechnology advancement where nanosized particles were added together either using one step or two-step method. The morphology mostly different in both the synthesizing methods which played major role in the thermal properties of nanofluid. The current paper reviewed MWCNT based mono/hybrid nanofluid applications as heat transfer fluid in the nano lubrication process. With highest surface to volume ratio nanoparticles efficiently impacted on frictional loss and heat generation by creating a nanolayer film on the surface. From the available literature various modelling equations along with their margin of deviation were presented in the paper.

***Keywords*: MWCNT; Hybrid nanofluid; Nano lubrication; solid volume fraction; MOD**

Nomenclature:

Wt%	: Weight percent	MOD	: Margin of deviation
O.D	: Outer diameter	Vol%	: Volume percent
φ	: Solid volume fraction	μ	: Dynamic viscosity
PEC	: Performance evaluation criterion	T	: Temperature (°C)
k	: Thermal conductivity (W/mk)	ANN	: Artificial neural network
MWCNT	: Multi-walled carbon nanotube	EG	: Ethylene glycol
SWCNT	: Single-walled carbon nanotube	Gr	: Graphene
DWCNT	: Double-walled carbon nanotube	h	: Heat transfer coefficient
HEG	: Hydrogen exfoliated graphene	ΔP	: Pressure drop
W	: Weight (gm)	bf	: base fluid
ρ	: Density (gm/cc)	np	: nano particle
nf	: nano fluid		

I. Introduction

Various studies proved that the thermophysical properties of the base fluid can be altered by the addition of nanoparticles [1–10]. Currently, researchers are focusing on further variation of properties by the addition of hybrid nanocomposites in the base fluid/ binary base fluids. Water is the basic heat transfer fluid, which is used throughout the world but transportation in cold countries is the main issue. By adding agents like EG, propylene glycol, salts, and sugar we can lower the freezing point of water, but all the agents have their own limitations [11–20]. As salts can easily corrode the metal pipes and researchers came up with an alternative of using water-EG at different volume fractions thermophysical properties at different working conditions [21–30]. Further, the rate of heat transfer was varying with various parameters like, type of nanoparticle, size, shape, compatibility of hybrid nanoparticle, solid volume fraction and preparation methods [31–40]. Most of the studies concentrated on the effect of various nanoparticles like carbon nanotubes, and metals (oxides, carbides, nitrides) on the thermophysical properties like thermal conductivity, viscosity (newtonian/non-newtonian behaviour) was analysed. In this regard, the present review focused mainly on the combination of metal oxides and CNT at different solid volume fractions on the water-EG binary fluid heat transfer properties.

Combination of dissimilar nanoparticles of distinct size, shape, thermophysical properties to be blended in base fluid to form hybrid nanofluid. The essential properties could be tuned into the hybrid particle by adding at various concentrations of individual constituents. Which directly impact on the thermophysical properties like density, thermal conductivity, electrical conductivity and viscosity of the hybrid material [41]. These nanoparticles were added to a single/binary base fluid to form a nanofluid with better properties compared to base fluid like water, oil, ethylene glycol, propylene glycol etc. Different proportions of water and ethylene glycol or water and propylene glycol were mixed form an antifreeze solution [42–47]. Antifreeze nanofluid applicable at lower ambient conditions. Several studies were performed by adding single/hybrid nanoparticle to the base fluid and confirmed that the nanofluid have improved properties compared to base fluid.

$$\varphi = \frac{\left(\frac{w}{\rho}\right)_{np1} + \left(\frac{w}{\rho}\right)_{np2}}{\left(\frac{w}{\rho}\right)_{np1} + \left(\frac{w}{\rho}\right)_{np2} + \left(\frac{w}{\rho}\right)_{bf}} \quad \ldots\ldots\ldots\ldots.(1)$$

The reviewed papers suggested that carbon-based nanoparticle like MWCNT (3000 W/mk) and SWCNT (3500 W/mk) have the highest thermal conductivity compared to other carbon-based form like graphene oxide (2000 W/mk) [48]. Moreover, better thermophysical properties makes the nanofluid viable for heat transfer fluid. Table 1 represents the literature survey for MWCNT based single/hybrid nanofluid in various applications. Figure 1 shows the preparation for hybrid nano particle using one step or by two step method [49,50]. After the preparation of hybrid nano particle, they are subjected to characterization based on the proposed applications. Then the nanoparticles were added to the base fluid depending on the required solid volume fraction (φ %) from equation (1).

