China Petroleum Processing and Petrochemical Technology

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2895-2906

ENHANCING HEAT TRANSFER IN TRANSFORMER OIL WITH SIC NANOPARTICLES: AN EXPERIMENTAL STUDY

Mr. Manoj Damodar Salunke*1, and Dr. Eknath Raghunath Deore#

Abstract: This paper investigates the enhancement of heat transfer coefficients in SiC-Transformer oil Nano-fluid, with a focus on optimizing critical parameters using the Taguchi Method of Design of Experiments. The study explores the impact of three key factors: nanoparticle concentration, nanoparticle size, and surfactant concentration on heat transfer performance in transformer oil. By employing a structured experimental design, the research provides valuable insights into the interplay of these factors. Notable findings include the significant influence of nanoparticle concentration and size on heat transfer efficiency. Regression analysis and a confirmation experiment confirm the robustness of the study's predictions. The results suggest that even marginal improvements in heat transfer efficiency through the strategic use of nanoparticles can be cost-effective, offering practical avenues for enhancing transformer systems. Addressing challenges related to Nano-fluid production and stability remains critical for wider commercial adoption. The study's systematic approach, relying on the Taguchi method, not only reduces the required experimental effort but also provides a deeper understanding of the factors affecting heat transfer in Nano-fluids, making it a valuable resource for researchers, engineers, and practitioners in thermal management.
Keywords – Heat transfer, Nanoparticle, SiC (Silicon Carbide), Taguchi Method, Transformer.

1. INTRODUCTION

The transformer serves as the central component in both transmission and distribution systems, playing a pivotal role in their operation. Its performance significantly influences the overall efficiency of the entire system. In transmission lines, transformers step up voltage, while in distribution lines, they step down voltage. During this voltage transformation process, heat is generated within the transformer core. To ensure safe operation and prevent overheating, it is essential to dissipate this heat into the surrounding environment.

In regions with hot and tropical climates like India, where summer temperatures can soar above 40°C, maintaining optimal operating temperatures for transformers becomes particularly challenging. To address this challenge, additional desert coolers are sometimes employed at substations to regulate transformer temperatures.

Recent research has explored the use of Nanoparticle suspensions in transformer oil to enhance heat transfer performance [1]. For instance, C. Choi et al. investigated the introduction of Al2O3 and AlN suspensions into transformer oil. They observed a 20% increase in the overall heat transfer coefficient when utilizing AlN particles at a volume fraction of 0.5%, as well as a similar increase when using spherical-shaped Al2O3 Nanoparticles at a 4% volume fraction [2].

Diaa-Eldin A. Mansour and colleagues conducted experiments with Al2O3 nanoparticle suspensions in transformer oil, incorporating surfactants at weight percentages of 0.1% and 1%.

Their study varied the concentration of Al_2O_3 Nanoparticles from 0.1 g/L to 0.6 g/L, revealing that heat transfer performance depended not only on Nanoparticle concentration but also on the weight percentage of surfactants [3].

In another investigation, B. X. Du explored the impact of Boron nitride (BN) and ferriferous oxide (Fe_3O_4) Nanoparticles on the thermal and dielectric properties of transformer oil. The results showed improvements in both breakdown strength and thermal properties, with BN Nanoparticles outperforming Fe_3O_4 nanoparticles [4].

Weimin Guan and colleagues conducted numerical simulations of transformers filled with Nano-oil, revealing improved heat transfer characteristics under natural convection. However, they noted slight changes in heat transfer characteristics under forced convection, primarily influenced by inlet velocity, as the distribution of Nano-oil depended on temperature and flow velocity [5].

Joyce Jacob et al. compared the thermal resistance and thermal capacitance of pure transformer oil with AlN nanoparticle-filled transformer oil using simulation models, validating their results experimentally. An optimal nanoparticle concentration of 0.20% by weight demonstrated a 1.54% reduction in thermal resistance and a 1.58% reduction in capacitance compared to pure transformer oil [6].

