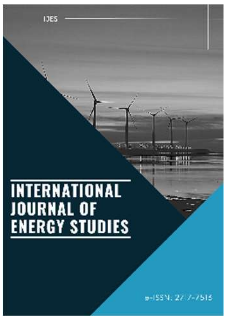
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2024; 9(1): 135-153

DOI: 10.58559/ijes.1427442

Received	:	29 Jan 2024
Revised	:	16 Feb 2024
Accepted	:	20 Feb 2024

Numerical analysis of the journal bearings of Keban Hydroelectric Power Plant using different type nanofluids

Murat Öztürk[a,b], Erdem Çiftçi[c*]

[a]*Graduate School of Natural and Applied Sciences, Gazi University, Türkiye, ORCID: 0000-0002-0668-8075*

[b]*Mechanical Engineering Department, National Defence University, Türkiye, ORCID: 0000-0002-0668-8075*

[c]*Energy Systems Engineering Department, Gazi University, Türkiye, ORCID: 0000-0003-2493-5962*

*(*Corresponding Author:erdemciftci@gazi.edu.tr)*

Highlights

- Heat and fluid flow analysis were perofrmed.
- Mobil DTE 68 Oil based nanofluids of alümina and silica nanoaparticles were used.
- Pressure distributions, temperature and velocity contours were obatined.
- With the use of alumina and silica-based nano lubricants, block surface temperature was reduced from 80°C to 64°C and 61°C, respectively.

You can cite this article as: Öztürk M, Çiftçi E. Numerical analysis of the journal bearings of Keban Hydroelectric Power Plant using different type nanofluids. Int J Energy Studies 2024; 9(1): 135-153.

ABSTRACT

Energy production in line with demand rapidly increases. Fossil fuel systems in use today pose a great threat to the future of the world and in this sense, the interest to the renewable energy sources such as hydroelectric energy systems is increasing. In this study, the heating problem of the journal bearings one of the parts of the hydroelectric energy systems was evaluated, various analysis were performed with the Computational Fluid Dynamics (CFD) approach to eliminate this problem and the results obtained were shared. Initial analyses were performed and evaluated for Mobil DTE 68 oil, which was commonly used as a refrigerant in journal bearings. Then, Al2O3 nanoparticles at concentrations of 3%, 7% and 10% were then added to the refrigerant oil and necessary analyses were performed for these three conditions. Finally, similar analyses were performed in the 3%, 7% and 10% concentration for SiO2. When the obtained temperature changes were examined accordingly, it was obtained that the increase in the concentration of nanoparticles exhibited a characteristic that was inversely proportional to the surface temperature. With the addition of nanoparticles, surface temperatures have been observed to decrease from 80°C to 68°C, but the effect on sharp corners is quite low. In this sense, it has been obtained that nanoparticles can significantly increase the thermal characteristics of Mobil DTE 68 oil, and it has been concluded that nanofluids may be an alternative solution for the overheating problem that occurs in journal bearings.

Keywords: Nanofluids, Computational fluid dynamics (CFD), Heat transfer, Journal bearings, Hydroelectric power plants

1. INTRODUCTION

In today's century which aimed to increase clean energy production, the use of hydroelectric energy systems, which are the most important source of clean energy used to ensure energy continuity protect popular. In these systems, which provide useful energy through the transformation of kinetic energy into mechanical energy, the aim is to establish a harmonious working system and to provide maximum energy production by producing solutions to various problems. In this sense, the uninterrupted movement of the turbines for the mechanical energy conversion causes these particles to heating with the friction effect, and this heating causes various problems and lead them to prevent of maximum performance. In order to prevent worked with the low performance at high temperatures in the journal bearings, Mobil DTE 68 fluid is used and the system is protected with this fluid. In this sense, Oliveira and Daniel (2024) have examined the problems that may be caused by deficiencies in oil of journal bearing with numerical analysis. As a result of the analyzes, it was observed that the deterioration in the input parameters of the fluid entering the system can cause more than one malfunction in the machines that tend to rotate [1]. Similarly, Sing and Rajput (2024) examined a hybrid sliding tapered bearing and examined piezo viscous polar lubrication. As a result of the analyzes, there is stated that piezo viscous polar lubrication provides significant improvements in bearing characteristics and that the piezo viscous polar lubricant offers high stability in bearing systems compared to Newton type fluids [2].

Nano lubricants are the next generation of fluids, also called nanofluids. In the case that the basic fluid is oil, it is called as the relevant nanofluid nano lubricant [3]. Especially when the studies on heat transfer are examined in the last 10 years, it is seen that the fluids in which solid particles are located have many advantages in terms of thermophysical properties compared to their solid particleless counterparts. Solid nanoparticles in the nanoscale participating in the fundamental fluid increase the heat conduction coefficient of the fluid - because the heat conduction coefficients of the solids are greater than those of the liquids - It is known that the will increase the specific heat value and the effective heat transfer area of the fluid with the participation of nanoparticles. In addition to the increase seen the turbulence and number of surface contact areas between the fluid surface and the fluid flow will increase as a result of the interactions and collisions of the nanoparticles [4-7]. Although nanoparticles used in nanofluid preparation are generally metals with high thermal conductivity (Zn, Fe, Cu, etc.) or compounds with high metal content (Al_2O_3, CuO, Fe_2O_3, etc.), they are, recently, materials such as ceramics and carbon nanotubes have also been used for this purpose.

Afzal et al. (2023), studied the heat transfer properties of the engine oil-based hybrid nanofluid. In this study, which aims to minimize entropy generation, carbon nanotubes and CuO_2 nanoparticles were used. In the obtained results, they found that when the concentration was 4% in both nanofluids, the rate of increase in heat transfer was 24% [8]. Du et al. (2023) studied the effect of graphene-based water nanofluid on surface tension and its change in heat transfer. In their results, they emphasized that the surface tension was lower in nanofluidics, and accordingly, the friction increased and the heat transfer coefficient increased [9]. In addition, in many studies, it is indicated that the concentration of nanoparticles in the base fluid increases the heat transfer coefficient at the right rate [10-12].

