Results in Physics 70 (2025) 108139

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.elsevier.com/locate/rinp

Investigation of thermal and electrical properties of ternary composite nanofluids using MgO, ZnO, and MWCNT nanoparticles

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ARTICLE INFO

Keywords:
Ternary nanofluids
Nanoparticles
Percent mass ratios
Parametric
pH
Electrical conductivity

ABSTRACT

Composites in nanofluids are currently being considered to improve thermal properties. This article uses a two-step technique to prepare a ternary composite nanofluid with a 0.10 vol% of H_2O-based MgO, ZnO, and MWCNT nanoparticles at different weight ratios. Morphological surface and structure of nanocomposites were investigated using a high-resolution scanning electron microscope and XRD. The stability of the ternary composite nanofluid was determined through viscosity tests and visual inspection techniques, and the results showed that the nanofluids have good stability. Viscosity and electrical conductivity were evaluated and measured by a sine wave viscometer and conductivity meter of composite nanofluid at different temperatures, respectively. Both the electrical conductivity and viscosity of composite nanofluids were improved by increasing the mass ratio of MgO and ZnO particles. On the contrary, the viscosity of the ternary composite nanofluid decreases with increasing bath temperature. A maximum increase of 34.0 % and 907.4 % was obtained for the viscosity and electrical conductivity of the ternary composite nanofluid, respectively. The results show that the ternary composite nanofluid is found to have a reduced viscosity compared to the single nanofluid, which is a massive benefit for engineering applications.

Introduction

Nanofluids (NFs) are obtained by dispersing nanoparticles in base liquids. In the meantime, the use of nanofluids as widely used and innovative liquids has attracted global attention and has received wider requests including various heating and cooling applications for heat transfer applications [1–5]. This progression has positively impacted NFs investigation, leading to the method of hybridization of diverse NPs by different nanosize, nano shapes, temperatures, and base fluids to formulate hybrid nanofluids (HNFs) and ternary hybrid nanofluids (THNFs) nanofluids [1,6]. Composite nanofluids (CNFs) are doing better in enhancing thermal applications because BNFs have good thermo-physical possessions over base fluids [7], which stretches good credibility to THNFs. Binary hybrid nanofluids perform well and have been one of the target researchers in recent years [8–11]. However, THNFs become an extension of studies for single and binary nanofluids, which is done by the hybridization of three different nanoparticles inside base fluids, which will achieve a better thermal or rheological performance [4,12]. These nanomaterials are a mixture of their combined physical and chemical possessions.

Many researchers have studied this issue; Zayan et al. (9) experimentally premeditated the rheological performance of graphene-based ternary nanofluid (TNF), which exhibited Newtonian performance at the maximum concentration. Also, Azmi et al. [13] examined the stability of tri-hybrid nanoparticles of Al_2O_3, SiO_2, and TiO_2, suspended in EG-Water base liquid at a φ of (0.05 vol% to 0.30 vol%). The THNFs achieved good stability. Furthermore, Kashyap et al. (3) simulated a

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https://doi.org/10.1016/j.rinp.2025.108139
Received 26 October 2024; Received in revised form 30 December 2024; Accepted 27 January 2025
Available online 28 January 2025

Nomenclature

Ag	Silver
AIN	Aluminium nitride
Al	Aluminium
Al_2O_3	Aluminium oxide
AR	Aspect ratio
Au	Gold
BNFs	Briny nanofluids
CC	Carboxymethyl cellulose
CNT	Carbon nanotube
Co_3O_4	Cobalt oxide
Cu	Copper
CuO	Copper oxide
DIW	Deionized water
DW	Distilled water
DWCNT	Double-walled carbon nanotube
EG	Ethylene glycol
W/EG	Ethylene deionized water
EO	Engine oil
Fe	Iron
Fe_2O_3	Iron (III) oxide
Fe_3O_4	Iron (II) oxide
G	Graphene
GA	Gum arabic
GL	Glycerol
GNF	Green nanofluid
GO	Graphene oxide
GON	Graphene oxide nanosheet
GNP	Graphene nanoplatelet
HNF	Hybrid nanofluid
HNP	Hybrid nanoparticle
MgO	Magnesium oxide
PMR	Particle mass ratio
SVF	Solid volume fraction

Greek symbols

ΔT	Temperature gradient, °C
Φ	The weight concentration of nanoparticles, %
μ	Viscosity, kg/m2 s
β	Thermal coefficient of expansion, 1/k
P	Density, kg/m^3
K	Thermal conductivity, W/m K
δ	Uncertainty
σ	Electrical conductivity, μS/cm
∂	Partial differential

Subscripts

thnf	Trenary Hybrid nanofluid
nf	Nanofluid
bf	Base fluid
en	Enhancement
rel	Relative

ternary composite nanofluid as a coolant in place of H_2O as a base liquid, resulting in enhanced performance with associated challenges. In addition, Muzaidi et al. (1) stated the thermal characteristics of CuO-TiO_2-SiO_2 ternary nanofluid as suitable for future solar thermal applications. Safiei et al. [4] developed a machining working fluid using SiO_2-ZrO_2-Al_2O_3 tri-hybrid nanofluids, which enhanced machining performance with good surface finishing and reduced cutting temperature. Guedri et al. [14] described the thermal characteristics Cu:TiO_2: Al_2O_3/water ternary hybrid nanofluid. The result showed that thermal characteristics were detected to enhance through an increase in temperature, radioactivity, Brownian motion, thermophoresis, heat generation, fraction factors, and volumetric fraction.

