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DEVELOPMENT OF FUZZY RULE BASED SYSTEM FOR PREDICTION OF PROPERTIES OF BIO FLUIDS

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Abstract

This study develops a fuzzy logic model to predict the thermal conductivity and absolute viscosity of bio fluids. Triangular membership functions are utilized for fuzzification of inputs including type of oil, percentage of oil and stirrer speed. Gaussian membership functions then convert fuzzy sets into output values during defuzzification. The model is assessed for prediction accuracy using testing data. Performance metrics of R2, MSE and RMSE quantify the model's effectiveness.

1. INTRODUCTION

In solar thermal systems, numerous alterations are implemented to optimize the heat transfer process and enhance the overall efficiency of the collector. One of the most noteworthy adjustments involves the substitution of the heat transfer fluid. Due to their tremendous capability to enhance the performance of the system, nanofluids are progressively gaining popularity. Aluminum oxide, in varying proportions of 0.1%, 0.4%, and 0.8%, is employed in the heat exchanger to achieve improved outcomes[1]. The utilization of the appropriate quantities of nanofluids and water leads to a respective enhancement of 18%, 25%, and 30% in the heat transfer coefficient. Furthermore, notable improvements have been observed in terms of thermal conductivity and pressure drop. The implementation of Thermos fluids also enhances the cavitation flow [2]. Within solar thermal applications, a multitude of modifications are carried out to enhance the heat transfer process and overall effectiveness of the collector. One of the most significant adaptations involves the replacement of the heat transfer fluid. As a result of their capacity to enhance system performance, nanofluids are experiencing a surge in popularity. C. Selvam et al. conducted an investigation on silver nanofluids with ethylene glycol and water thermophysical properties. The research findings, obtained through the utilization of diverse instruments and methodologies, have demonstrated an augmentation in thermal performance as well as a substantial impact on other properties such as thermal conductivity, viscosity, density, and specific heat. The respective increases observed were approximately 12%, 35%, 2.16%, and 7% [3].Metals with high thermal conductivity are utilized as nanofluids, and this phenomenon has progressed to the extent that biofluids are produced. Nanotechnology employs biofluids, which are derived from biological plant components. Brominated vegetable oil, an additive derived from plants, is assessed and contrasted with natural, unaltered oil[4]. The data reveal an increase in density and viscosity, as well as a notable solubility. Moreover, the thermal conductivity of biofluids derived from plants was compared to that of several nanofluids[5]. By employing two different plant species, the enhancement in thermal conductivity ranged from 8% to 103% at various temperature settings. Additionally, the thermal properties of biofluids have significantly improved, thus prompting this study to investigate and analyze the various properties of biofluids. Various concentrations and stirrer speeds can be employed to produce biofluids, however, the optimal mixture must be identified to yield the most desirable outcomes[6].Attaining better outcomes with diverse combinations of biofluids necessitates the implementation of the most effective optimization method. Based on experimental data, artificial neural networks (ANN) were utilized to predict the thermal conductivity of the nanofluid[07]. On average, 35 data points were used, with 80% of the dataset allocated for training and 20% for testing. ANN proved to be a precise method for estimating the thermal conductivity of a nanofluid. The comparison results demonstrated the accurate estimation capability of the ANN model for unknown thermal conductivity values of hybrid nanofluids [08]. Yeping et al. employed a feed-forward multilayer perceptron of a neural network to predict the thermal conductivity of nanofluids in an Ethyl Glycol mixture. A total of 36 experimental variables were utilized to construct the ANN model. In this study, 25 data sets were used for training purposes, while 11 data sets were employed for validation. It was discovered that the proposed ANN approach effectively predicts the thermal conductivity of nanofluids and yields results that align well with practical observations[09].

The current research investigates the use of fuzzy logic modeling in combination with particle swarm optimization to enhance the efficiency of a shell and helically coiled tube heat exchanger by employing Al_2O_3/SiO_2 nanofluids. The accurate prediction of nanofluid properties, which is based on volume fraction and temperature, is achieved by the fuzzy logic model, and this prediction aligns well with experimental data. Through the integration of fuzzy logic and particle swarm optimization, the research successfully identifies the optimal properties of nanofluids to maximize the heat exchanger's efficiency while simultaneously minimizing the pumping power required. This integration of fuzzy logic and optimization techniques effectively illustrates the efficacy of fuzzy modeling in improving the performance of thermal systems [10]. The researchers have successfully developed a fuzzy logic model that analyzes the impact of various machining parameters such as spindle speed, feed rate, and drilling depth on both thrust force and surface roughness. Through a rigorous comparison of the outcomes between the fuzzy logic model, regression models, and empirical data, the researchers have concluded that the application of the fuzzy logic approach yields more precise predictions. By demonstrating the successful utilization of fuzzy rule-based modeling for forecasting drilling parameters with the use of VBCFs, this study effectively showcases the efficacy of fuzzy logic in the optimization of machining processes[11].