In addition to the type of nanoparticle used, it is also an important issue in which proportion they will be added to in the basic fluid (oil, water ethylene glycol, etc.). This parameter, called the concentration ratio, may not provide the expected performance if the prepared solution is not selected appropriately. Although the very high concentration would improve the thermophysical properties of the fluid, it would be a big problem for nanoparticles to combine and settle into larger solid particles during the study. Although surfactants are used to overcome the problem of precipitation, even this method is inadequate at very high concentration rates. However, the thermophysical properties of a nanofluid prepared at very low concentrations do not improve significantly and therefore there will be no comprise of a great benefit in terms of thermal properties. For this reason, in the process of preparing nanofluid, it attention should be given to determine the optimal values of both the type of nanoparticle and the concentration rate.

In this study, heat and flow analysis of the oil layer circulating performed in the journal bearings for the removal of heating problems in the journal bearings. In addition to, in the Ansys Fluent software, analysis performed by Computational Fluids Dynamics approach are discussed. Initially, heat and flow analysis were made by considering the thermophysical properties of the oil (Mobile DTE Heavy Medium 68) used on the present bearing model and it was tried to determine where the overheating regions in the current condition. Then, in order to draw more heat from these regions, heat and flow analysis were carried out under the same working conditions using the work fluids obtained by adding nanoparticles into the oil fluid and called nano lubricant..

2. MATERIAL AND METHOD

Nanofluids prepared by the use of oil fluid such as oil, polyol ester, paraffinic mineral are called nano lubricants. Nano lubricants are often used in compressors used in refrigeration systems and in other industrial applications that serve as lubrication to improve performance rather than conventional lubricants [6].

The specific thermal characteristics of a material (specific heat, heat conduction coefficient, etc.) and its properties related to heat transfer and heat storage that included thermodynamic state changes are called thermophysical properties. Accordingly, nano-sized particles participating in the basic fluid to improve the thermal performance in the system where the fluid is used, cause the liquid to increase its properties such as thermal conductivity (heat conduction coefficient), specific heat, viscosity and density. In addition, the physical properties of the nanoparticles used (shape, size, breed, etc.), the concentration rate, the type of the basic fluid and the working temperature also have an effect on the thermophysical properties of the nanofluid solution. When the studies on this subject are examined, it generally increases the heat conduction coefficient and viscosity of the fluid in a way that is directly proportional to the concentration rate of the nanoparticles involved in the basic fluid, and, specific heat has been shown to increase or decrease depending on the type of particle. Similarly, it is another result observed that the nanofluid density increases with the increase of the nanoparticle concentration [7].

For this purpose, it is planned to conduct heat and flow analyses for nano lubricants prepared using both metallic (Al_2O_3) and non-metallic type material (SiO_2), so that it is aimed to determine which type of material is more suitable. In addition, for the purpose of examining the effect of the concentration rate, nano lubricants prepared in three different concentrations were taken into consideration for each material separately (by weight 3%, 7% and 10%). In other words, analysis was performed out for the Mobile DTE 68 oil and six nano lubricants circulating in the system (Al_2O_3-Mobil DTE 68 (%3); Al_2O_3-Mobil DTE 68 (%7) Al_2O_3-Mobil DTE (%10); SiO_2-Mobil DTE 68 (%3); SiO_2-Mobil DTE 68 (%7) ve SiO_2-Mobil DTE 68 (%10)). In this way, it is foreseen that the most appropriate values can be selected by comparing the results obtained under the same working conditions. Thermophysical properties of alumina and silica nanoparticles were presented in Table 1.

Table 1. Thermophysial properties of alümina and silica materials

Properties / Material	Alumina (Al_2O_3)	Silica (SiO_2)
Density (kg/m^3)	3970	2650
Thermal conductivity (W/mK)	40	0.03
Specific heat capacity (J/kgK)	765	1130

2.1. Numerical Modelling

First of all, in the analyzes to be made for the journal bearing area, the flow area of the oil that circulates in the region by drawing the geometric model in the ANSYS software Geometry module and forming the film layer during the study was determined. For this purpose, taking into account the actual bed geometry and dimensions in Figure 1(a), the geometric model given in Figure 1(b) was created. Numerical analysis solution method is taken into account only the region where the fat layer is formed (flow area), without considering the solid geometry during the modeling phase.

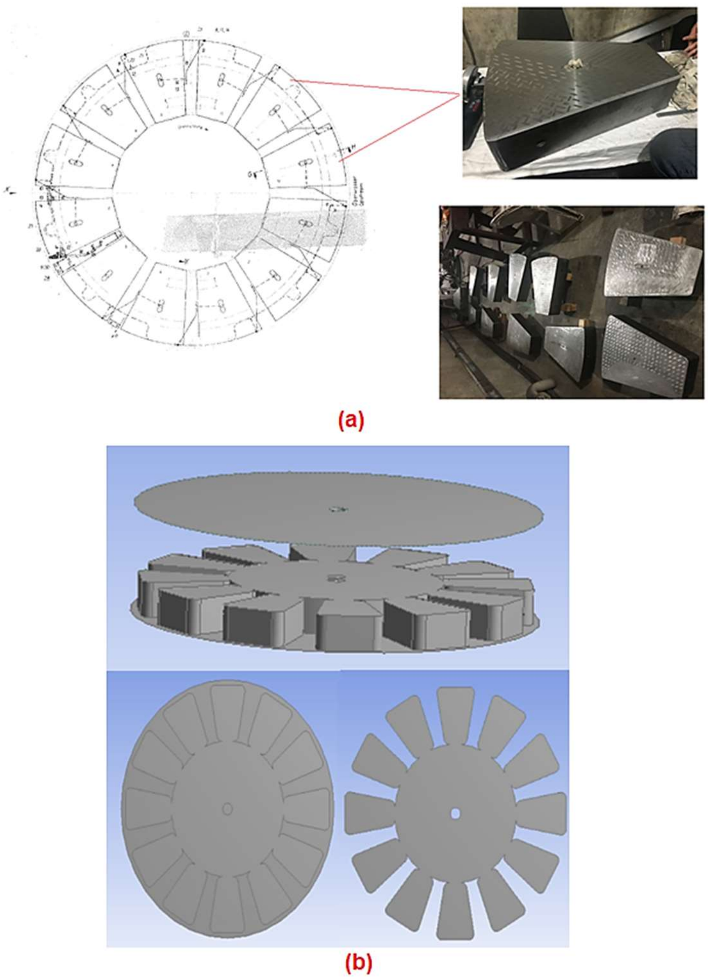


Figure 1. (a) Journal bearings and blocks used in the reference system (b) journal bearings and blocks in the modeled

In the modeling, the bearing diameter was taken 0.1138 m. The height of the flow area between the blocks and the bearing is determined as 0.02 m. Blocks are positioned at equal distances and 12 units as in the real system. The model was created so that each block has a height of 0.01 m, a length of 0.024544 m and a thickness of 0.018352 m.