Esfe et al. [15] examined the thermal conductivity of MWCNT- MgO-ZnO (15 %:50 %:35 %) distributed into H_2O for SVF variety from (0.02 % to 2.0 vol%) and temperature changing from 30 °C to 50 °C. The highest RTC value was 32.7 % at 50 °C and 0.6 % SVF. Giwa et al. [2] premeditated the viscous behavior of DIW-based ZnO-MgO hybrid nanofluids at diverse particle mass ratio (PMR), with temperatures range of (20–50 °C) and 0.10 % volume concentration. The composite nanofluids exhibited an enrichment of viscous behavior as the temperature augmented with (0.60 %MgO–0.40 %ZnO/DIW). The HNFs were experiential to be greater than those of ZnO/DIW and MgO/DIW single nanofluids through a determined augmentation of 17.46 % for (0.60 % MgO–0.40 %ZnO/DIW) at 50 °C. Giwa et al. [16] empirically considered the effects of changing φ of (0.10 vol%–1.5.vol.%) and changing temperatures from 15 °C to 55° C, on the viscosity (μ) and electrical conductivity (EC) of (MWCNT)-Fe2O3/DIW composite nanofluid. Their result established the viscosity enhancement by 35.7 % and EC by 1676.4 %, compared to the base fluid. Both possessions were seen to increase as the φ and temperature augmented. Mousavi et al. [17] dispersed CuO-MgO-TiO_2 nanoparticles into deionized water to prepare DIW ternary hybrid nanofluid at φ of (0.1–0.5 vol%), with five diverse mix ratios, and the thermal possessions were tested at temperatures ranging from 15 to 60 °C. The outcomes indicated that the THNTs through a mixture ratio of (0.60 CuO-0.30MgO-0.10TiO_2) bay mass was the good sample as it had the lowermost μ is 36.4 % (at 0.50 vol%, and 60 °C), maximum κ of 78.60 % at (0.10 vol% at 15 °C), and deepest surface tension when related to the base liquid. Sahoo et al. [18] have considered the influences of changing a VF from 0.01 vol% to 0.10 vol% and changing temperature from 35 °C to 50 °C of H_2O-based Al_2O_3-CuO-TiO_2 ternary hybrid nanofluid on the dynamic viscosity. Their outcomes revealed that the maximum enhancement of dynamic viscosity of 55.41 % has been experimental for 0.1 % vol. at a temperature of 45 °C of Al_2O_3-CuO-TiO_2/H_2O THNFs. Dezfulizadeh et al. [19] have prepared a Cu-SiO2-MWCNT ternary hybrid nanofluid and investigational study of the effect of temperature ranging from 15 °C to 65 °C and ϕ variety of (1.0 vol% – 3.0 vol%) on the μ and κ. Their outcome showed the THNFs' Newtonian behavior.

This research examines the use of new types of nanofluids for thermal management applications. According to the authors' knowledge, no research has been reported to study the new MgO-ZnO-MWCNT/H_2O tri-hybrid nanofluid, especially on its thermal properties. So, in this study, a new tri-hybrid nanofluid of MgO-ZnO-MWCNT/H2O was designed and formulated, and its thermal properties and performance were investigated.

Experimental methodology

Materials and instrumentations

ZnO measuring 20 nm diameter with ≥99.5 % purity, and MgO nanoparticles measuring 20 nm diameter with purity ≥99 %, both procured from NANOSTRUCTURED and AMORPHOUS MATERIALS Inc. in Houston, USA, were synthesized through *f*-MWCNT of 10–30 µm length, and diameters (outer and inner) of 10–20 nm and 3–5 nm brought at MKnano Company, Ontario, Canada, with 98.5 % purity, Sodium Dodecyl Sulfate (SDS) of ≥98.5 % purity was procured at Sigma-Aldrich, Germany, engaged in attaining stable THNs. The deionized water DIW was used as a base fluid in the current investigation to make THNFs. Digital balancing balance (precision of ± 0.01 g and with a capacity ranging from 10 g to 220 g – Radwag AS 220.R2 Poland) for measuring nanopowder and the amount of (SDS) required weight, hot-plate magnetic stirrer Ha400 HSB (Indonesia) with a magnetic agitator, an Ultrasonicator (Germany – Hielscher UP200S: 50 Hz and 400 W) was engaged to standardize the mixture of binary nanoparticles and base fluid, thermal bath RE1225 (LAUDA ECO) was used to possess the solution at a constant temperature during homogenization period. Other instruments used involved, a pH meter (with capacity range –2 to 19.999 and precision of ±0.003 – Jenway 3510), electrical conductivity meter (EUTECH Meter: ±1 % precision, CON700), (TEM) (JEOL JEM-2100F) transmission electron microscope and sine wave SV-10 viscous meter (±1% precision – A&D, Japan) was used to measure the properties of nanofluid in the current work.

Preparation of ternary nanofluids and stability

The primary part of making ternary nanofluids is dispersing the necessary amount of ZnO, MgO, and MWCNT NPs in the base fluid by using the two-step technique. To make different φ of the ternary NFs, the essential quantities of mass were initially considered. Eq. (1) was applied to estimate the values of nanoparticles and base liquid and the necessary quantities of them for the preparation of diverse φ.

$$\varphi = \left[\frac{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{ZnO} + \left(\frac{w}{\rho}\right)_{MgO}}{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{ZnO} + \left(\frac{w}{\rho}\right)_{MgO} + \left(\frac{w}{\rho}\right)_{bf}}\right] \times 100 \quad (1)$$

