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A new model for viscosity prediction for silica-alumina-MWCNT/Water hybrid nanofluid using nonlinear curve fitting

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ABSTRACT

One of the most crucial concerns is improving industrial equipment's ability to transmit heat at a faster rate, hence minimizing energy loss. Viscosity is one of the key elements determining heat transmission in fluids. Therefore, it is crucial to research the viscosity of nanofluids (NF). In this study, the effect of temperature (T) and the volume fraction of nanoparticles (φ) on the viscosity of the silica-alumina-MWCNT/Water hybrid nanofluid (HNF) is examined. In this study, a nonlinear curve fitting is accurately fitted using MATLAB software and is used to identify the main effect, extracting the residuals and viscosity deviation of these two input variables, i.e., temperature (T = 20 to 60 °C) and volume fraction of nanoparticles (φ = 0.1 to 0.5 %). The findings demonstrate that the viscosity of silica-alumina-MWCNT/ Water hybrid nanofluid increases as the φ increases. In terms of numbers, the μ_{nf} rises from 1.55 to 3.26 cP when the φ grows from 0.1 to 0.5 % (at T = 40 °C). On the other hand, the μ_{nf} decreases as the temperature was increases. The μ_{nf} of silica-alumina-MWCNT/ Water hybrid nanofluid reduces from 3.3 to 1.73 cP when the temperature rises from 20 to 60 °C (at φ = 0.3 %). The findings demonstrate that the μ_{nf} exhibits greater variance for lower temperatures and higher φ.

1. Introduction

Given the significance of energy on a global scale, one of the most crucial concerns is to increase industrial equipment's heat transfer rate and hence decrease energy loss [1]. Improving heat transmission in industrial equipment is of utmost importance due to its wide range of applications across various industries. Efficient heat transfer is crucial for enhancing the performance and efficiency of equipment such as heat exchangers, cooling systems, and thermal management devices. Conventional heat transfer fluids often exhibit limitations in terms of their thermal conductivity, leading to reduced efficiency in heat transfer processes. This limitation has prompted researchers to explore alternative solutions to enhance heat transfer performance, and one promising avenue is the utilization of nanofluids. Nanofluids, which are colloidal suspensions of nanoparticles in base fluids, have emerged as a potential solution to address the limitations of conventional heat transfer fluids. By dispersing nanoparticles with high thermal conductivity, such as silica-alumina-MWCNT, in a base fluid such as water, the overall thermal conductivity of the nanofluid can be significantly enhanced. This enhancement offers the possibility of improving heat transfer efficiency and ultimately enhancing the performance of industrial equipment. In this research, developing a new model for viscosity prediction for silica-alumina-MWCNT/water hybrid nanofluid using nonlinear curve fitting techniques will contribute to a better understanding of the rheological behavior of nanofluids. Accurately predicting the viscosity of nanofluids is crucial for designing and optimizing heat transfer systems using these

