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Research Article

Investigation Of The Effect Of Changing Air Flow Velocities In Electric Vehicles On Cylinder Geometry Battery Based On Computational Fluid Dynamics (CFD) Analysis

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Abstract

With the decrease in popularity of internal combustion engine vehicles in today's globalizing world, the engineering and scientific world are working to develop alternative vehicles for these vehicles. These stand out as hybrid and electric vehicles. Electric vehicles have zero emissions, costs, fuel consumption, etc. has an advantage in matters. Besides these advantages, scientists focused on these issues on the disadvantages of the range problem and the battery pack. Especially the battery thermal management system is one of these issues. The basic parameters to be focused on in the battery thermal management system can be listed as cell geometry, cell array within the battery pack, cell material, refrigerant, refrigerant inlet flow rate. Cell geometries investigated in the literature are seen as cylinder, prismatic and envelope type. Cylinder geometry design was chosen in this study. The cells are arranged in a 4x4 shape inside the battery pack. Steel has been assigned as the cell material. The refrigerant has been selected as air. The design in the research was made via CatiaV5R20. The analyzes are simulated using ANSYS CFD. The purpose of this research is to discuss to what extent different inlet air flow rates affect cell heating or cooling of cells. As a result of the research, it has been observed that the temperature of the cells decreases with the increase in the inlet air flow in the cylinder cells with different sizes and has a positive impact on the thermal system.

Keywords: Electric vehicles, thermal management system, computational fluid dynamics (CFD).

Elektrikli Araçlarda Değişen Hava Akış Hızlarının Silindir Geometri Bataryası Üzerindeki Etkisinin Hesaplamalı Akışkanlar Dinamiği (CFD) Analizine Dayalı Olarak İncelenmesi

Öz

Günümüz globalleşen dünyada içten yanmalı motorlu araçların popüleritesinin azalması ile birlikte mühendislik ve bilim dünyası bu araçlara alternatif araçlar geliştirme yönünde çalışmalar yapmaktadır. Bunlar hibrit ve elektrikli araçlar olarak öne çıkar. Elektrikli araçlar sıfır emisyon, maliyet, yakıt tüketimi vb. konularda avantaj sahibidir. Bu avantajların yanı sıra, menzil problemi ve batarya paketi konusundaki dezavantajlar üzerine bilim insanları bu konulara odaklanmıştır. Özellikle batarya ısıl yönetim sistemi bu konuların başında gelir. Batarya ısıl yönetim sisteminde odaklanılması gereken temel parametreler, hücre geometrisi, batarya paketi içerisindeki hücre dizilimi, hücre malzemesi, soğutucu akışkan, soğutucu akışkan giriş debisi olarak sıralanabilir. Literatürde araştırılması yapılan hücre geometrileri silindir, prizmatik ve zarf tipi olarak görülür. Yapılan çalışmada silindir geometri tasarımı seçilmiştir. Hücreler batarya paketi içerisine 4x4 şeklinde dizilmiştir. Hücre malzemesi olarak çelik atanmıştır. Soğutucu akışkan hava olarak seçilmiştir. Araştırmada tasarım CatiaV5R20 ile yapılmıştır. Analizler ANSYS CFD kullanılarak simüle edilmiştir. Bu araştırmanın amacı farklı giriş hava debilerinin hücre ısınması ya da hücrelerim soğutulmasını ne ölçüde etkilediğini tartışmaktır.

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Araştırma sonucunda farklı boyutlara sahip silindir hücrelerde giriş hava debisinin artmasıyla hücrelerin sıcaklığının azaldığı ve termal sistemi olumlu etkilediği görülmüştür.

Anahtar Kelimeler: Elektrikli araçlar, Isıl Yönetim Sistemi, Hesaplamalı Akışkanlar Dinamiği.

1. Introduction

Electric motors have been developed as an alternative to fossil fuel-based internal combustion engines, which have the largest share in the automotive and transportation sector due to the significant contribution of fossil fuels to environmental pollution. When electrical motors are evaluated, they can be defined as more environmentally friendly due to zero emissions.

The ability to store high amounts of fuel, long range, and the number of fuel stations are the advantages of internal combustion engine vehicles. There are also many disadvantages such as not being able to use renewable energy, causing global warming and environmental pollution with the use of fossil fuels, and fuel cost (www.muhendishane.org). Compared to internal combustion engines, electric vehicles have various advantages such as high energy efficiency, performance, and being more environmentally friendly by reducing fossil fuel dependence.

Electric vehicles have various advantages such as high energy efficiency, performance, and being more environmentally friendly by reducing fossil fuel dependence. Despite all these advantages, it cannot be said that electric vehicle technologies are still fully elaborate. Especially, in terms of the ideal battery geometry and array, the controller, electric motor and thermal management studies continue rapidly. The battery is likened to the heart of an electric vehicle. For this reason, many of the problems that cannot be overcome are still in the battery module. In the literature and in the field, the most concentrated battery operation issues are charging time, cost, vehicle driving range and thermal management (Tamaldin, Yamin, Abdollah, Amiruddin and Abdullah, 2020: 305-312).

When these advantages are considered and evaluated in the long term, according to the KPMG report dated 2015, the potential for electric new vehicle sales in the EU and China to be between 11-15% by 2025 was highlighted (Becker, 2015: 20). These estimates conclude that by 2025, there will be 20% of new electric vehicle sales in North America and 11 million EV sales worldwide (Keskin, 2009: 597).

