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# Proposing a modified engine oil to reduce cold engine start damages and increase safety in high temperature operating conditions

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ABSTRACT

The effect of adding MWCNT-$ZrO_2$ nanoparticles (30%–70%) to engine oil (5w50) was studied to improve the performance of engine oil at low and high temperatures. The laboratory examination of this nanofluid was carried out at solid volume fractions of 0.05% to 1% and temperature range of 5 °C to 55 °C. Studies have shown the superiority of this nano-engine oil compared with produced nano-engine oils reported in literature and those are available in the market. The highlight point of this study is a 20% decrease in nano-oil viscosity (at solid volume fraction of 0.05%) compared with base oil. Also, the viscosity of the nano-oil was reduced in comparison to pure oil, in solid volume fractions below 0.75%, which is very useful and valuable in cold seasons and at low temperatures.



## 1. Introduction

Fluids play an important role in the industry. Oil, water and ethylene glycol are among the most widely used and traditional fluids in various industries. Lubrication and cooling can be considered as one of their important tasks in the industry. In surfaces that have relative movements while in contact with each other, lubrication plays a crucial role in doing correct, continuous and economic movement.

Inappropriate lubrication of machinery, in addition to reducing mechanical efficiency and lowering machine efficiency time, leads to excessive wear, fatigueless and early disability. Lubrication, heat transfer, impact, surface protection, sealing, transfer of materials, and transfer of power, are applications of oils in the industry [1].

Researchers have made great efforts to increase the efficiency of fluids for heat transfer and lubrication goals. In recent years, they have improved the properties of many fluids by adding the nanoscale particles experimentally [2–10] and numerically [11–17].

Among the industrial applications of nanoparticles, using them as additives in engine oils can be mentioned [1]. Engine oils have different characteristics, including non-oxidizing properties, proper cleanliness, and high continuity at high temperatures. The most important thermophysical properties of nanofluids are their viscosity, thermal conduction and convection, which have a significant effect on the performance of engine oils [18–35]. In winter, if the engine oil has a lower viscosity, the nanofluid flows more easily in the engine and its parts [1]. Considering the fact that 80% of the engine erosion occurs at the start stage, when engine is usually cold, the rapid movement of the nan-engine oil for lubrication is essential at the start of the engine operation process [36]. 29.3% [37], 19.18% [38], 24.4% [39], 11.13% [40], 15.2% [41], 18.8% [42], 25% [43], 38% [44], 88% [45] and 23% [46] viscosity enhancement after adding nanoparticles to various engine oils are samples of unwanted viscosity enhancements after enriching oils by nanoparticles. Hemmat Esfe et al. [47] have conducted an experimental study to control the viscosity changes after adding nanoparticles to engine oils and proposed a combination of nanoparticles to reduce viscosity at low temperatures and also improve viscosity index at high temperatures. In this study, MWCNT-$ZrO_2$ (30%–70%)/5W50 was experimentally investigated as a candidate for a new nano-engine oil. This research might be the start of a new age of engine oils. Investigated nano-engine oil viscosity has a lower sensitivity to temperature enhancement in comparison with other engine oils at high temperatures, so the nano-oil keep its suitable viscosity in high temperatures and will not excessively diluted. Moreover, in low temperatures, because of lower viscosity compared to other oils such as pure 5W50 oil, they have better conditions, because having lower viscosity at low temperatures leads to rapid engine lubrication in the engine and prevents causing damages to the engine and its parts. In the following, two

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**Table 1**
Nanoparticles properties.

| Properties | $ZrO_2$ | MWCNT |
|---|---|---|
| Purity | 99.95% | >97% |
| SSA | 30–60 $m^2/g$ | >233 nm |
| Color | White | Black |
| Morphology | Near spherical | Near tubes |

mathematical based models (RSM and ANN) were employed to forecast the viscosity of enriched industrial engine oils.

## 2. Experimental test condition

In order to investigate the nanofluid, as first step the nanoparticles should be dispersed in the base fluid uniformly to reach a homogenized nanofluid sample for the test. Two-step method used for making nanofluid. Nano-engine oil containing MWCNT (30%) and $ZrO_2$ (70%) nanoparticles were produced at 1%, 0.75%, 0.5%, 0.25%, 0.1% and 0.05% solid volume fractions as test samples. The added nanoparticles to pure oil are commercial type synthesized by US Research Nanomaterial, Inc. Properties of mentioned nanoparticles are as below in Table 1.

Then, for nano-engine oil homogenization, a magnetic stirrer was used for 2 h and also an ultrasonic device (Ultrasonic Homogenizer, Development of Ultrasonic Technology, Iran) was used for 3 h to homogenize the nano-engine oil using ultrasonic waves. The image of the nanofluid and the base fluid used in the laboratory are presented in Fig. 1. Having ensured the stability of the prepared nanofluids, the stability of these nano-engine oils was studied and evaluated two months after the production. No chemical dispersant is used to disperse the nanoparticles in host fluid, but as previously stated physical dispersants methods are used to reach the most precise disperse of nanoparticles in the base fluid.

After nanofluid samples preparation, BROOKFIELD CAP2000+ viscometer (as cone and plate type viscometer) was used for viscosity measurements. To provide a stable condition after turning on the instrument, the viscometer warmed up for 30 min. Also the cone calibration was done before starting the measurement procedure. To attain accurate experimental results, an appropriate amount of nanofluid sample onto the plate (not excess or reverse).

## 3. Results and discussion

In order to study the viscosity of MWCNT-$ZrO_2$ (30% -70%)/5W50, tests were done in six different solid volume fractions in the range of 0.05% to 1% and at 5–55 °C.

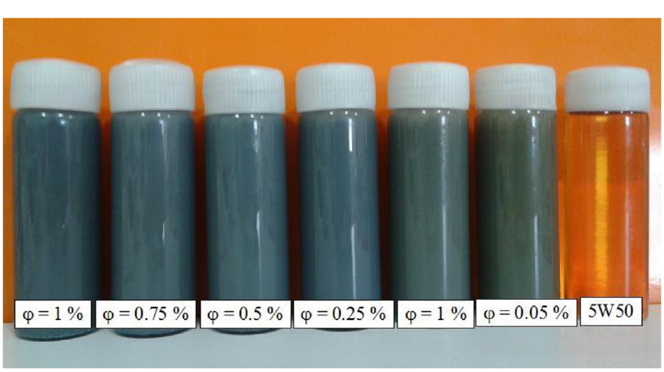


**Fig. 1.** Photograph of prepared nano-engine oil and pure oil.

### 3.1. Nanofluid behavior

Categorizing nanofluids behavior in Newtonian or non-Newtonian groups is one of the main steps of viscosity studies. One of the criteria for the recognition of nanofluid behavior is power law index. Power law index can be find in Newton's viscosity law's as below in Eq. (1). The power of shear rate "n" in below equation is power law index and the coefficient of presented equation "m" is consistency index.

$$\tau = m(\dot{\gamma})^n \tag{1}$$

Fig. 2 shows power law index for all concentrations and temperatures. Number 1 is a suitable criterion to separate Newtonian fluids from non-Newtonian ones.

If the power law index values are set to this line, it is a sign for Newtonian behavior. On the other hand, moving away from the mentioned line, indicates that the fluid has a non-Newtonian behavior. According to Fig. 3, the behavior of the nano-oil in the present study is closely related to the behavior of non-Newtonian fluids (quasi-plastic type).