Bizhan Mehrvarz et al. conducted three-dimensional simulations of three-phase transformers and studied the heat transfer performance of pure transformer oil versus TiO_2 nanoparticle-filled transformer oil. Their simulation results indicated that Nano-oil containing TiO_2 particles exhibited an increased heat transfer coefficient compared to pure transformer oil [7].

Diaa-Eldin A. Mansour also explored the suspension of barium titanate (BT) nanoparticles in transformer oil at concentrations of 0.01 g/L and 0.02 g/L. The study found that the 0.01 g/L concentration resulted in a 28.3% increase in the heat transfer coefficient and a 2% increase in breakdown voltage, while the 0.02 g/L concentration yielded unsatisfactory results due to nanoparticle agglomeration [8]. Mansour's team also investigated a hybrid Nano-fluid with a 0.01% volume fraction of TiO_2 nanoparticles and a 0.005% volume fraction of BT nanoparticles, which exhibited a 33% increase in heat transfer coefficient and a 45% rise in breakdown voltage [9].

Collectively, these studies highlight the potential of nanoparticle suspensions in transformer oil to enhance heat transfer rates compared to pure oil. However, it is important to note that the degree of improvement depends on various parameters, including nanoparticle concentration, surfactant usage, nanoparticle size, maximum temperature, and nanoparticle type. Unfortunately, there is a lack of statistical analysis to identify the most significant parameters and their interrelationships.

This current study addresses this gap by utilizing the Taguchi Method of Design of Experiments to analyze the effects of three key factors: the concentration of SiC nanoparticles, the size of these nanoparticles, and the concentration of surfactant, on the heat transfer coefficient of Copper oxide transformer oil Nano-fluid. The primary objectives of this investigation are:

1) To assess the individual impact of each factor on the heat transfer coefficient.

2) To determine the optimal combination of factor levels that maximizes the heat transfer coefficient.

2. SiC TRANSFORMER OIL NANO-FLUID SYNTHESIS

In this study, we prepared a total of nine samples by carefully manipulating several key factors, including the concentration of nanoparticles, the size of nanoparticles, and the concentration of the surfactant. These samples were created by dispersing SiC nanoparticles, each with average particle sizes of 10nm, 15nm, and 20nm and 99% purity, into transformer oil. We used Sodium dodecyl sulfate (SDS) as our chosen surfactant.

To create these SiC transformer oil nanofluid samples, we employed a two-step method, as illustrated in Figure 1. First, we mixed the nanoparticles, obtained from the laboratory, with the transformer oil. The precise amount of nanoparticles was measured using a sensitive weight balance and then dispersed into the transformer oil. This mixture was stirred using a magnetic stirrer for 20 minutes at 1800rpm.

To enhance the dispersion of nanoparticles within the transformer oil, we subjected the mixture to ultrasonic disruption for a total of 60 minutes, with 5-minute intervals after every 20 minutes. Subsequently, to eliminate any residual water content and gas bubbles that may have formed during stirring; we placed the obtained sample in a vacuum oven at 50°C for 24 hours. Afterward, the sample was allowed to cool for 15 minutes before proceeding with the heat transfer performance testing.

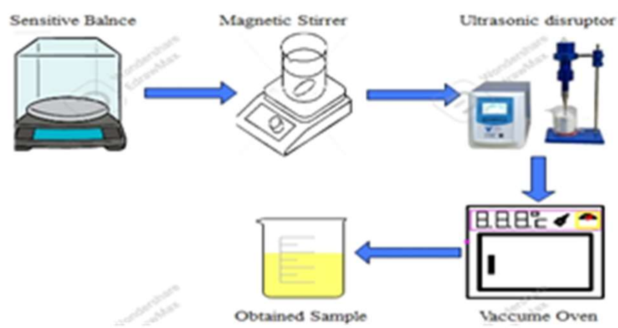

Fig. 1. Synthesis of SiC Transformer Oil Nano-Fluid

3. EXPERIMENTAL CONFIGURATION

The experimental arrangement employed for conducting the heat transferability test is thoughtfully depicted in Figure 2. This setup featured the integration of an alternating current (A.C.) power supply, operating at a voltage of 230V, which was securely connected to the heater plate. The core elements of interest in this experiment were the temperature measurements, which provided crucial insights into the heat transfer process.