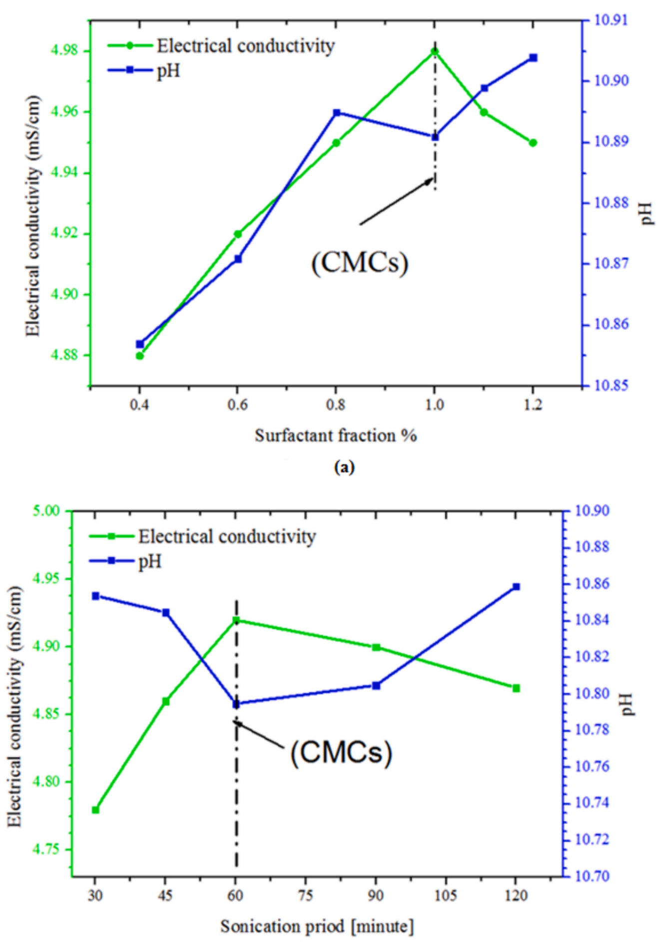

Fig. 1. Best surfactant fractions (SDS) required **(a)** and optimal sonication period **(b)** for THNF preparation.

where φ, ρ, and w are volume concentration, density, and weight, respectively.

The following part homogenized the mixture by stirring for 30 min to make the uniform distribution of the nanoparticles followed by the sonication method to form an excellent dispersion through SDS dispersion fraction of 0.6–1.3, sonication adjustment of period of 30–120 min, the amplitude of 70–80 %. The mixture was fixed inside a water bath at 20 °C through sonicating. The sonication adjustment period was first optimized by measuring the pH of the nanofluid, however the constant amplitude, the SDS dispersion fraction stirring time, and. Then optimize the amount of SDS required and amplitude. The optimized variables were used to ternary nanofluids with PMR of MWCNT:MgO: ZnO (20:80 (50:50)(sample A), 40:60(50:50) (sample B), 0.333:0.333:0.333 (sample C), 60:40(50:50)(sample D) and 80:20(50:50) (sample E) and 0.1 vol% and 100 ml were used for measurement of thermophysical properties of TNFs.

pH and electrical conductivity

The EUTECH Instrument was calibrated using standardization fluid delivered by the producer in the calibration terms of electrical conductivity. On calibration, a value of 1413 μS cm^{-1} was dignified at room temperature. Then, the EC of the base liquid and ternary nanofluids was evaluated at a bath temperature range of 15–60 °C. (5-degree recess). The pH meter was calibrated beforehand using clarifications of pH values of 4, 7, and 10, measuring the pH of the ternary nanofluid. The σ_{rel} and the enrichment (σ_{enhan}) afforded by the TNFs concerning base fluid were evaluated using Equations (2) and (3), respectively.

$$\sigma_{rel} = \frac{\sigma_{thnf}}{\sigma_{bf}} \quad (2)$$

$$\sigma_{enhan}(\%) = \left(\frac{\sigma_{thnf} - \sigma_{bf}}{\sigma_{bf}}\right) \times 100 \quad (3)$$

Where σ_{thnf} and σ_{bf} are the EC of THNFs and the base liquid, respectively.

Viscosity

Firstly, the SV-10 instrument was adjusted by measuring the μ of the base fluids at a bath temperature range of 15 – 60 °C (after the calibration process with the base fluids). A difference between the measured viscosity of the DIW and those [20] viscosity values was shown in Fig. 6 to check the μ after the meter was calibrated. At a similar bath temperature change the measurement was conducted to measure the μ of the THNFs. Relative μ and augmentation of the THNFs compared to base liquids were valued by Eq. (4) and (5), respectively.

$$\mu_{rel} = \frac{\mu_{thnf}}{\mu_{bf}} \quad (4)$$

$$\mu_{enhan}(\%) = \left(\frac{\mu_{thnf} - \mu_{bf}}{\mu_{bf}}\right) \times 100 \quad (5)$$

Where μ_{thnf} and μ_{bf} are the viscosity of ternary hybrid nanofluids and the H_2O, respectively.

In addition, the margin of deviancy (MOD) for the studied properties of THNFs is quantified by Eq. (6).

$$MOD = \left(\frac{V_{Exp.} - V_{Pred.}}{V_{Exp.}}\right) \times 100\% \quad (6)$$

Uncertainty analysis

The formula suggested by [21] was employed to predict the uncertainty of the valued outcomes such as μ, and σ that were dealt within this study by using Eq, (7) and (8), respectively. The uncertainties were