The current study focuses on utilizing empirical evidence to determine the relationship between input and output using the Fuzzy Rule-Based System, to reduce the costs associated with experimentation. The input factors included the type of oil, the concentration percentage, and the velocity of the stirrer. The output factors included thermal conductivity, density, and absolute viscosity. As a result, the developed model will be used for optimizing strategies in future projects.

2. MATERIALS AND METHODS

An electric stirrer with variable speed capabilities is utilized to produce biofluids at room temperature, ranging from 0 to 15000 revolutions per minute (RPM). The setup is depicted in Figure 1 (selvalakshmi et al. [12]). In the process of manufacturing the bio-fluid, water serves as the fundamental fluid. The mixture of oil and water in appropriate proportions takes place within a transparent glass container, which is then swirled for approximately 30 minutes to achieve thorough blending. It is worth noting that the qualities of the resulting bio-fluid blends surpass those of their base fluids, namely water and oil. To determine the thermal conductivity of the fluids produced, a KD2 Pro Thermal Properties Tester is employed. A total volume of 50 cc of the prepared sample is utilized for the assessment of thermal conductivity. To ensure accurate results, the experiment is repeated after a 20-minute interval, allowing the system to reach thermal equilibrium. To mitigate inefficiencies stemming from heat convection, the liquid sample is placed inside the measurement cylinder of the chamber. The needle and probe of the Tester are then immersed in the test sample and connected to the monitor. Consequently, the monitor can continuously monitor the thermal conductivity of the test materials. To measure the viscosity of the produced sample, a Redwood Viscometer is utilized. The viscosity is determined by employing a 50 mL prepared sample. The external bath is filled with water, and the sample is poured into the viscometer cup. Both a redwood viscometer cup and a stirrer are utilized in this process. The heater is activated until the sample reaches a temperature of 30 degrees Celsius. Subsequently, the sample is allowed to flow through the hole to measure the Redwood second. A timer is employed to track the collection of 50 mL samples in the volumetric beaker. The fixed speed levels for the stirrer are set at 5000, 10,000, and 15,000 RPM, respectively, while the percentage of oil concentration is arbitrarily determined based on economic considerations as 5%, 10%, and 15% [12]. The results of the experiment are presented in Table 1.

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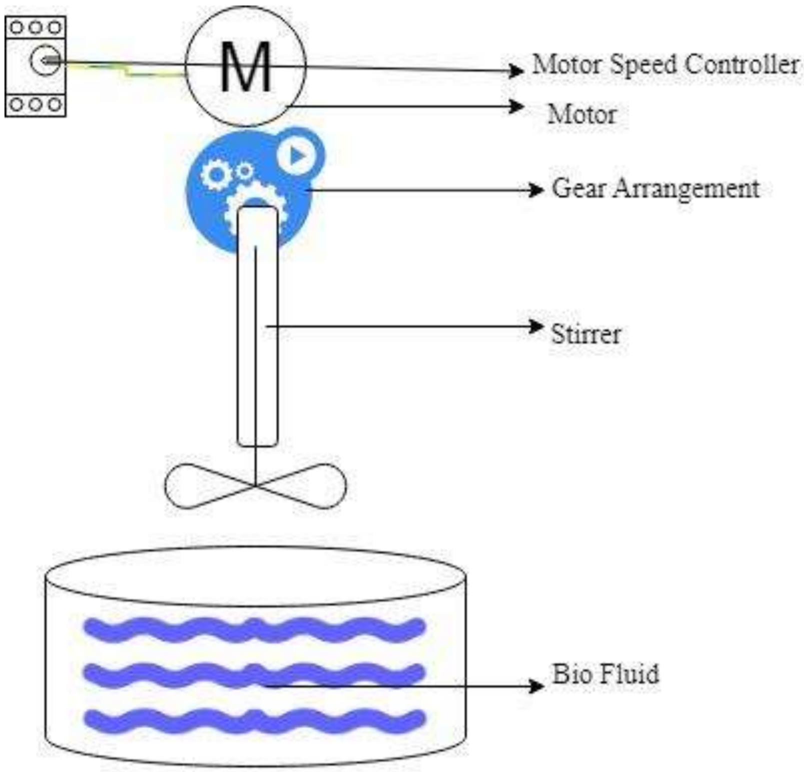

Fig. 1.Experimental setup of the Biofluid preparation process

Table 1. Experimental Results

		Input		Output	
Types of oil	Trail	Percentage	Speed	Thermal Conductivity	Absolute Viscosity
		%	(rpm)	W/mK	(Centipoise)
Coconut oil	1	5	5000	0.525	1.0382
	1	10	10000	0.506	1.0032
	1	15	15000	0.326	0.9883
Sunflower oil	2	5	5000	0.687	0.9963
	2	10	10000	0.606	1.0132
	2	15	15000	0.82	1.0482
Castor oil	3	5	5000	0.459	1.0482
	3	10	10000	0.533	1.0082
	3	15	15000	0.404	1.0032

3. FUZZY LOGIC SYSTEM

Fuzzy logic, a computing methodology grounded in fuzzy set theory, is concerned with the representation and inference of knowledge, particularly about vague or imprecise problems. This approach was originally introduced by Dr. Lotfi Zadeh in the year 1960. In the context of a fuzzy set, every member possesses a membership value that falls within the range of 0 to 1.