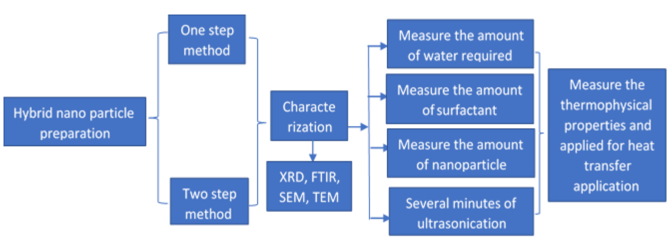

Fig. 1: The preparation of hybrid nanofluid

Over the last decade, various studies were performed on the heat transfer applications of CNT based nanofluids. The current paper reviewed nano lubrication application of the nanofluid. The addition of nanoparticles to the base fluid changed the fluid behaviour (Newtonian/non-Newtonian) based on the particle concentration and the lubrication could be even improved by nano meter surface spacing [51]. While lubrication, frictional heating can be formed and by the formation of nanoparticle layer onto the surface for the cooling process, as nanoparticles having better thermophysical properties with highest surface to volume ratio [51]. Based on their fluid behaviour studies, distinct correlations were proposed to predict the viscosity and thermal conductivity of the nanofluids as shown in Table 2.

Correlations predicted for viscosity and thermal conductivity of MWCNT based hybrid nanofluid

Although there were many studies carried out on the viscosity of the nanofluids. For hybrid nanoparticle with various solid loading Equation **2** is not valid. Experimental results could be numerically validated using ANN, CFD, tree random forest [52] and also predicted model equations for the given nanofluid at various concentrations. The results from model equations were verified and margin of deviation (MOD %) was calculated from equation (**3**). Most of the MOD predicted using nonlinear multiple regression was lesser than 10% which represent better validation [53]. Most of the predicted correlations included base fluid and nanoparticle properties, solid volume fraction (φ%), temperature, Reynolds number, Prandtl number, particle size, and sphericity of the nanoparticle.

$$\mu_{nf} = \varphi\mu_p + (1-\varphi)\mu_{bf} \quad \ldots\ldots\ldots\ldots.(2)$$

$$MOD\ \% = \frac{\mu_{nf} - \mu_{bf}}{\mu_{bf}} \quad \ldots\ldots\ldots\ldots(3)$$

II. Conclusion

This paper represents the overview of effective MWCNT based single/hybrid nano lubricant performance as nanofluid. The review concentrated on the heat transfer characteristics of various nano particle type, shape, size at low to medium solid volume fraction, Reynolds number and temperature (25-60°C) conditions. Thermal conductivity, density, specific heat, and viscosity were the main thermophysical properties playing major role in the nano fluid applications. Also, nano particle morphology, type of surfactant, its dosage and temperature conditions showing major impact. Various modelling equations were developed by considering solid loading, temperature, Reynolds number, dynamic viscosity, sphericity of the particle, density, and Prandtl number as main parameters and can predict the viscosity of the nanofluid within 10% margin of deviation.

TABLE 1
Important properties of MWCNT based hybrid nanofluid and its results reviewed