### 3.2. Check for possible laboratory error

To check the reliability of the test results, the maximum possible error of the viscometer device used in this study (BROOKFIELD CAP 2000+) was extracted in accordance with the operating instructions of this machine. The possible error of instrument has a maximum value of 2%. So the increase or decrease (compared with 5W50 oil) of the nano-engine oil viscosity (>2% variation) is beyond the amount of possible error of the device.

### 3.3. Viscosity analysis: experimental study

The effect of shear rate on viscosity for the studied nanofluid in different solid volume fractions and temperatures are shown in Fig. 3. The dependence of nanofluids viscosity on shear rate is an indication of the non-Newtonian behavior of nano-engine oil, and the independence of the viscosity on shear rate, shows the

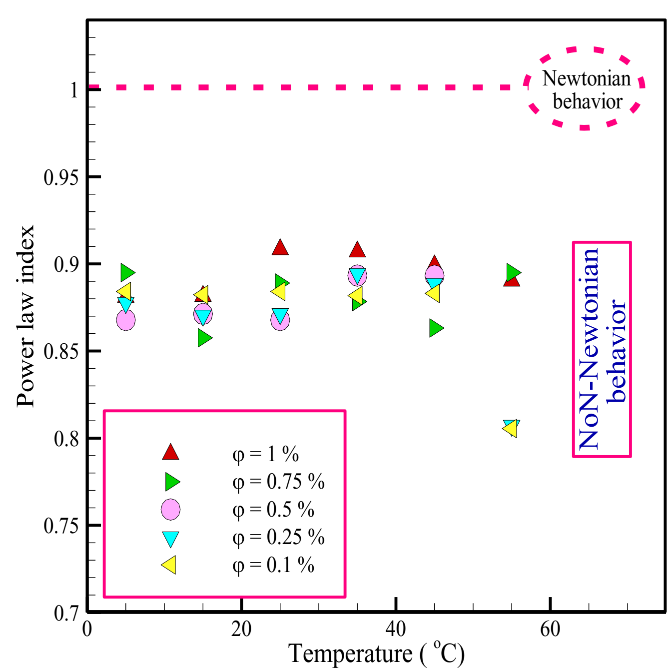


**Fig. 2.** Power law indices.

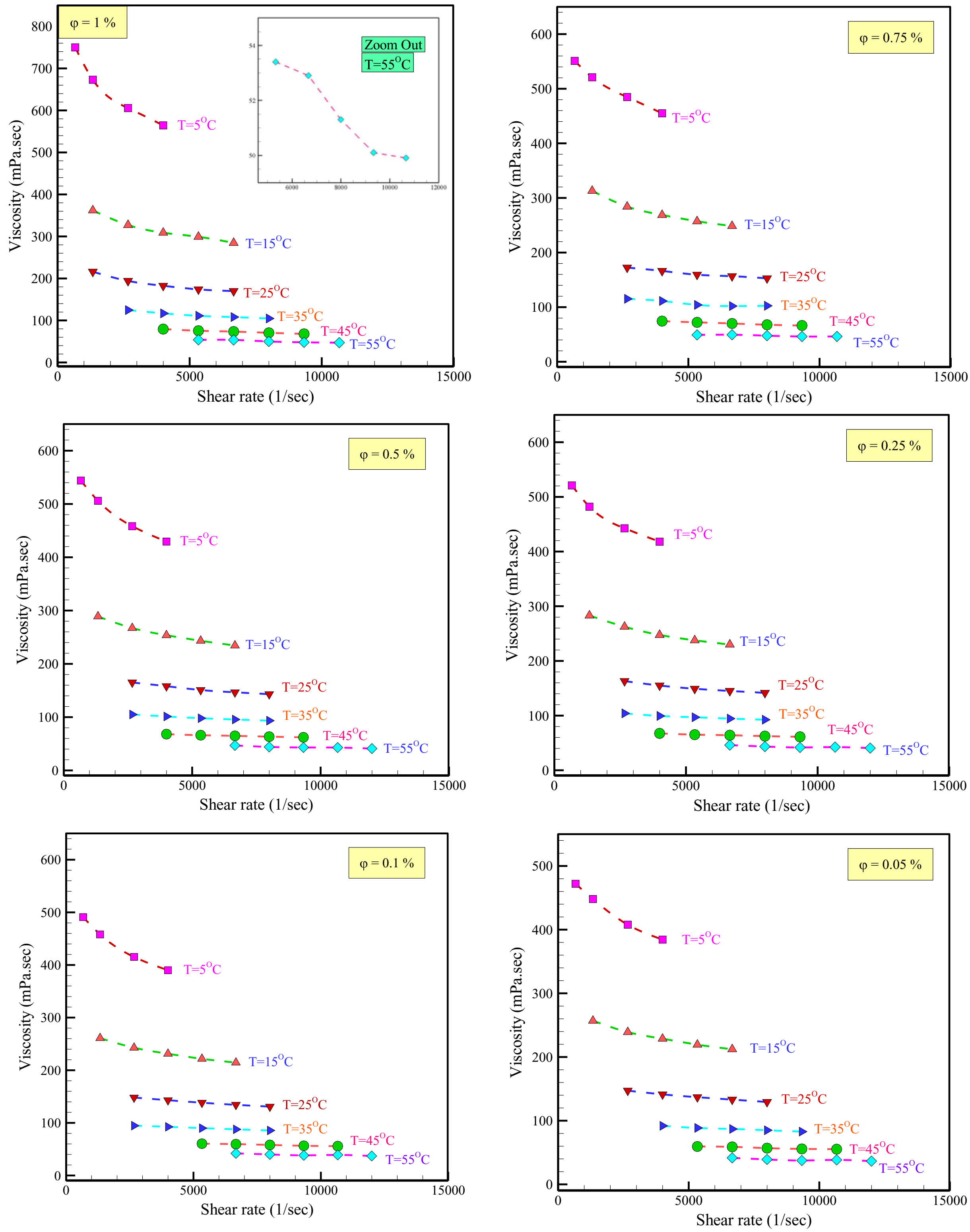


**Fig. 3.** Viscosity versus shear rate.

Newtonian behavior of the nano-engine oil. It can be seen that viscosity decreases with increasing shear rates at all temperatures and solid volume fractions. In solid volume fraction of 1% and temperature of 55 °C, the viscosity magnification versus shear rate is shown, which indicates a significant reduction in viscosity.

In the following, the Viscosity Enhancement is presented in Fig. 4 for shear rates of 6665 (1/s) and 3999 (1/s) at different environmental and combinational conditions. The mathematical relation of viscosity enhancement is presented in relation (2).

$$\text{Viscosity Enhancement}(\%) = \frac{\textit{Nano oil Viscosity} - \textit{Pure oil Viscosity}}{\textit{Pure oil Viscosity}} \times 100 \quad (2)$$