Specifically, we monitored two distinct temperature parameters. The first, denoted as $T2$, was indicative of the surface temperature at the heater plate. The second parameter, T1, represented the temperature at the outer surface of the oil under investigation. The meticulous recording of these temperatures occurred at regular intervals of 5 minutes, continuing until a state of thermal stability was achieved.

Once the system reached a stable thermal state, we proceeded to calculate a fundamental parameter known as the heat transfer coefficient (H). This coefficient serves as a critical indicator of the system's ability to transfer heat effectively. To compute H, we adopted a method grounded in Newton's law of cooling, which is encapsulated in the following equation:

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2895-2906

$$H=(1/A) * Q/\Delta T \quad (1)$$

Where $\Delta T = T_2 - T_1$

Here, Q represents the heat flux, and ΔT represents the corresponding temperature difference. The subscript 'A' denotes the surface area over which heat transfer occurs.

In this context, the heat transfer coefficient (H) was derived as the average value from the last five recorded temperature readings. This meticulous approach ensured that our assessment of heat transfer efficiency was based on a reliable and representative set of data points, enabling us to draw meaningful conclusions about the performance of our experimental setup and the heat transfer characteristics of the system under investigation.

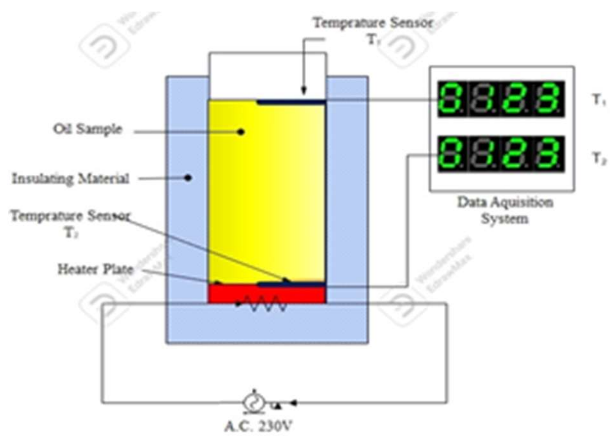

Fig 2. Experimental Configuration

4. EXPERIMENTAL DESIGN AND METHODOLOGY

The "Design of Experiments" (DOE) is a structured and systematic approach used to plan, execute, and analyze experiments with the goal of optimizing processes, enhancing product quality, and reducing costs. This methodology encompasses a wide range of techniques, including General Full Factorial Design, Two-Level Fractional Factorial Designs, Taguchi's Orthogonal Arrays, Two-Level Full Factorial Designs, Plackett-Burman Designs, and Response Surface Method (RSM) Designs, among others [13].

One particularly noteworthy technique within the DOE toolkit is the Taguchi method. This approach has gained popularity for its ability to improve both processes and product quality by applying statistical principles. It is widely adopted in engineering analyses due to its versatility and effectiveness when carefully applied to relevant factors [14]. The Taguchi method employs standard orthogonal arrays to construct a test matrix, allowing for the collection of a substantial amount of data while conducting the minimum number of tests. This ultimately leads to the determination of optimal parameter values [15].

In the context of the study at hand, the application of the Taguchi method in the design of experiments is a potent statistical tool for optimizing input parameters and enhancing output functions. The crucial input parameters in this study are (A) the concentration of nanoparticles, (B) the size of nanoparticles, and (C) the ratio of surfactant weight to nanoparticles weight, each having three corresponding levels. These parameters play a pivotal role in determining the heat transfer performance of the Nano-transformer oil. The primary objective is to optimize these input parameters using the Taguchi method, as outlined in Table No. 1, with the ultimate aim of improving the output, namely the heat transfer coefficient (H).