Hybrid nanofluid	Nanoparticle size	Measured properties	Application	The key findings	Reference
Al_2O_3-MWCNT/water 0.25-1.25 vol%	Al_2O_3-spherical, 45 nm MWCNT-cylindrical shape, 5–20 nm O.D	Thermal conductivity, Density, Viscosity, Specific heat @ 25-50°C	Cutting fluid	Cutting force, thrust force, roughness and contact angle reduced for hybrid nanofluid	[54]
Al_2O_3-MWCNT/D.I water, 0-1.5% (5:0 to 0:5) ratio $140<N_{Re}<460$	Al_2O_3- 45 nm MWCNT-20 nm	Thermal conductivity, Density, Viscosity, Specific heat @ 20-40°C	Mini channel heat sink	Optimal Particle ratio was 3:2, PEC=1.26	[55]
MWCNT-graphene nanoparticle (GNP) 0.075-0.125 wt% $200 < N_{Re}<500$	MWCNT- 15nm and GNP-120 nm	Entropy, Heat transfer coefficient (h)	Micro tubes	ΔP increased by 12.4%, h increased by 58% and entropy decreased by 37.5%	[56]
CNT (MWCNT & SWCNT) -Fe_2O_3/Water 0.1 vol%	-	Rate of heat flux	A symmetric channel	Runge kutta algorithm validation	[57]
WO_3-MWCNT/ Engine oil, 0-0.6 vol%, 20-40°C	WO_3<65nm and MWCNT < 30nm	Viscosity	Hybrid nanofluid	μ decreased by 81.6% at 60°C	[58]
MWCNT-Fe_2O_3/Water 0-0.003 vol%	-	Viscosity, Nusselt number	Natural convection	Lattice Boltzmann method validation	[59]
MWCNT-TiO_2/Water-EG 0-0.85 vol%, 10-50°C	MWCNT -15nm, TiO_2-30nm	Viscosity	Anti-freeze	μ increased by 83% at 10°C, 0.85 vol%	[60]
MWCNT-solar glycol 0.2-0.6 vol%	MWCNT-30nm	Nusselt Number	Double pipe heat exchanger	k increased by 31%	[61]
MWCNT-Alumina/EG-water 0.0625-1 vol%, 25-50°C	MWCNT-15nm, Alumina-20nm	Density, Viscosity	Anti-freeze	<0.5 vol% Newtonian behaviour and up to 1 vol% non-Newtonian behaviour	[62]
MWCNT-TiO_2(80:20%) /oil 5W50, 0.25-2 vol%, 25-50°C	MWCNT-7nm TiO_2-40nm	Viscosity	Rheological behaviour	μ could be increased by 42% at 2% solid concentration	[63]
MWCNT-ZnO(20-80%)/5W30, 0.05-1%, 5-55°C	-	Viscosity	Statistical analysis of nanofluid behaviour	Non-newtonian behaviour, μ increased by increasing temperature	[64]
CuO-MWCNT/ water, 0.1-0.25 wt%	MWCNT-15nm	Optical absorption property	Solar thermal energy harvest	0.15 wt%/0.005 wt% hybrid ratio temperature increase was about 14.1°C compared to water	[65]
COOH-MWCNT-(SiO_2, Al_2O_3,MgO, ZnO)/SAE 40 engine oil, 0.01-1 vol%,25-50 °C	<70 nm	Viscosity	Rheological behaviour	Experimental μ results were numerically validated using RBF-ANN & tree random forest	[52]
MWCNT-CuO (30-70%)/SAE 50, 0-1 vol%, 25-50 °C	MWCNT-15nm, CuO-40nm	Viscosity	Rheological behaviour	μ reduced by 15% for ≤0.25 vol%	[66]

