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Comparison of experimental data, modelling and non-linear regression on transport properties of mineral oil based nanofluids

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ABSTRACT

This research suggests new experimental outcomes regarding the viscosity and thermal conductivity of silver, copper and titanium oxide nanoparticles dispersed in mineral insulating oil by high-pressure homogenization process without using any additives or surfactants. Later, via employing non-linear regression, an adaptive neuro-fuzzy inference system (ANFIS) and achieved experimental data, new models were evolved to predict the viscosity besides thermal conductivity of nanofluids. For modelling, viscosity as well as thermal conductivity of nanofluids was picked as the target factor, and the volume concentration in addition to types of nanoparticles was regarded as the design (input) factors and all experimental data was classified into a train and a test data set. The model was conducted through the train set and the outcomes were contrasted with the experimental data set. Predicted thermal conductivities as well as viscosities were compared with experimental data for three different nanofluids, having nanoparticles volume concentrations of 0.00125% and 0.050%. A comparison was made between the ANFIS and regression outcomes. To evaluate the results, the coefficient of determination (R^2) and root-mean-square error (RMSE) are reported. The achieved results of this research indicate that thermal conductivity of nanofluids enhance by nanoparticles concentration increment. Thermal conductivity of silver is higher compared to thermal conductivity of titanium oxide and copper nanoparticles. According to the ANFIS and non-linear regression outputs, two sets of correlations for calculating the dynamic viscosity as well as thermal conductivity were suggested. Comparing the experimental data with suggested correlations demonstrate very good agreement between the suggested correlations and experimental data. However, equations of previous researches would not be perfectly able to predict the experimental data of present study.

1. Introduction

A broad range of industrial fields such as oil and gas, electrical or nuclear energies have considered energy transport as a necessary section. Traditional heat transfer fluids (HTFs) are comprised of water, oil and ethylene glycol (EG) which are low thermal conductive materials. Nevertheless, an extremely significant topic in the performance of energy systems is the progress in heat transfer fluids with an enhanced thermal conductivity [1–3]. The word “nanofluids” has been first used by Choi and Eastman [4] which was about fluids with dispersed nano-sized particles in them, having a higher thermal conductivity. So far, a number of researches have been carried out to improve the thermal characteristics of carrying fluids via adding thermal conductive nanoparticles [5–7]. Lately, carbon-based nanostructures such as carbon nanotubes (CNTs) [8], graphite flakes [9], graphene [10] and graphene oxide (GO) [11] have drawn complete attention of researchers.

Majority of the performed studies in this field shows the importance of nanofluids thermal conductivity estimation, as scientists suggest any increase in thermal conductivity of nanofluids causes an enhancement in their heat transfer capability [12,13].

Nevertheless, the investigations have not been limited to this, and some scientists have studied other properties of these types of heat transfer media. They proposed the viscosity of nanofluids as the second

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Table 1
Physical properties of the base fluid and nanoparticles.

	Mineral oil	Titanium oxide	Silver	Copper
Purity		99%	99%	99%
APS (nm)		10	10	50–80
SSA (m^2/g)		≥60	9–11	30–50
Color		White	Black gray	Black
Morphology		Ellipsoidal and spherical	Spherical	Spherical
Melting point (°C)		1830–1850	960.8	1083
Boiling point (°C)		2500–3000	2210	2595
Thermal conductivity (W/m K)	0.157	6.531	429	401
Odor		Odorless	Odorless	Odorless
Molar mass (g/mol)		79.87	107.8682	63.546
Density (kg/m^3)	848	3900	10,491	8940
C_p (J/kg K)	1860	686	234.4	385
Viscosity (Pa s)	0.0120	–	–	–

Table 2
Nanoparticles mass used for nanofluids preparation.

Samples	Nanoparticles mass (±0.001) [g]
TiO_2 + MO Φ = 0.00125%	0.0401
TiO_2 + MO Φ = 0.0025%	0.0803
TiO_2 + MO Φ = 0.005%	0.1607
TiO_2 + MO Φ = 0.01%	0.3214
TiO_2 + MO Φ = 0.05%	1.6077
Ag + MO Φ = 0.00125%	0.1104
Ag + MO Φ = 0.0025%	0.2209
Ag + MO Φ = 0.005%	0.4418
Ag + MO Φ = 0.01%	0.8837
Ag + MO Φ = 0.05%	4.4202
Cu + MO Φ = 0.00125%	0.0948
Cu + MO Φ = 0.0025%	0.1896
Cu + MO Φ = 0.005%	0.3793
Cu + MO Φ = 0.01%	0.7587
Cu + MO Φ = 0.05%	3.8000

most significant matter, since system pressure drop is a result of adding solid particles to the carrying fluid which causes the power consumption of the pump will raise [14].