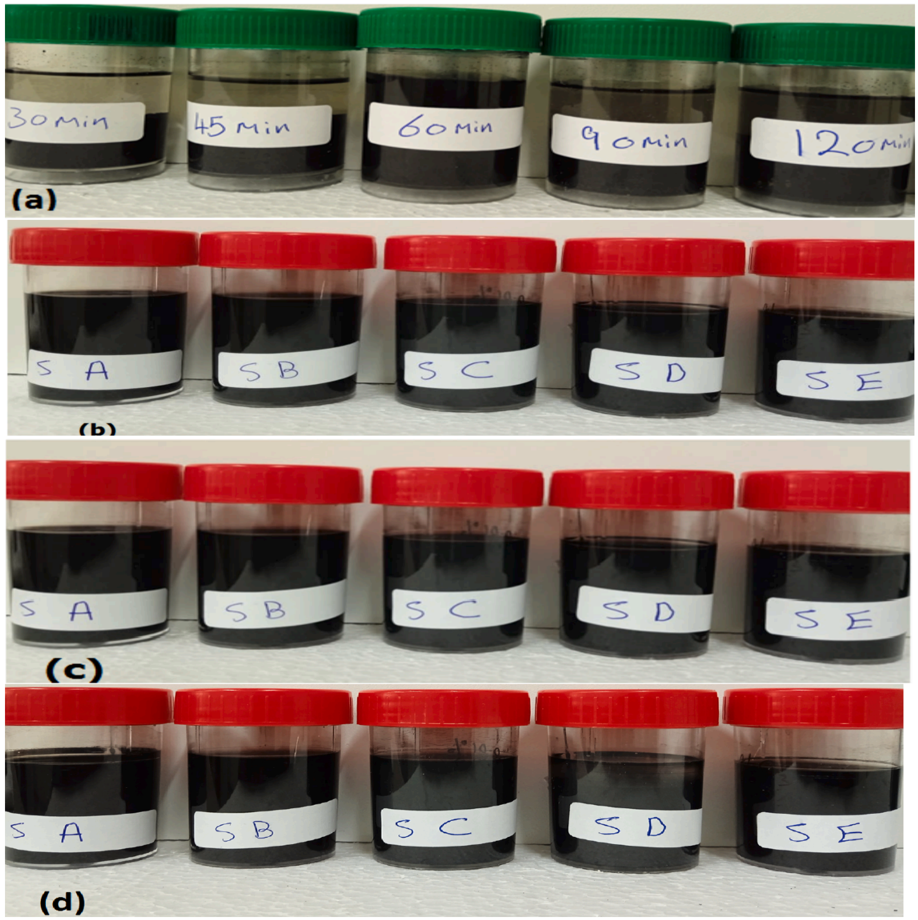

Fig. 2. (a) Optimam sonication period. (b, c and d) Inspecting the stability through visual inspection over one month for the distribution of MWCNT-ZnO-MgO nanoparticles into the base fluid (DIW).

evaluated within the 95 % probability. The instrument accuracies were evaluated based on the bias error used to determine the measurement precision that the manufacturer of the device typically quantifies. The viscosity and electrical conductivity measurement uncertainty was ± 1.93 % and ± 2.19 %, respectively.

$$U_{\mu} = \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta T}{T}\right)^2 + \left(\frac{\Delta \mu}{\mu}\right)^2} \tag{7}$$

$$U_{K} = \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta T}{T}\right)^2 + \left(\frac{\Delta \sigma}{\sigma}\right)^2} \tag{8}$$

Results and discussion

Dispersibility and characteristics of nanofluids

Dispersibility

In this work, a two-step technique was used in formulating the THNFs. The required quantities of ZnO, MgO, and MWCNT, nanoparticles, and SDS based on the mass amounts of MWCNT:MgO: ZnO (20:80(50:50), 40:60(50:50), 0.333:0.333:0.333, 60:40(50:50) and 80:20 (50:50) and 0.1 vol% considered were distributed into base fluid DIW.

The formulation of stable THNFs is a precise energetic step preceding their thermophysical properties and characterization measurement hence, for good distribution of the NPs inside the base fluid the effective adjustable variables were used such as the sonication (period and amplitude), and the surfactant fraction amount required was adapted by measuring the EC and pH of the formulated THNFs of (Sample C) with 0.10 vol% to achieve the optimum point of the stability of the operative variables. This point is called CMC. The (CMC) is the point of change in the tendency of the values of EC and pH which directs the optimum of the adjustable variables. Fig. 1(a & b) presents the optimum (period and surfactant fraction required). A point of inflection was detected for both the EC and pH at a dispersion fraction of 1.0 Fig. 1(a) to obtain the

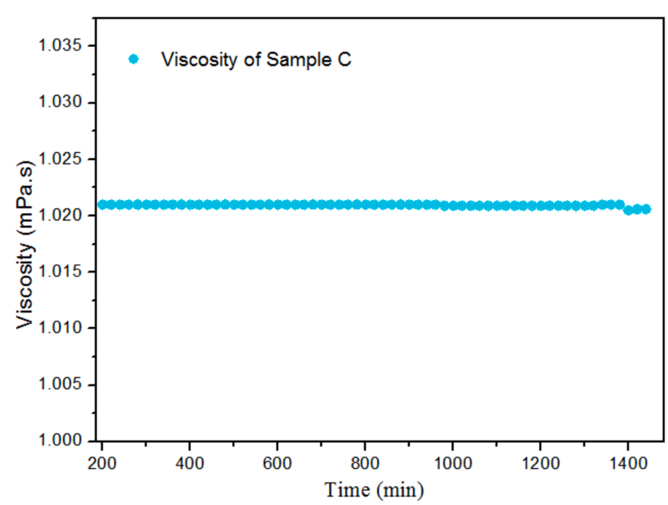

Fig. 3. Variation μ of sample C of MWCNT-ZnO-MgO THNFs through time at 25 °C.