Hybrid nanofluid	Nanoparticle size	Measured properties	Application	The key findings	Reference
MWCNT (30%)-Al_2O_3 (70%)/ 5W50, 0.05-1 vol%, 5-55°C	MWCNT-15 nm, Al_2O_3-5nm	Viscosity	Industrial cooling cycles	μ increased by 24% at 1 vol%	[67]
MWCNT-Graphene/kerosene, 0.05-0.5 wt%, 20-60°C 2100<N_{Re}<4450	-	Optimum operating conditions	Hybrid nanofluid	Maximum h enhancement was @ N_{Re} 4448, 0.5 wt% at 40.26% MWCNT & 22.79% graphene	[68]
MWCNT-Al_2O_3/thermal oil, 0.125-1.5 vol%, 25-50°C	-	Thermophysical properties	ANFIS optimization method, ANN	PSO analysis showed better than GA	[69]
SiO_2-MWCNT/SAE40 0-1%,25-60°C	MWCNT-15nm SiO_2-30nm	Viscosity	Coolant and lubricant in heat engines	μ increased by 37.4%	[70]
MWCNT-MgO (20-80%)/SAE50, 0.25-2%, 25-60°C	-	Viscosity	Nano lubrication	μ increased by 65% at 2%, 40°C	[71]
MWCNT-SiO_2(20-80)/SAE40, 25-50°C, 0-2 vol%	MWCNT-15nm, SiO_2-30nm	Viscosity	Hybrid Nano lubrication	μ increased by 30.2%	[72]
F-MWCNT-Fe_2O_3/EG, 0-2.3%, 25-50°C	MWCNT-15nm, Fe_2O_3-30nm	Thermal conductivity	Hybrid nanofluid	k enhancement was 30% at 50°C, 2.3 vol%	[73]
MgO-MWCNT/EG, 0.05-0.6%, 25-50°C	-	Thermal conductivity	Optimal ANN	ANN with 12 neurons best model	[74]
FMWCNT-MgO/Engine oil, 0.0625-1 %, 25-50°C	MWCNT-30nm, MgO-40nm	Rheological behaviour	Hybrid nanofluid	k dropped by 75% at 25-50°C	[75]
MWCNT-CuO (30-70%)/SAE40, 0.0625-1%, 25-50°C	MWCNT-30nm, MgO-40nm	Rheological behaviour	Nano lubricant	k increased by 29.47% at 1 vol%	[76]
MWCNT-CuO/water, 0.05-0.6%, 25-50°C	MWCNT-15nm, CuO-30nm	Thermal conductivity	Hybrid nanofluid	k enhanced by 30.38%	[77]
FMWCNT-TiO_2/10W40 (10-90%), (55-45%), 0.25-1 vol%, 15-55°C	MWCNT-15nm, TiO_2-40nm	Viscosity	Nano lubricant	@0.75% k increase by 100%	[78]
ZnO-MWCNT(55-45%)/10w40, 0.05-1%, 5-55°C	-	Viscosity	Nano lubricant	Shear thinning nonnewtonian fluid behaviour	[79]
Fe_3O_4-MWCNT/EG,0.1-1.8 vol%, 25-50°C	MWCNT-15nm, Fe_3O_4-30nm	Viscosity	Rheological behaviour	0.1<Newtonian<0.8%, 1.25-1.8% Non-Newtonian behaviour	[80]
MWCNT-ZnO(30-70%)/5W50, 0.05-1 vol%, 5-45°C	MWCNT-35nm, ZnO-30nm	Viscosity	Rheological behaviour	Improved reduction in cold start engine damages	[81]
SiO_2-MWCNT (90:10)/10W40, 0.05-1%	SiO_2-30nm, MWCNT-20nm	Viscosity	Nano lubricant	ANN results validated experimental μ values with R^2=0.9948	[82]
ZrO_2-MWCNT (70-30%) /10W40, 0.05-1 vol%, 5-55°C	MWCNT-5nm, ZrO_2-40nm	Viscosity	Nano lubricant	ANN results validated experimental μ values with R^2=0.9905	[83]
MWCNT-Al_2O_3(10-90%) /10w40, 0.05-1 vol%, 5-55°C	-	Viscosity	Rheological behaviour	New correlation & ANN results validated experimental μ values with R^2=0.99703& 0.998	[84]

