Investigation of the Dielectric Behaviour of Propylene Glycol (100) Dispersed With Graphene Nano Powder to Determine the Optimal Conditions Using Response Surface Methodology

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Abstract

Response surface methodology (RSM) was used to study the dielectric behavior of a Propylene Glycol-Graphene Nanopowder nanofluid. This study used 3-11 mm distance and 2.77-3.13 kV breakdown voltage. The goal is to find the best prediction model and solution. The lack of consistency between laboratory behavior and real-world applications and the statistical-mathematical investigation of modelers' performance, contrast, and motives prompted this study. Two models are tested: linear and 2FI. Investigating and evaluating these modeling functions' statistical properties is new to the area. The 2FI model depicts nanofluids twice as accurately as other models, according to statistical analysis. Model evaluation indicators include R2, C.V%, and P-value. In order, the 2FI model indices are 0.9818, 8.74 %, and 0.0001. Nanofluids should have 1256.877 electrical conductivity at 11 mm and 2.77 kV breakdown voltage.

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1. Introduction

The enhanced thermal conductivity of nanofluids indicates that they may find widespread usage as heat transfer fluids. Nanofluids have drawn attention not just for their thermal qualities, but also for their electrical ones. When considering the potential applications of nanofluids in fields as varied as electronics, energy generation, and thermal management, their dielectric properties and electrical conductivity must be considered. [1][2].

There has been a lot of study on nanofluids prepared using propylene glycol and water. Because of its low toxicity and high thermal stability, propylene glycol (PG) is often employed as a coolant as well as heat transfer medium [3][4]. Upon being mixed with water, it creates a robust fundamental liquid that is extensively used in several sectors. While solutions of propylene glycol and water have beneficial thermal properties already, adding nanoparticles to them may improve their electrical properties [4].

The propylene glycol- graphene based nanofluid's electrical characteristics are impacted by many crucial aspects[5]. Nanoparticles dispersed throughout the base fluid are of particular interest, especially their kind and concentration. Copper and silver nanoparticles, alumina and titania nanoparticles, and carbon nanotubes as well as graphene are only a few of the most common types of nanoparticles employed today. The nanoparticles may alter the nanofluid's dielectric properties and electrical conductivity [6].

Important also are the nanoparticle's size and distribution in the propylene glycol- graphene+MWCNT mixture[7]. Due to increased interactions among particles and a greater area of contact with the fluid medium, the electrical conductivity of smaller, more uniformly dispersed nanoparticles is enhanced. Stability of the nanofluid, defined as freedom from particle aggregation and sedimentation, is crucial for preserving the nanofluid's electrical properties [8].

The temperature has a significant influence on overall electrical conductivity of nanofluids composed of propylene glycol and graphene. Changes in the dielectric constant and the interactions amongst particles as well as nanofluids [9] are two ways in which temperature variations might be affecting the electrical conductivity.

Propylene glycol- graphene nanofluids may be used for a wide variety of purposes, but their effectiveness can be improved by learning more about their electrical properties [10]. For instance, by using nanofluids with improved electrical conductivity, the frequency and severity of spikes in electronic cooling may be mitigated. Nanofluids with modified dielectric characteristics may be used as coolants for transformers as well as other high-voltage devices in power production facilities [11].

The electrical conductivity as well as dielectric characteristics of these nanofluids may be tailored by adjusting factors such nanoparticle type, concentration, dispersion, along with temperature [12]. Propylene glycol-water nanofluids' potential in electronic and electrical systems may be further exploited with more research and a deeper understanding of the underlying concepts [13].

2. Materials and Methodology

The International Union of Pure and Applied Chemistry (IUPAC) describes propylene glycol as a colorless, odorless, tasteless, as well as viscous liquid. Propylene glycol is the name given to the chemical compound that is propane-1,2-diol. The compound can be represented by the chemical formula CH3CH(OH) CH2OH. A diol is a type of compound that is distinguished from other types of alcohol by the presence of two separate alcoholic functional groups. It is possible to dissolve it in a variety of various solvents, including as water, acetone, and chloroform, among others. Glycols, in their natural state, are not irritant to the skin and have a low volatility. Propylene glycol is used for a variety of purposes, such as in the manufacturing of polymers and in food and beverages. It is also used in a number of other applications [14].

Carbon atoms in a two-dimensional honeycomb crystal lattice form graphene and other carbon nanostructures. Graphite's many double bonds were symbolized by adding "-ene" to the term "graphite". In a graphene sheet, each atom shares an electron amongst the three neighbors, creating a tight bond between all the atoms. This is the pathway that connects glassy carbon, PAHs, fullerenes, as well as carbon nanotubes. Graphene's close conduction as well as valence bands give it exceptional electrical characteristics, making it a semimetal. Theories using quantum particles without mass may account for these features. These concepts explain graphene's uniqueness. Because their energy varies linearly on charge carrier motion rather than quadratically, graphene field-effect transistors conduct bipolarly. Massive quantum oscillations, nonlinear diamagnetism, and long-distance ballistic charge transfer are seen. The graphene plane has amazing thermal and electrical conductivity. The black hue of graphite comes from its strong visible light absorption. Graphene is so light that a sheet is almost transparent. About 100 times stronger than the toughest steel, this composition. Graphene is widely used as a nanomaterial due to its exceptional qualities like the world's strongest, most conductive, most opaque, etc.

Graphene is the most robust and thinnest material in the world, existing in two dimensions. In 2012, the main demand for graphene came from the research as well as development sectors of businesses such as semiconductors, electronics, electric batteries, and composites. The demand played a crucial part in driving the expansion of the worldwide graphene market, which achieved a valuation of $9 million. The acquisition of graphene nano powder was done through Ultrananotech Pvt. Ltd. Graphene has a thickness of about 5-10 nanometers and is 99.9% pure. The main aim of this study is to examine the electrical conductivity of nanofluids made from propylene glycol as well as graphene nano powder and choose the optimal solution using RSM.

2.1. Electrical Conductivity (EC)

The electrical conductivity of a substance quantifies its ability to conduct electricity. The phenomenon is related to the velocity at which electrons, the particles carrying electric charge, may travel inside a substance. Metals, which are known for their superior electrical conductivity, have a high number of free electrons that are able to move around without restriction in response to an external voltage being applied [15]. As they are unbound to particular atoms, these "free electrons" possess the freedom to move unrestrictedly, facilitating their ability to conduct an electric current.

Insulating materials have low electrical conductivity due to their limited number of free electrons and lack of conductivity. This phenomenon occurs due to the electrons being tightly bound to the atoms and having restricted movement inside these materials [16].

Several factors impact the electrical conductivity of a substance. The temperature has a vital influence. Generally, the electrical conductivity of a substance diminishes as its temperature increases. This process takes place as a result of the increased heating of atoms that takes place at higher temperatures; as a result, the mobility of free electrons within a material is impeded [17].

Another element that may affect electrical conductivity is the impurities or faults in the material. They could cause problems for electrons that are free, lowering the material's electrical conductivity [18]. Electrical conductivity is a common criterion for assessing a material's quality, and it is often expressed as a measurement either siemens per meter (S/m) or ohms per meter. Low resistance is shown by highly conductive materials, whereas high resistance is exhibited by poorly conductive materials [19].

The electrical conductivity of a substance is crucial in several fields, including electronics, materials science, as well as electrical engineering. Materials with the optimal equilibrium between electrical conductivity and resistance are essential, for instance, when constructing electronic circuits [20] to get the appropriate performance characteristics. In the field of materials science, understanding the electrical conductivity of different materials may be helpful in creating new materials with certain characteristics.

3. Experimental Setup

Figure 1. Dielectric strength measuring apparatus

3.1. Experimental Procedure

1. This experiment entails applying a steadily increasing alternating current (AC) voltage at a frequency of 40-60 Hz to the electrodes. The voltage will grow at a steady rate of 2 kilovolts per second, starting from zero and continuing until it

reaches the point of breakdown, as seen in figure 1. The test is to be conducted six times in total, using the same cell for each iteration.

