Contents lists available at ScienceDirect

Arabian Journal of Chemistry

journal homepage: www.ksu.edu.sa

Presenting the best correlation relationship for predicting the dynamic viscosity of CuO nanoparticles in ethylene glycol -water base fluid using response surface methodology

Mohammad Hemmat Esfe [a], Seyed Naser Hosseini Tamrabad [b], Davood Toghraie [c,*], Hossein Hatami [d]

[a] Department of Mechanical Engineering, Imam Hossein University, Tehran, Iran
[b] Nanofluid Advanced Research Team, Tehran, Iran
[c] Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr, Iran
[d] Associate Professor, Department of Mechanical Engineering, Lorestan University, Khorramabad, Iran

A R T I C L E I N F O

Keywords:
Rheological behavior
Dynamic viscosity CuO
Ethylene glycol-Water
RSM
Nanoparticles

A B S T R A C T

The types of correlation relationships by different models for predicting of the dynamic viscosity of CuO nanoparticles (NPs) in the ethylene glycol (EG) (80 %)-Water (20 %) base fluid (BF) by using response surface methodology (RSM) statistical method under temperature conditions of T = 15 to 50 °C, solid volume fractions of SVF = 0.05 to 1 % and shear rate SR = 26.6 to 933.1 s^{-1} were investigated. Models of Quadratic, Cubic, 2FI and Quartic were investigated. These different models were analyzed based on the measurement criteria such as Correlation deviation, coefficient of determination, standard deviation, reliability and P-values; there are important parameters that were used to compare the models. Among these four models, the Quartic model has been chosen as superior model and used to optimize nanofluid (NF) viscosity. The optimization was done in cold environmental conditions and SVF, T, SR variables and viscosity were selected as minimum values and applied to the system. In the conditions of T = 25.303 °C, SVF = 0.05 % and SR = 26.660 sec^{-1}, most optimal NF viscosity value was 8.565 mPa.sec.

1. Introduction

Today, modelling of properties of mixtures is seen in medical sciences, mathematics, biology, chemistry, physics, etc. (Alizadeh et al., 2023; Dai et al., 2023; Ruhani et al., 2022). Nanofluid (NF) was first introduced by Choi in 1995 (Dai et al., 2023). NFs are expanded liquids that are obtained by combining nanoparticles (NPs) with 1 to 100 nm size in a base fluid. Adding NPs to base fluids (BFs) improves thermophysical properties. The use of NFs has a wide role in various scientific and industrial fields and improves heat transfer properties. Adding NPs to BFs increases thermal conductivity (TC) and viscosity of NPs compared to BFs. Many studies were done by researchers in this field (Apmann et al., 2021; de Oliveira et al., 2019; Omrani et al., 2019; Urmi et al., 2022; Younes et al., 2022; Choi and Eastman, 1995). NF is used in heat exchangers, cooling, chillers and many industries (Li et al., 2020; Krishnakumar et al., 2019; Elfaghi and Hisyammudden, 2021; Pordanjani et al., 2019; Arora and Gupta, 2020). The combination of water and ethylene glycol (EG) has an acceptable performance at different temperatures and conditions and increases and improves heat transfer (HT) rate. This compound is used as a BF in many energy systems because of the high heat capacity of water and protection against EG corrosion. Many studies were done in the field of adding NPs to BFs of water, EG or a mixture of them (Kazem et al., 2021; Khan et al., 2019; Neves et al., 2022; Ramadhan et al., 2021; Vallejo et al., 2019). Many studies were

Abbreviations: R -Squared (R^2), Coefficient of Determination; Adjusted R- Squared, Adjusted Coefficient of Determination; Predicted R – Squared, Predicted Coefficient of Determination; C.V, Coefficient of variation; C.D, Correlation deviation; Std. Dev, Standard deviation; P-value, Probability value; RSM, Response surface methodology; ANN, Artificial neural network; Eq, Equation; HN, Hybrid nanofluid; NPs, Nanoparticles; MWCNTs, Multi-walled carbon nanotubes; CNTs, carbon nanotubes; SVF, solid volume fraction; SR, Shear rate; EG, Ethylene glycol; $\mu(mPa.\text{sec})$, Viscosity; T(°C), Temperature; φ, solid volume fractions; NFs, nanofluids.

* Corresponding author.
E-mail address: Toghraee@iaukhsh.ac.ir (D. Toghraie).

https://doi.org/10.1016/j.arabjc.2023.105467
Received 27 June 2023; Accepted 18 November 2023
Available online 19 November 2023

Table 1
Studies conducted by researchers on dynamic viscosity NF effect.

Ref.	Author	NF	BF	method	Results
(Fan et al., 2022)	Asadi et al.	$CuO-TiO_2$	water	Experimental	maximum dynamic viscosity at SVF = 1 % and T = 25 °C, and also prepared NF had a Newtonian behavior.
(Ramadhan et al., 2021)	Hemmat Esfe et al.	CuO	EG	Experimental, ANN	Sensitivity analysis shows that SVF has a greater effect on viscosity.
(Asadi et al., 2020)	Ghasemi et al.	CuO	liquid paraffin	Experimental	NF viscosity is more sensitive to SVF compared to temperature
(Esfe et al., 2018)	Ahmadi et al.	CuO	water	M5-tree, MPR, ANN-MLP, GMDH, and MARS	The value of R^2 and AAPR with ANN-MLP model are 0.9997 and 1.312 %, respectively.
(Ghasemi and Karimipour, 2018)	Kole et al	CuO	gear oil	Experimental	The viscosity of NFs increases with decreasing temperature and increasing SVF.
(Ahmadi et al., 2020)	Karimipour et al	CuO	liquid paraffin	ANN	Dynamic viscosity NF ratio to BF viscosity decreases significantly by increasing T and increases by increasing of SVF.