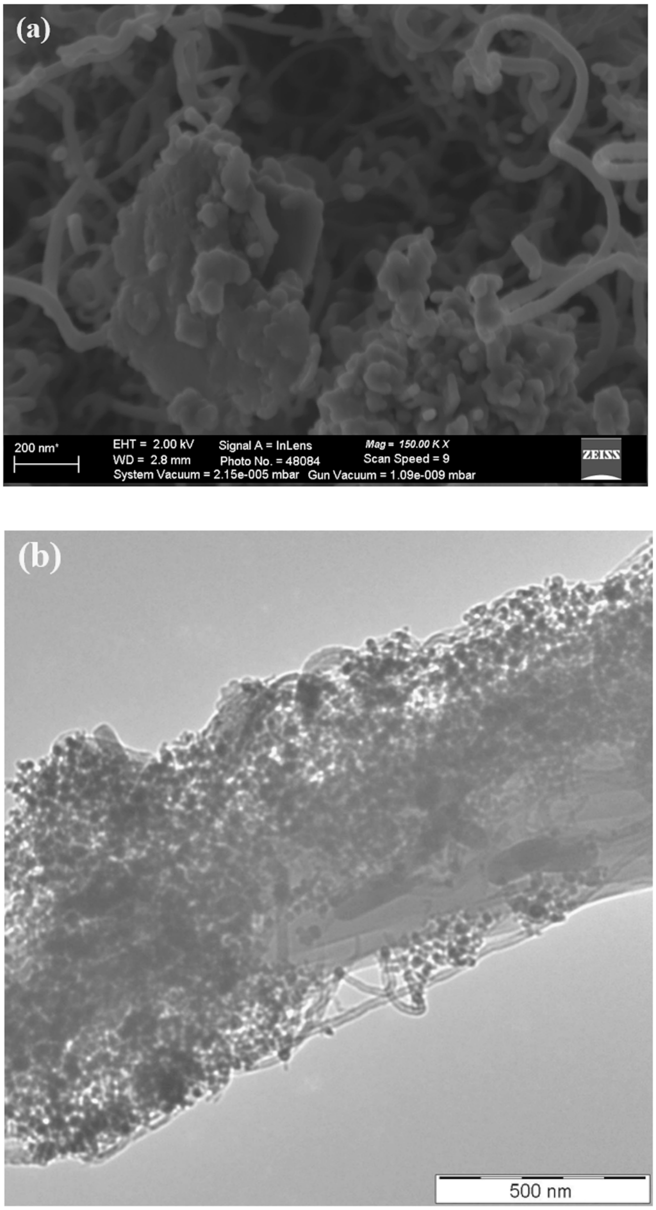

Fig. 4. (a) SEM image of MWCNT-ZnO-MgO nanocomposite (b) TEM image of MWCNT-ZnO-MgO nanocomposite.

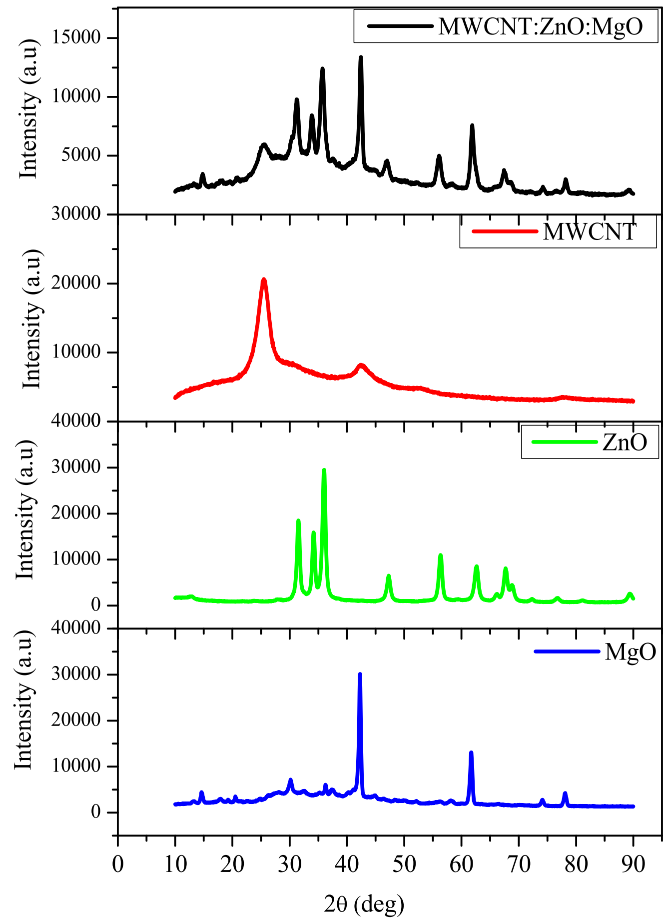

Fig. 5. X-ray diffraction pattern of carboxylated MgO, ZnO, MWCNT, and MWCNT:ZnO: MgO nanocomposite.

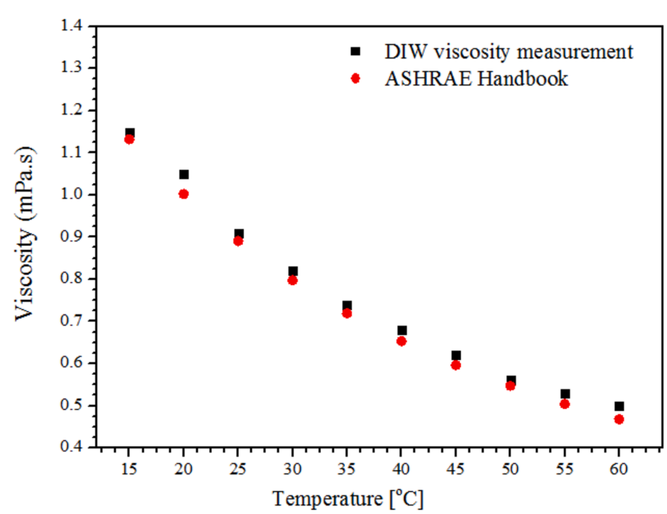

Fig. 6. Measured μ of the water and the [20] of diverse temperatures.

optimum amount of SDS required. Also, the point of variation was observed at 60 min for the EC and pH in determining the optimal sonication period Fig. 1(b). This fall in significance point of variation meant the (CMC) and consequently, the optimal amount of surfactant required [21]. Furthermore, in Fig. 2(a, b, c, and d) optical approach was applied to confirm the stability, the photographic approvals of the stability of the samples at the sonication period of THNFs showed that sedimentation occurred at diverse sonication periods cleared the best sonication period at 60 min Fig. 2(a). So, the samples were found to be stable after one month from the preparation day Fig. 2(b, c, and d). Furthermore, the viscous behavior of the nanofluids of the samples was measured for sample C for one day to confirm the stability of the formulated nanofluid, which is presented in Fig. 3.