2. Right away as it is technically possible, the initial voltage is supplied once the cell gets completely loaded. Assuming there are no lingering air bubbles as well as oil in the cell, you'll need to perform this within a ten-minute period after the cell's first filling to account for any potential mistakes.
3. A clean, dry glass is used to gently swirl the oil between the electrodes before the following flue tests, after which the voltage is recorded. This is done to prevent the creation of air bubbles.

4. RSM

Empirical models are developed using the statistical and mathematical techniques of response surface methodology (RSM). In RSM designs, the response variable is the focus, since it is influenced by a small subset of other factors. The effectiveness of several models was evaluated using the Response Surface Methodology (RSM) in this research. To get the highest possible viscosity, the best possible model is chosen and analyzed.

4.1. Comparison of various models

This section evaluates several models based on quality metrics and chooses the most optimum model.

4.1.1. Analysis of R^2 correlation

Table 1. Assessment criteria for various models

Model/Values	R^2	Adjusted R^2	p-value	CV%
Linear	0.9756	0.9634	<0.0001	8.76
2FI	0.9818	0.9637	<0.0001	8.74

The value of the coefficient R2 might be anything from 0 to 1. A value of 1 indicates that the input variables have a large impact on the output variable, where as a value of 0 indicates that the parameters have no effect on the system. Table 2 and Figure 1 show that the quartic model provides the most precise illustration of the nanofluid's dielectric behaviour.

4.1.2. Probability value evaluation index

It is possible to verify the reliability of statistical results by using the P-value index. P values may be used to quantify the impact of various system parameters on behaviour. When this index is little, the model's predictive power is high. The P-value for the 2FI model is the smallest of all the models shown in Table 1. That's why it's the prototype of choice.

4.1.3. Evaluation of the coefficient of variation (C.V)

Measuring C.V. is also a significant indication of the model's efficacy in terms of the quality of the items it produces. The level of inaccuracy as well as random error of an experiment may be estimated by first doing a reproducibility analysis, which is one of the first stages in the control phase of a laboratory procedure.

It is important for laboratories to keep an eye on their repeatability over time to make sure that their influencing variables, randomness, and suitable dispersion of measurement findings are all accurate and adequate. Just run the experiment again and you'll get the data you need. 2FI model has higher dependability and reproducibility than other models, as shown by the numbers in Table 1 and the comparison in Fig. 2 and Fig 3.

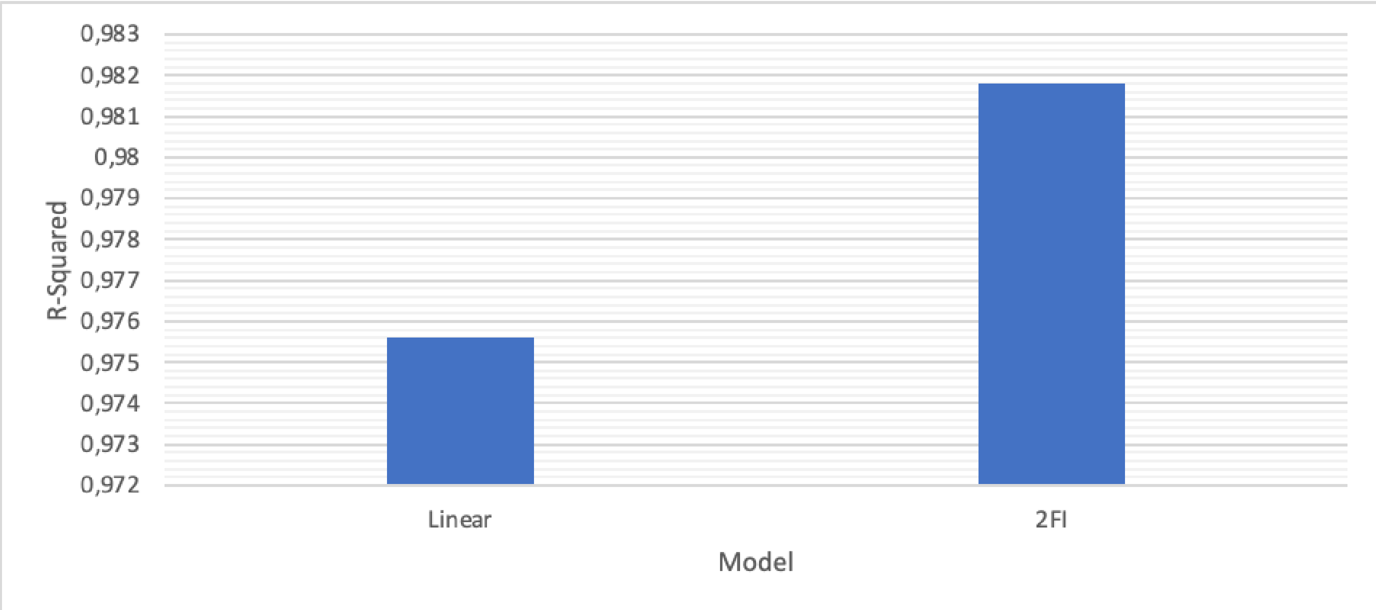


Figure 2. Coefficient of determination values for various models.

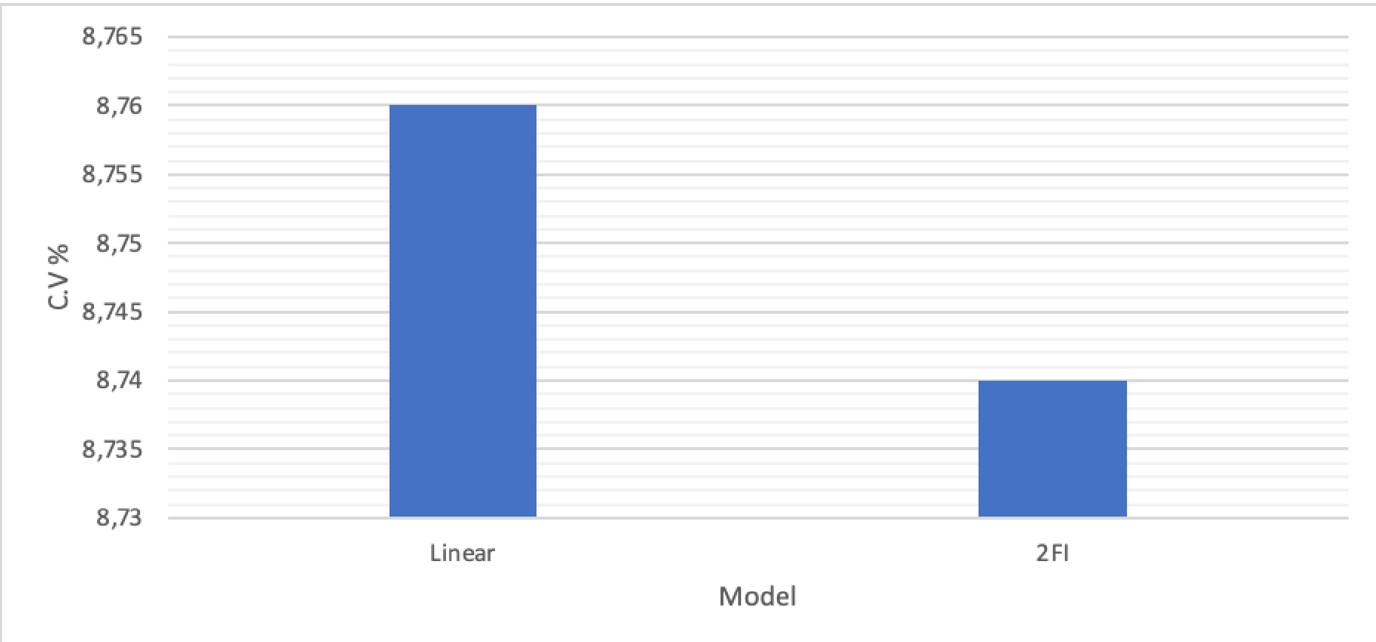


Figure 3. Diagram displaying the confidence coefficient (CV%) for several models.