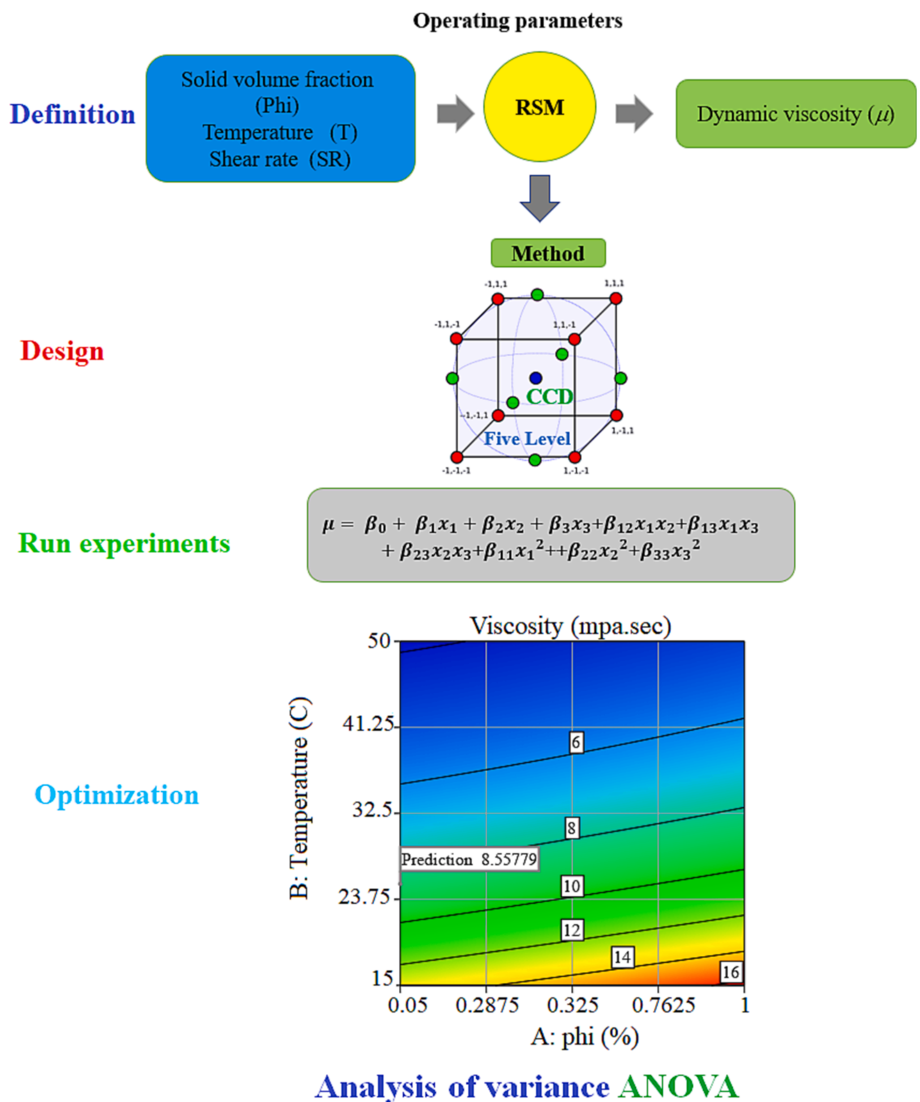

Fig. 1. Schematic of RSM in design of experiment method.

done by researchers on NFs effect on dynamic viscosity. In Table 1, some studies on dynamic viscosity NF effect are presented.

Hemmat et al. (Kole and Dey, 2011) by adding MWCNT, SiO_2 NPs to 5 W50 engine oil as a BF, investigated dynamic viscosity NF experimentally in T conditions between 5 and 55 °C, SR between 50 and 800 rpm and SVF between 0 and 1 %. For example, coefficient of

Table 2
ANOVA of 2FI model.

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2060.10	5	412.02	944.12	< 0.0001	significant
A-***SVF***	31.14	1	31.14	71.36	< 0.0001	
B-T	472.90	1	472.90	1083.62	< 0.0001	
C-***SR***	27.22	1	27.22	62.37	< 0.0001	
AB	7.57	1	7.57	17.35	< 0.0001	
BC	32.37	1	32.37	74.18	< 0.0001	
Residual	84.66	194	0.4364			
Cor Total	2144.76	199				

Table 3
Validation parameters for 2FI model.

Std. Dev.	0.6606	R-Squared	0.9605
Mean	7.94	Adjusted R^2	0.9595
C.V. %	8.32	Predicted R^2	0.9572
p-value	4.80109569518e-134	Adeq Precision	113.3196

Table 4
ANOVA of Quadratic model.

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2136.72	5	427.34	10312.03	< 0.0001	significant
A-***SVF***	11.72	1	11.72	282.90	< 0.0001	
B-T	262.93	1	262.93	6344.64	< 0.0001	
AB	14.48	1	14.48	349.33	< 0.0001	
A^2	0.1975	1	0.1975	4.77	0.0302	
B^2	109.75	1	109.75	2648.30	< 0.0001	
Residual	8.04	194	0.0414			
Cor Total	2144.76	199				

Table 5
Validation parameters for Quadratic model.

Std. Dev.	0.2036	R-Squared	0.9963
Mean	7.94	Adjusted R^2	0.9962
C.V. %	2.56	Predicted R^2	0.9959
P-value	3.36147981671e-233	Adeq Precision	329.0804

Table 6
ANOVA of Cubic model.

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2141.98	10	214.20	14557.18	< 0.0001	significant
A-**SVF**	6.75	1	6.75	458.79	< 0.0001	
B-T	23.97	1	23.97	1629.10	< 0.0001	
C- SR	0.2387	1	0.2387	16.22	< 0.0001	
AB	2.14	1	2.14	145.36	< 0.0001	
BC	0.1740	1	0.1740	11.82	0.0007	
A^2	0.1829	1	0.1829	12.43	0.0005	
B^2	6.53	1	6.53	443.85	< 0.0001	
AB^2	0.8435	1	0.8435	57.32	< 0.0001	
B^2C	0.1300	1	0.1300	8.84	0.0033	
B^3	2.47	1	2.47	167.98	< 0.0001	
Residual	2.78	189	0.0147			
Cor Total	2144.76	199				

determination was $R^2 = 0.9914$, which indicates a favorable value. Hemmat Esfe et al. (Karimipour et al., 2018) experimentally investigated dynamic viscosity of MWCNT-MgO / SAE40 engine oil NF. Obtained results from examining the graphs of NF viscosity in SR terms show that NF has a non-Newtonian behavior. Increasing temperature increases this non-Newtonian behavior. In the study conducted by Ghasemi et al. (Asadi et al., 2020) show that NF viscosity is more sensitive to SVF compared to temperature. Also, increasing T decreases NF dynamic viscosity. When SVF of CuO is higher than 1.5 %, viscosity increases. While SVF less than 1.5 %, the viscosity did not change much. Finally, using regression analysis, they obtained a unique statistical correlation that included temperature and SVF. Hemmat Esfe et al. (Esfe and Arani, 2018) investigated NF dynamic viscosity by using CuO and MWCNT NPs in 10 W40 motor oil as BF. Their study was done in the conditions of SVF = 0.05 to 1 % and T = 5——55 °C. Increase in SVF increases NF viscosity compared to pure lubricant; so that maximum increase of 43.52 % in NF dynamic viscosity was achieved at SVF = 1 %. They used a statistical correlation 0.9846 with a 2th order accuracy to estimate NF viscosity. Khetib et al. (Esfe and Esfandeh, 2018) investigated the viscosity of CuO-liquid paraffin NF using RSM and ANN methods. In their study, a third-order model was selected and evaluated by ANOVA in the RSM. Comparing the results of these two methods shows that ANN method is better than RSM to predict NF viscosity. RSM is an experimental methods. This method is one of the statistical and mathematical methods to build a model. In this study, RSM is used to predict NF viscosity using CuO NPs in EG-Water base fluid. Fig. 1 shows RSM method schematic.

Bhat et al. (Esfe and Sarlak, 2017) investigated NF viscosity using CuO NPs with sizes of 15, 45 and 75 nm. In this study, NF viscosity has been measured in SVF = 1——4 % and T = 293——353 K. Increasing T from 293 to 353 K leds to decrease of about 80 % in NF dynamic

Table 7
Validation parameters for Cubic model.

Std. Dev.	0.1213	R-Squared	0.9987
Mean	7.94	Adjusted R^2	0.9986
C.V. %	1.53	Predicted R^2	0.9985
P-value	5.32248028411e-267	Adeq Precision	433.5400

Table 8
ANOVA of Quartic model.

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2142.48	13	164.81	13440.48	< 0.0001	significant
A-***SVF***	1.20	1	1.20	98.07	< 0.0001	
B-T	2.31	1	2.31	188.19	< 0.0001	
C-***SR***	0.2670	1	0.2670	21.78	< 0.0001	
AB	0.2261	1	0.2261	18.44	< 0.0001	
BC	0.1912	1	0.1912	15.60	0.0001	
A^2	0.1784	1	0.1784	14.55	0.0002	
B^2	0.6009	1	0.6009	49.00	< 0.0001	
AB^2	0.0721	1	0.0721	5.88	0.0163	
B^2C	0.1454	1	0.1454	11.86	0.0007	
B^3	0.2256	1	0.2256	18.39	< 0.0001	
AB^3	0.0336	1	0.0336	2.74	0.0996	
B^3C	0.1166	1	0.1166	9.51	0.0024	
B^4	0.1053	1	0.1053	8.58	0.0038	
Residual	2.28	186	0.0123			
Cor Total	2144.76	199				

Table 9
Validation parameters of Quartic model.