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A fuzzy set, in essence, is a set in which each element is assigned a membership value, with such values determined through the utilization of membership functions. Hence, fuzzy set A can be depicted as follows.

$$A = \{(x, \mu A(x)), x \varepsilon X\} \quad (1)$$

Where X is a universe of discourse and x is a particular element of X, μA(x) is a membership value of x. The fuzzy logic system consists of a Fuzzy rule base, fuzzifier, and defuzzifier. A fuzzy rule base system contains IF_ THEN rules and also describes the relationship between input and output and fuzzy inference can use the Sugeno and Mamdani inference mechanism. Fuzzification is the process of converting crisp value into the fuzzy set, which can be achieved using membership functions. there are different types of membership functions triangular, trapezoidal, and Gaussian. Here the triangular membership function and Gaussian were used. Defuzzification is the process of converting a fuzzified output into a single crisp value. the few defuzzification methods are the Center of Sums Method (COS), Centroid of Area (COA) Method, Weighted Average Method, and Mean of maxima. The Block diagram of Fuzzy logic system for Predicting Bio-Fluid Thermal performance was shown in figure 2.

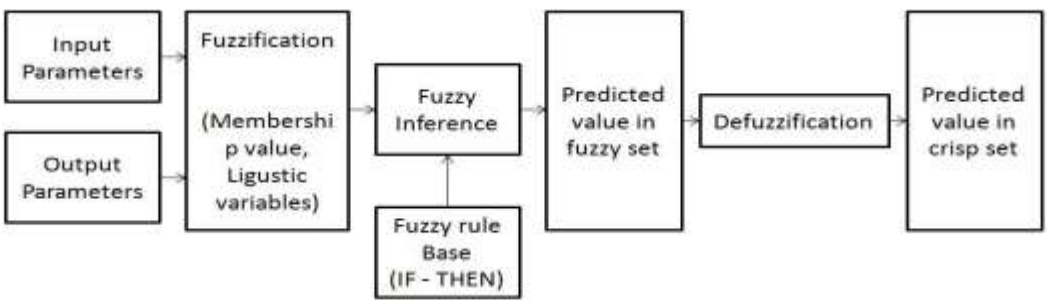

FIGURE 2. Block diagram of Fuzzy logic system for Predicting Bio-Fluid Thermal Performance

1. If (Oil is Coconut_oil) and (Percentage is 5) and (Speed is 5000) then (ThermalConductivity is 3)(Absolute_Viscosity is 4) (1)
2. If (Oil is Coconut_oil) and (Percentage is 10) and (Speed is 10000) then (ThermalConductivity is 3)(Absolute_Viscosity is 3) (1)
3. If (Oil is Coconut_oil) and (Percentage is 15) and (Speed is 15000) then (ThermalConductivity is 1)(Absolute_Viscosity is 1) (1)
4. If (Oil is Sunflower_oil) and (Percentage is 5) and (Speed is 5000) then (ThermalConductivity is 4)(Absolute_Viscosity is 1) (1)
5. If (Oil is Sunflower_oil) and (Percentage is 10) and (Speed is 10000) then (ThermalConductivity is 4)(Absolute_Viscosity is 2) (1)
6. If (Oil is Sunflower_oil) and (Percentage is 15) and (Speed is 15000) then (ThermalConductivity is 5)(Absolute_Viscosity is 5) (1)
7. If (Oil is Castor_oil) and (Percentage is 5) and (Speed is 5000) then (ThermalConductivity is 2)(Absolute_Viscosity is 5) (1)
8. If (Oil is Castor_oil) and (Percentage is 10) and (Speed is 10000) then (ThermalConductivity is 3)(Absolute_Viscosity is 2) (1)
9. If (Oil is Castor_oil) and (Percentage is 15) and (Speed is 15000) then (ThermalConductivity is 1)(Absolute_Viscosity is 3) (1)

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FIGURE 3. Rule Viewer for Predicting Bio-Fluid Thermal Performance

FIGURE 4. – Fuzzy inference system for Predicting Bio-Fluid Thermal Performance

$$X^* = \frac{(\sum_{i=1}^{N} x^i) * (\sum_{k=1}^{N} \mu A(k) x(i))}{(\sum_{i=1}^{N} x^i) * (\sum_{k=1}^{N} \mu A(k) x(i))} \quad (2)$$

fuzzy inference can take the form of either Mamdani or Takagi-Sugeno. In the proposed model it is opted for the Mamdani method for inference as shown in figure 4. A fuzzy rule-based system was employed in the inference system. Let us denote the input parameters as X, which may include types of oil, percentage, and speed. Similarly, the output parameter is denoted as Y, which may represent Thermal conductivity and absolute viscosity. Assuming we have an input-output pair (X, Y), the rule can be expressed as follows: If x belongs to X, then y belongs to Y, where X and Y are elements of the real numbers (R).Rule Viewer for Predicting Bio-Fluid Thermal Performance was shown in figure 3.