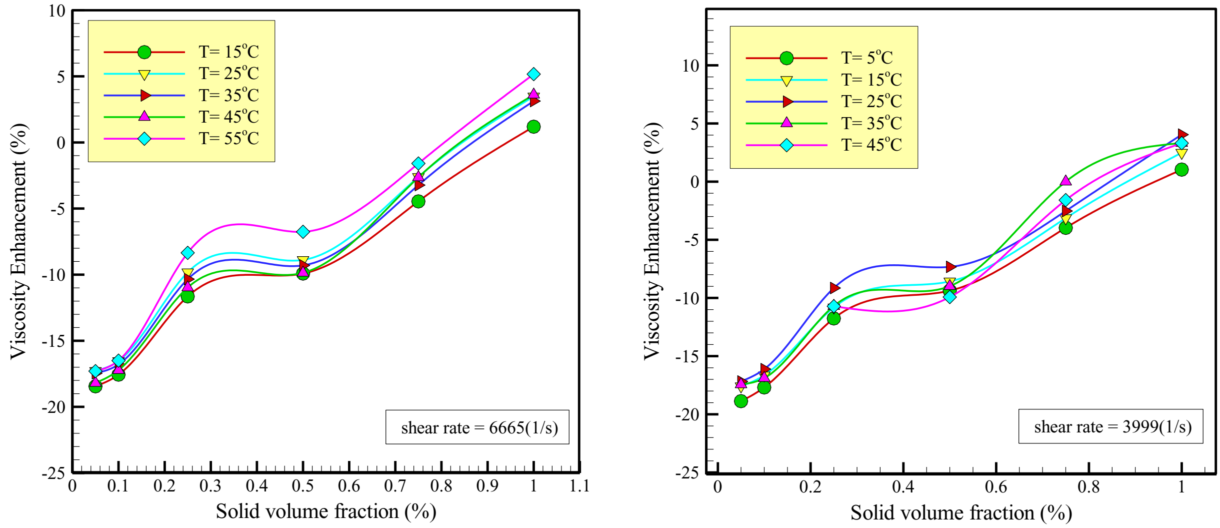


**Fig. 4.** Viscosity enhancement analysis.

A notable point in Fig. 4 is viscosity reduction of enriched engine oil by nanoparticles in comparison with pure 5w50 oil at solid volume fractions <0.75%. This viscosity reduction reaches 20% at some temperatures and solid volume fractions. In fact, adding nanoparticles to oil not only did not increase the viscosity of 5W50, but also decreased it. This viscosity reduction is shown in Fig. 4. This nano-engine oil is an exceptional phenomenon to use in the automotive industries. The lower viscosity of the nano-engine oil compared to the base oil will provide conditions for faster lubrication of the engine oil in the lubrication cycle and better and faster heat transfer.

Also, the comparison of Viscosity Enhancement values versus volume fraction diagram of studied nanofluid with MWCNT-$Al_2O_3$ (65%–35%)/5W50 [48], MWCNT-$TiO_2$ (55%–45%)/10W40 [49], MWCNT-$SiO_2$ (10%–90%)/10W40 [50] and MWCNT-CuO (15% -85%)/10W40 [51] nano-oils are presented in Fig. 5. As shown in Fig. 5, the nano-engine oil studied in this investigation compared to other nano-oils has an important feature. In fact, in low volume fractions, with increasing nanoparticles, not only does not viscosity increase, but also it has a lower viscosity than other nano-engine oils and base oil of 5w50. As a result, the nano-oil has a higher performance than the base oil and other nano-oils studied in the car engine and therefore, its temperature range is higher than other oils and nano-oils, and at lower temperatures and cold start conditions because it responds well to the lubrication of the car. The low viscosity of the engine oil at cold engine start condition and cold weather, will cause less damage to the engine due to faster lubrication of the engine oil.

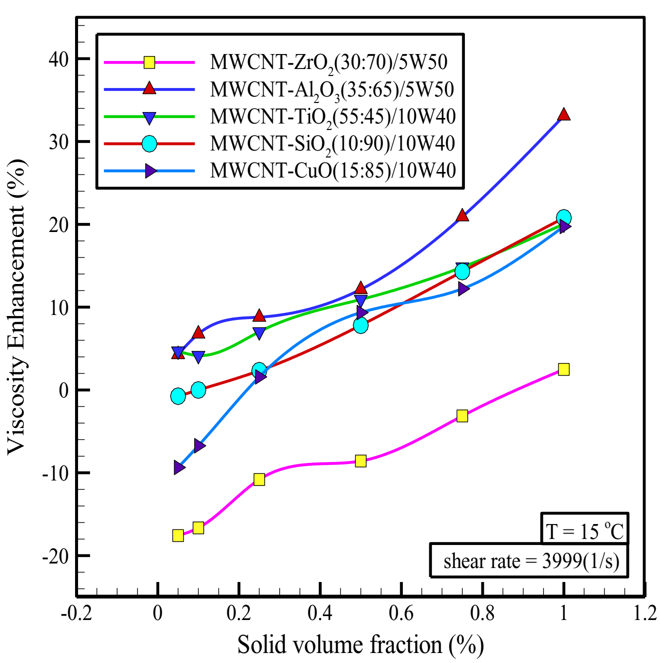


**Fig. 5.** Viscosity enhancement of MWCNT-ZnO(30%–70%)/5W50 and other nanofluids.

### 3.3.1. Viscosity analysis of oil for summer and winter usage

One of the features of good engine oils is their optimal performance in all seasons, summer and winter in particular. For example, for a country like Iran with a vast different weather conditions (Tabriz [52] and Shahrekord [53] as two cold cities samples and Bandar Abbas [54] and hero Dezful [55] as two hot cities samples in Iran), the ability of car engine to operate in different situations is of high importance. In this experiment, pure full synthetic SAE 5W50 Oil (Behran Co. [1]) was used as a base oil. Due to symmetry, proper distribution, and uniformity of molecules of synthetic engine-oils, synthetic oils are more effective than mineral ones in preventing engine damage. A schematic representation of synthetic and mineral oil molecules is presented in Fig. 6.

Comparison results of the viscosity-temperature curves for the MWCNT-$ZrO_2$ (30–70%)/5W50 nanofluid with MWCNT-$Al_2O_3$ (65–35%)/5W50 nanofluid and 5W50 oil were reported in Fig. 7. Since 80% of the engines damage happen at engines cold start condition, rapid oil flow for engine lubrication in cold weather is vital. The engine oil with lower viscosity cause the higher protection against engine damage. According to Fig. 7, the investigated nanofluid viscosity is lower than the base oil and MWCNT-$Al_2O_3$ (35%–65%)/5W50 nanofluid, so it will have better performance in winters.

The engine-oil viscosity used in the summer should have the lowest level of dependency against temperature variations, because if

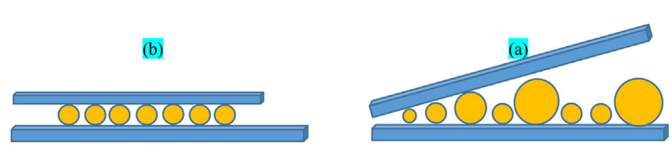


**Fig. 6.** (a) non synthetic oil (mineral oil), (b) synthetic oil, particles distribution and size between two moving surfaces.