Std. Dev.	0.1107	R-Squared	0.9989
Mean	7.94	Adjusted R^2	0.9989
C.V. %	1.39	Predicted R^2	0.9987
P-value	8.49355472751e-269	Adeq Precision	424.6076

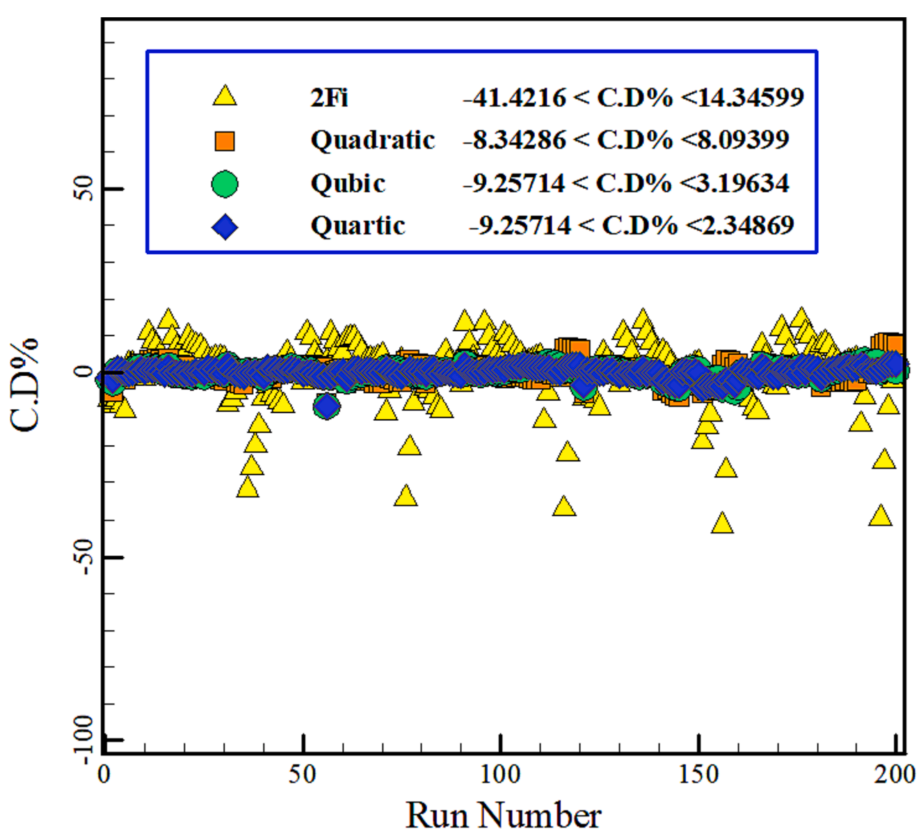

Fig. 2. Correlation deviation for 4 different models.

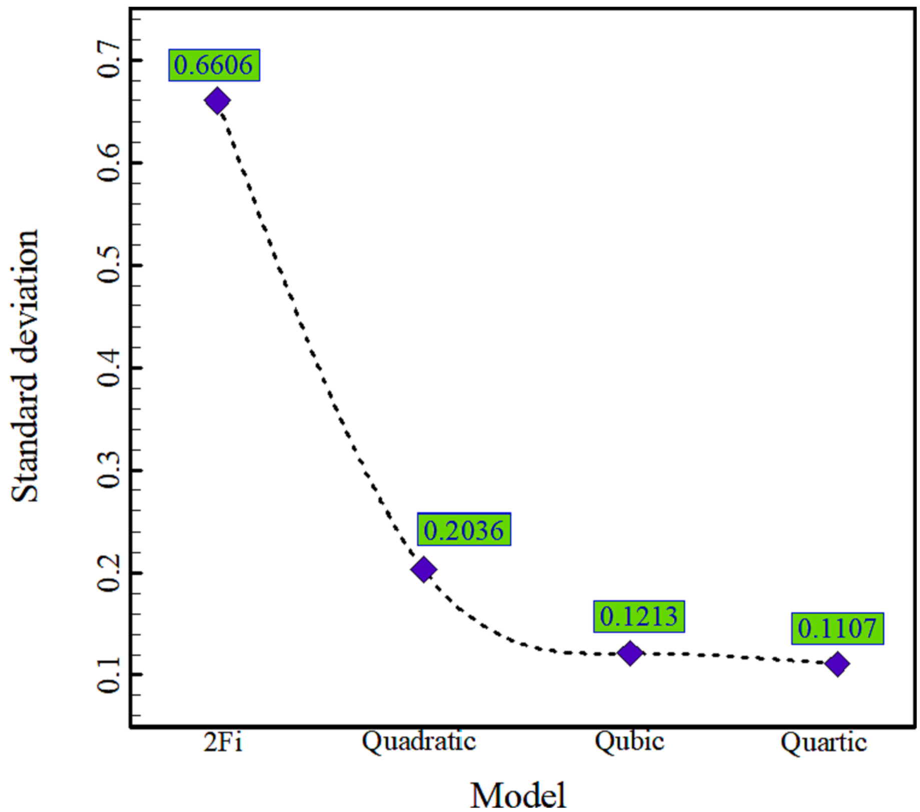

Fig. 3. Standard deviation for 4 different models.

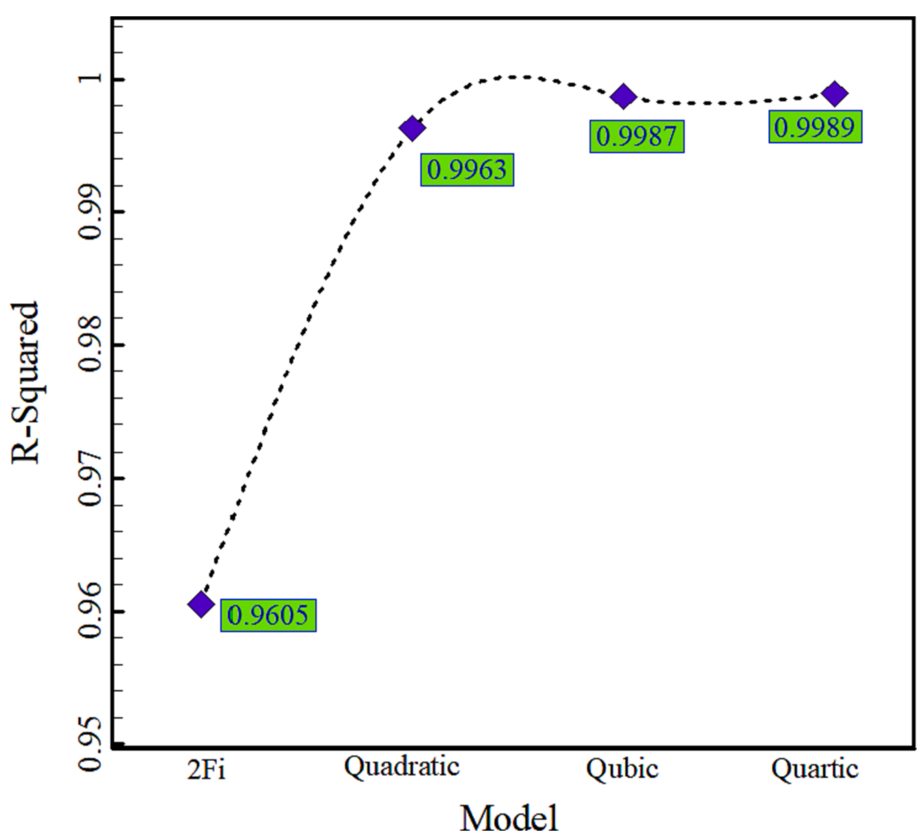

Fig. 4. Determination coefficient for 4 different models.