3.1 Performance evaluation

The aforementioned numbers were computed to assess the effectiveness of the formulated model. The ensuing criteria pertain to the statistical evaluation of performance.

- Coefficient of determination

$$R^2 = \frac{\sum_{i=1}^{n} \left(X_{p,i} - X_{o,i}\right)^2}{\sum_{i=1}^{n} \left(X_{o,i} - \overline{x_{o,i}}\right)^2}$$

- Mean square error (MSE)

$$MSE = \frac{\sum_{i=1}^{n} (a_{p,i} - a_{o,i})^2}{n}$$

- Root mean square error (RMSE)

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$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(a_{p,i} - a_{o,i})^2}{n}}$$

Where $X_{o,i}$ is observed value, $X_{p,i}$ is predicted value, n is number of observations and $\overline{x_{o,\iota}}$ is average observed value. The linear correlation between the measured and correlated values was measured using R^2.The linear correlation between the measured and correlated values was quantified using a measurement technique. In the case where the value of the correlation coefficient equals one, it is deemed to be an optimal correlation. The greater the reduction in the root mean square error (RMSE), the higher the level of accuracy in predicting future outcomes.

3.2 IMPLEMENTATION OF FUZZY LOGIC

The parameters that are given as input to the fuzzy system are the types of oil, percentage, and oil. These input parameters consist of types of oil, percentage, and speed. The output parameters, on the other hand, are thermal conductivity and absolute viscosity. They are transformed into linguistic variables and the triangular membership function is applied to convert the crisp set into a fuzzy set. Each member in the fuzzy set is assigned a membership value. A fuzzy knowledge base is then created based on fuzzy rules. These rules are identified to determine the relationship between the input and output variables. The Mamdani method is utilized for fuzzy inference, and the center-of-sum defuzzification method is applied to the predicted fuzzy set to obtain a crisp value. The fuzzy rule for predicting Bio-Fluid Thermal Performance is shown in Figure 3. A total of 9 rules are generated, where the input parameters are passed in the antecedent part and the output parameters are passed in the consequent part. The error value can be calculated as the difference between the actual and predicted values. In a fuzzy system, these processes are conducted. The rules were fed into the knowledge base based on which the predictions were made**.**

4. RESULTS AND DISCUSSION

In the fuzzy logic, the ranges of parameters are identified first. Minimum and maximum values of input/output parameters used in this were calculated. Then, to obtain fuzzy sets, a triangular membership function was used for fuzzification. In fuzzification, numerical input and output values are converted into linguistic terms such as low, medium, high, etc. Membership functions and their ranges of input parameters are shown in Figs 5-7. After that fuzzy rules were described to obtain fuzzy values. Finally, the gaussian membership function was used to defuzzify it to obtain the outputs. Defuzzification is the process of conversion of fuzzy quantity into precise quantity. The Centroid defuzzification method which calculated the centroid of the area under the membership

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function was applied in this study. Membership functions and their ranges of output parameters were shown in Figs 8-9.