The Taguchi Method classifies desirable performance into three categories: "smaller-the-better," "larger-the-better,"

And "nominal-the-best." Signal-to-Noise (S/N) analysis is employed to assess the quality characteristic, and it is expressed as follows:

$$S/N = -10\log_{10}(MSD) \quad (2)$$

Where MSD = Mead Squared Division

For Smaller the better characteristic

$$MSD = (Y_1^2+Y_2^2+Y_3^2+ \quad .)/n \quad (3)$$

For Larger the better characteristic

$$MSD = [(1/Y_1^2)+(1/Y_2^2)+(1/Y_3^2)+ \quad]/n \quad (4)$$

For Nominal the best characteristic

$$MSD = [(Y_1-m)^2+(Y_2-m)^2+(Y_3-m)^2+ \ .]/n \quad (5)$$

Through the systematic application of the Taguchi method, this study seeks to efficiently explore and optimize the interplay between input parameters and their impact on the heat transfer coefficient (H), thus contributing to a deeper understanding of the underlying processes and improving overall performance.

Within the scope of this study, we introduced a framework for assessing the responses, denoted as Y1, Y2, and Y3, which are critical indicators of the experiment's outcomes. In this context, 'n' signifies the total number of tests conducted in each trial, and 'm' represents the desired or target value that we aim to achieve in our results.

For this particular investigation, we adopted a specific quality characteristic known as "larger-the-better." This quality characteristic aligns with the notion that achieving larger values of the heat transfer coefficient (H) is indicative of superior heat transfer performance [16]. In other words, we aim to maximize the heat transfer coefficient, as larger values signify more effective heat transfer processes.

By embracing the "larger-the-better" quality characteristic, we set the stage for an in-depth analysis of how various factors and parameters affect the heat transfer coefficient. Our objective is to identify the optimal conditions that result in the highest possible heat transfer coefficient values, ultimately leading to improved heat transfer performance in the context of this study.

Table No. 1 Specification of Input Parameters and Corresponding Levels

Sr.No	*Factors*	*Levels*		
		1	*2*	*3*
1	Concentration of Nanoparticles (A) g/Lit	0.1	0.2	0.3
2	Size of Nanoparticles(B) (Nm)	10	15	20
3	Ratio of Surfactant weight to the weight of Nanoparticles (C)	0.1	0.5	1.0

Since there were three control factors, each with three levels, Taguchi recommended employing the L9 orthogonal array for conducting experiments, as presented in Table No. 2.

Table No. 2 L9 Orthogonal Array

Trial No.	*A*	*B*	*C*	*H*	*SNRA1*
1	0.1	10	0.1	480	53.62
2	0.1	15	0.5	490	53.803
3	0.1	20	1	520	54.319
4	0.2	10	0.5	490	53.803
5	0.2	15	1	520	54.319
6	0.2	20	0.1	510	54.151
7	0.3	10	1	520	54.319
8	0.3	15	0.1	510	54.151
9	0.3	20	0.5	530	54.485

4. RESULTS AND DISCUSSION

4.1 Findings from Taguchi Experiments

The analysis of the results involved the utilization of Qualitek-4 (QT4) software, specifically version 4.75, which is a Windows-based application tailored for the analysis and automated optimization of Taguchi experiments. Conforming to the methodology detailed in Table 2, a series of L-9 experiments was carried out to evaluate the primary impact of control factors, elucidating the trends in their effects. Subsequently, the main effects were computed by averaging the results. Figures 3, 4, and 5 serve as powerful visual tools that offer a comprehensive and intuitive insight into the complex dynamics governing the heat transfer characteristics of transformer oil-based Nano-fluids. These figures specifically illuminate the multifaceted relationships between three pivotal variables: the concentration of nanoparticles, the size of nanoparticles, and the ratio of surfactant weight to nanoparticle weight.