4.1.4. Model quality determination charts.

When comparing theoretical predictions with empirical findings, the correlation error index is a useful metric. Figure 5 shows the index associated with each of the four different models. Comparison of the data to a straight bisector line is shown in Figure 4. Higher data variation in a non-linear model is indicative of less accuracy, whereas larger data dispersion on the half line is indicative of better accuracy. Figure 4 (a-b) shows the experimental data along the x-axis and the modelled predictions along the y-axis. Figure 4b shows that when compared to competing models, the 2FI model provides the most reliable results.

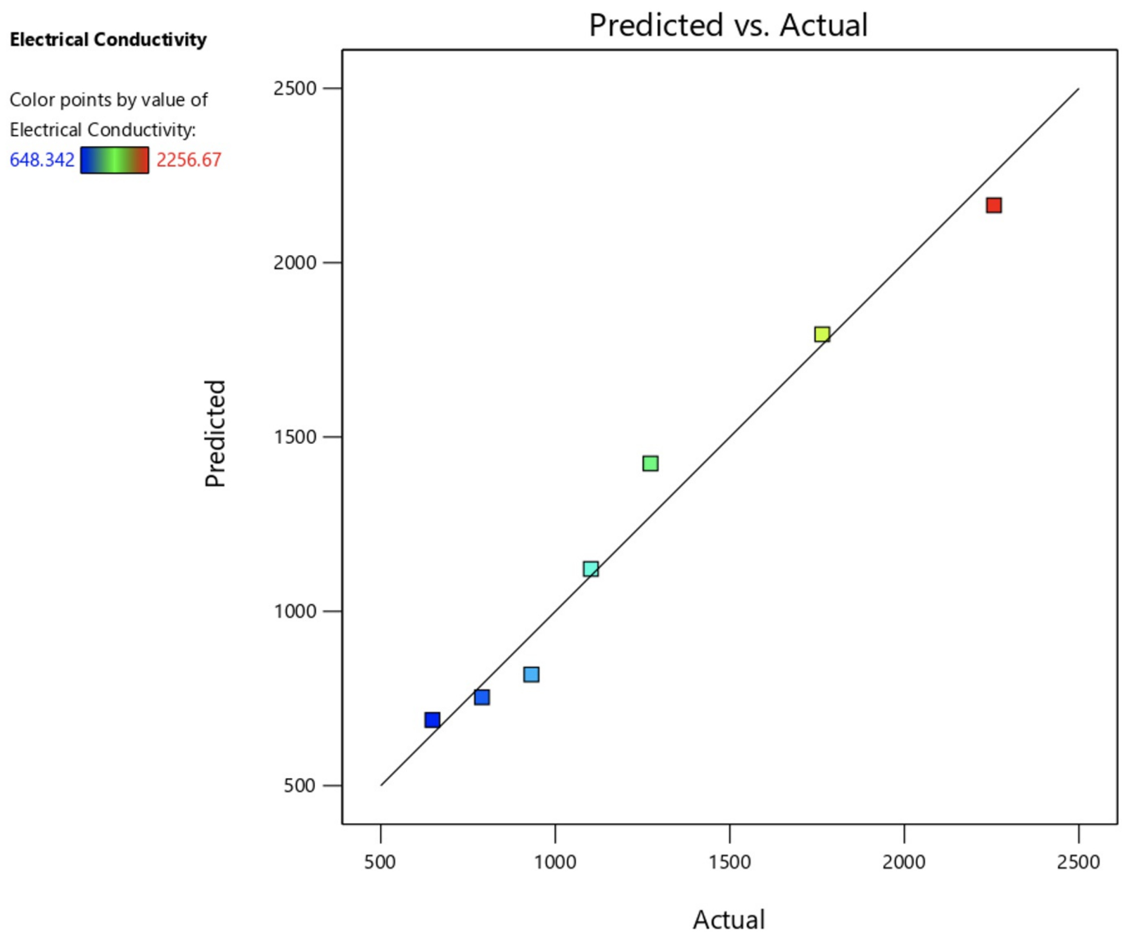


Figure 4a. Correlation between predicted data and actual data for linear model

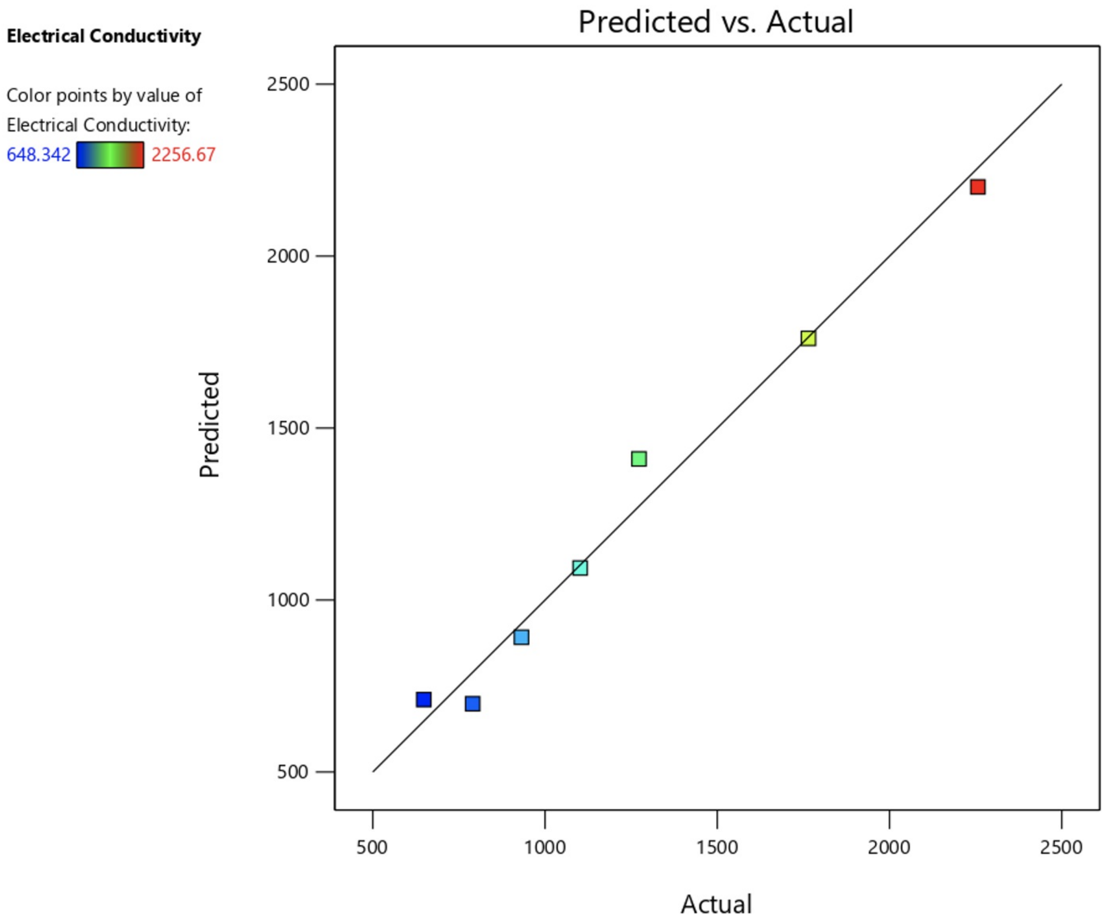


Figure 4b. Correlation between predicted data and actual data for 2FI model

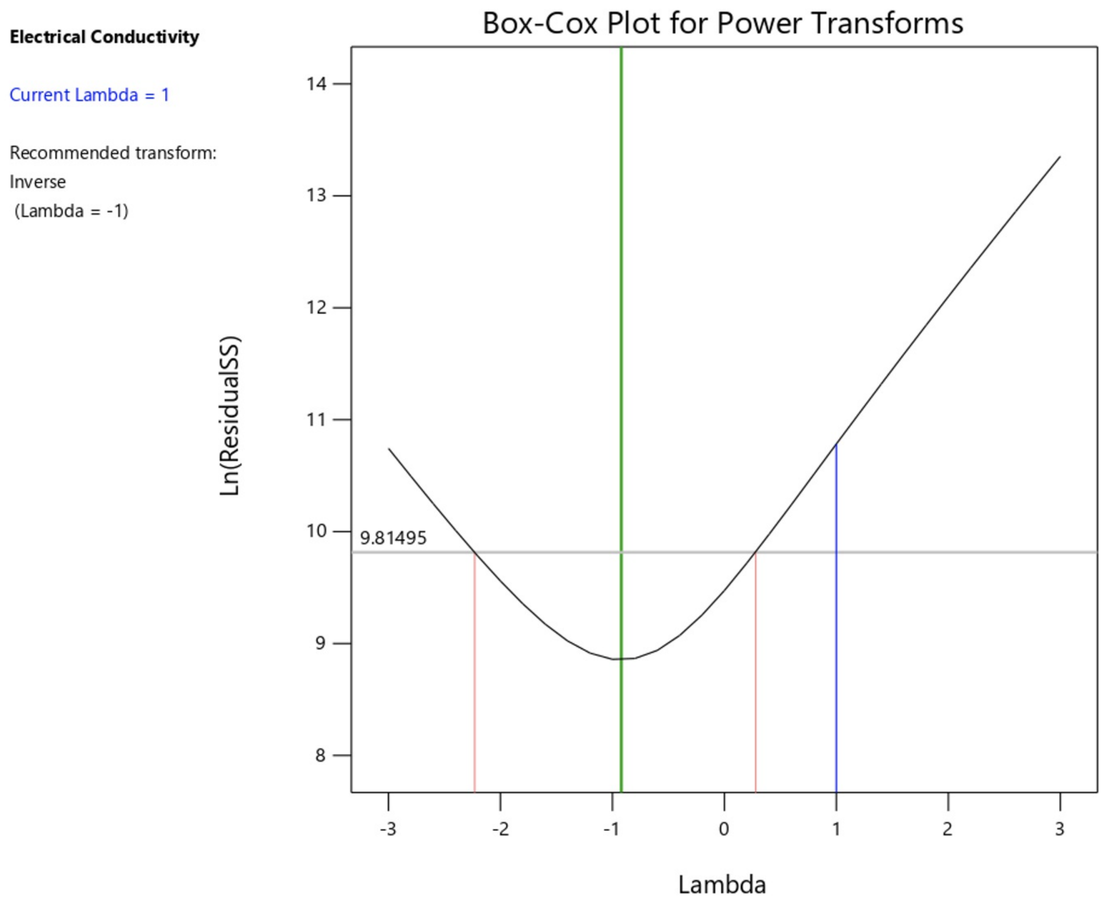


Figure 5a. Box-Cox diagrams presented for linear model

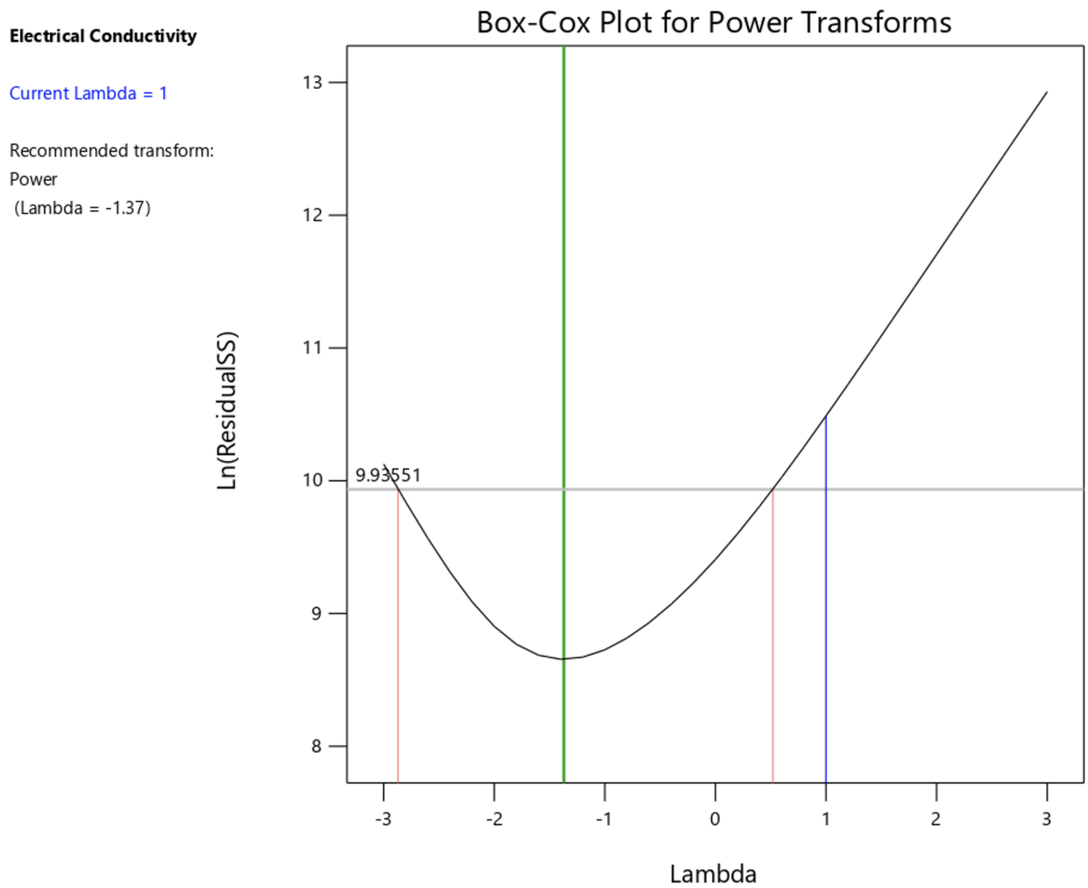


Figure 5b. Box-Cox diagrams presented for 2FI model

The Box-Cox figure, shown in Figure 5 (a-b), is used to calculate all models' Lambda parameters. A suggestion for calculating a transfer function is provided by the Box-Cox plot. Based on the recommended lambda value, a transfer function is proposed. The 2FI model exhibits favourable performance in comparison to other models, as depicted in Fig. 5b.

4.2. Selecting the optimal model

The 2FI model was shown to be the most accurate after comparing many validation indices. Tables 2 and 3 provide all the data from the ANOVA run on the 2FI model. Table 3 demonstrates that among the several independent variables including their interaction effects, the temperature parameter has the greatest impact. The statistical plots in Figure 5 indicate how reliable the selected model is.

4.3. The process of electrical conductivity changes in the chosen model

Experimental data and modeling carried out using DOE software and assessments were used to determine the electrical parameters of the Propylene Glycol/Graphene nanofluid. The 2FI theory proved out in the tests. The electrical conductivity of nanofluid can be determined at many locations using the chosen model. Figure 6 (a-d) and Figure 7 (a-b) illustrates variations in electrical conductivity based on distance and breakdown voltage factors. It is evident that increasing the distance leads to a reduction in electrical conductivity.