Characterization of the THNFs

The morphology of the THNFs materials was monitored by FESEM and TEM devices and presented in Fig. 4(a and b). From Fig. 4(a) it can be realized in the FESEM image that the uniform distribution of ZnO and MgO wrapper by the MWCNT. The NPs at the nanometer scale can be realized in images in Fig. 4(b) on the TEM images. It can be noticed that excellent suspension of the nanoparticles and nanotubes into the aqueous base liquids was attained in the basic to stable nanofluids, furthermore for confirming the types of NPs, an XRD examination was used and presented in Fig. 5. It was established that the drawn spectra belong to each of the marked NPs. It should be distinguished that the determined highest angle specifies the space between the crystal plates

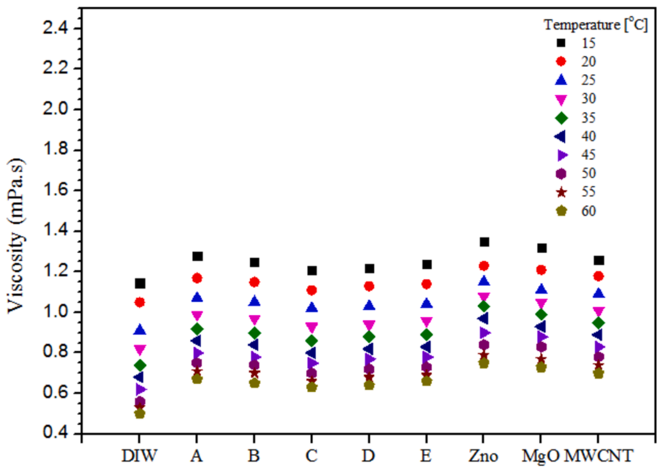

Fig. 7. The effect of PMR on the μ of the THNFs at diverse temperatures.

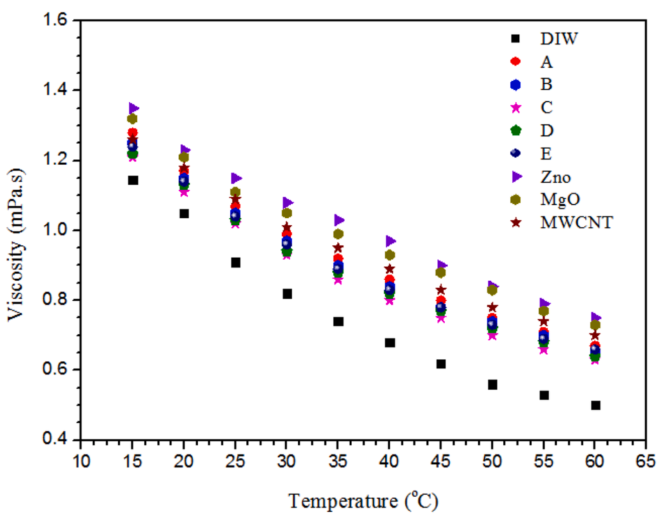

Fig. 8. Effect of diverse temperatures on the viscous behavior of THNFs at PMR.

and the strength of every peak covers evidence of how the particles are arranged. Lastly, the wavelengths of the taster XRD investigational data are matched by the reference patterns.

A visco-cohesive attribute of nanofluids

The viscous behavior of the nanofluids is a significant parameter and it plays a major quantity in the enhancement of heat transfer. In this current work, an investigation into the viscous behavior of ZnO-MgO-MWCNT /water ternary nanofluids for diverse PMR and thermal bath temperatures ranging from 15 °C to 60 °C at 0.1 vol% has been carried out. The influences of PMR and thermal bath temperature on the μ of the THNFS are demonstrated in Figs. 7 and 8. It is obvious that the dispersal of ternary diverse nanoparticles at various PMRs in the base liquid increased the viscosity of that base liquid (Fig. 7). However, it influences the dense nature of the nanotubes and nanoparticles; they should also be imagined based on their nature although interrelating through the H_2O molecules. Besides, it is obvious that the viscous behavior of ternary nanofluids declines with an escalation in thermal bath temperature due to the decrease in intermolecular interactions among the molecules of ternary nanofluids (Fig. 8). sample C of ternary composite nanofluids shows lesser viscosity results in comparison to other samples as well as mamo samples through similar investigational conditions. This might be

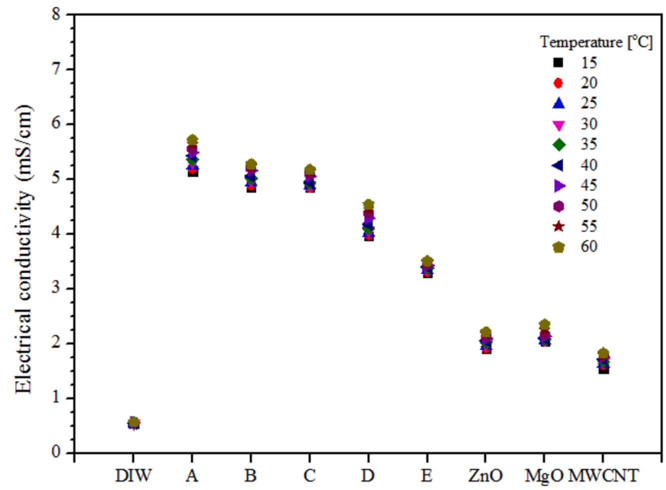

Fig. 9. Electrical conductivity with dissimilar mixture ratios at different temperatures.

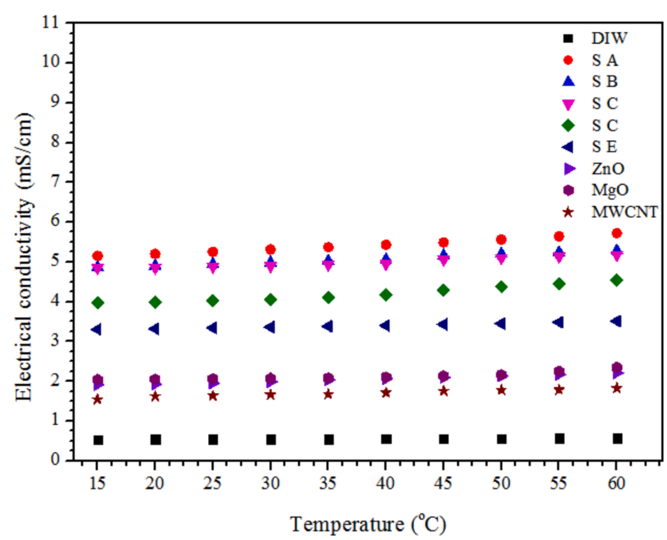

Fig. 10. Electrical conductivity with the temperature at diverse mixture ratios of THNFs.

attributed to the equal quantity of all three types of nanoparticles, the shapes can have a contact contrivance and connection nature that affects the viscosity of the liquid with which it is related. Such contrivances deliver intense intermolecular strength among the atoms themselves and among atom and liquid atoms, decreasing the Brownian motion, and therefore the liquid resistance. But such resistances are overcome by a higher temperature of the thermal bath that helps Brownian contact, therefore flagging such intermolecular forces principal to detrimental viscosity of THNFs.