After the creation of the model, the mesh structure creation process was completed with the Meshing module in ANSYS software. Images of the mesh structure created on the model are given in Figure 2. The created mesh structure contains 1442760 elements. In the mesh structure creation process, the mesh structure of tetrahedrons, which is used especially a lot and has relatively few sharp corners, is preferred. Each model was analyzed using mesh structures with the same number of elements and nodes.

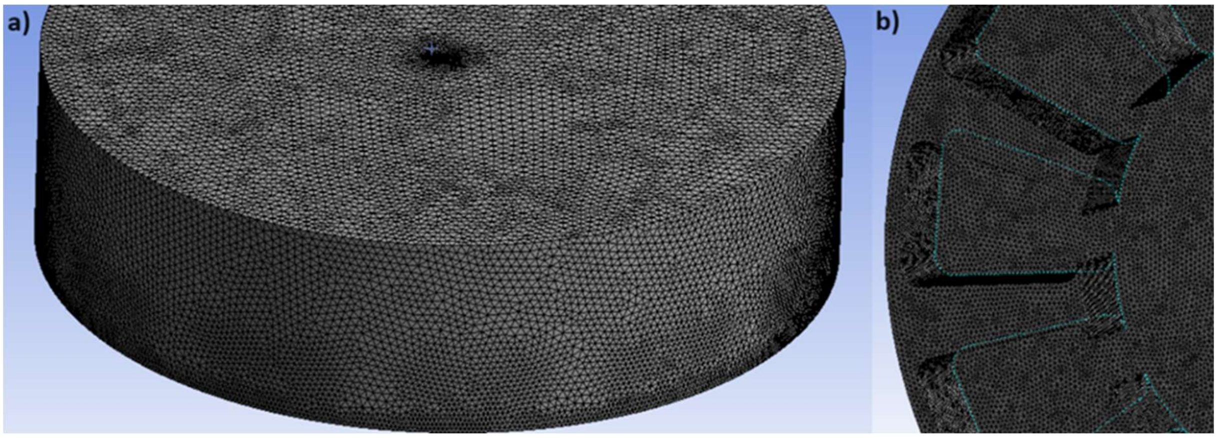


Figure 2. Views of the mesh structure created [(a) the journal bearing area, (b) the block area]

The mesh structure should consist of high-quality elements. Otherwise, it should be remembered that no results can be reached after the solution or that the results obtained should be considered suspicious in terms of their accuracy and reliability. In this context, the images showing the quality of the mesh structure created are given in Figure 3 and Figure 4. It shows that Figure 3 the element quality of the mesh structure, and Figure 4 the skewness (the distortion rate of the elements) values. It has been observed that the mesh structure created in the line of the data in the shapes is of appropriate quality (Eleman quality should be close to 1 and skewness value should be close to 0).

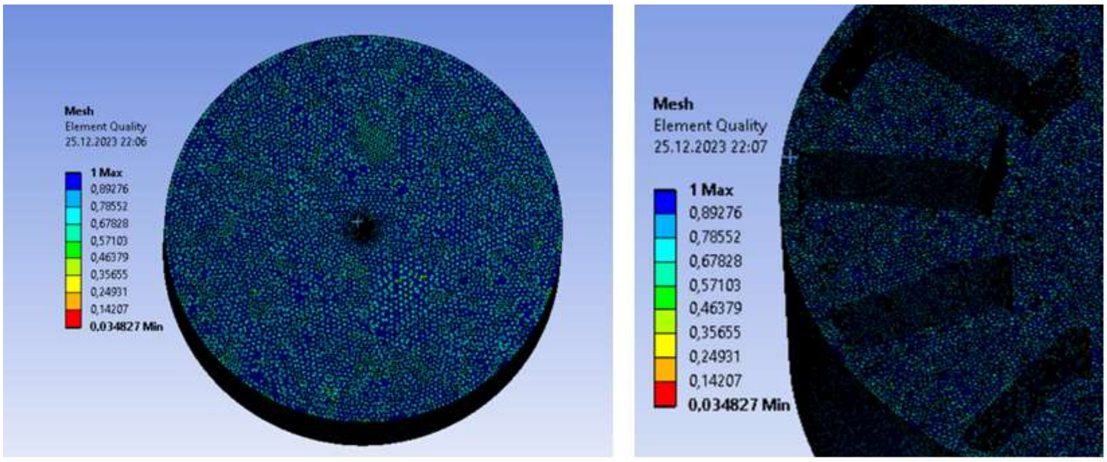


Figure 3. Element quality values of various regions on the model

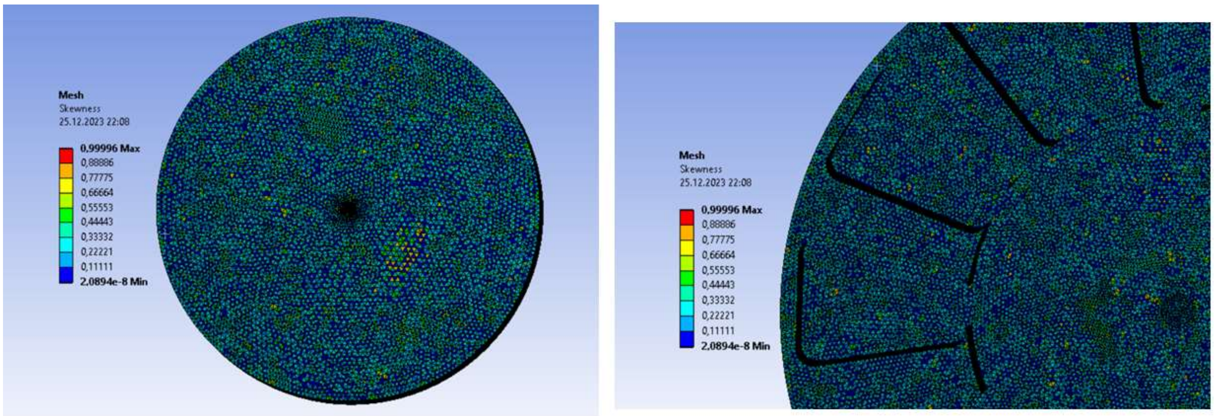


Figure 4. Skewness values of various regions on the model

After the mesh structure creation process, the initial and boundary conditions of the commercial HAD software are defined in the Fluent module. Since the Mobile DTE Heavy Medium 68 fluid circulating in the flow field and the nano lubricants prepared with this fluid are not available in the program library, the thermophysical properties of these fluids are added through new fluid identification. When calculating thermophysical properties, widely used and accepted theoretical links have been used in the literature [8-11]. The bearing material was taken as cast iron and the surface temperature was defined as 80°C.

