Comparison study of copper oxide nanofluid and borak 22 oil used for cooling an immersed coil

Said Azzi [1], **Belkacem Belkacem** [1], **Mohamed Bouhafs** [1], **Imadeddine Dehimi** [1], **Abderaouf Zenadra** [1]

[1] Lab of Industrial Production and Maintenance Engineering, Institute of Maintenance and Industrial Safety, University of Oran2 Mohamed Ben Ahmed; P.B 1015 El M'naouer 31000 Oran Algeria

E-mail: azzi.said@univ-oran2.dz, belkacem.belkacem@univ-oran2.dz, bouhafs.mohamed@univ-oran2.dz, dehimi.imadeddine@univ-oran2.dz, abderraouf1zenadra@gmail.com.

Abstract: A heated coil with varying current values immersed in a rectangular cavity that has ambient temperature in the walls filled with cooling fluid was numerically investigated, the finite element method (FEM) was the utilized to solve this computation system. Isothermal contours are shown in this article for varying parameters such as the current and the choice of the fluid. The results shown that increasing the current leads to a rise in temperature whenever the type of the fluid that has been used. Additionally, to investigate which is the best cooling fluid in term of dissipating heat, we focused on how much time is needed to get the coil heat up.

Keywords: nanofluid, ambient temperature, natural convection, FEM method, heat transfer.

1. INTRODUCTION

The problem of overheating in electronic devices and electrical equipment's which leads to a decrease in their performance, has led researchers to develop several cooling methods due to the increasing demand for these equipment's such as electronic devices (Adel Ahmed Almubarak & Almubarak, 2017), transformers (Guo Jin Chen et al., 2013).One of the methods used for cooling are those that employ nanofluid. (Fontes et al., 2014; Pendyala et al., 2021) which is a suspensions of nanoparticles in a base fluid.(Zouhaier Mehrez et al., 2015). Nanofluids have been studied in a wide range in various heat transfer systems, including flow in inclined cylinders by (Kafel Azeez Mohammed et al., 2021; Khanafer & Vafai, 2020), flow of Cu-water nanofluid in inclined open cavities (Saleh et al., 2022), entropy generation of nanoparticles (Souayeh et al., 2021), mixed convection of MHD flow in nanofluids (Öztop et al., 2017; Selimefendigil & Öztop, 2016). These studies demonstrate the significant potential of nanofluids in improving heat transfer efficiency in cavities. Furthermore, it has been various studies on cooling of the transformers devices due to significant heat losses during the transformation of electrical energy, which can lead to overheating and reduce the lifespan according to (K. S. Kassi et al., 2015; Xiang Zhang et al., 2013). Transformer overheating poses fire hazards and can disrupt the operation of the electrical grid. There is a study by (Muhammad Haziq Mohd Wazir et al., 2024) who numerically investigated the hot spot temperature (HST) of a distribution transformer using numerical software; it has been take into consideration three phases of unbalanced harmonic loads, they analyzed the system using the finite element method (FEM), it has been found that increasing loads leads for the unbalanced harmonic currents to impact the HST increment. Also, the study that has been made by (Zoran Radaković et al., 2017) presented a dynamic thermal model for an indoor transformer station which includes an oil-immersed power transformer with a kiosk with inlet and outlet ventilation openings and high-voltage and low-voltage compartments. Hence (Li et al., 2018) established a three-dimensional model of high frequency transformer windings, they simulate the proximity effect and skin effect and the eddy current effects loss in the transformer using the finite element method. A study by (T. Gradnik, 2006) explained the effect of the transformer oil and winding temperatures on the achievement of the expected transformer lifetime, the effect of cooling optimization has been discussed in order to have long residual life-time. These mentioned investigations share a common problem, which is that an increase in loads causes to an increase in current, which in turn raises the temperature of the device.