Hybrid nanofluid	Nanoparticle size	Measured properties	Application	The key findings	Reference
MWCNT-SiO_2/EG-water, 0.0625-2 vol%, 25-50°C	-	Viscosity	Rheological behaviour	modelling results were validated using ANN	[85]
MWCNT-SiO_2(50-50 wt%) /EG-water (60-40),0.0625-1 vol%, 25-50°C	MWCNT-20nm, SiO_2-30nm	Thermal conductivity	Antifreeze	k increased by 30% at 1 vol% and 50°C	[86]
$Mg(OH)_2$-MWCNT/engine oil, 0.25-2 vol%, 25-60°C	$Mg(OH)_2$-10nm, MWCNT-30nm	viscosity	Nano lubricant & coolant	k enhanced by 50%	[87]
MWCNT-Fe_3O_4/water, 0-0.003 vol%, N_{Re}=100, hartmann number(Ha): 0≤Ha≤60	-	Rate of heat transfer	Forced convection heat transfer	At Ha=60 highest rate of heat transfer	[88]
MWCNT-CuO (10 wt%)nano composite, 0.4-1.2%, 25-50°C	20nm	Thermal conductivity	Double pipe heat exchanger	Optimization of exergy efficiency	[89]
Alumina-MWCNT (10:90)/ 5 vol% vegetable oil-water, 0.25-1.25 vol%,	Alumina-45nm	Thermal conductivity, wettability	Nano lubricant	k enhanced by 2.6%, smallest Contact angle was 39.5 at 1.25 vol%	[90]
Alumina-MWCNT/vegetable oil	-	Surface roughness, cutting force	Cryogenic cooling	Reduction %: Surface roughness -9%, cutting force-12% Tool life enhanced by 23%	[91]
Fe_3O_4-CNT/water, gum Arabic, 0-1.35%, N_{Re}-500 to 200	-	Thermal conductivity, viscosity	Counter current double pipe mini channel HE	Heat transfer coefficient and effectiveness enhanced.	[92]
MWCNT-SiO_2/water-EG,0.0625-1%, 25-50°C	-	Thermal conductivity	Antifreeze	Ridge regression was capable to estimate nanofluid properties	[93]
MWCNT-Fe_3O_4/water, 0-0.3 vol%,	MWCNT& Fe_3O_4-30nm	Density, specific heat, thermal conductivity	Natural convection heat transfer	Nusselt number was high at rayleigh number between 10^5 to 10^6	[94]
ZnO-MWCNT (25-75 vol%) /Engine oil, 0.05-0.8%, 5-55°C	MWCNT-15nm, ZnO-35nm	Viscosity	Hybrid nano lubricant	Nanofluid was Newtonian at all volume fractions	[95]
Silver decorated MWCNT/water, 0.5-1 wt%,	Ag-10nm	Thermal efficiency	Thermosyphon heat exchanger	Thermal η enhanced by 16.5% at 1 wt%	[96]
Silver coated(1 wt%-3wt%)-MWCNT(0.05 wt%)/water	MWCNT-20nm	Thermal conductivity	Better heat transfer fluid	k enhanced by 14.5%	[97]
MWCNT-Fe_3O_4/water, 0.1-0.3%,	MWCNT-30nm	Nusselt number	Hybrid nanofluid	Nusselt number enhanced by 31% & pumping power enhanced by 1.18 times	[98]
MWCNT-ZnO/Engine oil,0.125-1%, 5-55°C	30nm	Viscosity	Hybrid nano lubricant	μ increased by 45% at 1% and decreased by 85% at 55°C	[99]
MgO-MWCNT/ EG, 0-1%, 30-60°C	MWCNT-20nm, MgO-40nm	Viscosity	Hybrid nano lubricant	μ enhanced by 168% at 1% solid loading	[100]
CNT-CuO/gasoline oil	-	Entropy	Hybrid nanofluid	Entropy production, Nusselt number were higher for hybrid nano fluid	[101]

Hybrid nanofluid	Nanoparticle size	Measured properties	Application	The key findings	Reference
SiO_2-MWCNT (85:15%)/EG, 0.05-1.95%, 30-50°C	<30nm	Thermal conductivity	Cost effected heat transfer fluid	k enhanced by 22.2% at 50°C	[102]
ZnO-MWCNT (50-50%)/ EG -water(50:50%), 0.02-1%, 30-50°C	<30nm	Thermal conductivity	Anti-freeze	k enhanced by 28.1% at 1% solid loading and 50°C	[103]
F-SWCNT-MgO (20-80%)/EG, 0.05-2%, 30-50°C	MgO-40nm	Thermal conductivity	Hybrid nanofluid	k enhanced by 25 % at 2% solid loading and 50°C	[104]
CuO-SWCNT (50:50%) /EG-water (40:60%), 0.02-0.75 vol%, 20-50°C	CuO-40nm	Thermal conductivity	Anti-freeze	k enhanced by 36.2% at 0.75% solid loading and 50°C	[105]
MWCNT-MgO (15-85%)/water,0.25-2 vol%, 20-40°C	MWCNT-15nm,	Thermal conductivity, viscosity	Natural convection heat transfer	The bigger rigid body configurated refrigerant enhanced the Nu and entropy generation	[106]
MWCNT-SiO_2/Ag (4:1 to 1:4)/water, CTAB-0.25 wt%, 0-0.1%, 30-70°C	MWCNT-15nm,	Thermal conductivity, absorption fraction	Solar thermal conversion	0.1% MWCNT enhanced the k by 7% that improved the light absorption rate and rate of heat transfer	[107]
TiO_2-MWCNT (50:50%)/ water-EG,0.05-1%, 20-50°C	<30nm	Thermal conductivity	Antifreeze	k enhanced by 39%	[108]
COOH-DWCNT/ water-EG(50:50 vol%), 0.05-1vol%, 25-50°C	5nm	Viscosity	Antifreeze	μ decreased with increased shear rate	[109]
SiO_2-MWCNT /SAE40,0-0.1%, 25-60°C,	<30nm	Viscosity	Coolant and lubricant in heat engine	μ enhanced by 37.4%	[110]
Gr-MWCNT/Cu/EG, 30-60°C, 0.05-0.035 vol%	<18nm	Thermal conductivity	Hybrid nanofluid	k enhanced by 41% at 0.035 vol%	[111]
Ag/MWCNT-HEG/EG	<50nm	Thermal conductivity	Hybrid nanofluid	k enhanced by 8% at 0.04 vol%, 25°C, h by 570% at 0.005 vol% at N_{Re}=250	[112]
CNT (0-1.35%)-Fe_2O_3 (gum Arabic), 0.1.0.9%, N_{Re}=500 to 2000,	-	Viscosity, entropy, thermal conductivity	Mini channel heat exchanger	Maximum thermal entropy generation at highest CNT concentration	[113]
MWCNT-SiC/ water-EG, 0-0.75 vol%, 25-50°C	<65nm	Thermal conductivity	Antifreeze	K enhanced by 33% at 50°C, 0.75 vol%	[114]