Originally, analysis was conducted for the Mobile DTE Heavy Medium 68 fluid. The inlet temperature of the fluid into the system was taken 30°C, and the thermophysical properties of the fluid at this temperature were entered into the program [12]. Based on the actual working conditions and the mass flow rate of the fluid, the input speed of the fluid was calculated as 32 m/s and entered into the program. The analysis was performed under laminar flow conditions and using the SIMPLE algorithm. In the subsequent analysis, nanofluid identification was made taking into account the thermophysical properties calculated and calculations were carried out in the initial conditions mentioned above. Then all the results were compared and it was determined which model the best performance was achieved.

2.2. Theoretical Calculations

The density, heat capacity, thermal conductivity and viscosity of the nanofluid planned for use in the heat transfer process; it is very important to evaluate the advantage to be obtained from the nanofluid through numerical analysis. In this sense, the density of the basic fluid-based nanofluid can be calculated by the eq.1 [20]:

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_{np} \tag{1}$$

Here ρ_{nf} refers to the density of the new nanofluid developed. ρ_{bf}, ρ_{np}, $\emptyset$ refer to the density of the base fluid, the density of the nanoparticles and the volumetric concentration, respectively. In addition, the heat capacity, another important component, can be expressed with eq.2 [20]:

$$C_{p_{nf}} = (1-\emptyset)C_{p_{bf}} + \emptyset C_{p_{np}} \tag{2}$$

In equation 2, located Cp indicates that the specific heat of each material. Apart from this, equation 3 can be used to calculate the coefficient of thermal conductivity, which is the basic parameter for heat transfer. The equation 2 states the thermal conductivity for each type of material [20].

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2\emptyset(k_{np} - k_{bf})}{k_{np} + 2k_{bf} - \emptyset(k_{np} - k_{bf})} \tag{3}$$

In addition, to calculate viscosity, the eq. 4 can be benefitted from [20]:

$$\mu_{nf} = \mu_{bf}\,(1 + 2.5\emptyset) \tag{4}$$

For numerical analysis of the developed model, it is necessary to calculate the speed and pressure values in the three-dimensional plane. In this sense, the continuity equation under constant density and incompressible flow conditions can be expressed with eq. 5 [21]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial z}{\partial z}=0 \tag{5}$$

Accordingly, the momentum and energy equations in line x are indicated in the eq. 6 and 7 respectively [21]:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right) = \rho g_x-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(2\mu\frac{\partial u}{\partial x}+\lambda\vec{\nabla}.\vec{V}\right)+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right] \tag{6}$$

$$\rho C_P\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\vec{\nabla}k\vec{V}T+\varphi \tag{7}$$

φ given in both equations can be specified as energy source, C_P can be specified as the specific heat capacity of the material.

3. RESULTS AND DISCUSSION

The findings obtained as a result of the calculations were visualized with the help of the post-processing module of ANSYS Fluent™ commercial CFD software. For this purpose, temperature distribution contours of the flow area, that is, the oil layer, have been obtained.

The temperature distribution contour obtained as a result of the analysis of the conventional journal bearing system, is given in the Figure 5. The goal here is to get an idea of how much heat the oil draws from which regions. When the chart is examined, it is seen that the oil largely fulfills the expected cooling feature, but the heat transfer process is slower, especially in the base areas of the block, and the oil is ineffective in these regions. As a result of the analyzes, it was concluded that the fluid temperature (or the surface temperature of the block) is 68°C on average.

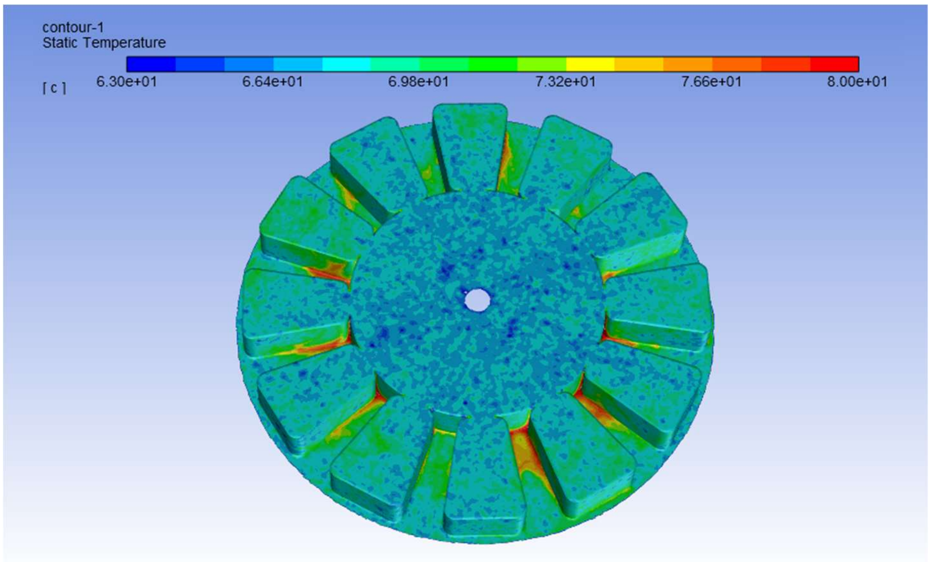


Figure 5. Temperature distribution as a result of analysis for mobile DTE Heavy Medium 68 oil