4.4. Optimum Electrical Conductivity

Table 4 displays the most efficient responses under various test settings, where distance of 11 mm and breakdown voltage of 2.770 kV are identified as value of the ideal electrical conductivity as 1256.877.

Table 2. ANOVA of the selected model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.940E+06	3	6.466E+05	54.03	0.0041	significant
A-Distance	153.85	1	153.85	0.0129	0.9169	
B-Break Down Voltage	1809.16	1	1809.16	0.1512	0.7234	
AB	12289.85	1	12289.85	1.03	0.3855	
Residual	35899.09	3	11966.36			
Cor Total	1.976E+06	6				

Table 3. Parameter values of the chosen model that have a significant impact.

Std. Dev.	109.39		**R^2**	0.9818
Mean	1252.31		**Adjusted R^2**	0.9637
C.V. %	8.74		**Predicted R^2**	0.8104
			Adeq Precision	18.1744

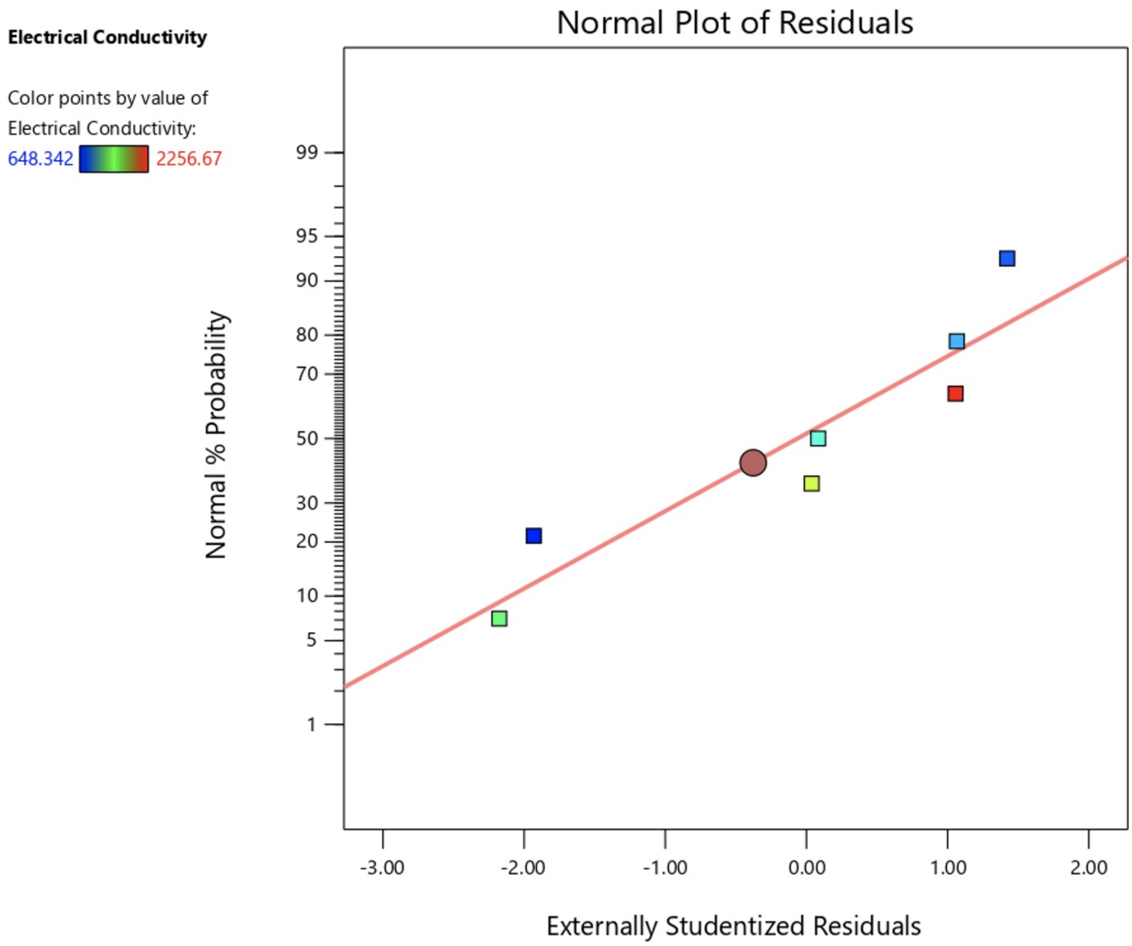


Figure 6a. Normal plot of Residuals for 2FI model

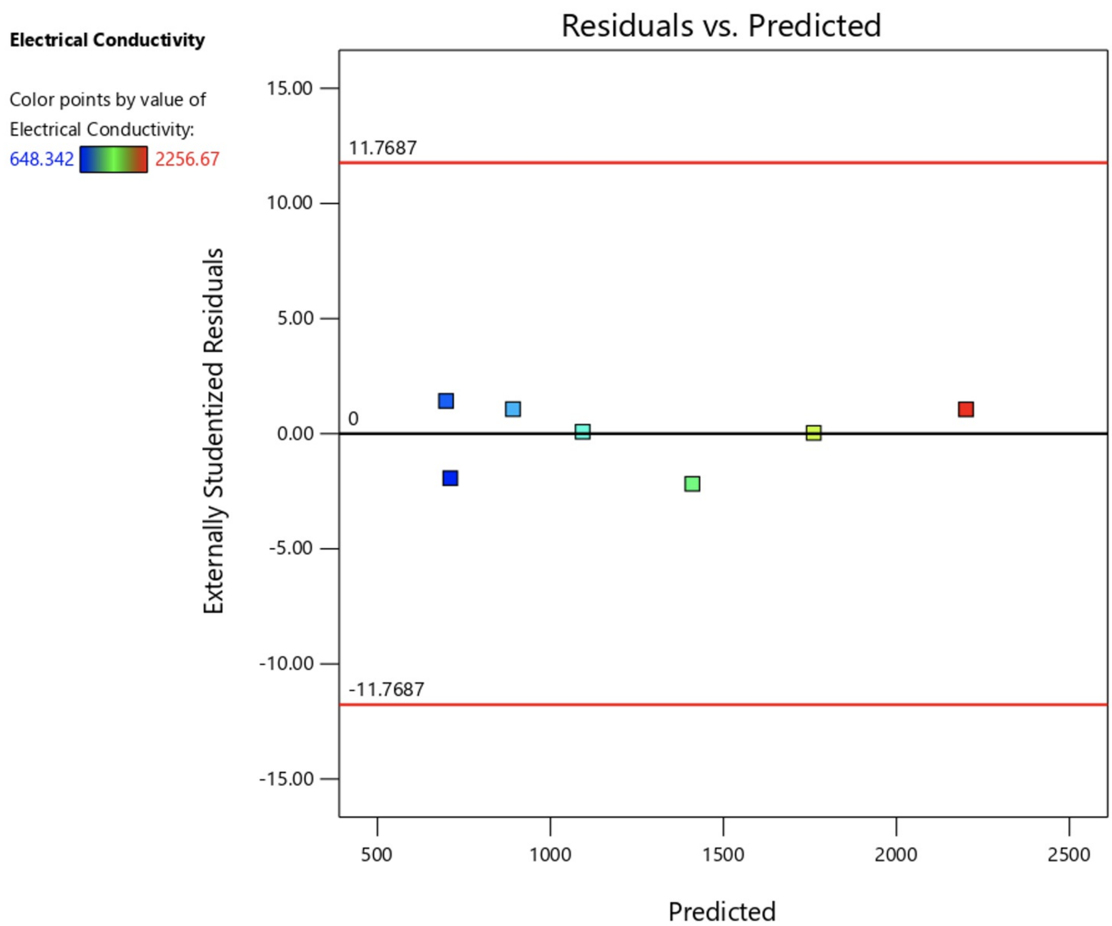


Figure 6b. Residuals vs Predicted plot for 2FI model

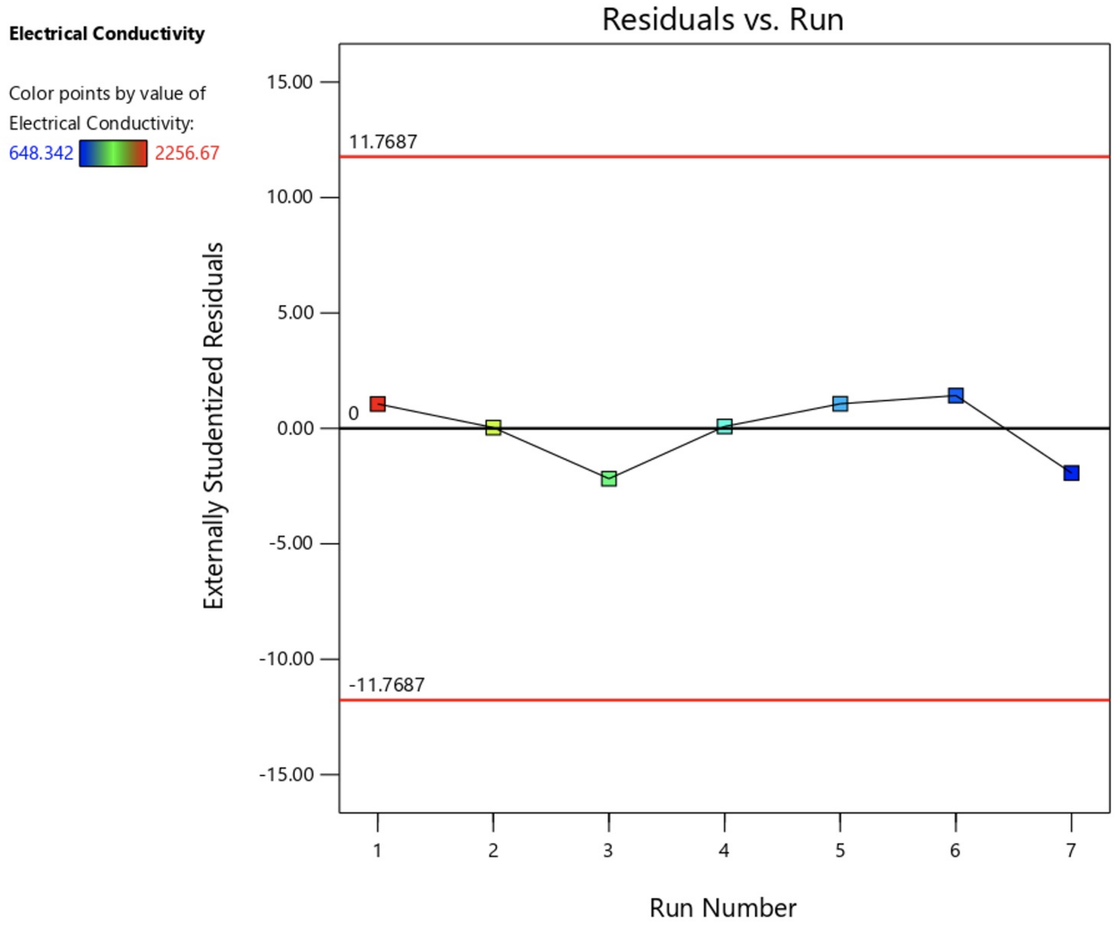


Figure 6c. Residual vs Run plot for 2FI model

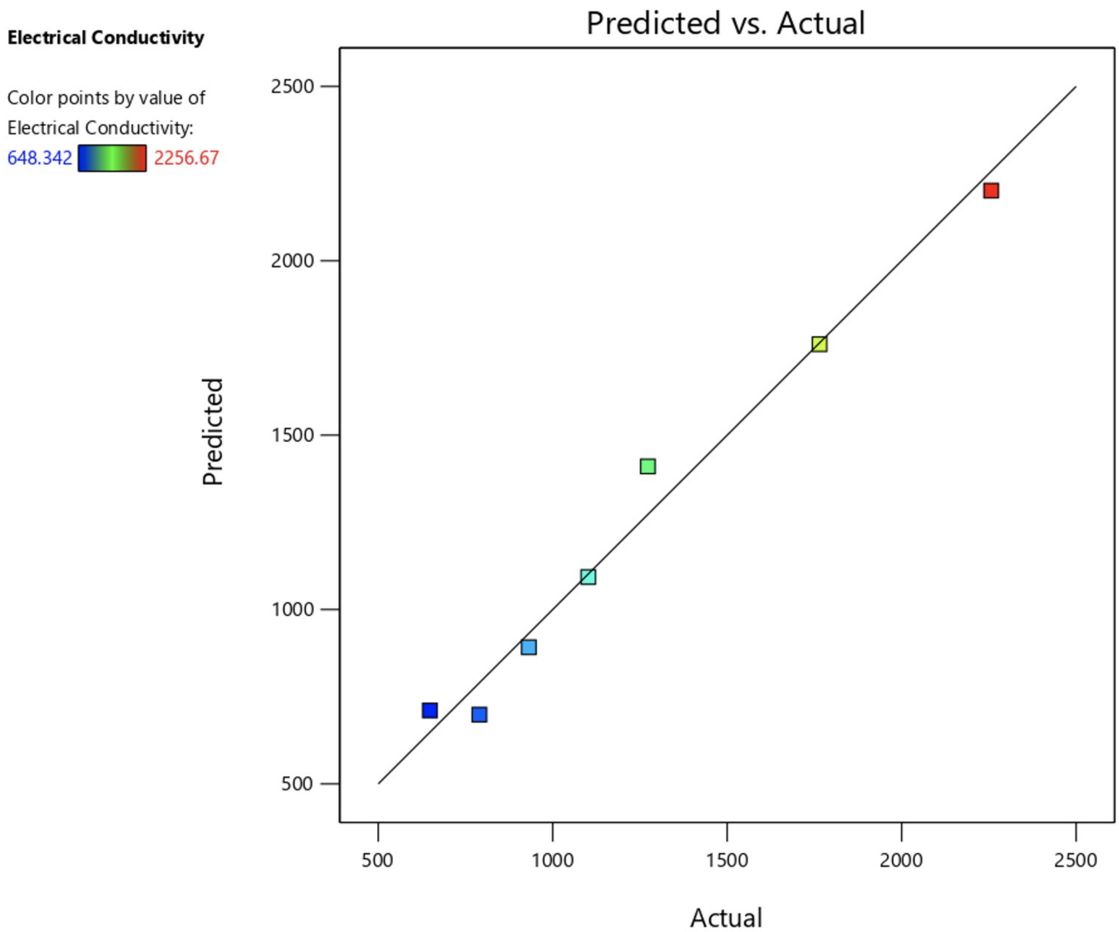


Figure 6d. Predicted vs Actual plot for 2FI model

Table 4. Optimum solution for electrical conductivity

Number	Distance	Break Down Voltage	Electrical Conductivity	Desirability	
1	**11.000**	**2.770**	**1256.877**	**1.000**	**Selected**
2	11.000	2.774	1253.741	0.994	
3	10.828	2.770	1203.820	0.989	
4	10.659	2.770	1151.561	0.978	
5	10.575	2.770	1125.696	0.973	
6	11.000	2.790	1241.196	0.972	
7	10.501	2.770	1102.895	0.968	
8	10.317	2.770	1046.068	0.956	
9	10.136	2.770	990.061	0.944	