TABLE 2
Predicted correlations for MWCNT based hybrid nanofluid

Nanofluid	Thermo physical property	Margin of deviation	Reference
MWCNT-TiO_2 (80:20%) /oil 5W50, 0.25-2 vol%, 25-50°C **Predicted correlation** $\mu_{nf} = 2.936T + \frac{2e^4}{1.68 + T - 1.68\varphi} - 448.8 - \tan(1.68\varphi - 1.68)$	Viscosity	4%	[63]
$Al_2O_3(\varphi_1)$-MWCNT (φ_2)/water, 0-1.5%, 140< N_{Re} < 460, φ-0.01 vol%, 6.84≤Pr≤7 **Predicted correlation** $Nu = 0.3035Re^{0.4407}Pr^{0.36}(1+R)^{0.317}$ $f = 43.16Re^{-0.85}(1+R)^{0.66}$ $R = \frac{\varphi_2}{\varphi_1 + \varphi_2}$	Nusselt number, Friction factor	-3≤Error≤4%	[55]
MWCNT-Alumina/EG-water, 0.0625-1 vol%, 25-50°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 1.0560 + (8.5662\varphi^{3.0971}) + (\varphi^{8.5662})^5$ @25°C	Viscosity	<8%	[62]
MWCNT-ZnO (20-80%)/5W30, 0.05-1%, 5-55°C **Predicted correlation** $\mu_{nf} == 458.77 - 23.13T - 0.01\gamma - 3.16\varphi T + 5.82 \times 10^{-4}\gamma + 0.44T^2 + 2.48 \times 10^{-7}\gamma^2 + 9.6 \times 10^{-5}\varphi T\gamma + 0.02\varphi T^2 - 8.37 \times 10^{-6}T^2\gamma + 71.2\varphi^3 - 2.81 \times 10^{-3}T^3$	Viscosity	<5% up to 35 °C, <10% up to 55 °C	[64]
MWCNT-CuO (30-70%)/SAE 50, 0-1 vol%, 25-50 °C $\frac{\mu_{nf}}{\mu_{bf}} = 0.99 + 0.49\varphi - 0.0077T + 6.81 \times 10^{-6}\gamma - 0.00249\varphi T + 0.00011T^2 - 2.19 \times 10^{-7}\gamma^2 - 0.19\varphi^2$	Viscosity	-6% to +8%	[66]
MWCNT (30%)-Al_2O_3 (70%)/5W50, 0.05-1 vol%, 5-55°C **Predicted correlation** $\mu_{nf} = 688.46 + 347.09\varphi - 33.12T - 0.04\gamma - 7.36\varphi T - 0.0087\varphi\gamma + 0.0014T\gamma - 305.24\varphi^2 + 1.49 \times 10^{-6}\gamma + 0.61T^2 + 1.87 \times 10^{-7}\varphi\gamma^2 - 0.0001\varphi T\gamma + 0.065\varphi T^2 - 7.25 \times 1$	Viscosity	<10%	[67]
SiO_2-MWCNT/SAE40, 0-1vol%,25-60°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 0.9566 + 0.9841\varphi - 4.4687\varphi^2 + 7.89\varphi^3 - 4.0731\varphi^4$ @ 25°C	Viscosity	0.75%	[70]
MWCNT-MgO (20-80%)/SAE500.25-2%, 25-60°C **Predicted correlation** $\mu_{nf} = 328201T^{-2.053}\varphi^{0.0936}$	Viscosity	<8%	[71]