The temperature distributions obtained as a result of the analyzes made with the nano-lubricant prepared with alumina nanoparticles are presented in the Figure 6. For the Al_2O_3-Mobil DTE 68 nano lubricants, which contain 3%, 7% and 10% alumina nanoparticles by weight for easy comparison, the results are respectively Figure 6(a), Figure 6(b) and Figure 6(c) are given in. When the first result that out as the respective contours were examined, was a significant decrease in the average fluid temperature due to the increased nanoparticle concentration rate. In the light of the data provided by the program, the average fluid temperatures for Al_2O_3-Mobil DTE 68 nano lubricants containing alumina nanoparticles of 3%, 7% and 10% as weight are approximately 65°C, 65,6°C, 67°C. Here, it is seen that alumina nanoparticles, a metallic material with high thermal conductivity that is incorporated into the oil, significantly increase the heat transfer rate between the oil and block surfaces. In particular, the increase in the concentration of the added nanoparticle has been more effective on the heat transfer in direct proportion. As it is known, the viscosity values of the oil type fluids are greater compared to water and they have a tendency to increase the viscosity of the basic fluid that the nanoparticles are involved in. Here, the increased viscosity value by adding nanoparticles made a balanced fluid flow possible, preventing the viscosity of the oil whose temperature rises. Data in Figure 6 showing balanced distributed temperatures is the biggest indicator of this. In addition, it can be said that the viscosity of the oil increasing in temperature decreases, but the nanoparticles added to it raise the viscosity provides to the optimum working condition.

The temperature distributions obtained as a result of the analysis for the SiO_2-Mobile DTE 68 nano-lubricant are given in the Figure 7. As mentioned earlier, a series of analyses were conducted to investigate how the use of a non-metal nanoparticle in nano-lubricant preparing would perform. Results for SiO_2-Mobile DTE 78 nano-lubricant containing silicon dioxide (SiO_2) nanoparticles at 3%, 7% and 10% as weight, are shown in the Figure 7(a), Figure 7(b) and Figure 7(c), respectively. When the relevant contours were examined, it was observed that there was an improvement in heat transfer with the use of silicon dioxide nanoparticles, the fluid was able to draw more heat from the block surfaces. Using silicon dioxide nanoparticles with lower thermal conductivity compared to alumina nanoparticles is a result that the heat transfer rate is expected to be slightly less. In line with the data provided by the program, average fluid temperatures for SiO_2-Mobile DTE68 nanoparticles containing %3, 7% and 10% as weight, measured approximately as 65,8°C, 65,2°C and 64,1°C, respectively. In addition, by using silicon dioxide nano lubricant, the surface temperature was reduced by a maximum of 4°C compared to the conventional oil circulating in system.

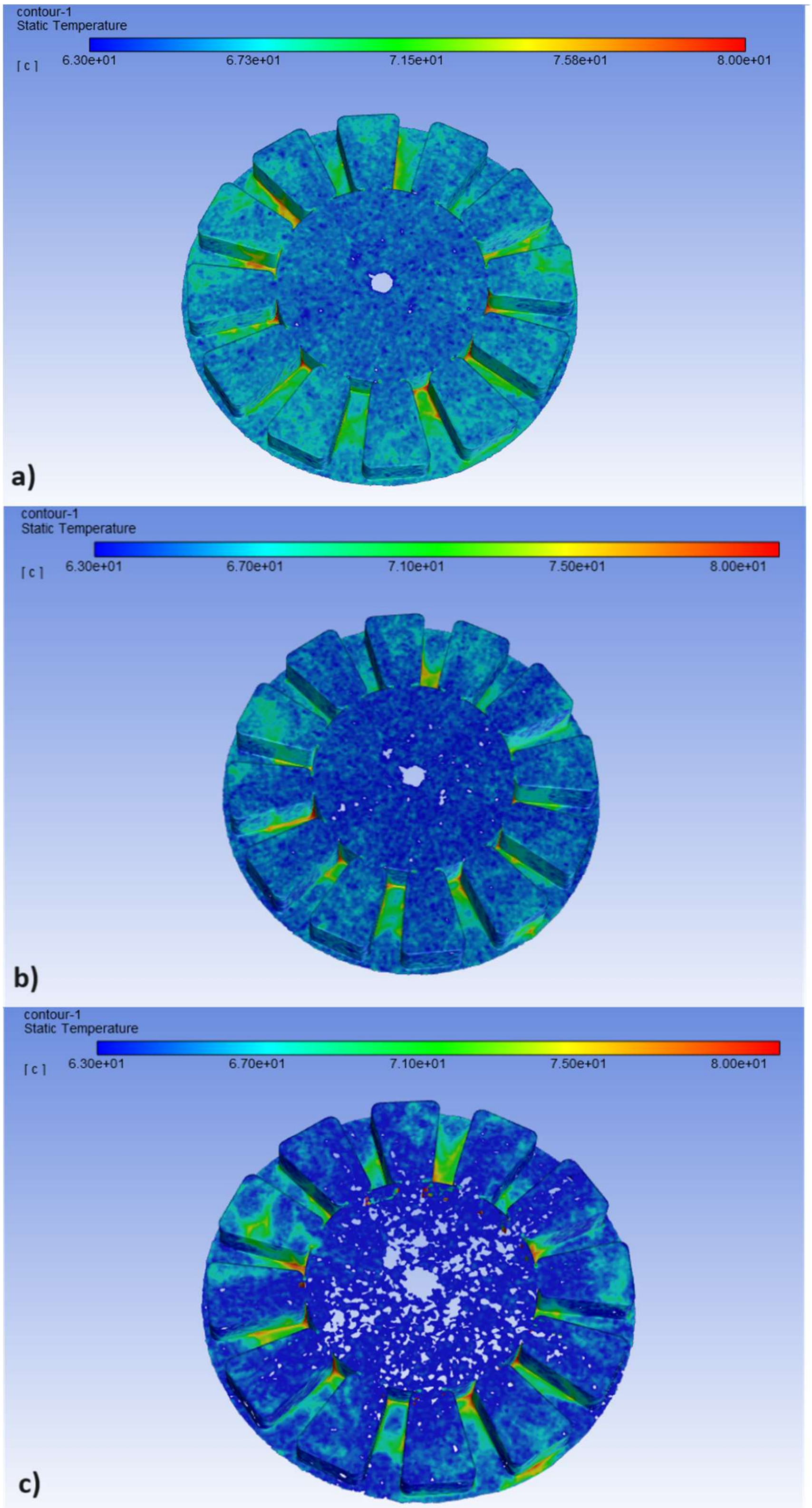


Figure 6. Temperature distributions obtained as a result of the analysis for nano lubricants (Al_2O_3-Mobile DTE 68) containing (a) 3%, (b) 7% and (c) 10% alumina