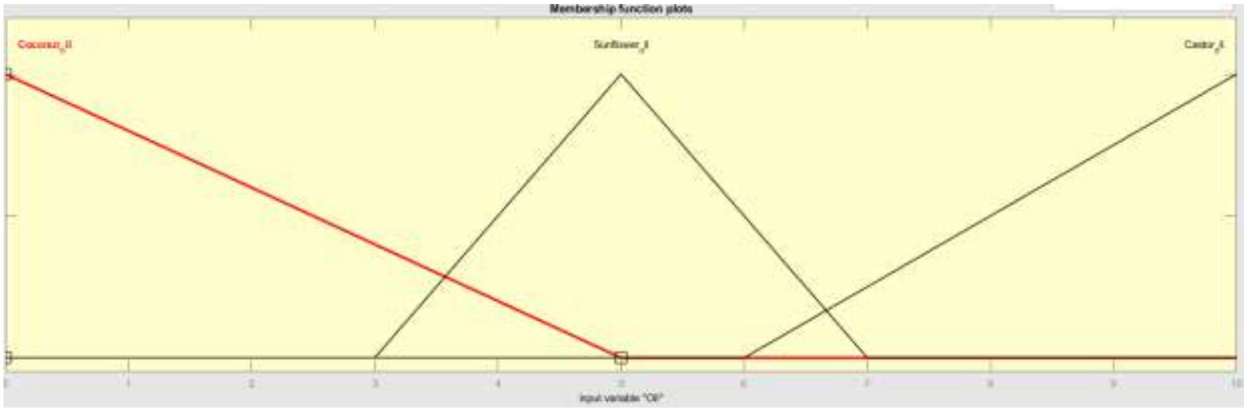

FIGURE 5. Membership function for Type of oil

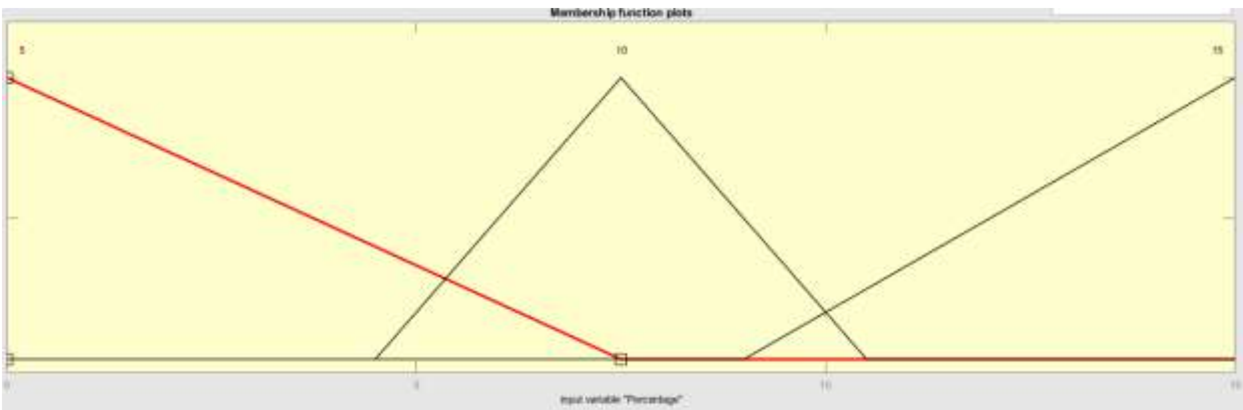

FIGURE 6. Membership function for Percentage of oil

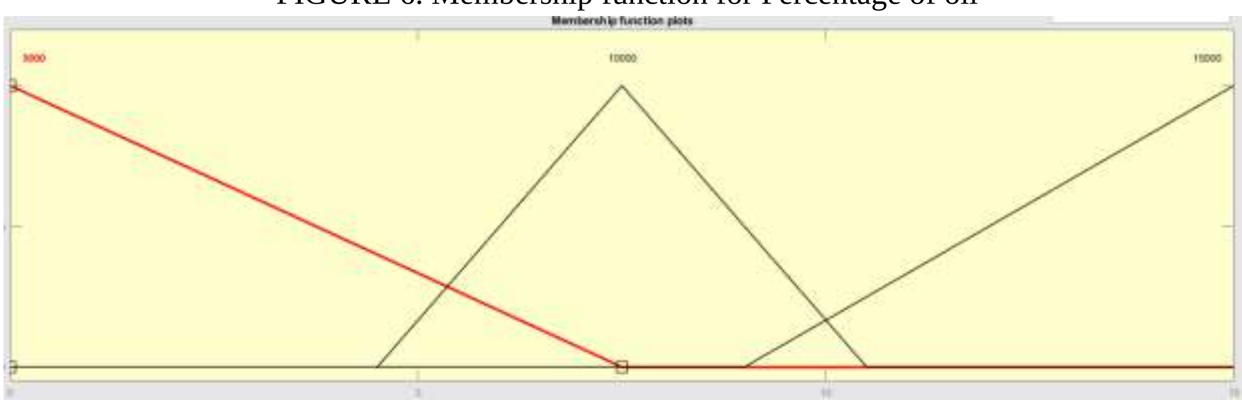

FIGURE 7. Membership function for Speed of stirrer

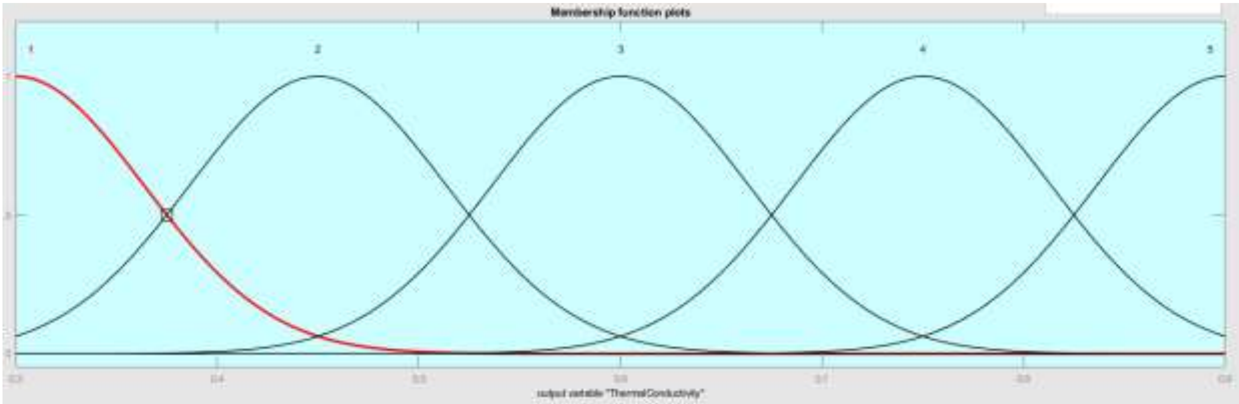

FIGURE 8. Membership function for Thermal Conductivity