Nanofluid	Thermo physical property	Margin of deviation	Reference
MWCNT-SiO_2(20-80)/SAE40, 25-50°C, 0-2 vol% **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 1.0343 + 0.2236\varphi - 0.26\varphi^2 + 0.2375\varphi^3$	Viscosity	1.2%	[72]
F-MWCNT-Fe_2O_3/EG, 0-2.3%, 25-50°C **Predicted correlation** $\frac{k_{nf}}{k_{bf}} = 1 + 0.0162\varphi^{0.7038}T^{0.6009}$	Thermal conductivity	1.58%	[73]
MgO-MWCNT/EG, 0.05-0.6%, 25-50°C **Predicted correlation** $k_{nf}/k_{bf} = 0.9787 + \exp(0.3081\varphi^{0.3097} - 0.002T$	Thermal conductivity	0.8%	[74]
FMWCNT-MgO/Engine oil, 0.0625-1 %, 25-50°C **Predicted correlation** $\mu_{nf} = 4 \times 10^4 + 145\varphi - 240T - 0.061\gamma + 1.9 \times 10^6\,\varphi^2 + 0.36T^2$	Viscosity	<0.3%	[75]
MWCNT-CuO(30-70%)/SAE40, 0.0625-1%, 25-50°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 0.9554 + 1.211\varphi\exp(\varphi) - 3.616\varphi^2 + 0.6647\varphi^3$	Viscosity	<0.75%	[76]
MWCNT-CuO/water, 0.05-0.6%, 25-50°C **Predicted correlation** $\frac{k_{nf}}{k_{bf}} = 0.907\exp(0.36\varphi^{0.311} + 0.000956T)$	Thermal conductivity	-	[77]
ZnO-MWCNT (55-45%)/10w40, 0.05-1%, 5-55°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 1.035 + \frac{\varphi e^{-1.023}\left(2.046\frac{\varphi}{T} + 0.4015\varphi^2 T\right)}{T^{0.8441}}$	Viscosity	0.25% @55°C	[79]
Fe_3O_4-MWCNT/EG,0.1-1.8 vol%, 25-50°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = \frac{-2.0987 + (4.65\varphi)^{0.0969} + (0.87T)^{0.263} + 62323\varphi^2}{143T^2}$ $\frac{k_{nf}}{k_{bf}} = 1 + 0.0162\varphi^{0.7}T^{0.6}$	Viscosity	1.95%	[80]
MWCNT-ZnO(30-70%)/5W50, 0.05-1 vol%, 5-45°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 0.866 + 0.802\varphi + 8.38 \times 10^{-3}T - 7.86 \times 10^{-6}\gamma - 5.83 \times 10^{-4}\varphi T - 6.26 \times 10^{-7}T\gamma - 1.081\varphi^2 - 2.44 \times 10^{-4}T + 2.38 \times 10^{-9}\gamma^2 + 1.26 \times 10^{-8}T^2\gamma + 0.572\varphi^3 + 1.63 \times$	Viscosity	-	[81]

