Surface Temperature Distribution Aluminum Block with Cone Tube Profile Calculated Using ANSYS Fluent

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Abstract. Thermal Cycler is the main part of the Polymerase Chain Reaction (PCR), which becoming a gold standard for Covid-19 diagnosis. The virus multiplication in order to a detectable concentration is done by placing the virus solution at a deterministic temperature cycle. The solution is placed in a small tube inserted in a temperature block. Temperature distribution of the thermal block is important to make all the tube with sample treated at the same at desired target temperature. Study on the thermal block made of aluminium 7075 was simulated using fluid dynamic finite element method. Heating and cooling to the target temperature was done by providing heat source and heat absorber. The temperature distribution on the surface was mapped. The temperature gradient perpendicular to the heat source was calculated. Assuming the environment of the thermal block was still air, the heating and cooling speed at given heat source and heat removal were calculated using the model. The temperature gradient from the top surface to the bottom surface is less than 2.5°C. The temperature difference among point at the surface is less than 0.1°C.

1. Introduction

In the polymerase chain reaction (PCR) system, thermal cycler is the core of the instrumentation system. The thermal cycler works to multiply the number of the specific DNA sample. The process was conducted by cycling the DNA in a specific sequence of temperature. To do the process, the thermal cycler requires a heating and cooling system with appropriate electronic control system. Currently, the heater and cooler element is implemented using a thermoelectric. The thermoelectric is placed in the bottom of a thermal block where the DNA in tubes is placed. During heating, the heat is transferred from the thermoelectric to the thermal block, and during cooling the heat is removed by the thermoelectric from the thermal block.

The importance factor of the thermal block is the temperature distribution [1] and the speed of the temperature change from each step of the thermal cycling process. Aluminum is light, has a good specific heat, thermal block, easy to be profiled and cheap. Material such as silver and gold has higher heat transfer, but much more expensive. A low-cost thermal cycler has a temperature ramp up to 1°C/s. However, the temperature ramp is not only depending on the thermal block material, but also the heat source and the thermal block profile. Material with high heat transfer or lower specific heat is good to
achieve shorter time to change the temperature. One also developed a microtube for faster thermal cycling [2].

Temperature in the chamber should be maintained at a homogeneous temperature as possible to make biochemical reactions during the DNA multiplication works. Therefore, temperature distribution of the thermal block is critical. Commonly the thermal block of the PCR reaction chamber's has a temperature different during the heating or cooling process [3]. The thermal block also has a temperature gradient as the heat source is placed only in one side of the thermal block.

This simulation works was carried out using Fluent in ANSYS to estimate the temperature distribution of aluminium thermal block on the thermal block surface. ANSYS Fluent known as a good tool for simulating a dynamic heat system transfer [4]. ANSYS is used as shows a good tools for thermal analysis such as used for simulating a heat transfer and thermal distribution of various heaters [5], simulate thermoelectric element cooler TEC in cooling [6]. Other thermal analysis using ANSYS can be found in many papers [5,7].

2. Simulation Method and Setting
The aluminum block design was constructed with a based dimension of 40mm×40mm with a thickness of 2mm. On top of the base, with a dimension of 36mm×36mm and thickness of 10mm the tube placement hole was made. The system aluminum block design and the meshing in ANSYS is presented in Figure 1. The tube place is a cone shape with a top diameter of 5mm and a depth of 10mm and vertical angle of 17° according to the PCR mini tube. The aluminum property used in the simulation is listed in Table 1.

Finite Element analysis was performed using ANSYS Fluent. The mesh used is made with the tetrahedron method which has a 0.8 mm relationship in the thermal block. Whereas in the atmosphere, the mesh has a resolution of 1.5 mm in the area close to the surface of the thermal block to 3 mm in the atmospheric area farthest from the thermal block. This meshing method produces a mesh with 873530 nodes and 623390 elements. The mesh on the thermal block can be seen in Figure 1.

![Figure 1. The aluminum thermal block model and meshing](image)

Table 1. Aluminum property used in the simulation

| Property                        | Value  |
|---------------------------------|--------|
| Density (kg/m3)                 | 2810   |
| Isotropic thermal conductivity (W/mK) | 196    |
| Specific Heat (J/KgK)           | 714.8  |
In the fluids, i.e., in the air, the energy transport equation is presented in equation 1. The first three variables in the equation show the energy transfer based on conduction, species diffusion, and viscous dissipation. In the aluminum thermal block, the energy transport equation is shown in equation 2, where in solid objects, energy only flows in the conduction process.

\[
\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\bar{v}(\rho E + P)) = \nabla \cdot (k_{\text{eff}} \nabla T - \sum_j h_j \bar{J}_j + (e_{\text{eff}} \cdot \bar{v})) + S_h
\]

(1)

\[
\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\bar{v} \rho h) = \nabla \cdot (k \nabla T) + S_h
\]

(2)

Where \( \rho \) = density, \( k_{\text{eff}} \) = effective conductivity, \( k \) = conductivity, \( T \) = temperature, \( h \) = sensible enthalpy, \( \bar{J}_j \) = diffusion flux of species \( j \), and \( S_h \) = Volumetric heat sources.