2. APPROACH METHOD

2.1 Computation model

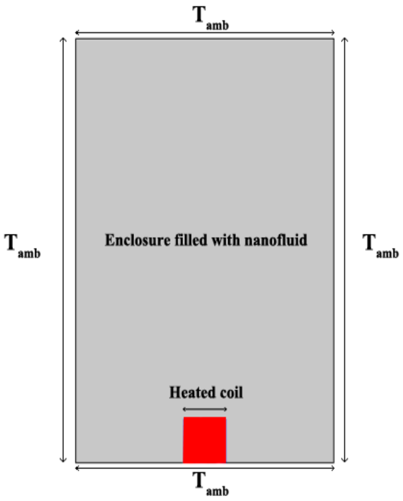

Figure 1: Geometry of the system

We simulated a coil with several turns immersed in a cavity filled with cooling fluid. We assumed that all the walls of the cavity are taken by the ambient temperature; the heat source came from the losses of the coil. When the current in the coil increased, this produced losses, which in turn generated heat. The finite element method (FEM) was applied to solve this system.

The shape of the coil is numeric. Also, we conducted it with different values of current so we can see the losses causes by it, which in turn will generate the heat.

The cavity was filled with fluid called Borak 22 oil at the first time. Then, it was filled with another fluid called Copper Oxid nanofluid to make the comparison between these two fluids to decide which one of them has the best cooling characteristics.

Table 1. Characteristics of the fluids

fluid	Electrical conductivity S/m	Thermal conductivity W/ (m.K)	Viscosity Pa.s
Borak 22 oil	2.690*10^-12	0.12	0.02
Copper oxid nanofluid	10^{-6}	0.700	0.004

2.2 The governing equations

In the current study, we used several main equations to model the system that is the thermal characteristics; the fluid flow and the magnetic field of the system, they are fully coupled, and the governing equations are as follow:

$$Continuity\ equation$$

$$\nabla . u = 0 \quad (1)$$

$$Magnetic\ field\ equations$$

$$\nabla \times H = J \quad (2)$$

$$B = \nabla \times A \quad (3)$$

$$J = \sigma E + jwD + \sigma v \times B + J_e \quad (4)$$

$$E = -jwA \quad (5)$$

$$Momentum\ Equation$$

$$\rho \frac{\partial u}{\partial t} + \rho (u . \nabla) u = -\nabla . p + \mu \nabla^2 u + \rho g \beta (T - T_0) \quad (6)$$

$$Heat\ transfer$$

$$\rho C_p u . \nabla T + \nabla . q = Q + Q_{ted} \quad (7)$$

$$q = -K \nabla T \quad (8)$$

$$for\ convective\ heat\ transfer$$

$$-n . q = q_0 \quad (9)$$

$$q_0 = h(T_{ext} - T) \quad (10)$$

3. RESULTS AND DISCUSSION

In this section we studied the effect of the variation of the current on the coil. The interval of the current was varied between 0.1A and 15A, the main mechanism of the fluid was the natural convection causes by the dissipation of heat from the heat source of the coil to the ambient temperature.

Figure 2 and figure 3 depicts that the current in the coil generates heat, with the temperature varying based on the changes in the current. We noticed that when the current value is low, the temperature remains low in both fluids. In this case, the temperature is nearly equal to the ambient temperature. As the current increases, the heat generated by the coil also increases. At a current value of 5 A, a remarkable rise in temperature around the coil is observed. This increase in temperature affects the cooling fluid, causing its temperature to rise. Consequently, the fluid begins to transfer the heat away from the coil. The effectiveness of this heat transfer process is crucial in managing the coil's temperature and maintaining its efficiency. When the current is low, the heat generated is minimal, and the cooling fluid can easily dissipate this small amount of heat, keeping the temperature close to that of the surrounding environment. However, as the current increases, the amount of heat generated also increases, placing a greater demand on the cooling fluid's ability to absorb and transfer this heat. At a higher current, the two figures show a significant increase in the temperature around the coil. The heat generated is more substantial, and the cooling of both fluids' temperature begins to rise more noticeably. This increase in the both fluids temperature indicates that it is absorbing more heat from the coil. As the fluids heats up, it starts to circulate, enhancing the heat transfer process. Figure 2 shows the effect of Borak 22 oil on the cooling of the coil while in figure 3 shows the effect of copper oxide nanofluid on the coil. At current value of 1 A, in the case of Borak 22 oil, the temperature of the fluid near the coil is approximately 26°C, while at the farthest distance from the coil, the fluid temperature is 24.9°C. In the case of copper oxide nanofluid, the temperature of the fluid at the closest point to the coil is 25.1°C, and at the farthest point, it is 24.9°C. When we increased the current to 5 A, we observed that in the case of Borak 22 oil, the fluid temperature at the closest point to the coil reached 46°C, while at the farthest point, it was 26°C. In the case of copper oxide nanofluid, the temperature at the closest point to the coil was 31.7°C, and at the farthest point, it was 26°C. At a current value of 15 A, in the case of Borak 22 oil, the temperature at the closest point to the coil reached 222°C, whereas at the farthest distance from the coil, the fluid temperature was 42°C. In the case of copper oxide nanofluid, the temperature at the closest point reached 89°C, and at the farthest point, it was 34°C.