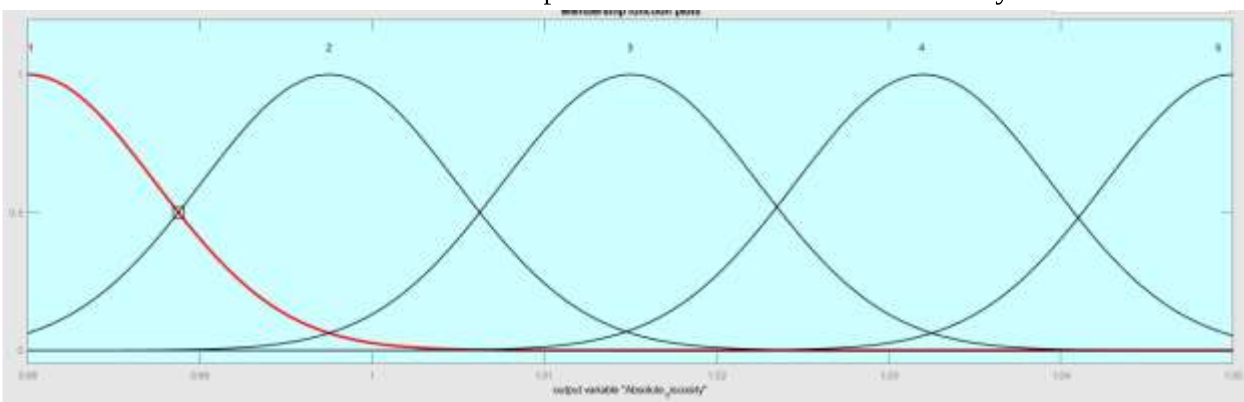

FIGURE 9. Membership function for Absolute viscosity

The relation of input and output linguistics variables using fuzzy rule based system visualized in surface viewer was shown in figure 10.

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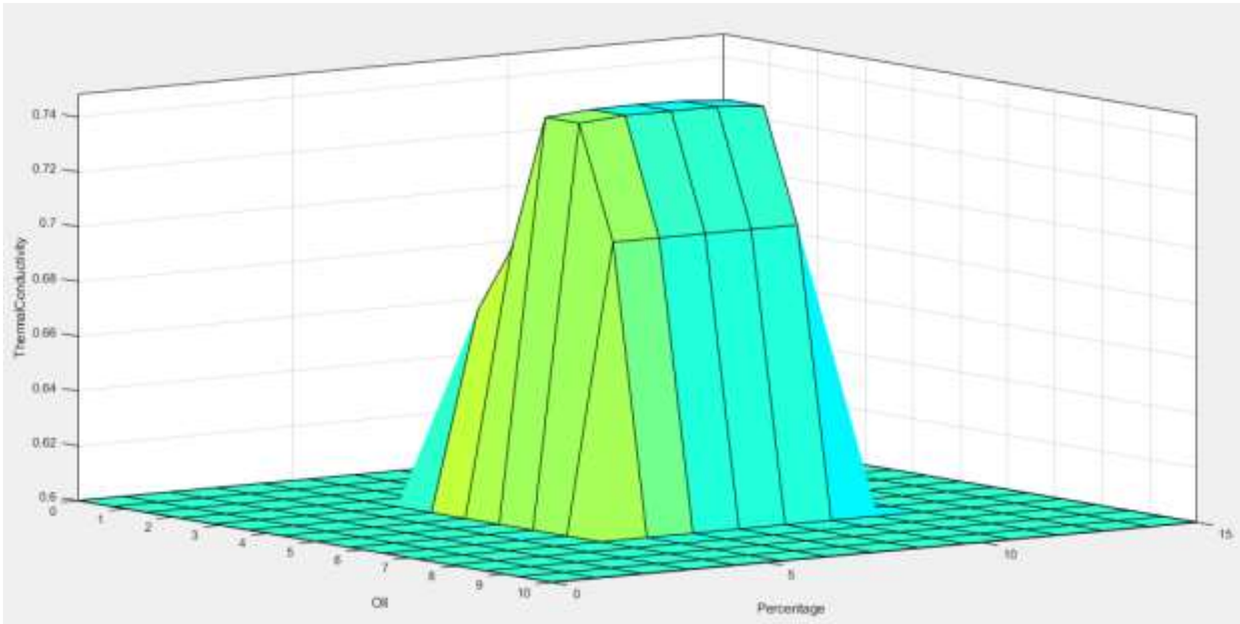