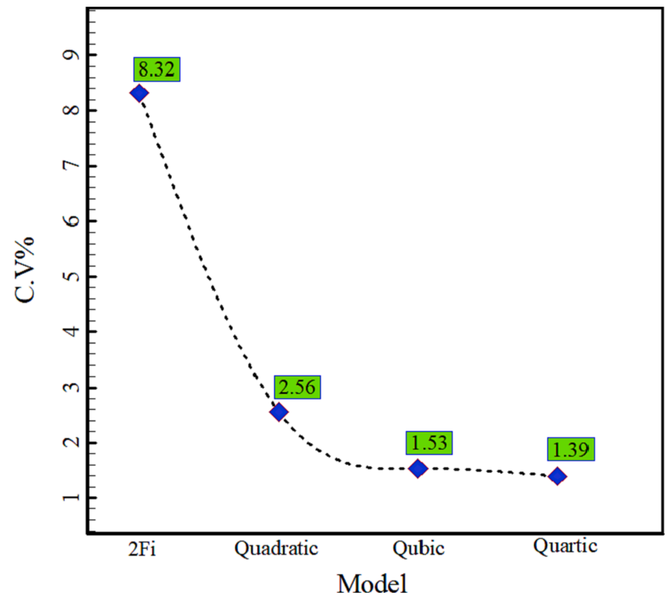

Fig. 5. C.V% values for 4 different models.

Table 10
P-values for 4 different models.

Model	P-value
2FI	4.80109569518e-134
Quadratic	3.36147981671e-233
Cubic	5.32248028411e-267
Quartic	8.49355472751e-269

viscosity. 0.5 % increase in viscosity with an increase in SVF. Hemmat Esfe et al. (Khetib et al., 2021) investigated NF dynamic viscosity by adding MWCNT, ZrO_2 NPs to 5 W50 engine oil at T = 5—–55 °C and SVF = 0.05 to 1 % to improve performance of NF. There is 20 % reduction in dynamic viscosity at SVF = 0.05 %. Also, in SVFs below 0.75 %, the viscosity decreases compared to BF. Hemmat Esfe et al. (Ramadhan et al., 2021) investigated CuO-EG dynamic viscosity NF at T = 27.5—–50 °C and SVFs = 0—–1 % using experimental and ANN methods. NF viscosity increases with increasing of SVF and decreasing of

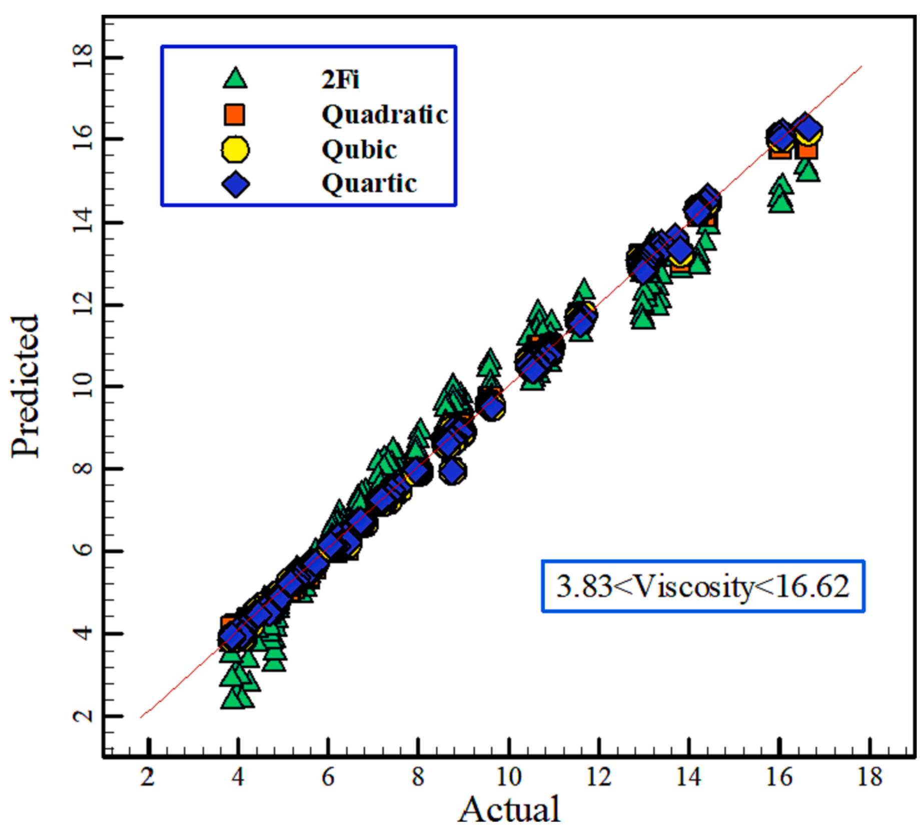

Fig. 6. Graph of predicted values of NF viscosity versus actual values of NF viscosity for four different models.