In our focused analysis of Figure 3, we drill down into the intricate role of nanoparticle concentration in shaping the average response value. This particular facet of the study is paramount in understanding how the manipulation of this factor can directly influence heat transfer efficiency. The graph in Figure 3 vividly illustrates a compelling pattern. It becomes readily apparent that as nanoparticle concentration ascends, traversing the spectrum from level 1 (0.1g/Lit) to level 3 (0.3g/Lit), there is a direct and proportionate augmentation in the average heat transfer coefficient. This positive correlation signifies that higher nanoparticle concentrations within the Nano-fluid lead to enhanced heat transfer coefficients, a crucial finding in the realm of thermal management. Notably, the pinnacle of this phenomenon manifests at level 3, where the nanoparticle concentration is 0.3g/Lit. At this optimal concentration, the average response value achieves a remarkable 520W/m2 K. This pinnacle underscores the critical importance of finely tuning the nanoparticle concentration to maximize heat transfer efficiency in transformer oil-based Nano-fluids. In essence, the data derived from Figure 3 substantiates the pivotal role of nanoparticle concentration as a key determinant in optimizing heat transfer efficiency. This knowledge provides valuable guidance to researchers, engineers, and practitioners in their quest to fine-tune Nano-fluid systems for optimal heat dissipation and thermal management.

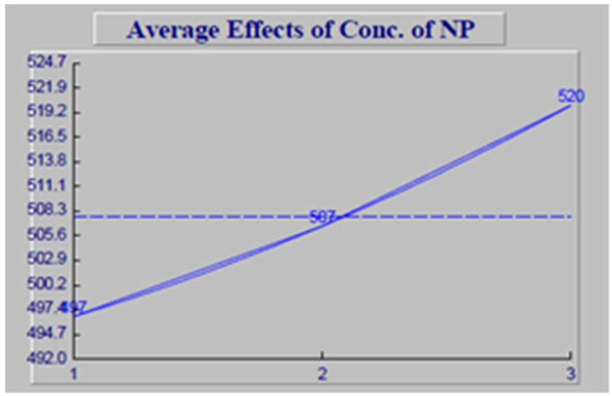

Fig. 3: Influence of Nanoparticle Concentration on Heat Transfer Coefficients

Figure 4 offers a clear depiction of a noteworthy trend. As we progress from level 1 to level 3, corresponding to an increase in nanoparticle size from 10 nanometers to 20 nanometers, a positive influence on the average response value is prominently observed at each level. In essence, the data suggests that embracing larger nanoparticle sizes enhances the average response value in a systematic manner. To optimize and attain the maximum response value, it becomes crucial to adopt the largest possible nanoparticle size, which is 20 nanometers. This empirical observation underscores the significance of nanoparticle size in enhancing heat transfer efficiency, emphasizing that a larger size can lead to superior heat transfer coefficients and, consequently, improved thermal performance in the studied system.

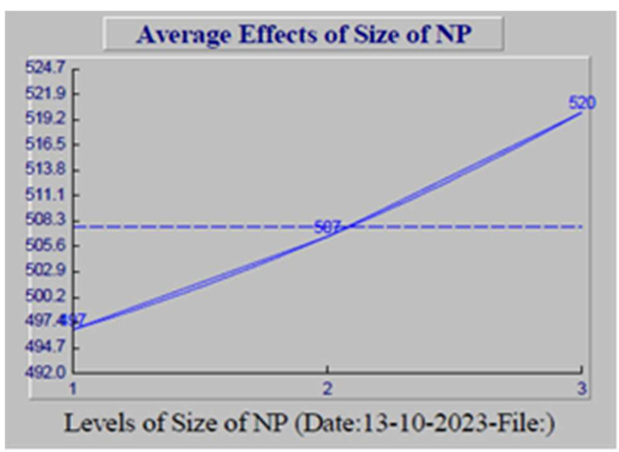

Fig.4: Influence of Nanoparticle Size on Heat Transfer Coefficient

Figure 5 delivers valuable insights into the intricate relationship between surfactant concentration and its impact on the average response value. As expected, elevating the concentration level from 1 to 3, encompassing a range from 0.1 to 1.0 weight percent of nanoparticles, yielded a discernible increase in the average response value. This upward trajectory culminated at level 3, where the response value reached its zenith at an impressive 520W/m2K. This empirical observation resonates with prior research findings, which have consistently indicated that the augmentation of heat transfer in Nano-fluids can be attributed to a combination of contributing factors. These factors include nanoparticle concentration, size, and in this context, surfactant concentration. This collective understanding underscores the multifaceted nature of heat transfer in Nano-fluid systems and highlights the importance of meticulously optimizing each variable to enhance thermal performance. The results presented in Figure 5 further substantiate the significance of surfactant concentration as a key player in this intricate interplay, emphasizing its potential to yield significant improvements in heat transfer efficiency.