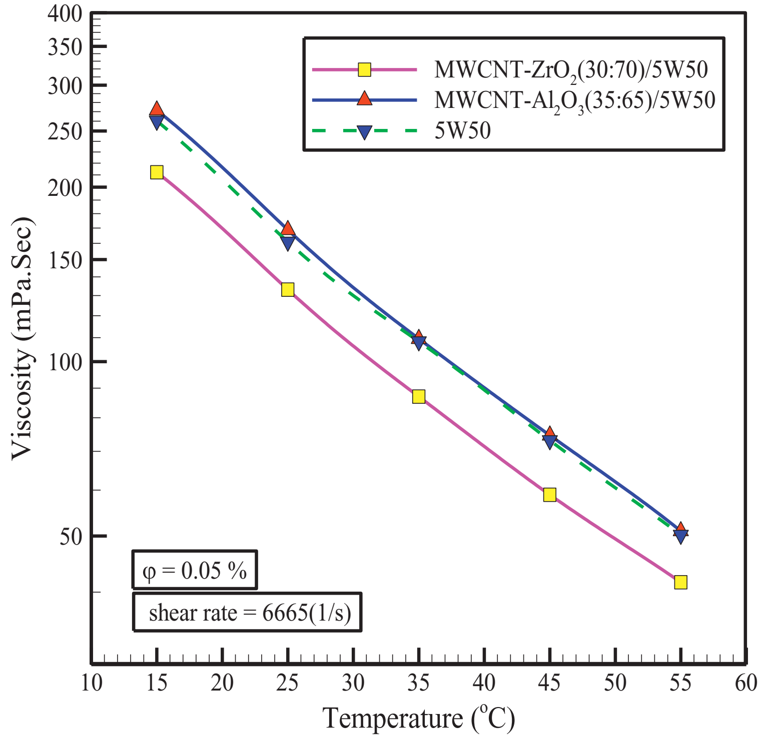


**Fig. 7.** Viscosity versus temperature.

the viscosity decreases with increasing temperature, the engine oil between the parts will not be desirable and the parts will wear due to the increased friction and quality degradation. As a result, the oil should be viscous at high temperatures, usually in the summer, and should remain among parts and maintain its performance at the highest level.

The viscosity-temperature curves for the nanofluids in different solid volume fractions and shear rates are presented in Fig. 8. According to the results of Fig. 8, single grade oils have a low viscosity index (high viscosity sensitivity to variations in temperature or high slope gradients), and multigrade oils and nano enriched oils have a high viscosity index (low viscosity sensitivity to temperature variations, or low slope gradients). In the summer, engine oils with a high viscosity index (less viscosity variation slope relative to temperature) are definitely more practical.

With respect to viscosity variation slope of semi-synthetic 10W40 oil (uneven and non-uniformity of oil molecules) compared to 5W50 oil viscosity variation curve (in Fig. 8), it can be concluded that 5W50 oil has optimal conditions compared to 10W40 oil. In other words, the 5W50 oil has a higher viscosity index and provides better conditions for proper engine operation in hot weather. Also, the operating temperature range of 5W50 oil is −35 to 50 °C, while the 10W40 is effective in the temperature range of −30 to 40 °C and covers a more limited range [1,37]. In addition, slope of viscosity changes of MWCNT-$ZrO_2$ (30%–70%)/5W50 nano-engine oil and its base oil (SAE 5W50) is compared in Fig. 8 (at temperatures higher than 35 °C). As it is obvious, in a volume fraction of <0.75%, the MWCNT-$ZrO_2$ (30%–70%)/5W50 nanofluid curve slope is less than pure 5W50 and therefore has a higher viscosity index. Indeed, the viscosity sensitivity of the MWCNT-$ZrO_2$ (30%–70%)/5W50 nano-engine oil to temperature is less than that of 5w50 oil. As a result, the proposed nano-engine oil is more suitable than all of the oils described in Fig. 8 and shows better performance in summer and hotter seasons.

By decreasing solid volume fraction of nano-engine oil, the difference in the curve slope for the present studied nano-oil and 5W50 oil increases, and the quality and efficiency of nano-oil with presented combination of nanoparticles in hot weather and summer seems to be higher and clearer compared to other oils. Nonetheless, there is no significant difference between viscosity-temperature curves for $ZrO_2$ (30%–70%)/5W50 nano-oil and 5W50 oil in the volume fraction of 1% and no tangible improvements were observed in comparison with pure 5W50 oil.

### 3.4. Viscosity prediction using RSM model

Using the response surface method (RSM) statistical method to create a mathematical model (correlation) to predict the desirable answer is one of the common methods in many sciences. In fact, this is an effort to provide a mathematical model that is adapted to data from laboratory results. In this research, a mathematical model for predicting nano-oil viscosity is presented using this statistical methods (RSM). The results of this model are presented in Fig. 9, which shows the difference between laboratory values and predicted values by the RSM model. As a result of RSM, Eq. (3) is presented to predict the relative viscosity of nanofluid. Presented equation is a three variable correlation that its independent variables are φ as solid volume fraction, T as temperature and $\dot{\gamma}$ as shear rate. The shear rate was used in proposed mathematical correlation because of non-Newtonian behavior of investigated nano-engine oil in present study. According to rheological laws fluids with non-Newtonian behavior viscosity relates to shear rate. As it can be seen the proposed correlation has polynomial form.

$$\frac{\mu_{nf}}{\mu_{bf}} = 0.77956 + 0.55096\varphi + 3.74\times10^{-3}T - 1.86\times10^{-6}\dot{\gamma} + 1.30\times10^{-3}\varphi T - 1.00\times10^{-5}\varphi\dot{\gamma} - 0.788\varphi^2 - 1.55\times10^{-4}T^2 + 8.95\times10^{-6}\varphi^2\dot{\gamma} + 0.4605\varphi^3 + 1.66\times10^{-6}T^3 \quad (3)$$

The value of $R^2$ for the proposed correlation is 0.9624. In Tables 2 and 3, the mathematical correlation statements are individually