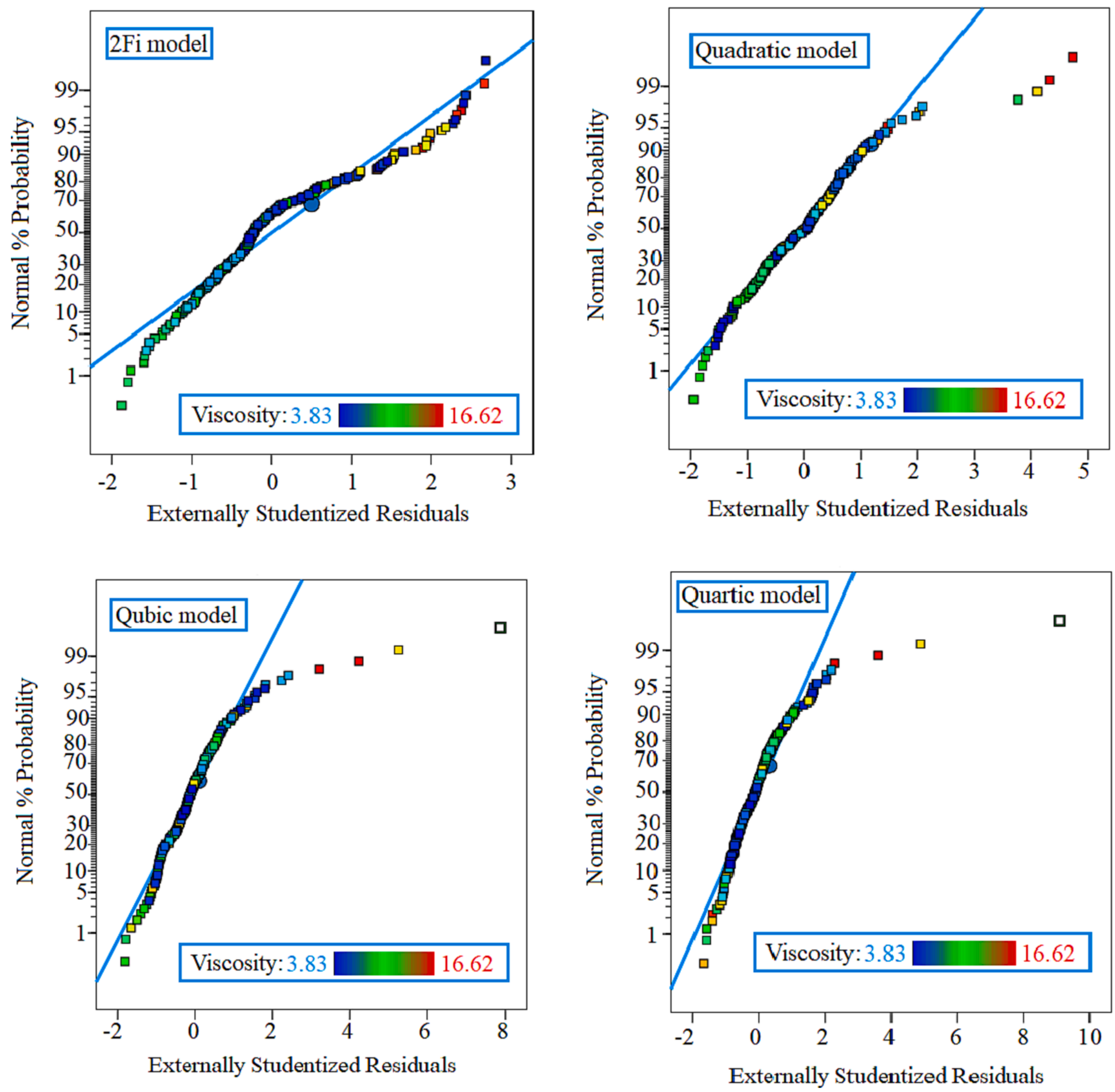

Fig. 7. Normal probability plots in four different models.

T. The results also show that the effect of temperature is significant in low SVFs. In this model selected by ANN, it was estimated with an $R^2 = 0.999$ and an average relative error = 0.0175, which had an allowed match with tests. Also, sensitivity analysis shows that the SVF has a greater effect on the dynamic viscosity of NF than temperature. In this study, 200 experimental data have been used to optimize the dynamic viscosity of CuO nanoparticles in EG (80 %)-Water (20 %) base fluid using RSM. The aim is to obtain a correlation relationship to predict NF dynamic viscosity. To obtain this correlation coefficient, different Quadratic, Cubic, 2FI and Quartic models are used, and best model is selected by comparing some accuracy indicators and quality determination, and NF optimization is done based on selected model. After obtaining correlation relationship, NF viscosity can be obtained at different temperatures and SVFs, which saves time and money.

2. RSM statistical method

One of the mathematical and statistical methods for experiment design is the RSM. In this method, different mathematical models are used to check the influence of independent input variables and optimizing of response. To use this method, experiments with different levels of Moore's variables must be performed and data related to them must be collected. Then, using mathematical models related to the RSM, the optimal response is estimated for different values of the variables. Among the advantages of this method, we can mention the possibility of analyzing the interactions of input variables and their influence on response variable. Also, by using this method, the optimal answer can be reached with the least effort and the shortest time. Therefore, it saves time and money. In the present study, using the RSM, the following items are examined:

- Check different models
- Examining some indicators and model validation charts
- Compare different models and choose the best model
- NF viscosity optimization using superior model

2.1. Different models

2.1.1. 2FI model

The correlation created by the 2FI model to predict NF viscosity values is shown in Ea. 1. This equation includes independent input parameters and interaction between these input variables. Table 2. It shows the independent input parameters and the interaction between these parameters using ANOVA analysis. In Table 3, some parameters and validation indices for the 2FI model are presented.

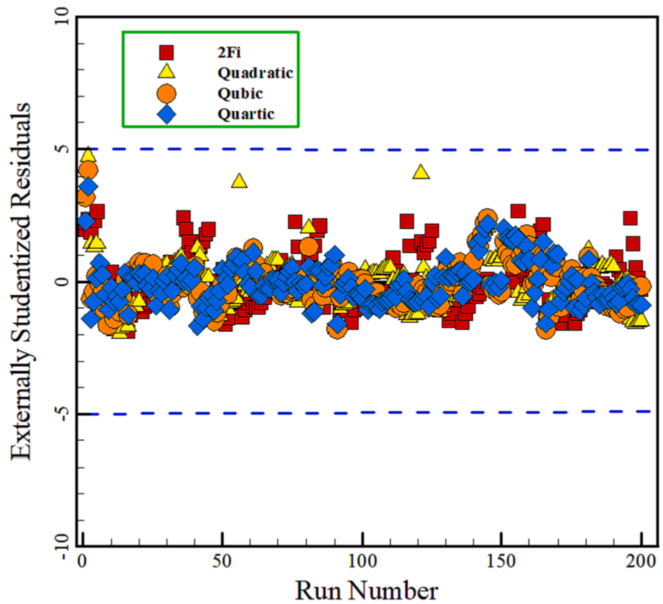

Fig. 8. Diagram of externally studentized Residual versus run number for 4 different models.

$$\mu_{nf} = +17.33372 + 3.42541\boldsymbol{SVF} - 0.306427\mathrm{T} - 0.007237\boldsymbol{SR} - 0.049088\boldsymbol{SVF}\mathrm{T} + 0.000187\mathrm{T}*\boldsymbol{SR} \quad (1)$$

2.1.2. Quadratic model

In Eq. (2) and Table 4, independent input variables and interaction are presented by ANOVA analysis. In Table 5, some parameters and validation indices for the Quadratic model are presented.

$$\mu_{nf} = 21.28854 + 3.63415\boldsymbol{SVF} - 0.666561\mathrm{T} - 0.066798\boldsymbol{SVF}*\mathrm{T} + 0.367225\boldsymbol{SVF}^2 + 0.006466\mathrm{T2} \quad (2)$$

2.1.3. Cubic model

The correlation created by the input independent variables and the interaction between these variables to predict NF viscosity values for the Cubic model is presented in Eq. (3). Analysis of ANOVA for Cubic model is reported in Table 6. In Table 7, some important validation parameters for the Cubic model are presented.

$$\mu_{nf} = 24.38302 + 5.09863\boldsymbol{SVF} - 0.999683\mathrm{T} - 0.002372\boldsymbol{SR} - 0.171799\boldsymbol{SVF}*\mathrm{T} + 0.000117\,\mathrm{T}*\boldsymbol{SR} + 0.353987\boldsymbol{SVF}^2 + 0.017768\mathrm{T2} + 0.001642\boldsymbol{SVF}\mathrm{T2} - 1.39472\mathrm{E} - 06\,\mathrm{T2}\,\boldsymbol{SR} - 0.000120\mathrm{T3} \quad (3)$$

2.1.4. Quartic model

The correlation created by the input independent variables and the interaction between these variables for Quartic model is presented in Eq. (4). In Table 8, input variables and interaction between them that affect the viscosity of NF (response variable) are provided by ANOVA analysis for the Quartic model. In Table 9, some important validation parameters for the Quartic model are presented.

$$\mu_{nf} = +27.48983 + 5.98349\boldsymbol{SVF} - 1.41478\mathrm{T} - 0.007358\boldsymbol{SR} - 0.270986\boldsymbol{SVF}\mathrm{T} + 0.000603\mathrm{T}*\boldsymbol{SR} + 0.349623\boldsymbol{SVF}^2 + 0.037372\mathrm{T2} + +0.004996\mathrm{T2}\boldsymbol{SVF} - 0.000016\mathrm{T2}\boldsymbol{SR} - 0.000513\mathrm{T3} - 0.000035\boldsymbol{SVF}*\mathrm{T3} + 1.38049\mathrm{E} - 07\mathrm{T3}\,\boldsymbol{SR} + 2.83805\mathrm{E} - 06\mathrm{T4} \quad (4)$$

2.2. Important parameters for determining model quality

The evaluation of important validation parameters such as correlation deviation, standard deviation, coefficient of determination, reliability and P-values for different models are examined in this section.