FIGURE 10. surface viewer

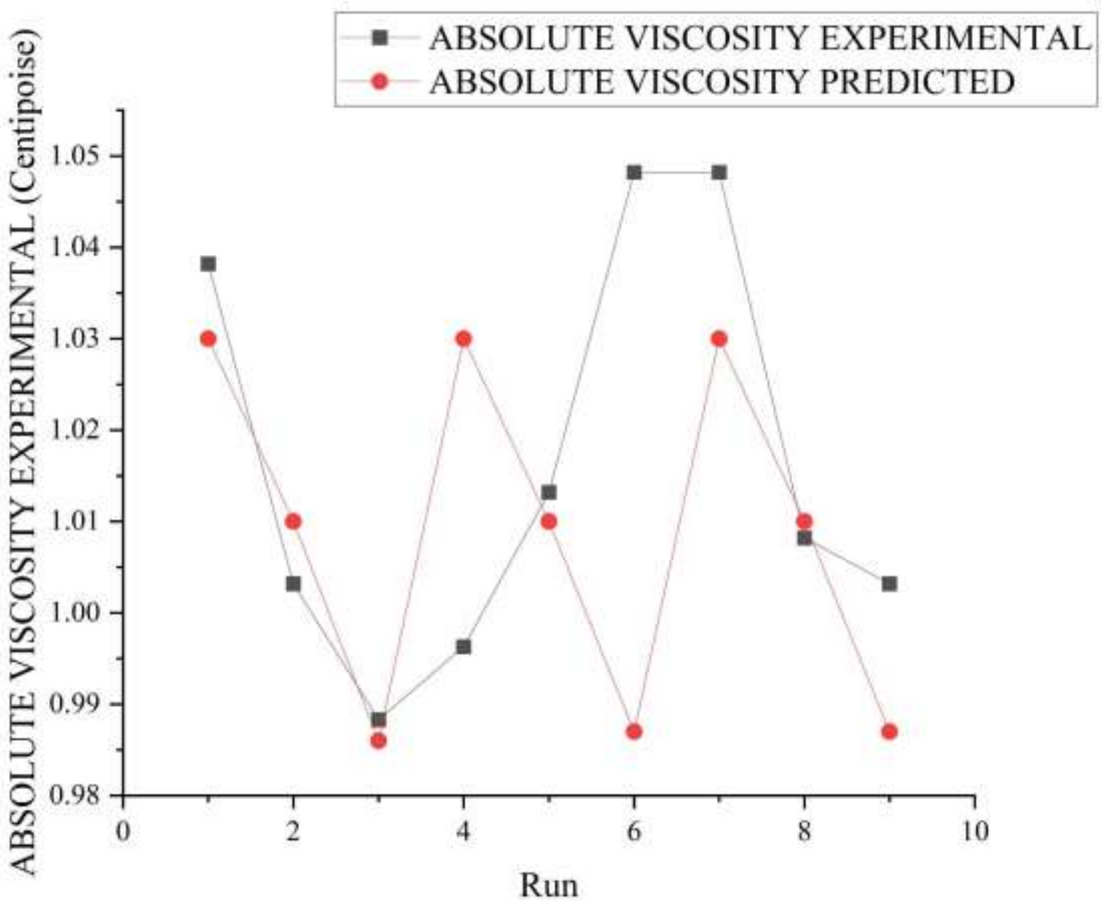

FIGURE 11. Comparison of Absolute Viscosity Experimental vs predicted

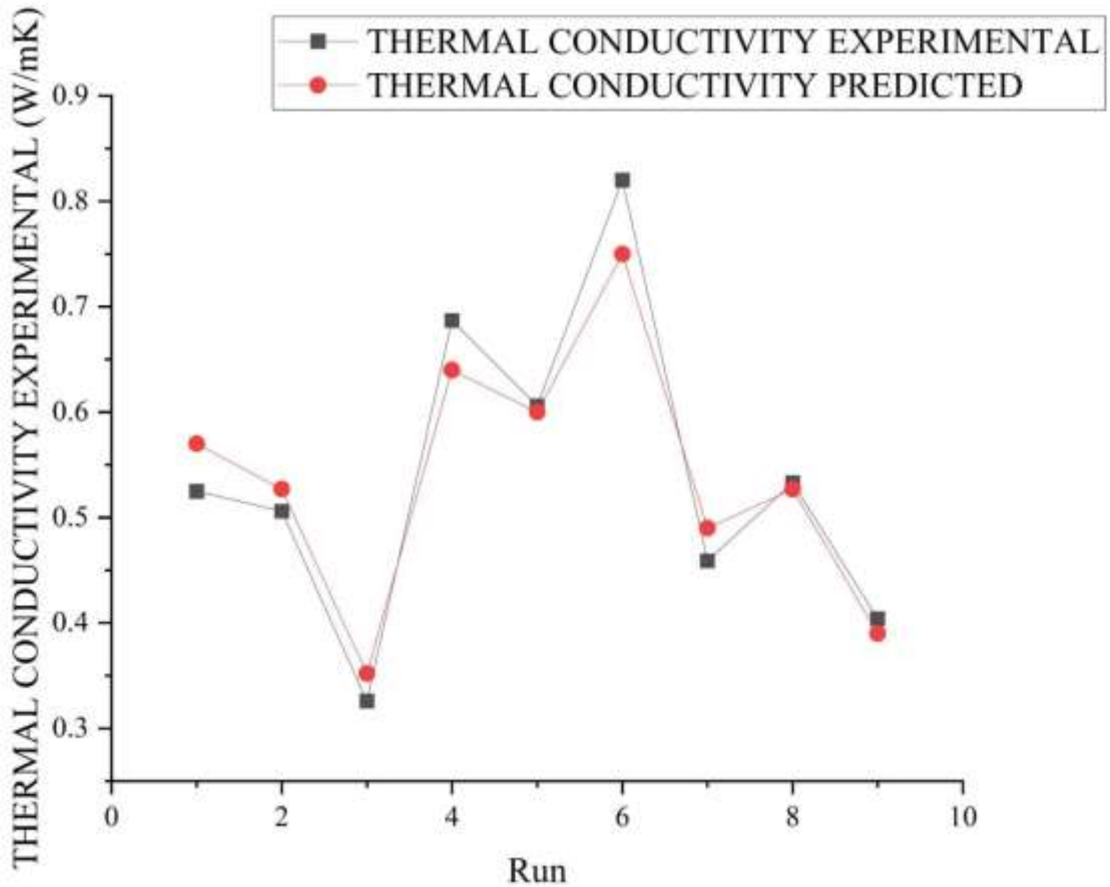

FIGURE 12. Comparison of Thermal conductivity Experimental vs predicted

The maximum error in the Thermal Conductivity is 0.07 and the minimum error in the Thermal conductivity is 0.006. The maximum error in the Absolute Viscosity is 0.0612 and the minimum error in the Absolute Viscosity is 0.0018. The average percentage of Thermal Conductivity is 5.378886. The average percentage of Absolute Viscosity is 1.640776. Thermal Conductivity is shown in Figure 11 and Absolute Viscosity is shown in Figure 12.The R^2 of Thermal conductivity is 0.960316 and the R^2 of Absolute Viscosity is 0.072181. The developed fuzzy logic model was evaluated on its predictive performance for Thermal Conductivity and Absolute Viscosity separately. The accuracy was quantified using the coefficient of determination (R^2) between actual and predicted values for each parameter. For Thermal Conductivity, the fuzzy model achieved a high R^2 value of 0.960316. In contrast, the R^2 for predicting Absolute Viscosity was markedly low at 0.072181. The fuzzy model demonstrates exceptional predictive capability for Thermal Conductivity with over 96% explained variance in actual values. This signifies that the model provides a very good fit for estimating Thermal Conductivity based on the given inputs and fuzzy rule base. The minimal unexplained variation of ~4% indicates reliable generalization performance. However, for Absolute Viscosity, the low

R^2 of 0.072181 reveals inadequate fitting by the current fuzzy model. It accounts for only around 7% of the variances in true Absolute Viscosity. The high unexplained variance of 93% highlights significant gaps in fully correlating the defined fuzzy rules and inputs to changes in the viscosity parameter.For Thermal Conductivity predictions, a MSE of 0.002025 was achieved. In contrast, Absolute Viscosity predictions resulted in a lower MSE of 6.724E-05. The higher MSE in Thermal Conductivity highlights greater average variability between true versus estimated values. Since MSE calculates the squared differences averaged, more