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fluids. By enhancing the prediction accuracy of viscosity, the proposed model can aid in the efficient design and optimization of industrial equipment, leading to improved heat transfer efficiency, reduced energy consumption, and potentially significant cost savings. This research can have a direct impact on various industries, including power generation, automotive, aerospace, and electronics cooling. Viscosity is one of the most crucial elements determining fluid-based heat transmission [2]. Therefore, it is important to research nanofluids' viscosity (μ_{nf}) [3,4]. Numerous studies have focused on the μ_{nf} so far [5,6]. Studies have shown that several variables, including temperature, pH, particle size, shape, and volume fractions of nanoparticles, among others, have an impact on the viscosity of fluids [7]. Due to the weakening of intermolecular interactions brought on by heat, the μ_{nf} typically decreases as temperature rises. Additionally, when the φ rises, the forces between its molecules become stronger and more strongly bonded, raising the μ_{nf} [8,9]. The rheological behavior of μ_{nf} of silica-alumina-MWCNT/Water hybrid nanofluid is studied in this research because its correspondence to independent variables is not investigated yet. Nanotechnology is a branch of applied knowledge and technology that has numerous uses in physics, chemistry, and mechanical engineering [10,11]. Its main topic is the inhibition of materials or objects smaller than one micrometer, often between one and one hundred nanometers. Because quantum qualities predominate over classical properties in these dimensions, nanotechnology is the understanding and use of novel systems and materials specifications that exhibit new physical effects [12,13]. Currently, the use of nanotechnology to enhance and improve the thermal specifications of industrial devices can be effective in reducing the hot spot temperature, which is one of their design limitations, and increasing the nominal power, decreasing the dimensions, and reducing consumables in this equipment lead [14,15]. In this regard, the researchers tried to improve the mixture's specifications by floating nanoparticles in it. For instance, Yiamsawasd et al. [16] studied how Titanium Oxide (TiO_2) and aluminum oxide (Al_2O_3) nanoparticles affected a water/EG mixture's heat transfer coefficient. The findings demonstrate that by upping the φ to 25 %, heat transfer rises. Jeong et al. [17], Abdullah et al. [7], Chandrasekar et al. [18], Sundar et al. [19], etc., have all provided similar results. There have also been other investigations into the mechanisms influencing the heat transfer of different nanofluids. For instance, Duangthongsuk et al. [20] determined the μ_{nf} of TiO_2/water nanofluid at various temperatures. The outcomes demonstrate that introducing TiO_2 nanoparticles into water improves thermal conductivity and μ_{nf}. On the other hand, the μ_{nf} diminishes when the temperature rises from 15 to 35 °C. μ_{nf} of CuO-TiO_2/water nanofluid was computed by Asadi et al. [21] for T = 25 to 55 °C and φ = 0.1 to 1 %. According to the findings, the μ_{nf} reduced by about 37 % when the temperature was raised to 55 °C, and it increased by around 54 % when the φ was raised to 1 %. The μ_{nf} of Al_2O_3-TiO_2-graphene/water nanofluid was determined by Vakilinejad et al. [22] for T = 25 to 65 °C. Esfe et al. [23] computed the μ_{nf} of TiO_2/water nanofluid at a temperature range of 30 to 70 °C. The μ_{nf} of a TiO_2/water nanofluid with different surfactants was determined by Das et al. [24]. Sahrma et al. [25] investigated recent advances in machine learning for nanofluid studies [25]. Said et al. [26] optimized density, dynamic viscosity, thermal conductivity and specific heat of a hybrid nanofluid via ANFIS-based model [26]. In another study, Sharma et al. [27] developed a new correlation for mixed ratio for viscosity and rheological behavior of Al2O3-Fe2O3/water-EG based hybrid nanofluid [27]. Prakash et al. investigated the effective parameters on viscosity of water-ethylene Glycol-based α-alumina nanofluids [28]. Malika et al. [29]examined the water/Fe_2O_3-SiC nanofluid's thermal characteristics at various T, φ, and particle sizes. Esfe et al. [30] examined the thermal characteristics of a hybrid alumina-MWCNT/thermal oil nanofluid at various T and φ. Cu- oil nanofluid was studied by Abdulrahman et al. [31] at various T, and shear rates. The μ_{nf} of a nanofluid made up of TiO_2-MWCNT and EG was computed by Rahman et al. [32]. Generally, all results reveal that by increasing the φ, μ_{nf} increases. While, by increasing temperature, in contrast, φ, μ_{nf} decreases. This paper studies the effect of temperatures and φ on the μ_{nf} of silica-alumina-MWCNT/ Water hybrid nanofluid. The μ_{nf} of silica-alumina-MWCNT/ Water hybrid nanofluid is determined at φ = 0.1, 0.2, 0.3, 0.4, 0.5 % and T = 20, 30, 40, 50, and 60 °C to investigate the effects of temperatures and φ on μ_{nf}. This research contributes to the understanding of the rheological behavior of nanofluids and provides insights into optimizing heat transfer performance in industrial applications. Potential applications of these findings include the design and improvement of cooling systems, heat exchangers, and other heat-intensive processes aimed at minimizing energy loss and enhancing thermal efficiency.

2. Experimental and methods

2.1. Preparation step

The prepared nanoparticles are manufactured by the American company US Research Nanomaterials [3,12,15]. The physical properties of nanoparticles used in the experiment are listed in Table 1.

In this research, pure water is used as the base fluid. The characteristics of water are presented in Table 2.

In this study, a two-step process was used to create the hybrid nanofluid. In the two-step approach, nanoparticles are first synthesized, and then they are dispersed in a suitable fluid in the second step. The high surface energy of the nanoparticles used in this process causes them to aggregate and deposit. As a result, the stability of nanofluid reduces as nanoparticles are deposited [33]. However, this approach was chosen since it was inexpensive and simple to use the scale. This hybrid nanofluid composition is presented in Table 3.