2.2.1. Correlation deviation parameter

Correlation deviation (C.D %) is one of the measurement criteria to show the degree of overlap between obtained software data and tests. C.D% is the points on the correlation line (measurement criterion line) in a two-variable data (data obtained from software and experimental work). This deviation indicates the deviation of the data from the correlation line. A positive correlation deviation means that the points are above the correlation line and a negative correlation deviation means that the points are below the correlation line. Therefore, the highest correlation deviation of C.D% means the highest overturning or deviation of the points from the correlation line. Eq. (5) is used to calculate correlation deviation. In Fig. 2, C.D% and deviation range are presented for four different models and Quartic model is more accurate in Fig. 2and the range of data deviation is smaller in this model.

$$\mathrm{C.D\%} = \frac{(\mu_{nf})_{pre} - (\mu_{nf})_{exp}}{(\mu_{nf})_{exp}} \times 100 \quad (5)$$

2.2.2. Standard deviation parameter

One of the applied criteria in statistics and probabilities is standard deviation. The smaller the correlation deviation is, it indicates that the dispersion of the data is closer to the mean value and has higher accuracy. In Fig. 3, standard deviation is plotted for four models. As it is clear from Fig. 3, standard deviation value is smaller for Quartic model, which shows the high accuracy of this model.

2.2.3. Determination coefficient or R^2

R^2 is a statistical measure that shows how much of the variation in a response variable is explained by one or more independent input variables. R^2 is between 0 and 1. Zero value means response variable is not dependent on independent variables. The $R^2$is useful for evaluating the quality of the model and predicting it in data analysis. In Fig. 4, the R^2 is presented for 4 different models. The highest and lowest R^2 belong to the quartic and 2FI models, respectively, with values of 0.9989 and 0.9605. Therefore, Quartic model is more accurate and best model.

2.2.4. Coefficient of variation parameter

One of the statistical criteria to determine the quality of the model is the coefficient of variation (C.V%). The lower the C.V value, the higher the accuracy of that model. The degree of reliability depends on the

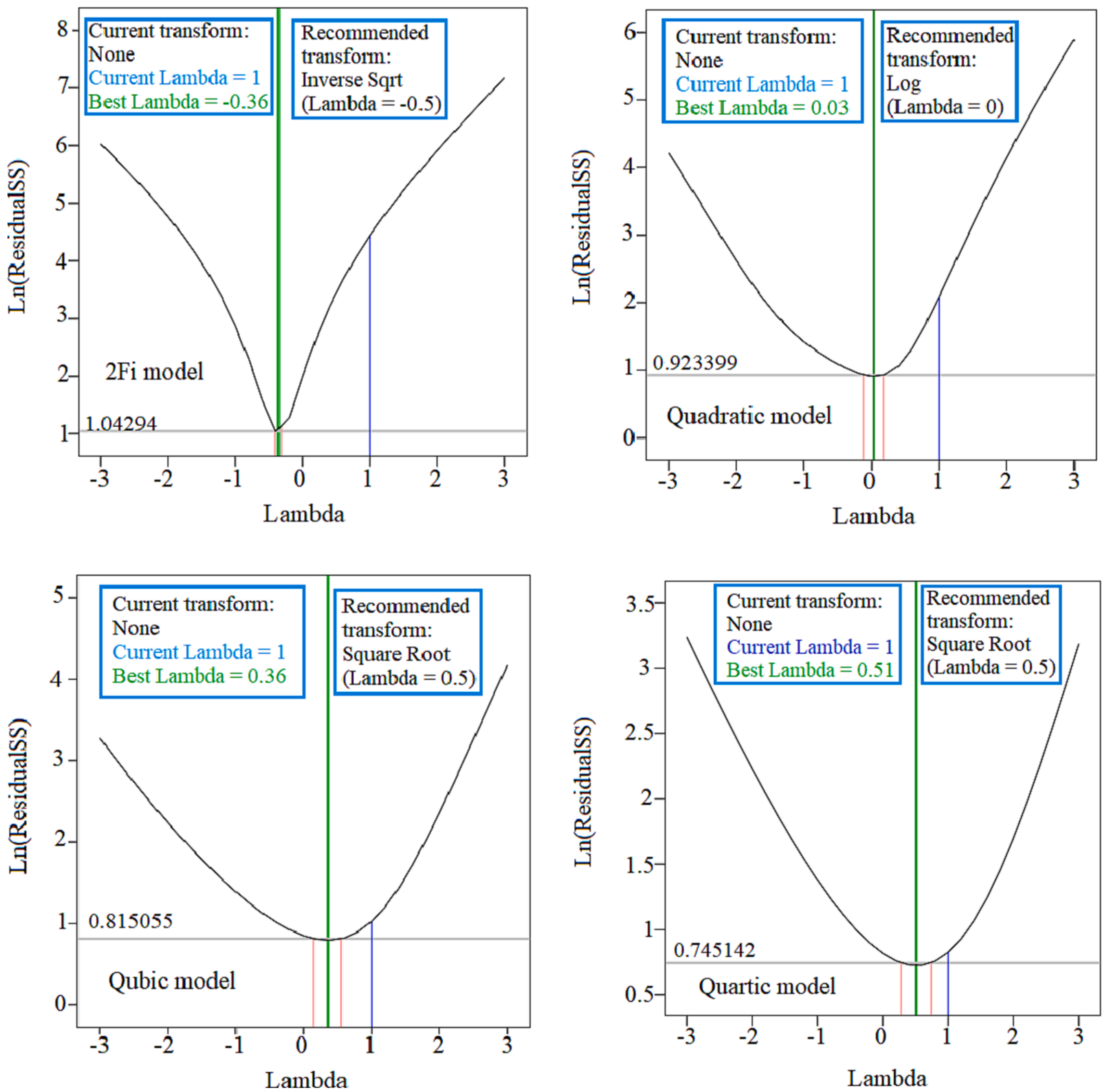

Fig. 9. Box-Cox curve of four models.

relationship between the input variables and the interaction between them. The value of C.V decreases with the increase in the number of parameters used in a model. Reliability values for four different models are reported in Fig. 5. Lowest and highest values of reliability with values of 1.39 and 8.32 belong to Quartic and 2FI models, respectively. Therefore, Quartic model is more accurate and best model.

2.2.5. P-value parameter

P-value means probability or confidence value in statistical methods. P value is used in many statistical methods to check statistical hypotheses. P-value less than 0.05 is used as significance level. In Table 10. P-values for four different models are presented. By comparing four different models, it is clear that the lowest P-value is 8.49355472751e-269 in Quartic model.

2.3. Model quality determination charts

In this section, the quality of the models and the selection of the best model are discussed using different charts. The graphs that are examined in this section include: predicted values graph versus actual values, normal probability graph, graph of the external studentized residual versus predicted values and Box-Cox graph.