Other important parameters of nanofluids which have been studied by other researchers are particle size, shape and type [15], particle diameter [16], temperature [17], volume fraction/weight percentage of dispersed nanoparticles in carrying fluid [18] and type of base fluid [19].

On the other hand, using statistical methods to study of heat transfer and fluid flow has been drastically increased in recent years [20,21]. However, using traditional statistical methods may be failed in different conditions where there are no logical correlations among data [22]. In this point of view, soft computing methods such as fuzzy logic [23], neural network [24], artificial neural fuzzy inference systems [25], reinforcement learning strategy [26] and evolutionary algorithms [27] may be proper for system identification. Regarding this, some researchers have used artificial neural network (ANN) model to predict the thermophysical properties of nanofluids specially thermal conductivity [28,29] and viscosity [30,31].

The review of literature reveals that nanofluids are advantageous coolants [32,33] which need to be studied excessively [34,35]. Particularly, the application of transformer oil based nanofluids on heat transfer performance and pumping power of electronics cooling systems is not well investigated. In the present research, the viscosity and thermal conductivity of three different nanofluids including copper (Cu), silver (Ag) and titanium oxide (TiO_2) as nanoparticles and mineral oil (MO) as base fluid have been studied experimentally. The nanofluids with various solid concentrations have been investigated and a number of correlations for prediction of the thermal conductivity and viscosity of the nanofluid have been suggested using ANFIS and curve fitting methods, as ANFIS method uses both neural network and fuzzy logic for considering data. Neural networks can only train the data while ANFIS correponds if-then rules and train data using them. Using ANFIS aids to consider the uncertainities and for this reaon may be useful for many applications [25]. The outcomes of this research may result in employment of the modern coolants in switchgears and electrical power transformer [36].

2. Nanofluid preparation

In the present study, nanofluids were prepared by a high-pressure homogenization process without using any additives or surfactants. The silver and copper nanoparticles were acquired from Nanostructured & Amorphous Materials, Inc. (NanoAmor) and titanium oxide nanoparticles were synthesized by the New Insulating and Semiconductors Materials Laboratory – LNMIS/UFU. The nanoparticles were dispersed in mineral oil (MO), which is utilized as coolant and dielectric fluid in switchgears and electrical power transformers. Supplementary information about characteristics of carrying fluid and the nanoparticles are represented in Table 1, provided by the manufacturers. The nanoparticles were dispersed in the base fluid by using a high-pressure homogenizer up to 800 bars. In the high-pressure

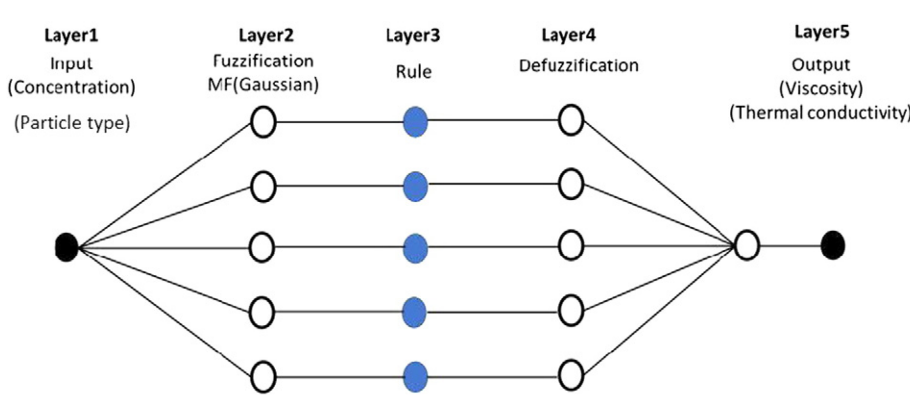

Fig. 1. ANFIS structure for present study with five layers.