2.2. Viscosity

The μ_{nf} was measured in this investigation using a cone and plate viscometer built to the Brookfield 2DV type. This viscometer has an integrated thermoelectric module that regulates temperature up to 75 °C, making it a medium/high shear tool. For each φ and T, all experiments were conducted again at various rotational speeds.

3. Results and discussion

In this paper, the experimental data for μ_{nf} versus T and φ are shown in Table 4.

The findings demonstrate that the μ_{nf} increases as the φ increases. In terms of numbers, the μ_{nf} increases from 1.98 to 4.76 cP with φ increase from 0.1 to 0.5 % (at T = 20 °C). Furthermore, μ_{nf} deviation decreases when temperature increased from 20 to 60 °C with the same variation of φ. To be more precise, at T = 60 °C, with a variation of φ, the μ_{nf} increases and changes from 1.24 to 2.40 cP. On the other hand, the μ_{nf} has decreased as a result of the temperature rise. The μ_{nf} drops from 4.76 to 2.40 cP when the temperature rises from 20 to 60 (at φ = 0.5 %). Although, researchers have used various methods of prediction such as curve fitting and neural network, curve fitting has a well-developed

Table 1
Physical properties of nanoparticles used in the experiment.

Nanoparticle Name	Silicon Oxide	Multiwalled Carbon Nanotube	Alumina
Molecular Formula	SiO2	C	Al_2O_3
Shape of Nanoparticle	spherical	cylindrical	spherical
Dimension	11–13 nm	Inner: 5–10 nm Outer: 20–30 nm	10–30 nm
Purity	>99 %	wt%>99 %	>99 %
Appearance	White powder	Black powder	White powder
Density	2.4 gr/cm^3	2.1 gr/cm^3	3.97 gr/cm^3

Table 2
Properties of pure water.

Chemical formula	H2O
Molecular mass	18.02 (g/mol)
Density	0.997 (g/cm^3)
Boiling point	100 (C°)
Melting point	0 (C°)

Table 3
Amounts needed to prepare ternary hybrid nanofluids.

Volume Fraction of nanoparticles (%)	Volume of the solution (ml)	water Mass (gr)	MWCNTs Mass (gr)	SiO_2 Mass (gr)	Al_2O_3 Mass (gr)
0	50	49.85	0	0	0
0.1	50	49.801	0.021	0.048	0.0794
0.2	50	49.750	0.042	0.096	0.1588
0.3	50	49.700	0.063	0.144	0.2382
0.4	50	49.651	0.084	0.192	0.3176
0.5	50	49.601	0.105	0.240	0.397

Table 4
Experimental data for μ_{nf} (cP) versus temperature and φ.

	φ(%)				
T (°C)	0.1	0.2	0.3	0.4	0.5
20	1.98	2.74	3.30	3.85	4.76
30	1.72	2.11	2.55	3.26	3.86
40	1.55	1.83	2.12	2.86	3.26
50	1.40	1.54	1.97	2.29	2.77
60	1.24	1.39	1.73	2.12	2.40

theory and used in this paper to create a nonlinear polynomial function based on the theory of curve fitting. The highest power of this polynomial was determined in a manner that the R-square and Adj R-square have the highest value. In contrast, the RMSE has the lowest value. The resulting function has a power of 3 versus φ and T. The following is a representation of the predicted function:

$$\mu(\varphi,T) = p_{00} + p_{10}\varphi + p_{01}T + p_{20}\varphi^2 + p_{11}\varphi T + p_{02}T^2 + p_{30}\varphi^3 + p_{21}\varphi^2 T + p_{12}\varphi T^2 + p_{03}T^3 \tag{1}$$

where the coefficients of Eq. (1) can be represented as below:

$$\begin{aligned} p_{00} &= 2.792\ (1.375,\ 4.209)\\ p_{10} &= 6.092\ (-\ 0.5803,\ 12.77)\\ p_{01} &= -\ 0.0837\ (-\ 0.1865,\ 0.01914)\\ p_{20} &= 9.571\ (-\ 10.44,\ 29.58)\\ p_{11} &= -\ 0.1809\ (-\ 0.333,\ -\ 0.02887)\\ p_{02} &= 0.001649\ (-\ 0.0009277,\ 0.004225)\\ p_{30} &= -\ 6.333\ (-\ 27.39,\ 14.73)\\ p_{21} &= -\ 0.005714\ (-\ 0.1567,\ 0.1453)\\ p_{12} &= 0.001157\ (-\ 0.0003531,\ 0.002667)\\ p_{03} &= -\ 1.15e-05\ (-\ 3.256e-05,\ 9.559e-06) \end{aligned} \tag{2}$$