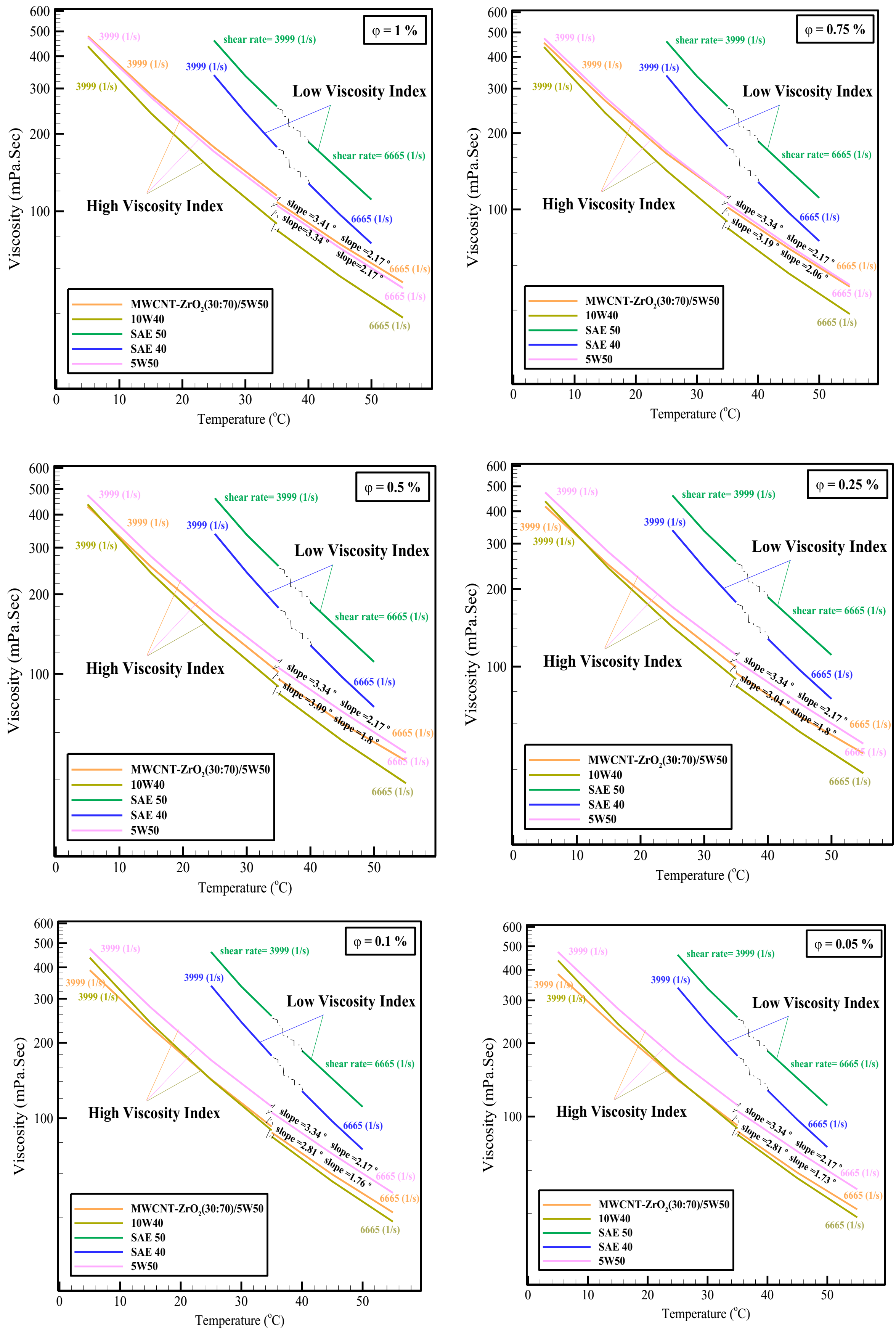


**Fig. 8.** Viscosity versus temperature (viscosity index).

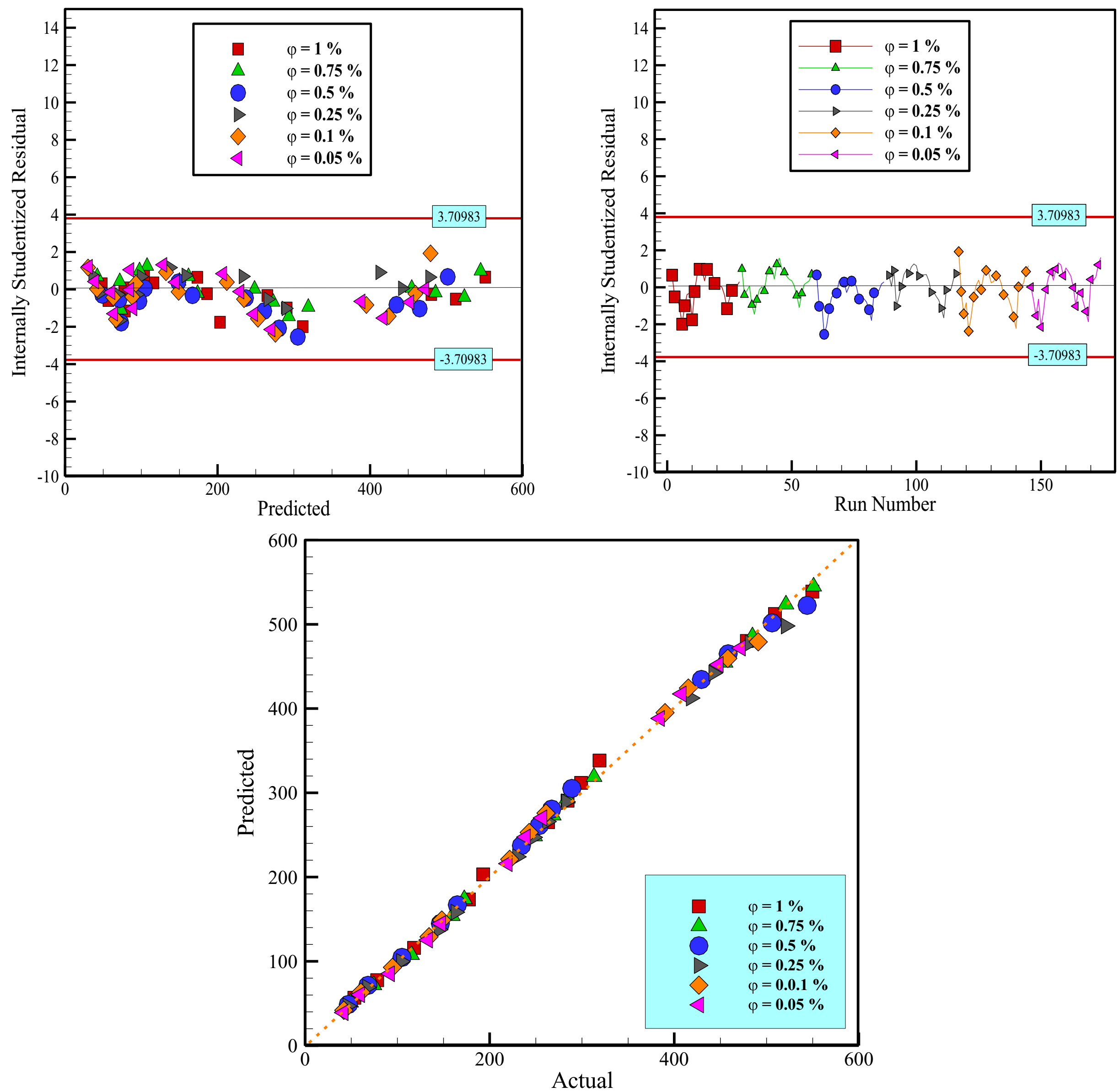


**Fig. 9.** comparison of experimental results and RSM results.

examined more closely and the importance of presence or deletion of each sentence of correlation is determined in making the proposed correlation accurate. The p-value was considered as a criterion to separate the important terms from unimportant terms in the proposed mathematical correlation. Terms with p-value <.05 are important; conversely, terms with p-values higher than 0.1 are unimportant and could be deleted.

In the following according to RSM results, three parameters were investigated to determine the effect of each of these parameters on the viscosity separately (Fig. 10). As shown in Fig. 10, the temperature has the biggest impact on the viscosity of this nano-oil.

Also, the simultaneous effect of both temperature and shear rate on the viscosity and temperature and solid volume fraction

**Table 2**
Importance of each mathematical equation terms.

| Source | Sum of squares | Mean square | p-value |
|---|---|---|---|
| Model | 1.14 | 0.11 | <0.0001 |
| A-φ | 0.035 | 0.035 | <0.0001 |
| B-T | 1.02E-03 | 1.02E-03 | 0.0555 |
| C-$\dot{\gamma}$ | 6.61E-03 | 6.61E-03 | <0.0001 |
| AB | 4.50E-03 | 4.50E-03 | <0.0001 |
| AC | 2.90E-05 | 2.90E-05 | 0.7453 |
| A2 | 4.67E-05 | 4.67E-05 | 0.6801 |
| B2 | 3.48E-04 | 3.48E-04 | 0.2614 |
| A2C | 8.12E-04 | 8.12E-04 | 0.0871 |
| A3 | 0.016 | 0.016 | <0.0001 |
| B3 | 5.02E-03 | 5.02E-03 | <0.0001 |
| Residual | 0.045 | 2.74E-04 | |

**Table 3**
Analysis of variance for proposed correlation.

| | |
|---|---|
| Std. Dev. | 0.017 |
| Mean | 0.91 |
| C.V. % | 1.82 |
| Press | 0.051 |
| R-Squared | 0.9624 |
| Adj R-Squared | 0.9601 |
| Pred R-Squared | 0.9569 |
| Adeq Precision | 67.915 |