Nanofluid	Thermo physical property	Margin of deviation	Reference
ZrO_2-MWCNT (70-30%) /10W40, 0.05-1 vol%, 5-55°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 0.8009 + 19\varphi e^{\varphi} - 28.6\varphi^{1.2} - 22.57\varphi^{3}$	Viscosity	<4%	[83]
MWCNT-Al_2O_3(10-90%) /10w40, 0.05-1 vol%, 5-55°C **Predicted correlation** $\mu_{nf} = 697 + 431.9\varphi - 33.4T - 0.04\gamma - 10.8\varphi T - 0.0069\varphi\gamma + 0.0015T\gamma - 334\varphi^{2} + 0.62T^{2} + 1.34 \times 10^{-6}\gamma^{2} + 0.0001\varphi\gamma T + 2.9\varphi^{2}T + 0.077\varphi T^{2} - 1.2 \times 10^{-7}T\gamma^{2} + 121\varphi^{3}$	Viscosity	-	[84]
MWCNT-SiO_2(50-50 wt%) /EG-water (60-40),0.0625-1 vol%,25-50°C **Predicted correlation** $\frac{k_{nf}}{k_{bf}} = 0.77T^{(0.15+0.023\ln(\varphi))}$	Thermal conductivity	<1.9%	[86]
Mg(OH)$_2$-MWCNT/engine oil, 0.25-2 vol%, 25-60°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 1604 + 256.8\varphi + 24.73\varphi^{3} + 1.6T^{2} + 0.07\varphi T^{2} - 83T - 7.4\varphi T - 0.01T^{3} - 74\varphi^{2}$	Viscosity	<6.5%	[87]
ZnO-MWCNT (25-75 vol%) /Engine oil, 0.05-0.8%, 5-55°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = 1 + 1.3\varphi - 5.1\varphi^{2} + 8.6\varphi^{3} - 4.6\varphi^{4}$ @ 5°C	Viscosity	0.86%	[95]
MWCNT-ZnO/Engine oil,0.125-1%, 5-55°C **Predicted correlation** $\mu_{nf} = 796.8 + 76.26\varphi + 12.88T + -0.7695\varphi T + \frac{-196.9T - 16.53\varphi T}{\sqrt{T}}$	Viscosity	-	[99]
MgO-MWCNT/ EG, <1%, 30-60°C **Predicted correlation** $\frac{\mu_{nf}}{\mu_{bf}} = [0.191\varphi + 0.24(T^{-0.342}\varphi^{-0.473})]\exp(1.45T^{0.12}\varphi^{0.158})$	Viscosity	-	[100]
SiO_2-MWCNT (85:15%)/EG, 0.05-1.95%, 30-50°C **Predicted correlation** $\frac{k_{nf}}{k_{bf}} = [0.905 + 0.002\varphi T + 0.044(T^{0.33}\varphi^{0.093}) - 0.0063\varphi]^{3}]$	Thermal conductivity	-	[102]
ZnO-MWCNT/ EG -water **Predicted correlation** $\frac{k_{nf}}{k_{bf}} = 1.024 + 0.59\varphi^{0.6}\exp\left(\frac{\varphi}{T}\right) + \frac{-8.06\varphi T^{0.2} - 2.24}{6.05\varphi^{2} + T}$	Thermal conductivity	<1.8%	[103]

Nanofluid	Thermo physical property	Margin of deviation	Reference
CuO-SWCNT(50:50%) /EG-water(40:60%), 0.02-0.75 vol%, 20-50°C	Thermal conductivity	<4%	[105]
Predicted correlation $\frac{k_{nf}}{k_{bf}} = 1 + (0.04\varphi T) - 0.003(\varphi T)^2 + 0.0001(\varphi T)^3 - 0.0000014(\varphi T)^4$			
MWCNT-MgO(15-85%)/water,0.25-2 vol%, 20-40°C	Thermal conductivity, viscosity	-	[106]
Predicted correlation $\frac{k_{nf}}{k_{bf}} = [0.997 + 0.0788\varphi + 0.0048T - 0.108\varphi^2 + 0.0078\varphi T + 0.091\varphi^3 - 0.006\varphi^2 T - 0.026]$ $\frac{\mu_{nf}}{\mu_{bf}} = [1.027 + 0.28\varphi - 0.00068T - 0.076\varphi^2 + 0.0086\varphi T - 1.732e^{-5}T^2 + 0.024\varphi^3 - 0.00092\varphi^2 T - 0.00018\varphi T^2]$			
TiO_2-MWCNT (50:50%)/ water-EG, CTAB, 0.05-1%, 20-50°C	Thermal conductivity	<1.2%	[108]
Predicted correlation $\frac{k_{nf}}{k_{bf}} = 0.006\varphi^{1.09}T^{1.051} + 1.014$			
SiO_2-MWCNT /SAE40,0-0.1%, 25-60°C	Viscosity	<0.75%	[110]
Predicted correlation $\frac{\mu_{nf}}{\mu_{bf}} = 0.956 + 0.9841\varphi - 4.47\varphi^2 + 7.8779\varphi^3 - 4.1\varphi^4$ @25°C			
Gr-MWCNT/Cu/EG, 30-60°C, 0.05-0.035 vol%	Thermal conductivity	-	[111]
Predicted correlation $k_{hybrid} = \varphi_{Gr}k_{Gr} + \varphi_{CNT}k_{CNT} + \varphi_{Cu}k_{Cu}$			

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