These coefficients were all calculated to give a 95 % confidence level in the curve fitting. These factors can be used to verify the suitability of this fitting:

$$\begin{gathered} \text{Goodness of fit:}\\ \text{SSE: } 0.1054\\ \text{R - square: } 0.9945\\ \text{Adjusted R - square: } 0.9912\\ \text{RMSE: } 0.08384 \end{gathered} \tag{3}$$

The fitted curve has a strong likelihood to predict μ_{nf} as a function of T and φ based on the aforementioned criteria [3,14,15]. Utilizing a comparison between the experimental points and the surface produced by Eq. (1), this validation was verified (See Fig. 1). On the three-dimensional surface, the experimentally plotted spots with dots coincide, demonstrating the accuracy of the curve fitting.

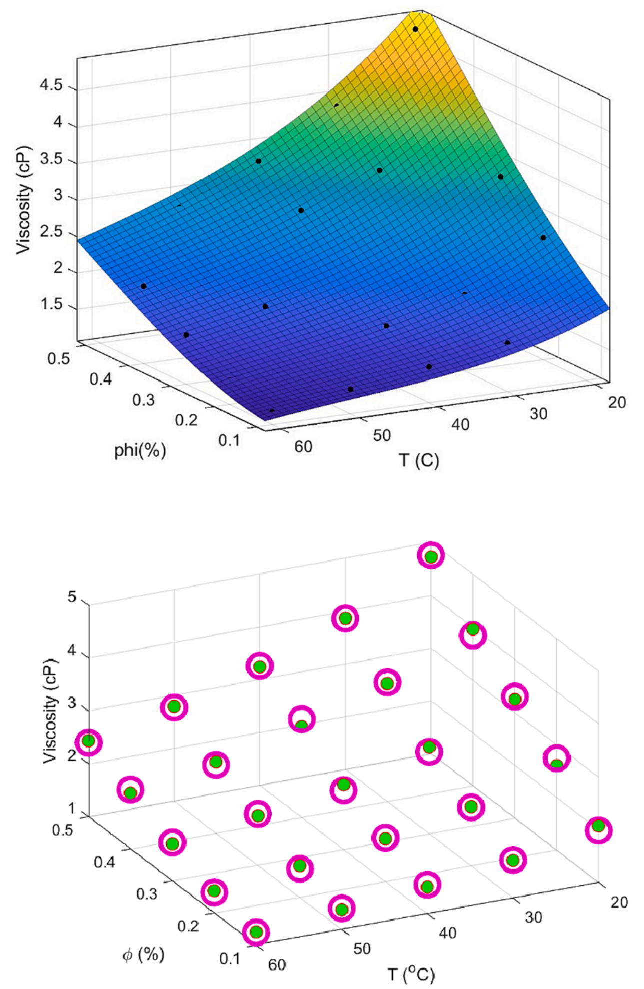

Fig. 1. fitted equation outcome comparison with the experimental data for μ_{nf}.

In Fig. 2, the prediction error is displayed in two ways using a heatmap graph and also a 3D plot of μ_{nf} versus two input parameters.

Table 5 presents the calculated outcomes and shows how accurately estimated and experimental findings compare.

These numbers make it clear that the proposed equation for the prediction of μ_{nf} has a respectable degree of accuracy. Fig. 3 displays the μ_{nf} deviation concerning T. It is clear from this graph that the μ_{nf} typically declines with temperature, but at lower temperatures, the rate of decrement is considerably higher, while at higher temperatures, the rate is lower.

Fig. 4 shows the μ_{nf} deviation versus φ.