2.3.1. Predicted values versus actual values

In Fig. 6, predicted values of NF viscosity versus actual values of NF viscosity for four different models are presented. In this diagram, the bisector line of 45 degrees is considered as the measurement criterion. If the data is located on bisector line, it has high accuracy model. In Fig. 6, vertical and horizontal axes represent the predicted values of NF viscosity and the actual values of NF viscosity, respectively.

2.3.2. Normal probability diagram

To check whether the data follows a normal distribution or not, a normal probability plot is used. In this diagram, the vertical and horizontal axes show the values of normal probability and the values of external ossified, respectively. In Fig. 7, diagram of normal probability is checked for four models. If the normal probability curve is S-shaped, non-normal data can be converted to normal data using the transfer function. How to recognize the transformation function is determined by the Box-Cox diagram, which will be examined further.

2.3.3. Externally studentized Residual diagram according to the number of test steps

The externally studentized Residual is a useful tool in regression analysis to detect outliers and evaluate the quality of a model. The main

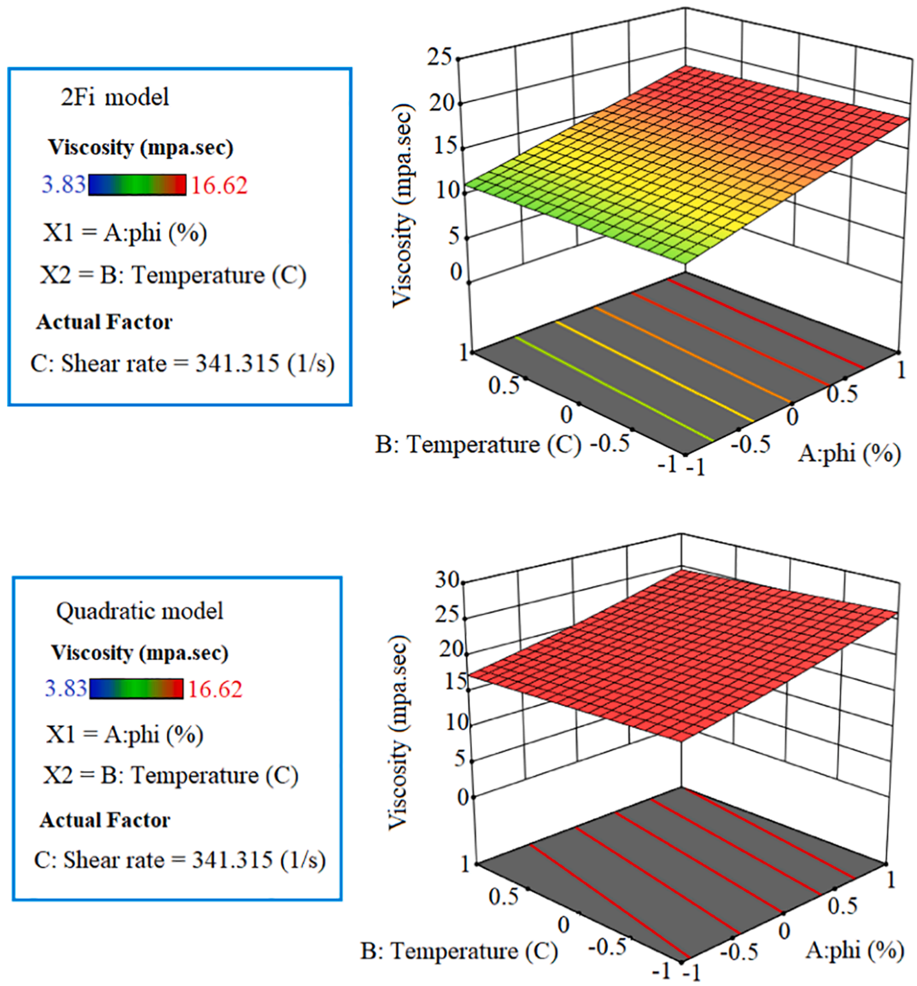

Fig. 10. The change trend of NF viscosity for 4 different models.

advantage of externally studentized Residual is that they are less sensitive to influential observations in the data set than standard residuals. This means they can be used to detect outliers that may not be detected by other methods. In this diagram, the vertical and horizontal axes show the externally studentized Residual and run number, respectively. Fig. 8 shows the externally studentized Residual for 4 different models.

2.3.4. Box-Cox chart

Box-Cox curve is an analytical tool in the field of statistics to improve the distribution of data and transform them into a normal distribution. Using Box-Cox transformation purpose is improving of data distribution and increase the accuracy of statistical analysis. Having a normal distribution, we can build statistical models more accurately and check the analysis results better. Box-Cox diagram for four models is displayed in Fig. 9. The lowest part of the Box-Cox diagram represents the best value of lambda.

2.3.5. How NF viscosity changes

NF viscosity change according to input variables (SR, SVF and T) for different models is shown in Fig. 10. Decreasing of T and increasing of SVF leads to increasing of NF viscosity. From the comparison of 4 different models, it can be seen that at the same temperature and SVF, the Quartic model shows a higher viscosity value.

2.4. Optimizing the NF viscosity

In this section, CuO NPs dynamic viscosity optimization in EG-Water BF is discussed using the selected model (Quartic model). This study was carried out in cold environmental conditions and according to the restrictions applied in Table 11. In Table 11, values of temperature, SR, SVF and NF viscosity are considered as minimum values. SVF is considered minimum value because of economic efficiency, and because study takes place in a cold environment, therefore, the NF viscosity is considered the minimum value until the engine is turned on; Spraying on parts should happen in the shortest possible time and avoid possible damage such as corrosion and wear. In Table 12, the best lubrication responses for cold environmental conditions are presented. According to Table 12, under conditions of T = 25.303 °C, SVF = 0.05 % and SR = 26.660 s^{-1}, most optimal NF viscosity was obtained 8.565 mPa.sec.

In Fig. 11, graphs of NF viscosity and desirability based on changes in temperature and SVF are presented. As can be seen, decreasing T and increasing SVF result to increasing of NF viscosity. According to Fig. 11 and Table 12, the approval rate for the proposed proposal was 81.6 %, which is an acceptable percentage.