scattering around the identity line lowers precision. However, in the scale of typical conductivity measurements, the MSE is adequately minimized below 0.01.Meanwhile, for viscosity, the extremely small MSE value in the 10^-5 range proves the fuzzy model's capability for very precise alignments between predicted and reference viscosities. With tiny squared errors despite fluid viscosity intricacies, the fuzzy logic approach shows promising accuracy improvements possible by tuning input membership functions.The higher Thermal Conductivity RMSE shows greater residual deviations between real and estimated conductivities after fuzzy inference. Since RMSE amplifies larger errors in its squaring effect, variability, and outliers translate to an RMSE of 0.045 - indicating scope for accuracy improvements. However, for practical interpretations of conductivities, this RMSE range would still retain acceptable tolerance levels.In comparison, the extremely small RMSE of 0.0082 for predicted Absolute Viscosities points to very minimal average deviations from precise values. By keeping residuals below 0.01 through sufficient fuzzy approximations of viscosity intricate phenomena, the model has shown reliability. Further expansion of knowledge-based fuzzy rules can aid in refining this precision level over various viscosity ranges

5. CONCLUSION

The fuzzy logic model demonstrated exceptional predictive capability for thermal conductivity, with an R^2 of 0.960 and low MSE and RMSE below 0.005. This signifies over 96% explained variance against testing data, proving reliable generalization. However, for absolute viscosity, an inadequate R^2 of 0.072 reveals a poor correlation between defined fuzzy rules and viscosity changes. While very low MSE and RMSE below 0.01 indicate precise alignments between predicted and actual viscosities, the high 93% unexplained variance highlights significant gaps in relating inputs to viscosity outputs through fuzzy logic. Expansion of fuzzy rules could further refine predictions across viscosity ranges. Overall, the fuzzy model shows reliable accuracy for thermal conductivity but requires tuning to better adapt to absolute viscosity estimation.

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