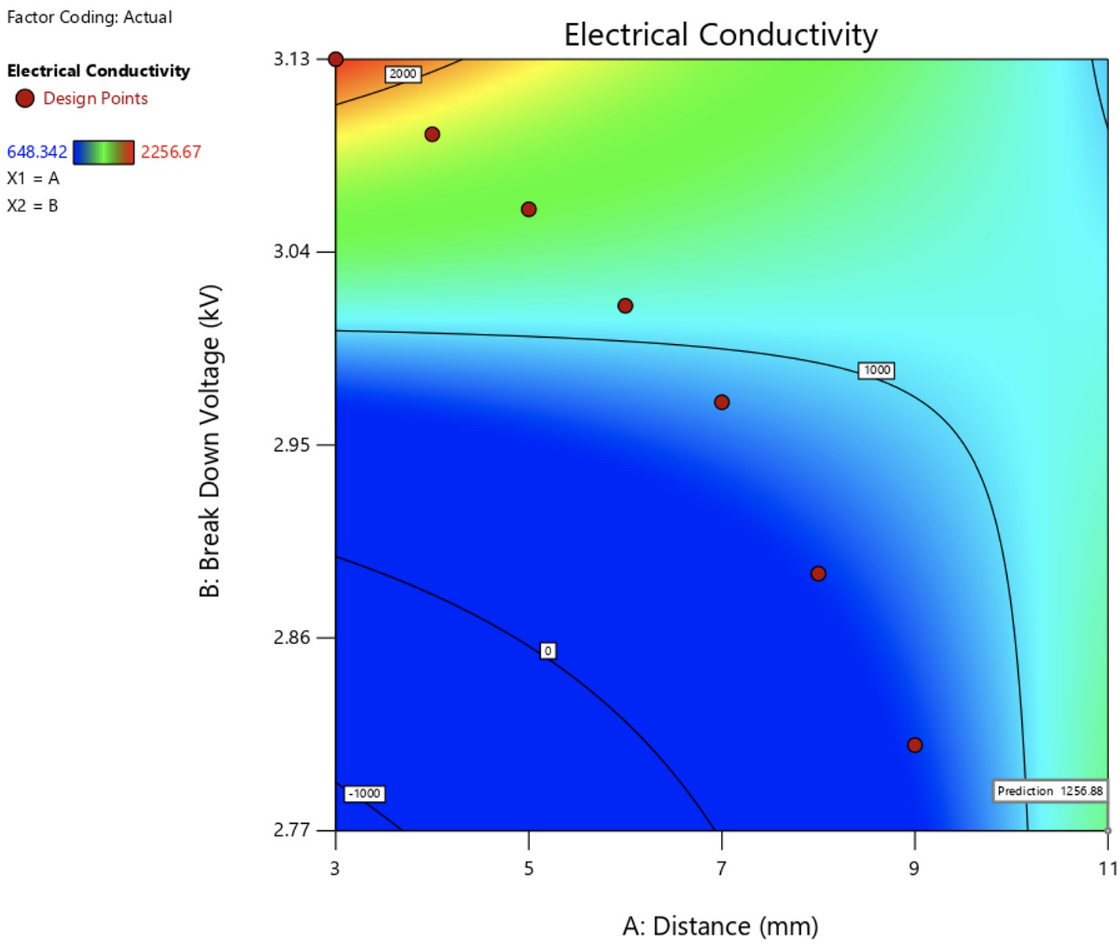


Figure 7a. The chosen model's electrical conductivity contour based on its breakdown voltage and distance factors.

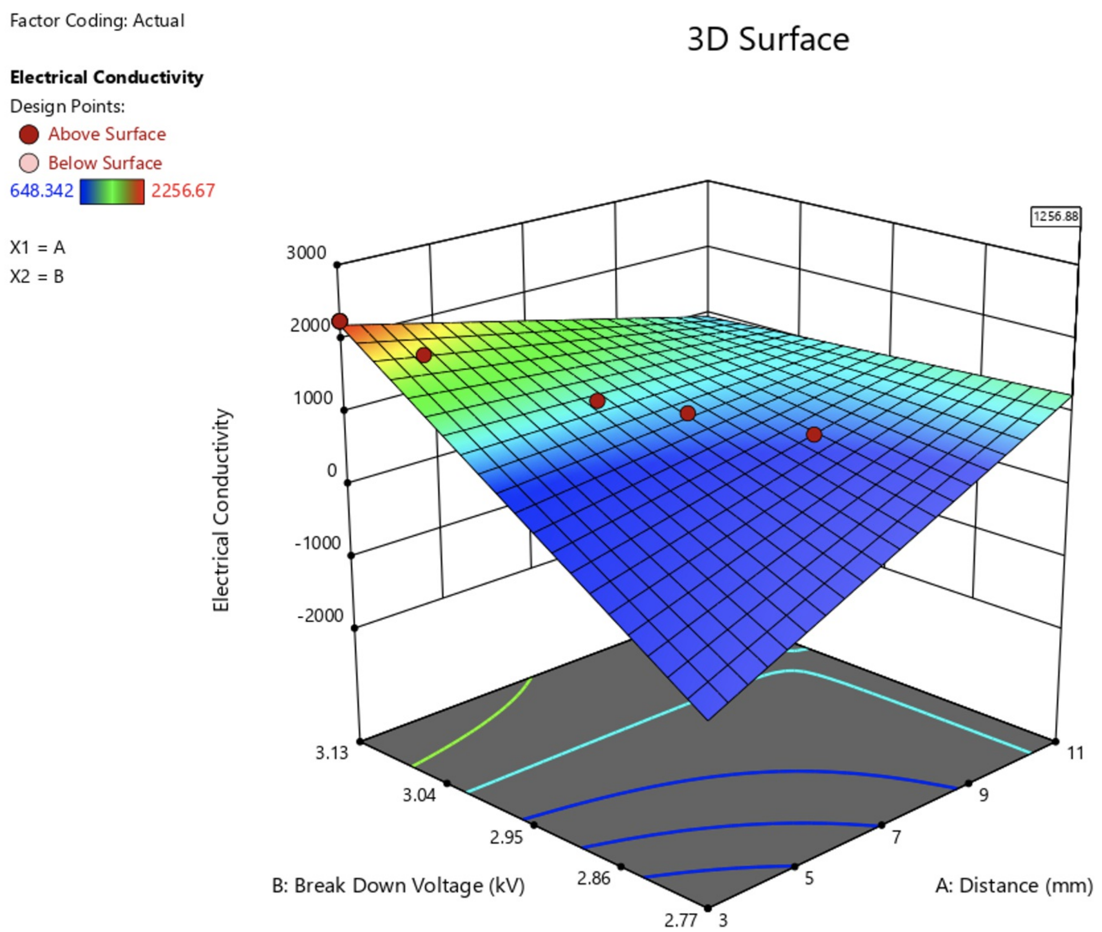
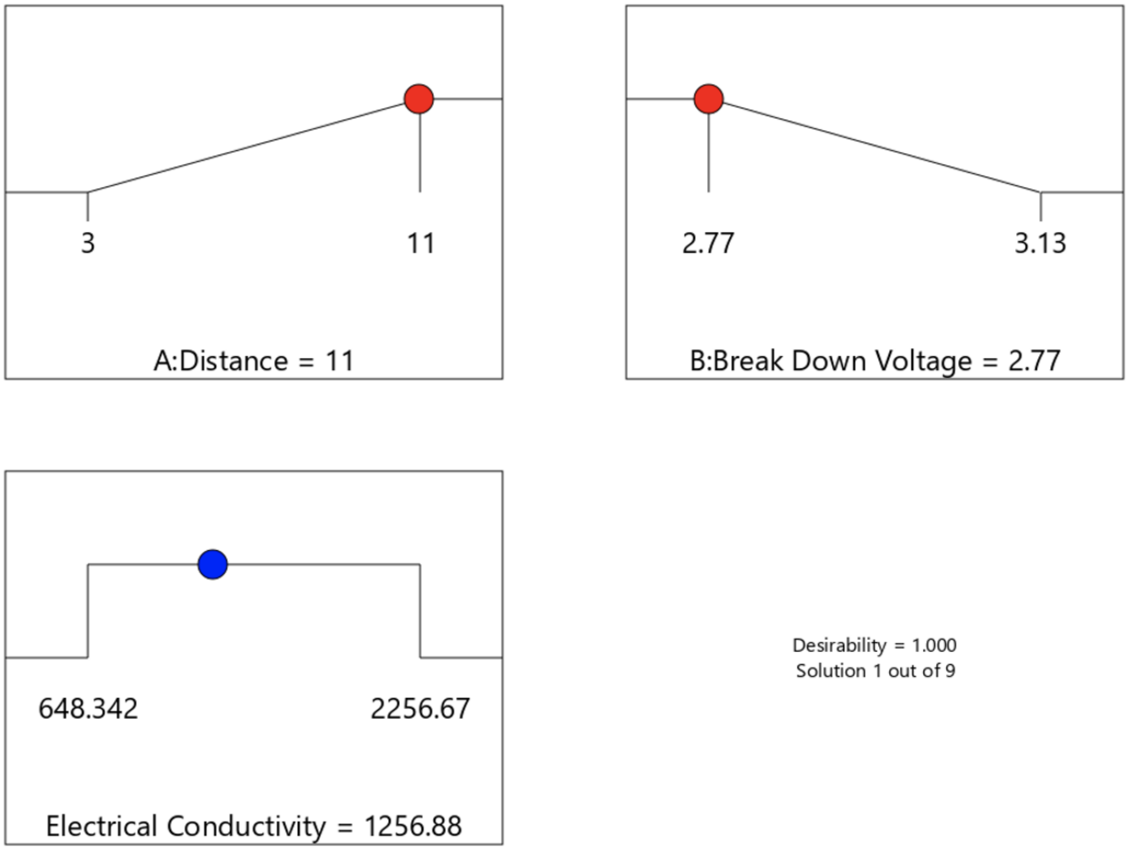