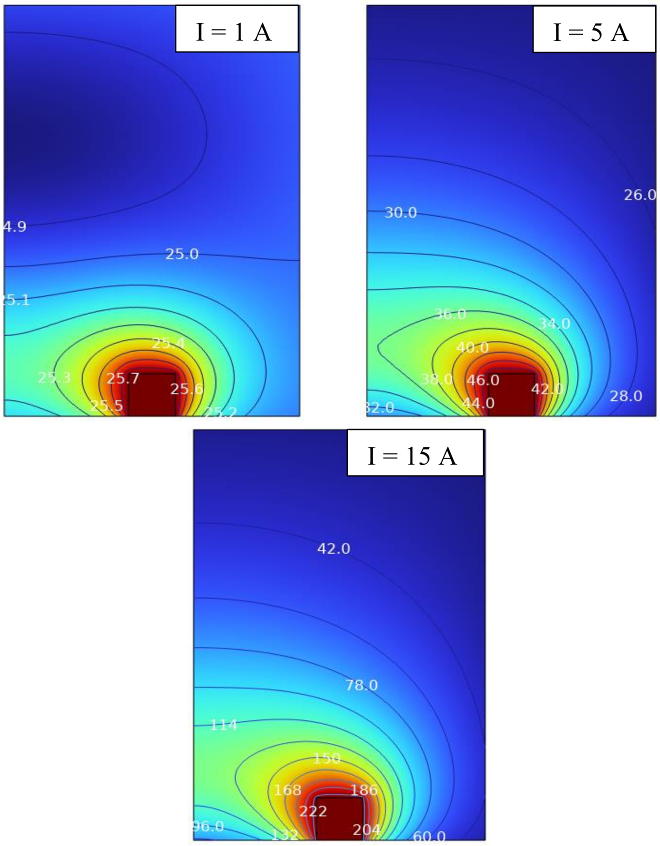

Figure 2: temperature of the system at t = 60 h with the variation of the current immersed with Borak 22 oil

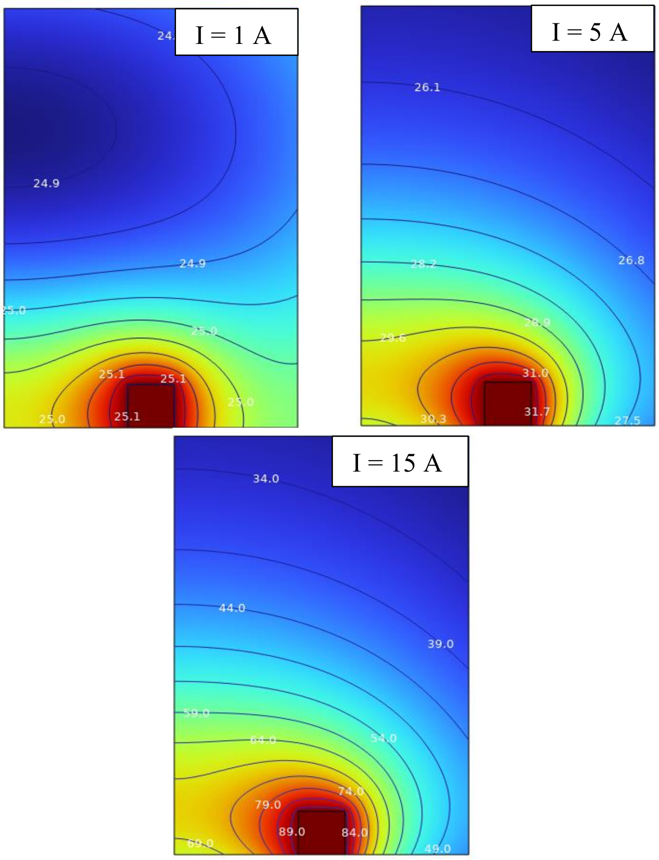

Figure 3: temperature of the system at t = 60 h with the variation of the current immersed with copper oxide nanofluid