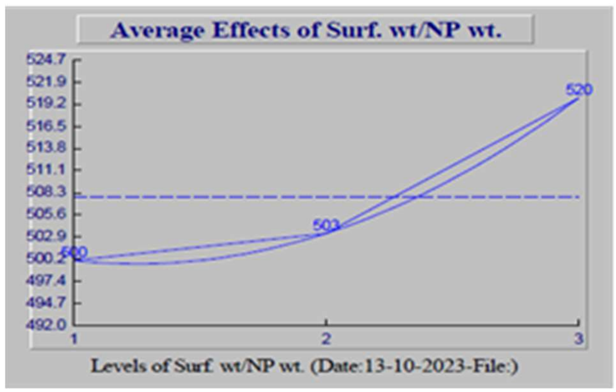

Fig. 5: Influence of Surfactant-to-Nanoparticle Weight Ratio on Heat Transfer Coefficients

4.2 Statistical Analysis of Variance (ANOVA)

A comprehensive analysis of variance (ANOVA) was systematically carried out employing the robust Qualitek-4 software. This advanced statistical tool not only delineated the extent of variation within the dataset but also provided a clear visualization of the significance of each individual factor. The results of this meticulous analysis are thoughtfully presented in the final column of Table 3, expressed as percentages. This presentation method offers a convenient and insightful way to gauge the relative impact of each factor on the observed variations, contributing to a deeper understanding of the overall data trends.

Table No.3 Analysis of Variance

S.N.	*Factors*	*DOF*	*SS*	*Variance*	*F*	*Pure Sum*	*%*
1	Concentration of NP(A)	2	3289	1644.3	247	3275.3	34
2	Size of NP(B)	2	3289	1644.3	247	3275.3	34
3	Ratio of Surfactant weight to NP weight (C)	2	2756	1377.8	207	2742.4	29
Error		29	193.3	6.7			2.4
Total		**35**	**9526**				**100**

From ANOVA it is clear that Concentration of nanoparticles and Size of nanoparticles are the equally significant factors. The Optimum conditions and the optimum results are calculated with the help of ANOVA and given in Table 4. Influence on significant factors on output parameter is shown in Figure 6.

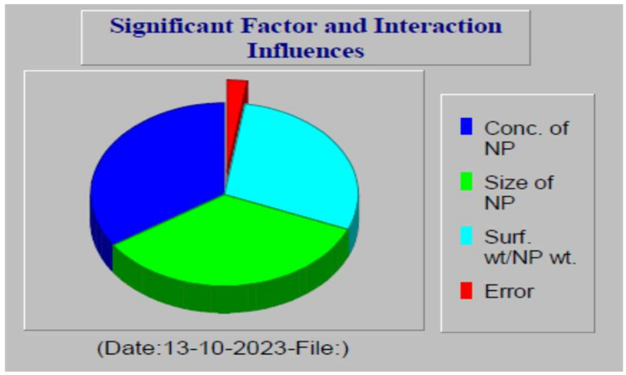

Figure 6: Significant factors and Interactions influences

Table 4 Optimum condition and Performance

Sr. no.	*Factors*	*Level Description*	*Level*	*Contribution*
1	Concentration of NP(A)	0.3	3	12.222
2	Size of NP(B)	20	3	12.222
3	Ratio of Surfactant weight to NP weight (C)	1	3	12.222

Total Contribution from all factors 36.665

Current grand average of performance 507.777

Expected result at optimum conditions 544.443 (Predicted by ANOVA done in QT4 software)

4.3 Regression Analysis

The examination of the test data through regression analysis elucidates the connection between the adjustable parameters and the average output. This connection is articulated in the form of the subsequent linear equation.

$$H=437.35+ 116.7 A+ 2.333 B+ 22.68C \quad (6)$$

Where H = Response i.e. Heat transfer coefficient (W/m2 K)

A = Concentration of Nanoparticles g/Lit

B = Size of Nanoparticles (Nm)

C = Ratio of Surfactant weight to the weight of Nanoparticles

By substituting the optimum parameters derived through ANOVA into equation no. 6, we will obtain the optimal value for the quality characteristic. This optimal value is expected to maximise the heat transfer coefficient on the Nano fluid.