From this figure, one can see the μ_{nf} deviation increases with φ increase. This point reveals that in higher φ, the temperature has higher effects on the μ_{nf} while by decreasing the φ value, the effect of temperature and accordingly the μ_{nf} deviation decreases. To explain this phenomenon, it's important to understand that when the volume fraction of nanoparticles in a nanofluid is higher, the interaction between the nanoparticles becomes more prominent. This interaction can lead to an increase in the effective viscosity of the nanofluid, making it more sensitive to changes in temperature. However, when the volume fraction decreases, the interactions between nanoparticles become less significant. As a result, the effect of temperature on the viscosity of the

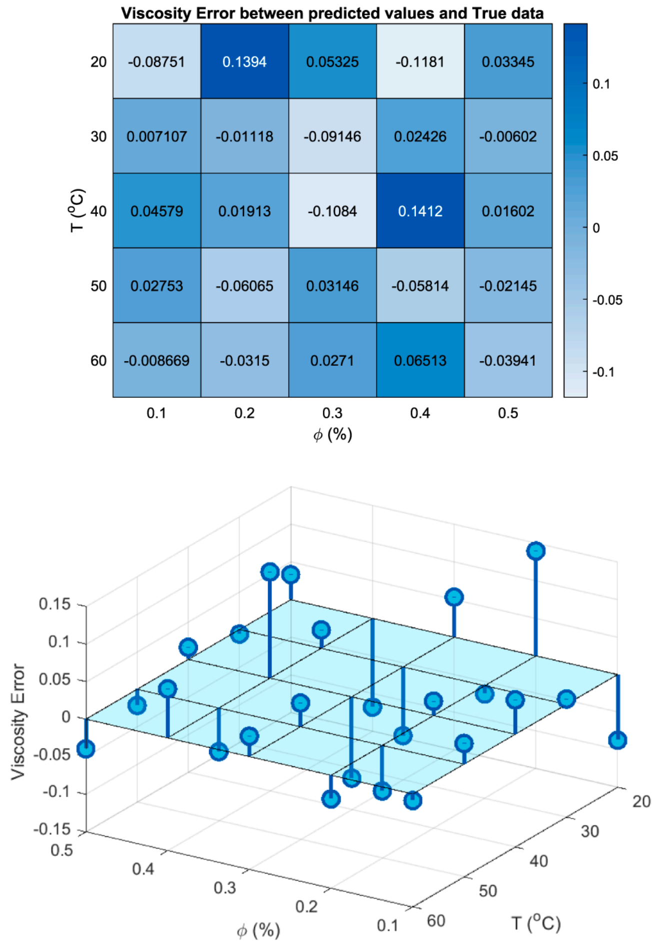

Fig. 2. Viscosity error between predicted values and True data: Top) Heatmap graph of errors, Bottom) Stem Graph of Errors.

Table 5
Accuracy of predicted data using fitted function vs. experimental results.

		φ(%)				
T(°C)		0.1	0.2	0.3	0.4	0.5
20	True value	1.9800	2.7400	3.3000	3.8500	4.7600
	Predicted	2.0675	2.6006	3.2468	3.9681	4.7266
	Error	−0.0875	0.1394	0.0532	−0.1181	0.0334
30	True value	1.7200	2.1100	2.5500	3.2600	3.8600
	Predicted	1.7129	2.1212	2.6415	3.2357	3.8660
	Error	0.0071	−0.0112	−0.0915	0.0243	−0.0060
40	True value	1.5500	1.8300	2.1200	2.8600	3.2600
	Predicted	1.5042	1.8109	2.2284	2.7188	3.2440
	Error	0.0458	0.0191	−0.1084	0.1412	0.0160
50	True value	1.4000	1.5400	1.9700	2.2900	2.7700
	Predicted	1.3725	1.6006	1.9385	2.3481	2.7915
	Error	0.0275	−0.0606	0.0315	−0.0581	−0.0215
60	True value	1.2400	1.3900	1.7300	2.1200	2.4000
	Predicted	1.2487	1.4215	1.7029	2.0549	2.4394
	Error	−0.0087	−0.0315	0.0271	0.0651	−0.0394

nanofluid diminishes, leading to a decrease in the deviation of viscosity from its expected value. It's worth noting that additional research and analysis may be required to fully understand the underlying mechanisms and factors influencing the viscosity-temperature relationship.