The electrical conductance of ternary nanofluids

The performance of the nanofluid to conducted currents can be defined as the ability of an aqueous solution to conduct electric current it is named as electrical conductivity. The EC of NFs is poorly considered in contrast with other thermophysical properties. Also, the EC of THNFs is based on the author's earlier works review, seems to be few investigations have been carried out so far.

The ability of ZnO-MgO MWCNT/DIW THNFs to conduct electric current has been studied for their EC as a function of temperature and PMR at 0.10 vol% as illustrated in Figs. 9 and 10, respectively. Fig. 9

Table 1
The EC enhancement data for different types measured through testing.

Enhancement EC %					
Temperature	A	B	C	D	E
15	855.47	801.67	799.81	636.55	512.24
20	862.96	807.41	800.00	638.89	514.81
25	870.43	813.12	802.03	643.07	517.38
30	877.90	817.13	802.39	647.70	518.78
35	885.32	821.10	804.59	652.29	520.18
40	892.69	825.05	804.94	664.17	521.57
45	882.11	823.08	805.19	667.44	513.60
50	889.32	825.27	807.47	679.36	513.88
55	898.23	827.43	809.73	687.61	515.93
60	907.04	829.58	811.97	699.30	517.96

shows the electrical conductivity of THNFs concerning various percent weight ratios for various thermal bath temperature ranges of 15–60 °C. Adding the nanocomposite into the base fluid caused a significant rise in the conduct current behavior of THNFs. It can be understood in Fig. 9 that as the proportions of (ZnO and MgO) nanoparticles increased through a reduction in non-metal (MWCNT) nanotubes the conduct current behavior of the THNFs increased. However, the consequences illustrated that EC depends on temperature much less than on (ZnO and MgO) concentration. This remark is well shown in Fig. 10, in which the EC of the THNFs is improved linearly through a temperature increase. So, the EC of the nanofluids is dependent on PMR and temperature. These results are consistent with earlier works in which the EC of NFs improved by an escalation in temperature, nanoparticle type, and PMR [2,22,23].

The improvement of the EC of the THNF related to the base fluid at diverse thermal bath temperatures and PMR is presented in Table 1. As stated previously, the EC improvement of the hybrid nanofluids is a function of both the ratios of the hybrid NPs and temperature. As the MWCNT nanoparticles increased in the nanofluids, the electrical conductivity was reduced. However, the electrical conductivity was augmented as the metal (ZnO and MgO) nanoparticles were augmented, signifying that this nanoparticle has superior EC related to non-metal MWCNT nanotube. Cumulative the thermal bath temperature of the nanofluids furthermore caused the augmentation of the ability to conduct current, which is agreed through earlier investigations as previously revealed. A determined enhancement of 907.04 % was achieved for sample A at 60 °C. It is noticeable that the EC enrichment of the ternary hybrid nanofluids drastically deteriorated through the high content of non-metal nanotubes MWCNT. The previous works of Giwa et al. [2] specified 550.62 % enhancement of EC for MgO–ZnO/DIW at 0.1 vol% and 55 °C when compared with DIW. Giwa et al. [16] reported 1676.4 % augmentation of EC for MWCNT-Fe2O3/DIW at 1.5 vol% and 45 °C compared with base fluid.

Correlation establishment

Investigational data of viscosity and EC were expected as the relative of THNFs results to base liquid results. The experimental results were fitted by regression analysis to advance relations for the prospect of the viscosity and EC. Eqs. (9) and (10), respectively are expressed as the recognized correlations for the considered properties as dependent on the PMR and temperature.

For the μ correlation, $R^2 = 0.93$ while for the EC relationship, $R^2 = 0.96$. These reveal comparatively high relationship coefficients through small faults for both relations.

$$\frac{\mu_{thnf}}{\mu_{bf}} = 5.51 \times 10^{-3} T - 2.91 \times 10^{-3} PWR + 1.0027 \tag{9}$$

$$\frac{\sigma_{thnf}}{\sigma_{bf}} = 0.00691 T - 0.951 PWR + 9.52 \tag{10}$$

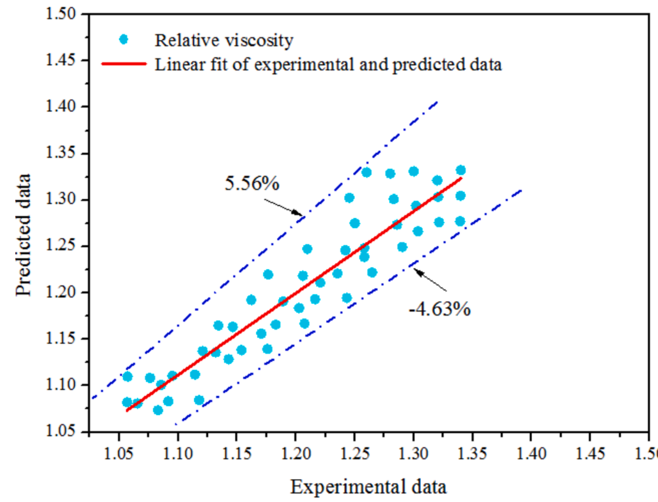

Fig. 11. Comparison among the empirical results and the proposed output for relative viscosity of THNFs.