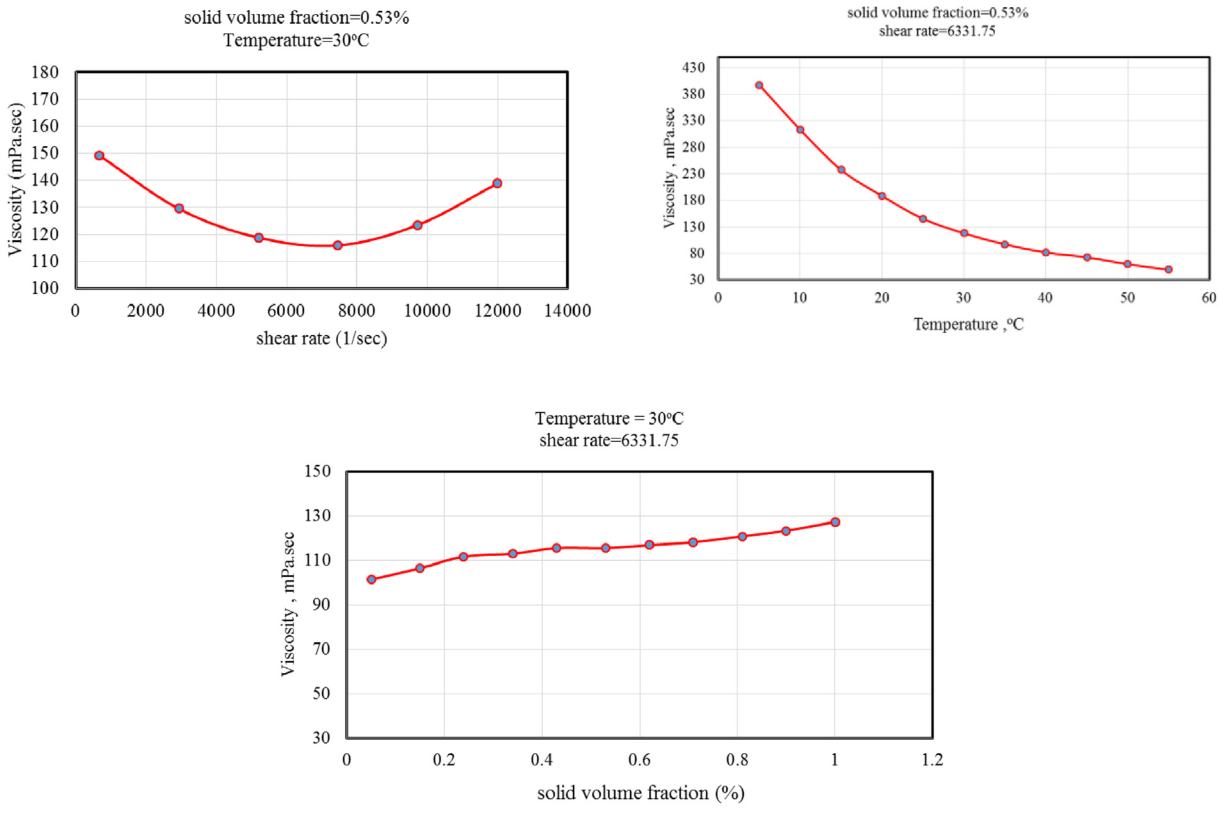


**Fig. 10.** Dependency level of viscosity to important parameters.

are shown by a three-dimensional procedure (Fig. 11). In this figure one of the three parameters was assumed to be constant. Depending on the need and application, having used these procedures, you can obtain the temperature, volume fraction and shear rates associated with the minimum and maximum viscosity values.

### *3.5. Viscosity prediction: artificial neural network*

ANN is a statistical and strong method that is used to solve complex modeling challenges such as estimating, categorizing, and recognizing patterns. There are no central processors in the neural network; therefore, many operations in this network were

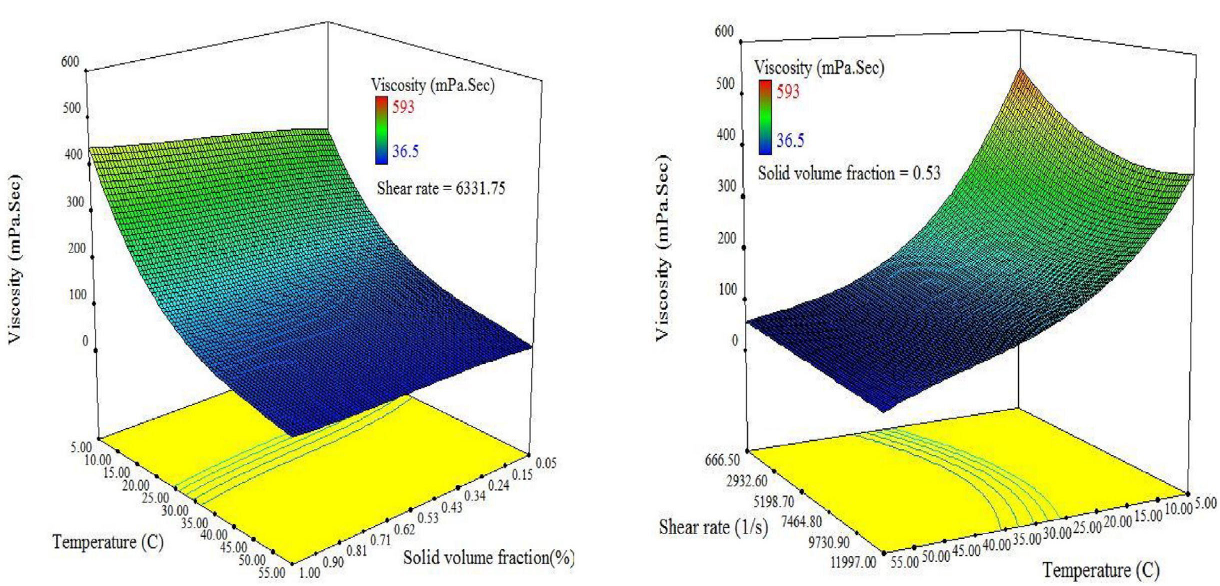


**Fig. 11.** Simultaneous effect of two factors on viscosity.

**Table 4**
Top three ANNs berween 100 analyzed topologies.

| No. | Number of neurons | Transfer functions | R | valR | tstR | trainR |
|---|---|---|---|---|---|---|
| 1 | [3 3] | [tansig tansig] | 9.999160e-01 | 9.999798e-01 | 9.997813e-01 | 9.999600e-01 |
| 2 | [3 5] | [logsig tansig] | 9.999389e-01 | 9.999537e-01 | 9.997474e-01 | 9.999697e-01 |
| 3 | [4 2] | [tansig tansig] | 9.999511e-01 | 9.999076e-01 | 9.998977e-01 | 9.999669e-01 |

done in parallel. After selecting the input and output data of the network and selecting training algorithms, the transfer function, the number of hidden layers and neurons in each hidden layer, network training begins. To evaluate better performance and optimal network selection, performance indicators (Eqs. (4) and (5)) are used to analyze the difference between the output of the network and the optimal output (in this case, the experimental data). In order to achieve the optimal structure of the neural network, in the present study, 100 different topologies of the neural network were studied (using MATLAB software) and the best structures were selected from them. The topology of designed artificial neural network in this study had two hidden layers, both first and second layers have tangent sigmoid transfer function. Also, in the proposed structure, 4 neurons in the first layer and 2 neurons in the second layer were placed.

$$R = \frac{\sum_{i=1}^{n}\left(T_{ij}-\overline{T}\right)\left(P_{ij}-\overline{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(T_{ij}-\overline{T}\right)^2\sum_{i=1}^{n}\left(P_{ij}-\overline{P}\right)^2}} \quad (4)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(T_{ij}-P_{ij}\right)^2 \quad (5)$$

In the above equations, $T_{ij}$ is the real value and $P_{ij}$ the value obtained from the neural network. Also, the $\overline{T}$ and $\overline{P}$ are average values of the laboratory results and the values predicted by the neural network for the n series of data, respectively.