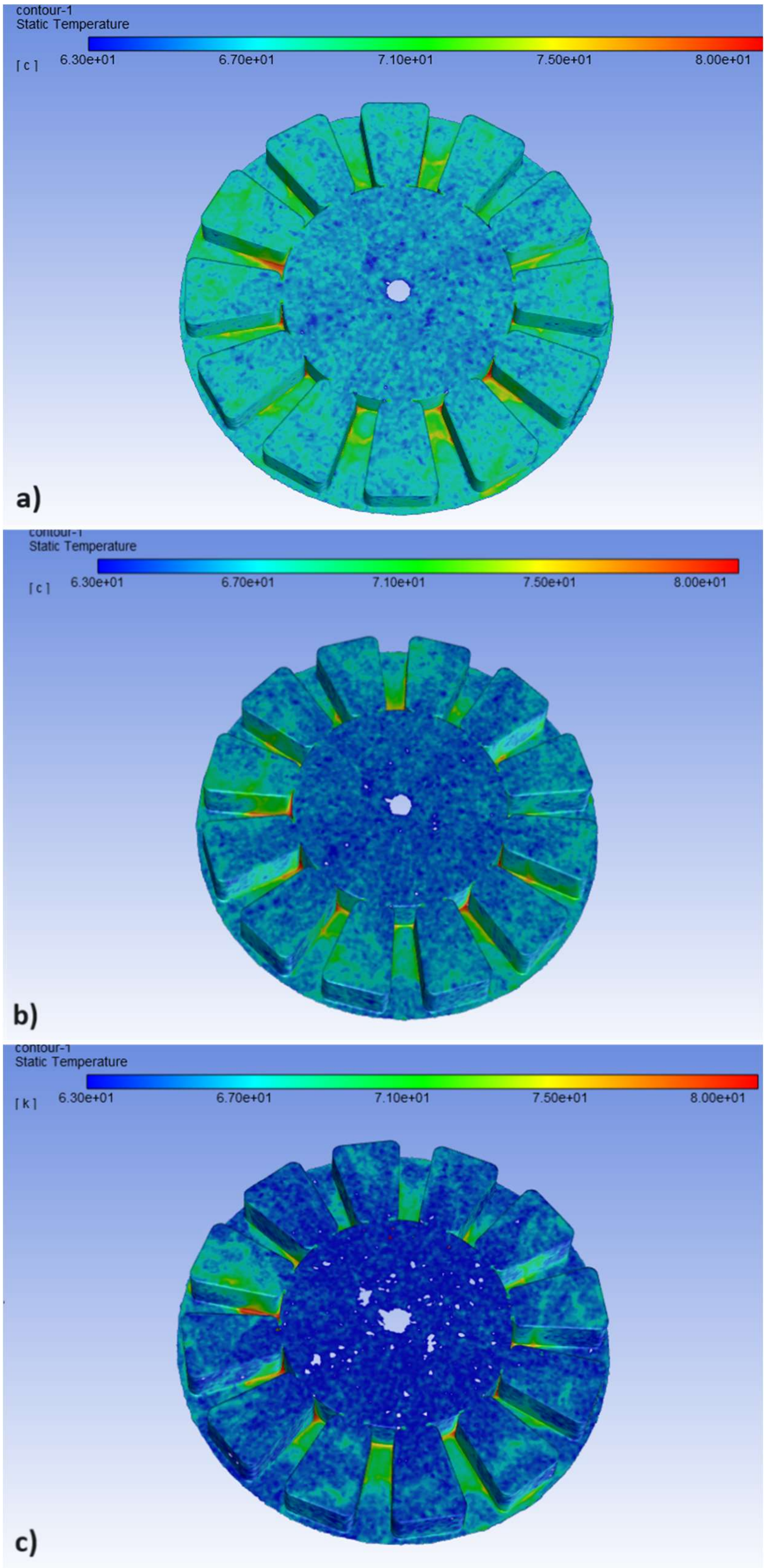


Figure 7. Temperature distributions obtained as a result of the analysis for nano lubricants (SiO_2-Mobile DTE 68) containing silicon dioxide by weight (a) 3%, (b) 7% and (c) 10%

In order to examine the changes in the blocks floor regions where the temperature values are higher in Figure 5, Figure 6 and Figure 7 more clearly, the temperature distributions of these regions are presented in Figure 8, Figure 9 and Figure 10. The contour given in Figure 8 shows the temperature distribution of the block underside regions obtained as a result of the analysis for Mobil DTE Heavy Medium 68 oil. Figure 9 and Figure 10 are temperature distributions of the bite bottom regions obtained as a result of analysis for Mobil DTE Heavy Medium 68 oils with alumina and silicon dioxide nanoparticles, respectively. The values in Figure 9 (a, b, c) and Figure 10 (a, b, c) represent data for each concentration ratio.