Figure 7b. The chosen model's electrical conductivity based on its breakdown voltage and distance factors.


3
11
A:Distance = 11
2.77
3.13
B:Break Down Voltage = 2.77
648.342
2256.67
Electrical Conductivity = 1256.88
Desirability = 1.000
Solution 1 out of 9

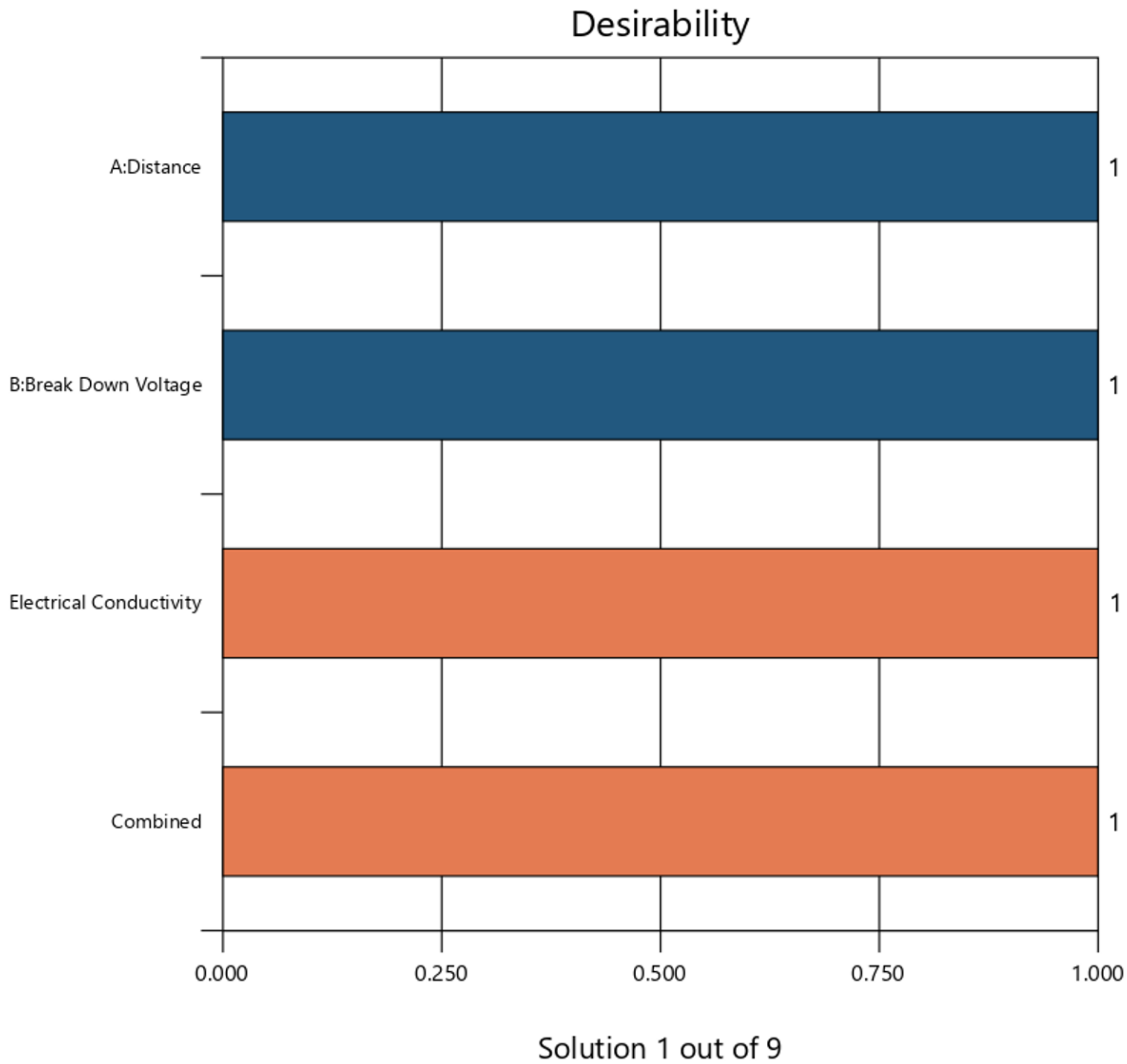


Figure 8. The optimal value for both the input as well as response parameters

Figure 8 displays the parameters with ideal values examined in current research and the desirability level for each of these characteristics, as well as the total satisfaction percentage. The satisfaction rating for the proposed offer is approximately 100%. Based on the satisfactory desirability of the answer, it can be inferred that the circumstances are very reliable. **Conclusion:**

A statistical-comparative study was done to analyze the rheological behavior of a nanofluid consisting of Propylene Glycol mixed with Graphene and MWCNT. Three distinct models were examined in this study. The 2FI model was found to be the best by comparing it to other mathematical functions using the criterion of correlation. R2, C.V., and the P value were used to evaluate the model that was ultimately selected. As compared to other work on NFs, this study benefits from a level of analysis that hasn't been done to this extent: a detailed and separate evaluation of quality factors for different models in the outcome section.

- The 2FI model demonstrated superior effectiveness in terms of both the input parameters and their interactions, compared to other models. The value of R2 is 0.9818.

- The 2FI model outperforms the alternatives, with a C.V index of 8.74 %, according to an analysis of several models' quality and accuracy.
- The 2FI model was found to have the lowest P-value after comparing it to other models using the P-value index. This implies that the 2FI model is extremely precise and signifies that the statistical discoveries are not arbitrary or surprising, but rather a consequence of the interactions inside the process and system. The p-value is statistically significant at a level of less than 0.0001.
- The optimal electrical conductivity value of 1256.877 was calculated using the chosen model under the parameters of distance equal to 11 mm and breakdown voltage of 2.770 kV.

5. Future Scope

With the help of the created nanofluids, the heat transfer coefficient in a helical coil heat exchanger will be calculated. The electrical properties as well as heat transfer characteristics may be tested using a propylene glycol-water solution and a variety of nano particles.

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