4. Conclusion

This paper represents a new fitting function for the prediction of μ_{nf} versus T and φ for silica-alumina-MWCNT/ Water hybrid nanofluid. In

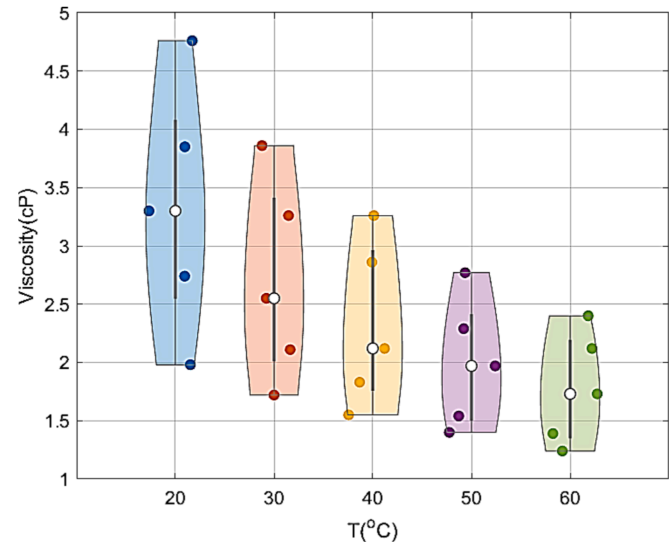

Fig. 3. Deviation of μ_{nf} as a function of T.

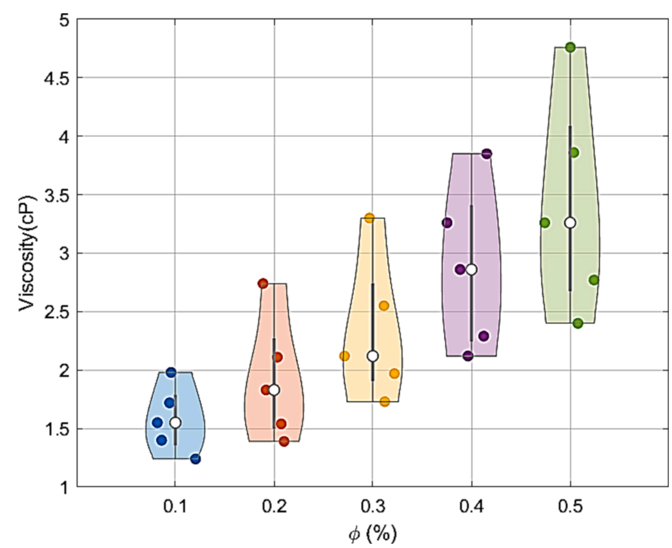

Fig. 4. μ_{nf} deviation as a function of φ.

this study, the temperature effect is considered in 5 levels from 20 ~ 60 °C and φ is studied in 5 levels from φ = 0.1–0.5 %. A nonlinear curve fitting function of power 3 versus T and φ is presented. To this end, MATLAB software was used and the fitting function is obtained as a power function. Additionally, ANOVA analysis was used to extract the residuals and μ_{nf} deviation from two input components, namely temperature and φ, to determine the main impact. The findings can be summed up as follows:

- The highest μ_{nf} would be achieved with the highest values of temperature and φ.
- μ_{nf} has a direct dependency to φ, and μ_{nf} increases when φ increases. For instance, the highest values of μ_{nf} can be obtained in φ = 0.5 % for various temperatures.
- As temperature increases, the μ_{nf} would decrease but the rate of μ_{nf} decrement is less than the effect of φ. To be more precise, the μ_{nf} decreases from around 2 to 1.25 cP in φ = 0.1 % when the temperature changes from 20 to 60 °C.

- The fitted function shows great accuracy having SSE = 0.1054, RMSE = 0.0838 and R^2 = 0.9945 and the obtained function is a valuable tool for the design and optimization of systems.
- The highest error value (0.1412) corresponds to φ = 0.4 % and T = 40 °C which is under 5 %.
- In the obtained function, the highest power of T and φ assumed to be 3 for the highest accuracy. Of course, the third power of T is negligible and this term can be omitted, but the third power of φ has a large coefficient and hence shouldn't be ignored.
- The violin plots clearly describe the variation of μ_{nf} versus two independent parameters. According to these figures, as the mean value of μ_{nf} is increased, its deviation is getting larger too.
- The mean values of μ_{nf} in these violin plots clearly show a concave trend for μ_{nf} versus φ and T that can be seen in the 3D plot too.

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.

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