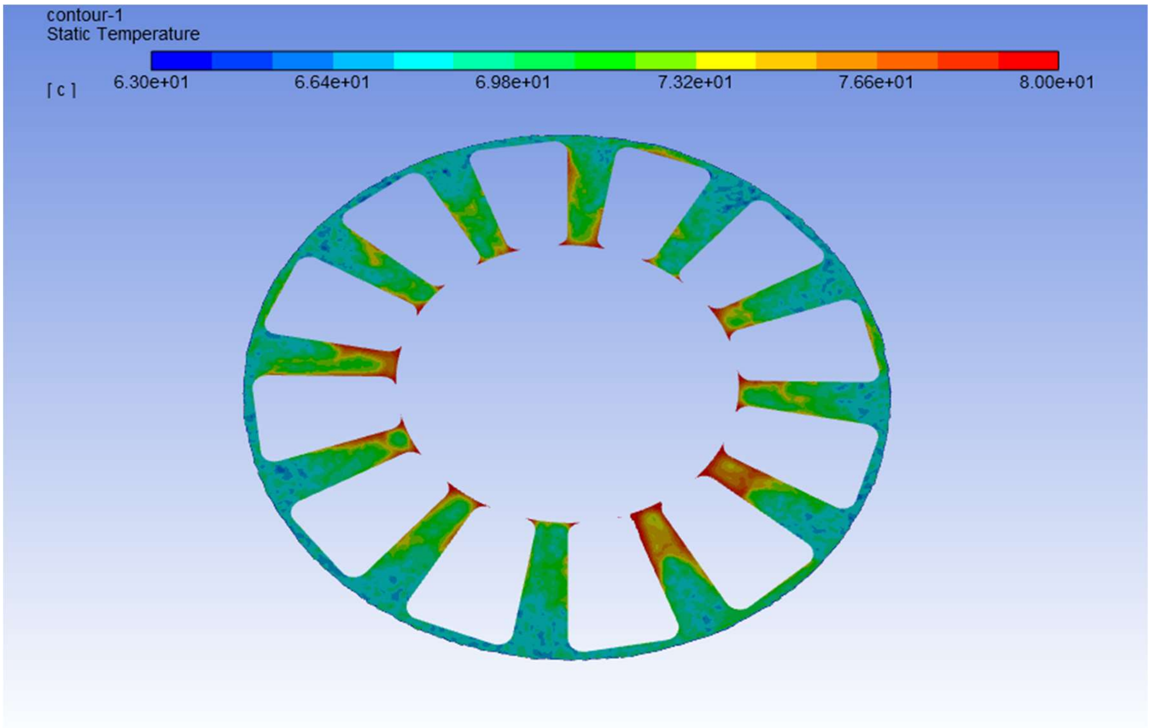


Figure 8. As a result of the analysis for mobile DTE Heavy Medium 68 oil, the temperature distribution obtained in the floor areas of the block

When the temperature distributions in Figures 8, 9 and 10 are examined, it is seen that it is possible to cool the hot regions formed in the base regions by adding nanoparticles to the oil regardless of the type of nanoparticle. In comparison to silicon dioxide, the use of alumina nanoparticles provided more efficient heat transfer and contributed to greater quantities of reduction of areas represented by the red color from which high temperatures are formed. Although it cannot provide complete cooling in all regions (especially sharp and narrow areas such as bed-locking junction points), considering that alumina nanoparticles lowers the average surface temperature by about

7°C, it is possible to say that oil containing alumina nanoparticles can be used to solve the heating problem.

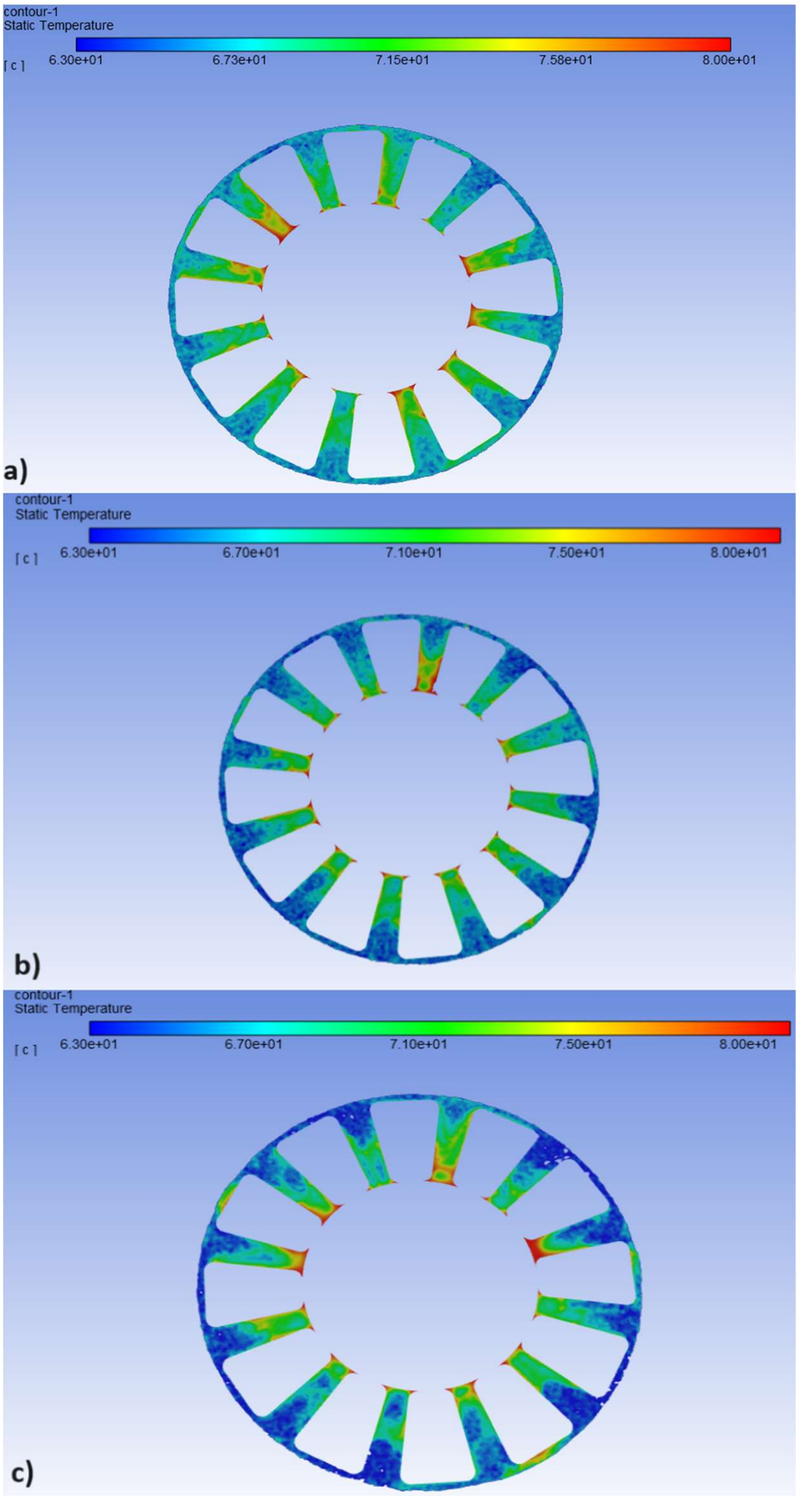


Figure 9. Temperature distributions obtained at the base sites of the blocks as a result of the analysis for nano lubricants (Al_2O_3-Mobil DTE 68) containing alumina by weight (a) 3%, (b) 7% and (c) 10%