H_{opt} = 437.35 + 116.7 * 0.3 + 2.333 * 20 + 22.68 * 1

H_{opt} = 541.7 W/m^2 K (Predicted by Regression equation)

4.4. Confirmation Experiment

To verify and affirm the accuracy of the anticipated outcomes, a confirmation experiment was meticulously executed, encompassing an additional set of four carefully designed trials. These trials were thoughtfully conducted under the exacting conditions established as optimal through the systematic ANOVA analysis. Specifically, the confirmation experiment entailed the preparation of a SiC Transformer oil Nano-fluid, where the concentration of nanoparticles was precisely set at 0.3 grams per litter, the nanoparticle size was fixed at 20 nanometers, and the ratio of surfactant weight to nanoparticle weight was maintained at 1. This rigorous adherence to the identified process parameters, as elucidated by the ANOVA, ensured that the conditions for the confirmation experiment were finely tuned for accuracy and reliability. This established an environment where the performance and effectiveness of the SiC Transformer oil Nano-fluid could be assessed with the utmost precision. The results stemming from this confirmation experiment, which focused on the determination of the heat transfer rate, are systematically documented and thoughtfully presented in Table 5. These results serve as a critical point of validation, aligning the predicted outcomes with real-world observations and underscoring the credibility and robustness of our study.

Table 5 : Results of Confirmation Experiments

Observation	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*	*Avg. Heat Transfer rate*
Heat Transfer rate in (W/m^2 K)	536.68	539.43	526	523.32	530.60

5. CONCLUSION

In the pursuit of evaluating the convective heat transfer coefficient of SiC-Transformer oil Nano-fluid, our experimental investigation was conducted, employing a meticulous and systematic approach. The study meticulously assessed the impact of several key controllable factors on the heat transfer coefficient, leveraging the Taguchi methodology. The parameters under scrutiny encompassed the Concentration of Nano-particles (A), featuring levels of 0.1, 0.2, and 0.3 grams per litter, the Size of nanoparticles (ranging from 10 to 20 nanometers), and the Ratio of Surfactant weight to Nano-particle weight (C), with variations of 0.1, 0.5, and 1.

The outcomes of this comprehensive investigation illuminated several key findings. Notably, the Heat transfer coefficient of SiC-Transformer oil Nano-fluid exhibited an upward trajectory with increases in Concentration of Nano-particles, larger Size of nanoparticles, and a higher Ratio of Surfactant weight to Nano-particle weight. Intriguingly, Concentration of Nano-particles and the Size of Nano-particles emerged as equally influential factors in shaping the heat transfer coefficient. These parameters were found to have a significant impact on the observed results.

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2895-2906

To further explore the relationships between the controllable parameters and the average output, we conducted regression analysis, leading to the formulation of a predictive equation. This equation closely mirrored the results obtained through ANOVA, reinforcing the robustness of our methodology and the soundness of our findings.

A confirmation test was thoughtfully executed, validating the accuracy of our predictions with a minimal prediction error of approximately 2.449%. This strong agreement between experimental and predicted values underlines the reliability of our research.

Our strategic use of the Taguchi method for experimental design streamlined the process significantly. By conducting only 9 runs, we achieved optimal Heat transfer coefficient values, a noteworthy reduction in the experimental effort required compared to the conventional approach of 27 runs.

It's essential to highlight the cost-effectiveness of incorporating even a small quantity of nanoparticles into the working fluid for marginal improvements in heat transfer efficiency. Optimization of the Concentration of Nano-particles and Size of Nano-particles offers a practical and cost-efficient avenue for achieving these enhancements. However, challenges such as the cost of Nano-fluid production and stability persist as significant barriers to the widespread commercialization of Nano-fluids. Addressing these challenges is imperative to unleash the full potential of Nano-fluids as effective working fluids in transformer systems.