In this paper we present the temperature distribution after heating and cooling. The heating and cooling process is carried out by providing a heat flow of 60 W from the bottom of the thermal block. Heat is applied to elevate the thermal block temperature from 24°C (room temperature) to 95°C. After reaching 95°C, the system is cooled down to 55°C. Air flow variations around the thermal block are carried out. The first simulation was carried out without providing air flow around the thermal block. While the second simulation is done by providing an air flow with room temperature (24°C) from above the thermal block with a speed of 0.1 m/s.

3. Result and Discussion

The aluminium block's temperature data was taken after the aluminium block's surface temperature reached the target temperature. The body temperature of the block was taken. In the first simulation (no air flow), the heating process from 24°C to 95°C took 34s. The maximum temperature is at the bottom of the thermal block which is close to the heat source and the minimum temperature is at the top of the thermal block as shown in Figure 2.

The heat transfer within the thermal block and the thermal block to the air took place. The hottest part at the base is at the corner of the aluminum which reached 97.7°C. The coolest place is in the surface center. The heat which came homogeneously from the bottom side conducted in the aluminum body. As at the point contact with air the heat transfer is low, the heat is accumulated at the edge horizontally. In the vertical direction, the temperature gradient is as expected. The temperature at the bottom is higher than at the top. This result is different from the simulation result done using finite FEA without considering thermal contact at steady state [8], further validation and proof need to be done experimentally.

![Figure 2. Surface temperature distribution at still air after 34s](image-url)
Surface temperature distribution on top of the aluminium thermal block where the tube will be placed is presented in Figure 3. The coolest temperature is 95.2°C around the central hole. In a horizontal direction, the temperature difference is less than 0.3°C. The temperature difference at the tube placement wall is around 1°C with the highest temperature in the bottom of the tube wall. It can be understood as the position of the bottom tube wall is the closest to the heat source in the bottom of the aluminum block.

Figure 3. The temperature distribution at the top surface of aluminium block after heated at 95°C

Based on other work [9] it is expected that the closest position to the heat source will have the highest temperature. The temperature distribution at the edge surface of the aluminium block is presented in Figure 4. It can be seen that at the same distance to the bottom, the temperature is lowest at the centre position in the horizontal direction, and highest at the edge. In the vertical direction, the temperature is highest at the closest position to the heat source (bottom) and lowest at the top.

Figure 4. The temperature distribution at the edge surface aluminium block after heating at 95°C

The second stage of the thermal cycler is the cooling to 55°C from 95°C. The heat released from the bottom of the aluminum block with a heat flow of 60W. The temperature distribution was taken when all points in the surface at a temperature lower than 55°C. The cooling process takes 20 seconds to reach the surface temperature below 55°C. Figure 5 shows the surface temperature of the aluminum thermal block after cooled to 55°C. The highest temperature at the surface was 54.91°C. At the same height to the bottom of the aluminum block, the highest temperature is at the center of the aluminum block, whilst the temperature lower at the edge. The coolest temperature is at the corner of the aluminum block. It can be seen both in the top surface as well as in the base part of the aluminum block. Temperature difference at the same distance to the bottom is less than 0.5°C.

In the tube wall, the maximum temperature difference in the vertical direction is less than 1°C with the coolest one at the bottom position. It is expected as the bottom of the tube wall is the closest position
to the bottom of the aluminum block where the heat is released. The result is obvious as the heat transfer by conduction is position dependent to the place where thermal energy is given or taken.

![Temperature distribution image](image1)

**Figure 5.** The temperature distribution at the top surface of aluminium block after cooled at 54°C

The temperature distribution at the edge surface of the aluminium block is presented in Figure 6. At the same distance to the bottom, the temperature is highest at the centre position in the horizontal direction, and lowest at the edge. In vertical direction the temperature is highest at the top and lowest at the bottom. Comparing the temperature distribution between the Figure 4 and 6, it can be seen that at the edge the temperature change is biggest. The lowest temperature change is at the centre of the aluminium block.

![Temperature distribution image](image2)

**Figure 6.** The temperature distribution at the edge surface aluminium block after cooling to 55°C.

The temperature profile taken by the simulation shows that the temperature of the aluminium block at the top surface and at the edge is not at the same value. There is a gradient temperature along the vertical direction as well as at the horizontal direction on the surface. Therefore, in the real design of the temperature block, the placement of the temperature sensor should be chosen carefully to obtain the best position to minimize the temperature deviation to the target temperature.

4. **Conclusion**

Temperature distribution at the surface of an aluminium thermal block with tube profile, which is intended for thermal cycler heating cooling block, has been simulated using ANSYS Fluent. The result shows that there is a temperature different at the surface of the aluminium block both at the top surface and the edge surface. During the heating process, the highest temperature is at the corner edge of the aluminium block. During the cooling process the lowest temperature is at the corner of the aluminium block.
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