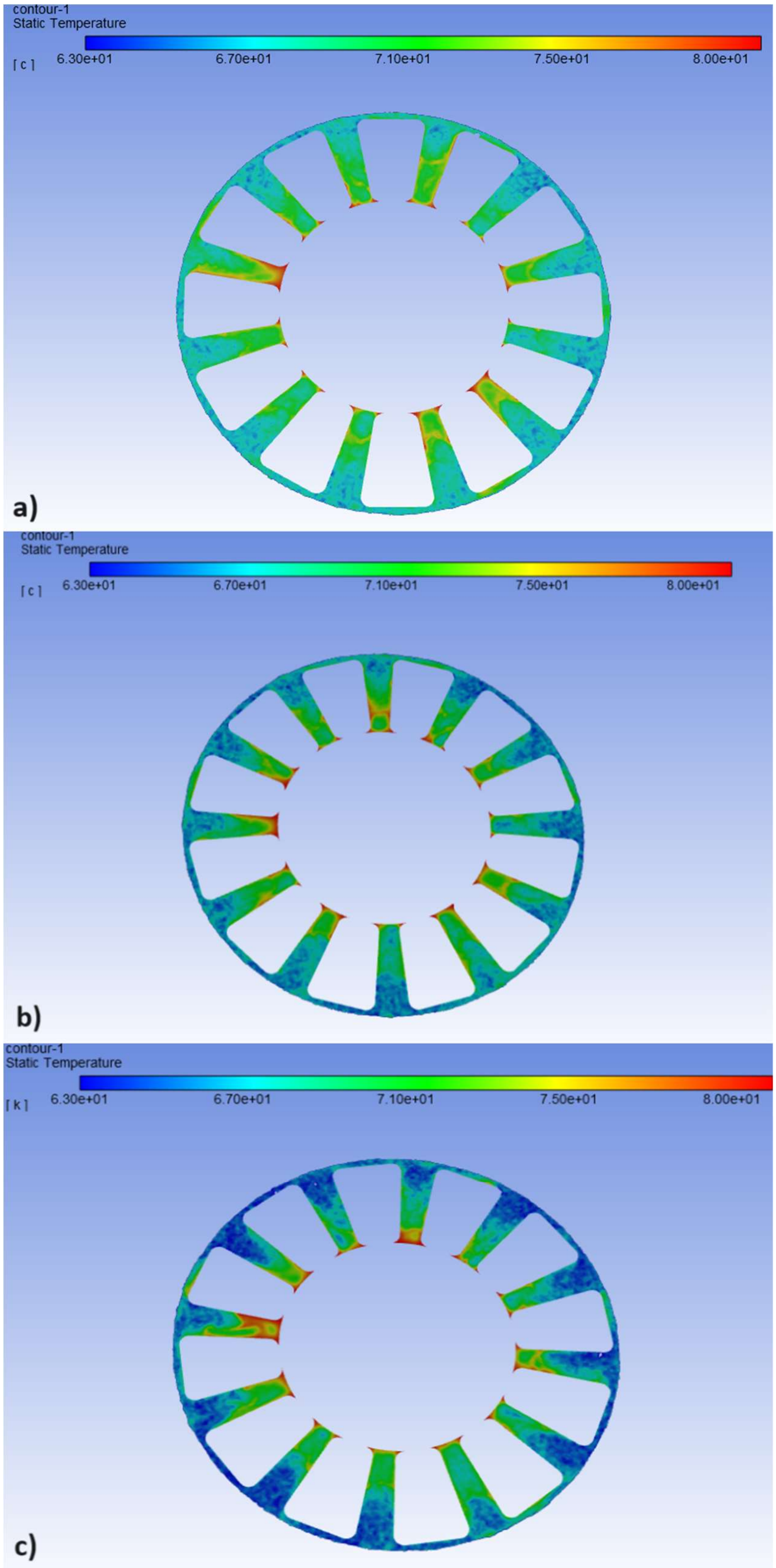


Figure 10. Temperature distributions obtained at the base sites of the blocks as a result of analysis for nano lubricants (SiO_2-Mobile DTE 68) containing silicon dioxide by weight (a) 3%, (b) 7% and (c) 10%

4. CONCLUSION

In this study, Mobil DTE 68 oil circulating between journal bearing and blocks and Al_2O_3-Mobil DTE 68 and SiO_2-Mobile DTE 68 obtained by adding alumina and silicon dioxide nanoparticles to this oil at different concentrations The results of heat and flow analyses for nano lubricates have been shared.

- As a result of the analyzes made in the conventional system where Mobil DTE 68 oil is used, the surface of the block that reaches high temperatures such as 80°C during operation can be reduced to about 68°C values, however, it has been observed that high temperatures can not provide effective cooling especially in sharp and narrow areas such as bed-locking compounding zones. This conclusion confirms that the Mobil DTE 68 oil, which has been used in the plant for many years, has greatly ensured its self-anticipated cooling and lubrication properties.
- As a result of the analysis for the Al_2O_3-Mobil DTE 68 nano-lubricant created with the idea of adding alumina nanoparticles into the mobile DTE 68 oil, the block surface temperature can be reduced to 61°C levels as compared to the conventional system.
- Similarly, the analysis of the SiO_2-Mobile DTE 68 nano-lubricant, created with the idea of adding silicon dioxide nanoparticles into the Mobil DTE 68 oil, reduces the temperature of the block surface to 64°C grades compared to the conventional system. As a result of the examinations made especially region of combination of block-journal bearing, it has been observed improved to heat transfer that the use of nano lubricant in these regions where the heat transfer rate in the conventional system is very low.
- When a general assessment is performed, adding metal-based nanoparticles such as alumina to Mobil DTE 68 oil will greatly increase the heat transfer rate and ensure in a more efficient heat transition in regions where high temperatures are formed.

For further studies, it is suggested that nano lubricants consisted of metal or metal oxide-based nanoparticles can be used to enhance the heat transfer performance. Besides, hybrid nano lubricants of binary or triple nanoparticles can also be preferred for this purpose.

ACKNOWLEDGMENT

This study was supported by YÖK-EÜAŞ Cooperation, Energy Academy Programme (Project No: 202308).

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Murat Öztürk: Performed the simulation, analysed the results and wrote the article.

Erdem Çiftçi: Supervised, edited and controlled the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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