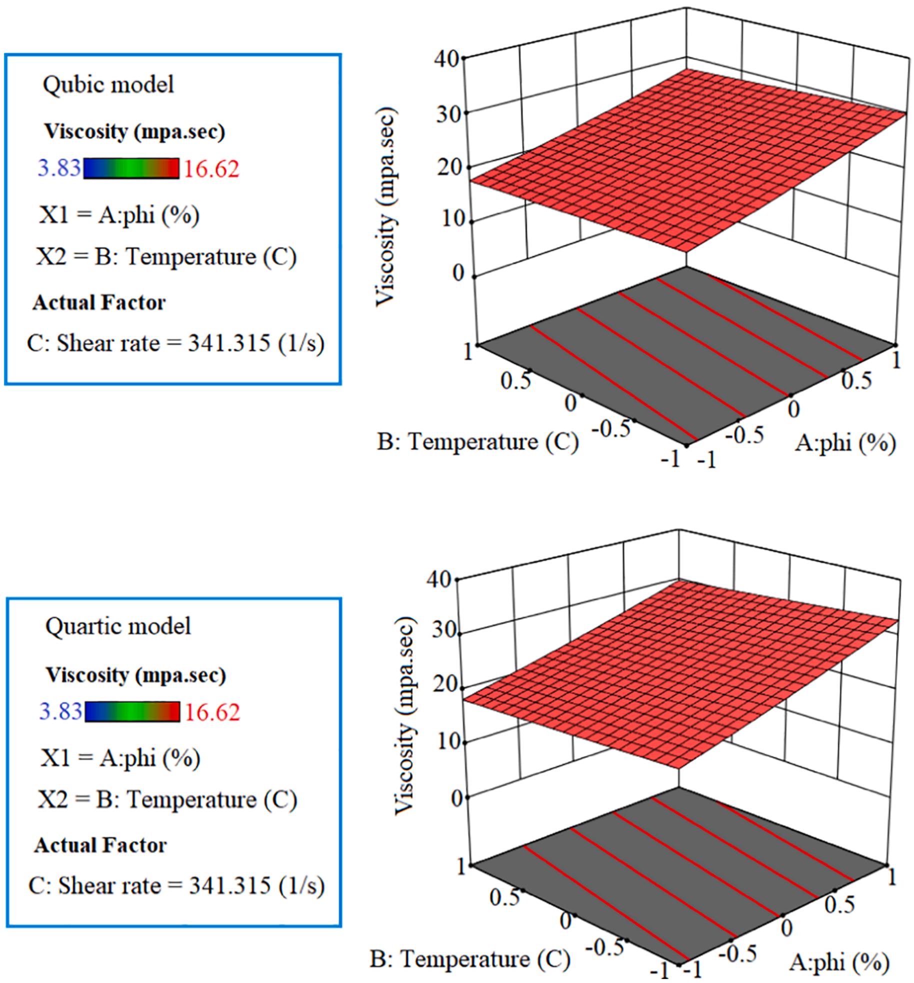

Fig. 10. (*continued*).

Table 11
Range of parameters applied to the system.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:*SVF*	minimize	0.05	1	1	1	3
B:*T*	minimize	15	50	1	1	3
C:*SR*	minimize	26.66	933.1	1	1	3
μ_{nf}	minimize	3.83	16.62	1	1	3

3. Conclusion

In this study, various types of correlation relations were investigated by different models to predict the dynamic viscosity of CuO NPs in EG-Water BF using RSM. Quadratic, Cubic, 2FI and Quartic models have been investigated. These four different models were analyzed based on the measurement criteria. Among these four models, the Quartic model have been chosen as superior model and used to optimize NF viscosity. The optimization was done in cold environmental and variables of SR, SVF, T and viscosity were selected as minimum values and applied to the system. The most important results of this study include the following:

- Based on the measurement criteria, the Quartic model has been chosen as best model that had higher accuracy than other models.
- The high coefficient of determination in Quartic model (R^2 = 0.9989) with compared to other models causes the percentage of influence and interaction of input variables to be higher.

Table 12
The best lubrication responses in cold environmental conditions.

Number	*SVF*	T	*SR*	μ_{nf}	Desirability	
1	0.050	25.303	26.660	8.565	0.816	Selected
2	0.050	25.313	26.660	8.561	0.816	
3	0.050	25.306	26.661	8.564	0.816	
4	0.050	25.298	26.660	8.567	0.816	
5	0.050	25.309	26.662	8.563	0.816	
6	0.050	25.337	26.661	8.554	0.816	
7	0.050	25.331	26.661	8.556	0.816	
8	0.050	25.321	26.662	8.559	0.816	
9	0.050	25.304	26.661	8.564	0.816	
10	0.050	25.298	26.661	8.566	0.816	
11	0.050	25.298	26.661	8.567	0.816	
12	0.050	25.319	26.662	8.560	0.816	
13	0.050	25.302	26.663	8.565	0.816	
14	0.050	25.349	26.661	8.550	0.816	
15	0.050	25.298	26.663	8.566	0.816	
16	0.050	25.326	26.662	8.557	0.816	
17	0.050	25.315	26.661	8.561	0.816	
18	0.050	25.336	26.661	8.554	0.816	
19	0.050	25.301	26.660	8.565	0.816	
20	0.050	25.278	26.660	8.573	0.816	

- The repeatability percentage of Quartic model is higher than other models due to the low C.V in this model (C.V = 1.39 %).
- Quartic model is more accurate than other models from the comparison of P-values in four models. (P-value = 8.49355472751e-269).

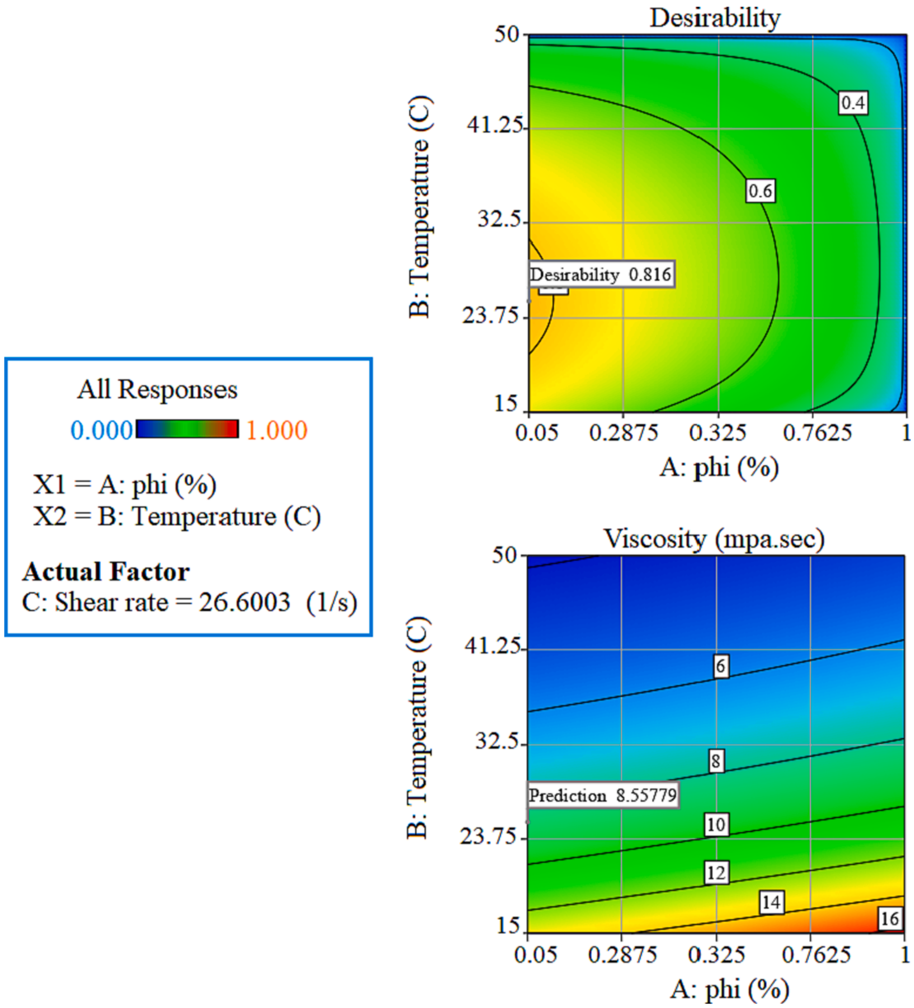

Fig. 11. Graphs of NF viscosity and desirability based on changes in T and SVF.

- According to the examination of the correlation deviation for four models, Quartic model has less error in predicting the data. (-9.25714 < C.D%<2.34869).
- At T = 25.303 °C, SVF = 0.05 % and SR = 26.660 *sec*-1, the most optimal NF viscosity value is 8.565 mPa.sec.

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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