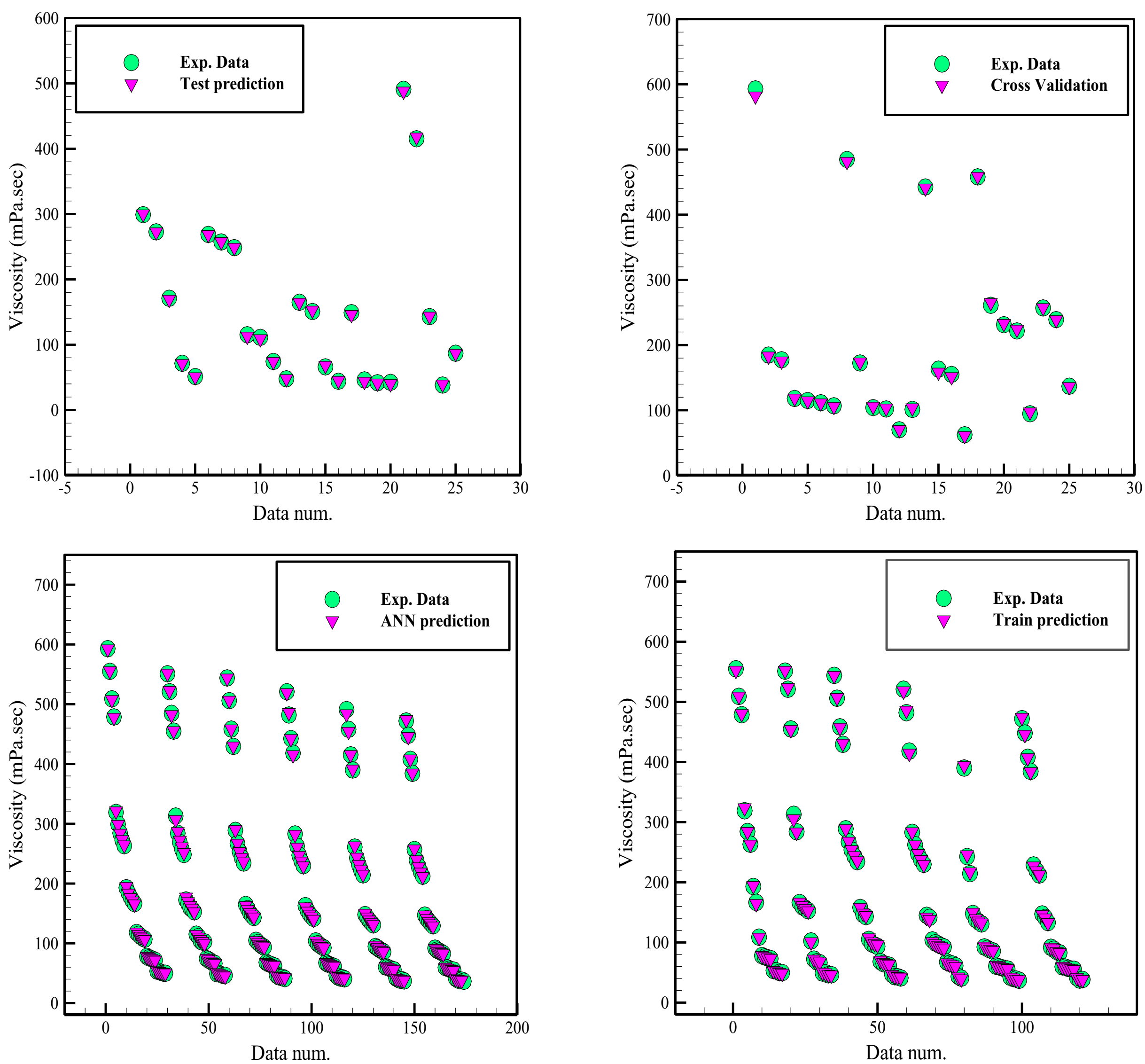


**Fig. 12.** Matching results of experimental and ANN results.

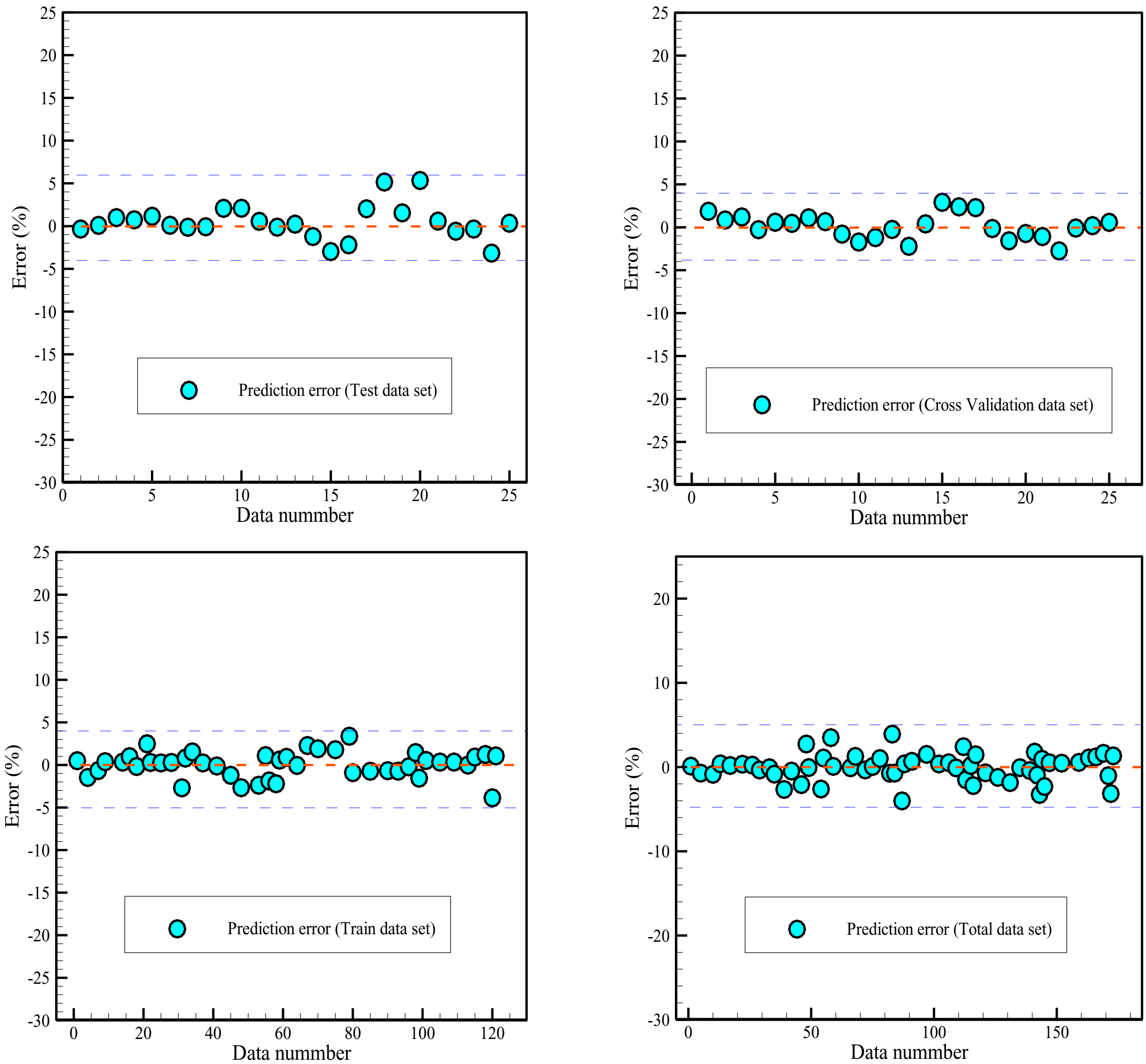


**Fig. 13.** ANNs errors (train, cross validation and test steps).

In Table 4, top three structures of the most optimal neural network structures (among the 100 different tested structures) were selected and introduced. Among the three structures, the best structure is identified by number 3. It should be noted that out of a total of 174 existing laboratory data sets, 70% of the data for the training phase, 15% of the data for the testing phase, and 15% for the validation phase are considered.

Comparison of laboratory results with the data obtained from artificial neural network is presented in Fig. 12. This comparison compares the results of the neural network with the laboratory results in four phases: training, testing, and validation and total phase. According to Fig. 12, there is a very good agreement between the experimental results and the data obtained from the designed neural network. In fact, this overlap indicates the proper neural network structure, good training, and the high precision of the designed artificial neural network to predict the nano-engine oil viscosity.

The error of designed artificial neural network to estimate laboratory results is also presented in Fig. 13. In all four steps for designing the neural network, the error value was <5%. This low error value indicates the high accuracy of the ANN. In the total data sets, most of the data had an error of <3%.