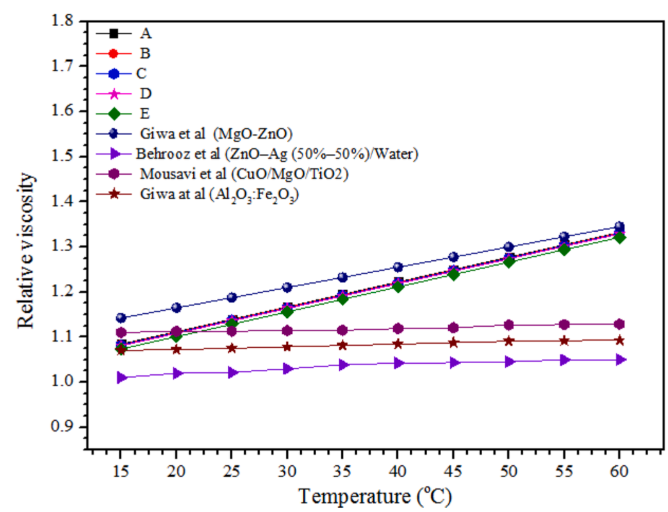

Fig. 12. Comparison of the relative μ of the considered ternary nanofluids from experimental results with different nanofluids.

Fig. 11 shows the MOD for the relationship among the expected and investigational results for the relative μ of the THNFs is estimated as ±3.48. A best straight line is observed between the experimental and predicted values presenting a correlation between both results sets. The margin of deviancy for the correlation is estimated as +5.56.48 % and −4.63 %.

Fig. 12 shows the relative μ correlation for this investigation and those expressed in earlier investigations [2,16,17,24]. It revealed that the obtainable correlations for approximating the relative μ of ternary nanofluids could not be appropriate for the achieved investigational results. They all overvalued the relative μ of the studied THNFs.

Fig. 13 shows the relative EC correlation between this current investigation results and those listed in earlier published works [2,16,25]. It can be seen that the correlations of the published works for the EC of the considered nanofluid could not be suitable for the accomplished investigational data. Seemingly, they completely underestimated the relative EC of the tested THNFs.

A direct correlation is established to be among the expected and investigational data associated with the fitted relationship via Eq. (10), as depicted in Fig. 14. MOD of ±9.50 % and −4.99 % is calculated.

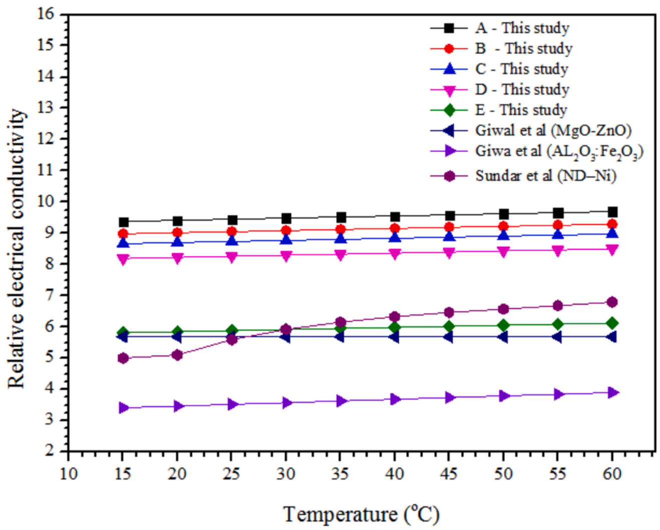

Fig. 13. Comparison of the relative EC of the considered THNFs from experimental results with different nanofluids.

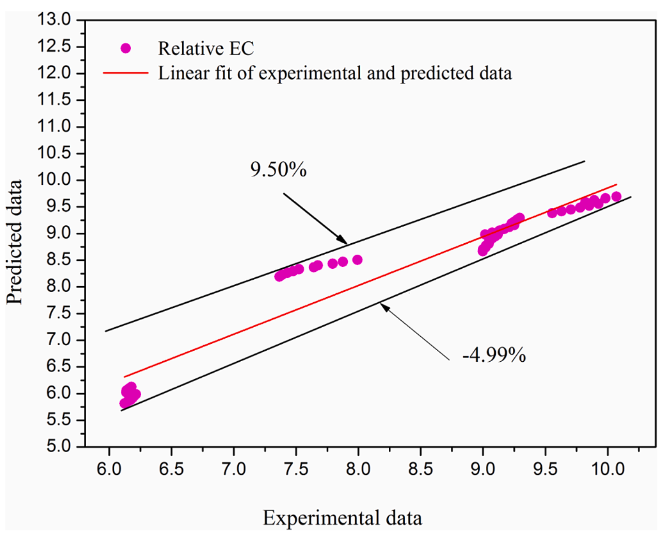

Fig. 14. Comparison between the empirical results and the proposed output for relative viscosity of THNFs.

Conclusion

In this investigation, the two-step technique was engaged to prepare a volume concentration of 0.10 vol% of water-based/(MgO:ZnO: MWCNT) ternary composite nanofluid at different weight ratios; samples were tested by visual assessment, viscosity, and imaging technique and the results confirming its stability and the considered nanofluid was noted to be well-distributed and stable. The behavior and the ability to conduct an electrical current of the ternary hybrid nanofluids at a thermal bath temperature changing from 15 to 60 °C have been studied experimentally; and the result shows at 60 °C, the highest augmentation of EC and viscosity of the nanofluids compared to base fluid, respectively. The review also proved that the results obtained through previous research in the literature are consistent.

CRediT authorship contribution statement

Modaser. Momin: Data curation, Validation, Formal analysis, Investigation, Writing – original draft. **C.N. Nwaokocha:** Investigation, Writing – original draft. **M. Sharifpur:** Methodology, Writing – review & editing, Supervision, Funding acquisition. **G. Cheraghian:** Investigation, Writing – review & editing. **J.P. Meyer:** Writing – review & editing, Resources, Project administration. **Magda Abd El-Rahman:** Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

Magda Abd El-Rahman extends her appreciation to the Deanship of Research and Graduate Studies at King Khalid University for funding this work through Large Research Project under grant number RGP2/39/46.

Data availability

Data will be made available on request.

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