6. REFERENCES

[1] Muhammad Rafiq, YuzhenLv, and Chengrong Li A Review on Properties, Opportunities, and Challenges of Transformer Oil-Based Nano fluids , Hindawi Publishing Corporation Journal of Nano materials, vol. 2016, Article ID 8371560, 2016

[2] C. Choi, H. S. Yoo and J. M. Oh, Preparation and heat transfer properties of nanoparticles in transformer oil dispersion as advanced energy efficient coolants , Current Applied Physics, Vol. 8 pp. 710-712, 2008

[3] Diaa-Eldin A. Mansour and Ahmed M. Elsaeed , Heat Transfer Properties of Transformer Oil-Based Nano fluids Filled with Al2O3 Nanoparticles , IEEE International Conference Power & Energy (PECON), pp123-127, 2014.

[4] B. X. Du, X. L. Li and J. Li, Thermal Conductivity and Dielectric Characteristics of Transformer Oil Filled with BN and Fe3O4 Nanoparticles , IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 22, No.5, pp. 2530-2536, 2015.

[5] Weimin Guan, Miao Jin, Jiaqi Chen, Pan Xin, Yonghe Li. Kejie Dai, HailongZahang, Tao Huang and Ruan, Finite Element Modelling of Heat Transfer in a Nano fluid Filled Transformer , IEEE Transactions on Magnetics, Vol. 50, No. 2, 2014

[6] Joyce Jacob, Dhanish Mon N and P Preetha, Experimental Validation of Thermal Model of Unfilled and Nano Filled Transformer Oils , IEEEPES Asia-Pacific Power and Energy Engineering Conference, 2017

[7]Bizhan Mehrvarz, FatemehBahadori, Saeed Zolfaghari Moghaddam, Heat transfer enhancement in distribution transformers using TiO2 nanoparticles , Advanced Power Technology, Vol. 30, Issue 2, pp 221-226, 2019.

[8] Diaa-Eldin A. Mansour, Essam A. Shaalan, Sayed A Ward and Adel Z. El.Dein Effect of BT Nanoparticles on Dielectric and Thermal Properties of Transformer Oil , Proceedings of 4th International Conference on Energy Engineering Faculty of Energy Engineering Aswan University Egypt, 2017.

[9]Diaa-Eldin A Mansour, Essam A. Shaalan, Sayed A Ward, Adel Z. El Dein and Hesham S. Karaman, Multiple Nanoparticles for Enhancing Breakdown Strength and Heat Transfer Coefficient of oil Nano fluids , Nineteenth International Middle East Power Systems Conference(MEPCON), Menoufia University, Egypt, pp-1406-1410, 2017.

[10] BehrouzRaei, Statistical Analysis of Nano Heat Transfer in a Heat Exchanger Using Taguchi Method , Journal of Heat and Mass Transfer Research, Vol. 8, pp29-38, 2021

[11] Ravi Babu.S and Sambasiva Rao. G, Experimental Investigation on Stability and Dielectric Break down Strength of Transformer Oil Based Nano-fluids , AIP Conf. Proc. 1952, pp 020075-1-020075-6, 2018."

[12] R. Rajesh, S.Sumathi, “Certain performance investigation on hybrid TiO2/Al2O3/MoS2 nanofiller coated 3ᴓinduction motor: A Taguchi and RSM based approach”, Energy Reports by Elsevier, Vol. 6, pp 1638-1647, 2020.

[13] Montgomery DC. Design and analysis of experiments: John wiley & sons; 2017

[14] Kotcioglu I, Cansiz A, Khalaji MN. Experimental investigation for optimization of design parameters in a rectangular duct with plate-fins heat exchanger by Taguchi method , Appl Therm Eng. 2013;50(1):604-13.

[15]Sivasakthivel T, Murugesan K, Thomas HR. Optimization of operating parameters of ground source heat pump system for space heating and cooling by Taguchi method and utility concept , Applied Energy. 2014;116:76-85.

[16] Roy, R. A Primer on the Taguchi Method , New York: Van Nostrand Reinhold; 1990