### 3.6. Comparison of mathematical methods accuracy

In this section the prediction accuracy of the artificial neural network was compared with RSM prediction. This comparison was carried out at 15, 25, 35, 45 and 55 °C. As shown in Fig. 14, although the results of the proposed mathematical relationship are close to the experimental results and are of good precision, the model results accuracy for viscosity prediction is higher by the neural network.

## 4. Conclusions

In this research, the laboratory investigation and introduction of MWCNT-$ZrO_2$ (30%–70%)/5W50 Nano-engine oil in volume fractions of 1%, 0.75%, 0.5%, 0.25%, 0.1%, 0.05% and temperatures of 55, 45, 35, 25, 15, 5 °C were presented. This nano-oil has some very interesting features, in a way that it can provide ideal engine oils for hot and cold seasons of the year. These properties make it even more useful in the summer and winter than the pure SAE 5W50 oil. Using a number of methods, a model for predicting nano-oil viscosity behavior was presented. A mathematical model was obtained using RSM based and ANN based methods.

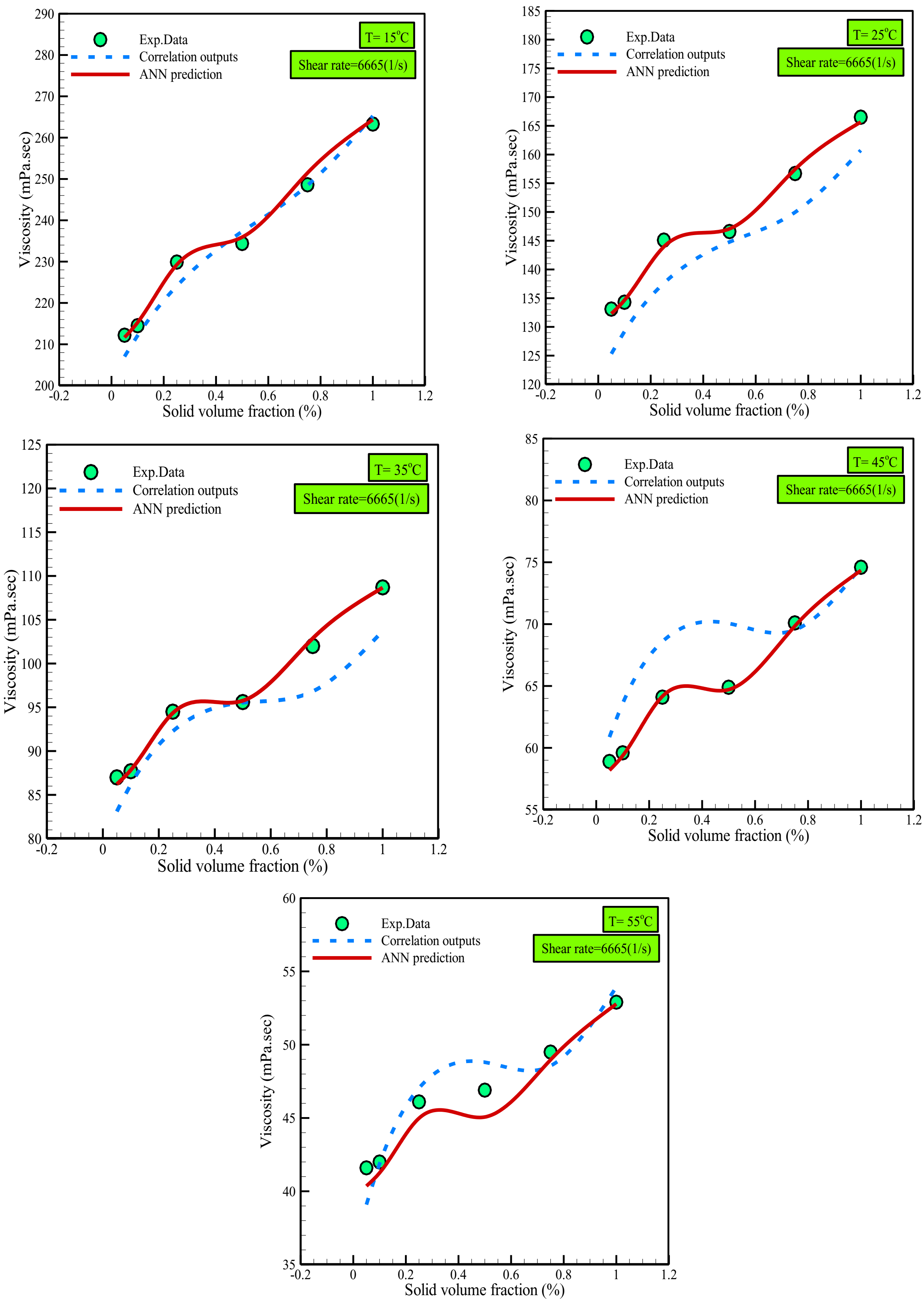


**Fig. 14.** comparison between experimental, correlation and ANN results.

Various results were obtained in this study that the most important ones are listed in the following:

1. Reducing the nano-engine oil viscosity in volume fractions of <0.75% compared to the 5W50 base oil and it improves efficiency of this nano-oil to use in low temperature working conditions.
2. Improvement of Viscosity Index (Increase) of introduced nano-oil in comparison with 5W50 base oils and SAE40 and SAE50 single grade oils as well as multi-grade 10W40 oil, which indicates the optimization and efficiency of introduced nano-oil in high temperature performance.
3. The neural network has a higher accuracy than predicted mathematical relationships in predicting viscosity values.

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