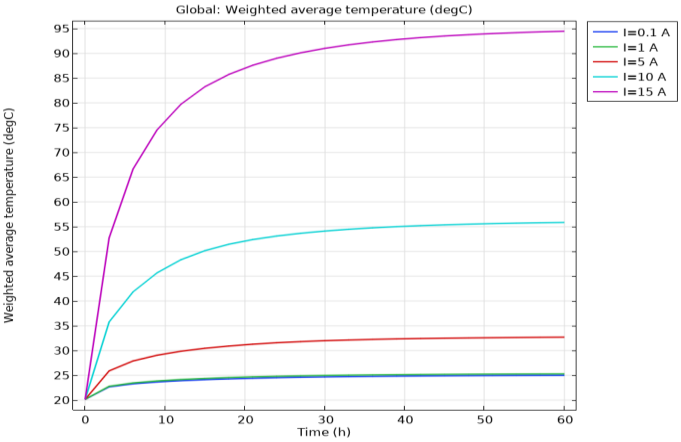

Figure 4: average temperature of the system immersed in Borak 22 oil for different current values

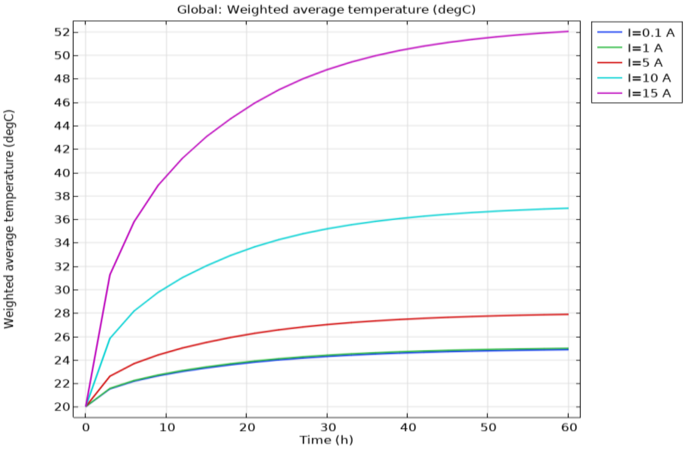

Figure 5: average temperature of the system immersed in copper oxide nanofluid for different current values

Figure 4 and figure 5 represents the average temperature within the enclosure with the variation of the current, the temperature goes in two phases the transient phase and the linear phase, as the current values gets higher the temperature rise up. In figure 4 that represent the Borak 22 oil as a cooling fluid, we can clearly see that for high current value of 15A the average temperature reaches almost 95 °C and for low current values the average temperature nearly equal to 34 °C.

In figure 5 depict the copper oxide nanofluid as a cooling fluid, when the current was 15 A the average temperature was approximately equal to 53 °C and when the current was at the lower values as 1 A, the temperature was almost equal to the ambient temperature.

In figure 4 the graph goes from the transient phase to the linear phase in 20 hours for the current values that equals to 0.1 A and 1 A and at t = 30 h when I = 5 A. when the current was equal to 10 A, the linear phase starts at t = 60 h. For I = 15 A, the linear phase was at t > 60 h.

In the case of copper oxide nanofluid as shown as in figure 5, for the interval values of current that goes from 0.1 A to 5 A, the linear phase starts when t > 50 h. For I = 10 A and 15 A, the linear phase was at t > 60 h. these results that represented from figure 2 to figure 5 shown that the copper oxide nanofluid has the ability of cooling the coil better than the Borak 22 oil.

4. CONCLUSIONS

A numeric shape coil immersed in a rectangular cavity filled with cooling fluid was investigated, the main results are as follows:

The temperature of the coil was depended on the value of the current, when the value of the current was low, the temperature of the coil was equal to the ambient temperature, when the current values was high, the temperature of the coil was high.

The temperature of the nearest point of the fluid from the coil was higher than the farthest point.

The values of temperature that was getting from the copper oxide nanofluid was lower than the borak 22 oil.

The copper oxide nanofluid was giving more time for the coil to get heated than the borak 22 oil.

From these previous results we concluded that the copper oxide nanofluid was more efficient in heat transfer than the borak 22 oil.

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