However, it is of course important to eliminate the disadvantages in electric vehicles in order to realize these predictions. Regarding thermal management, which is the main theme of this study, it can be said that the temperature gradients that may occur between cells and within the inner layers of individual cells are of great concern.

Yang et al. demonstrated that temperature gradients between cells connected in a parallel array can exacerbate unbalanced discharge, and that as the cell-to-cell temperature gradient increases, the aging rate of the cell increases linearly (Yang, Zhang, Shang and Li, 2016: 733-741). Fleckenstein et al. conducted studies at the cell level. Through simulation, he found that temperature variations along the interior of individual cylindrical cells caused inhomogeneities in cell flow density. He concluded that this caused a local state of charge (SOC) imbalance within the cell (Fleckenstein, Bohlen, Roscher and Baker, 2011: 4769-4778). Troxler et al. further investigated the effects of intracellular temperature gradients. They noticed that cell performance under a temperature gradient was performing as if the cell was operating at an average volume temperature rather than as if it were operating at a higher average temperature than theoretically (Troxler et al., 2014: 1018-1025). However, Hunt et al. recently stated that temperature changes do not only negatively affect cell performance and aging. They also noted that the nature of the gradient could worsen the effect and should be carefully evaluated by energy storage systems engineers tasked with assembling individual components into complete battery modules or packages. Specifically, it has been found that vertical gradients to layers within the cell induced by surface cooling accelerate the overall rate of cell disruption compared to the case where the gradient is along each of the layers (ie in the plane) obtained from the bounce cooling (Hunt, Zhao, Patel and Offer, 2016: 1846-1852).

In order to be able to monitor the thermal process inside the battery pack, the CFD simulation method is widely used. This method is well developed and powerful in terms of applicability (Huang et. al., 2017: 4029-4036). In the late 1900s, Dickinson and Swan used CFD methods for various battery analysis in electric vehicles. They explained that the high temperature difference has a significant negative impact on the capacity of the battery pack. They suggested controlling the battery temperature in the range of 35 ~ 40◦C. (www.sae.org)

As seen in the studies in the literature, attention should be paid to the design of the thermal management system to ensure that the method in which heat is added to the cell or extracted from the cell does not create an inappropriate temperature gradient that could compromise the benefit of absolute temperature control. In addition, it appears that the extraction will maintain the optimum operating temperature that should be kept uniform. Considering these parameters, it is desired to keep the inlet air flow rates in the optimum range depending on the design in the thermal management system.

In this study, thermal analyzes were carried out according to 3 different models and 3 different air inlet flows in coils with 3 cylinder geometry. The cooling strategy was designed using thermal modeling method and the effect of different air inlet flow rates on the modeling was investigated.

2. Material and Method

2.1. Geometry Design

The geometry was designed in CATIA V5R20 in order to examine the battery thermal performance of different air inlet flow rates according to different diameters in cylinder geometry in electric vehicles, which is the main purpose of the study.

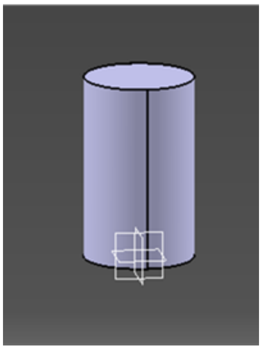

Figure 1. Design of cylinder battery cell

2.2. Geometry Types and Case Properties

As seen in the table below, thermal performance analyzes were made for each case by changing the diameters or areas. The height was kept constant at 70 mm in all casings. Analyzes were made in ANSYS Workbench 18.1 using the CFD module. Steel was chosen as the battery cell material and air was chosen as the coolant.

Table 1. Geometry Cases and Properties

Case of Cylinder Cell	Diameter (mm)	Number of Cell
Case 1	50	4x4
Case 2	45	
Case 3	40	

Along with these parameters, the inlet air flow rate was also examined in this study. It was investigated how the flow (air) velocity would affect the thermal performance and, accordingly, on the vehicle performance. Case and inlet flow rates are given in the table below.

Case of Cylinder Cell	Inlet Flow Rate (m/s)
Case 1	0.01
Case 2	0.015
Case 3	0.02

To express the table with an example from the literature, Tamaldin et al. proposed new designs to increase the cooling flow for battery modules, electric motor, and controller. The current air-cooled duct design caused overheating due to the low air velocity passing through it. Slotted ducts disturbed the airflow and the ideal cooling target was not achieved. Thus, low cooling efficiency was achieved with this design. With the new design they proposed, smoother surfaces were provided for smooth air flow at minimum resistance. Thus, better cooling efficiency was obtained (Tamaldin, Yamin, Abdollah, Amiruddin and Abdullah, 2020: 305-312).

3. Results and Discussion

CFD simulations with 3 different cylinder cell sizes and 3 different inlet flow rates are discussed in this section to decide on the optimum design for the battery. The analysis is based on the extent to which it can cool different sizes of battery cells at different inlet air flow rates.

3.1. Temperature Contour

In total, 3 models were created with 3 different diameters and 3 different air inlet flow rates.

3.1.1. Model 1

Diameter	50 mm
Height	70 mm
Element Size	0.02

Geometry properties are given below. For the first 3 different flow rates, the given dimensions are used.

a) v=0.01 m/s

The first model specified is the model consisting of 50 mm cylinders with the largest diameter. It consists of 4x4 cells. In this case of 0.01 inlet air flow, it was observed that the maximum temperature was seen in 4 cells at the air outlet.

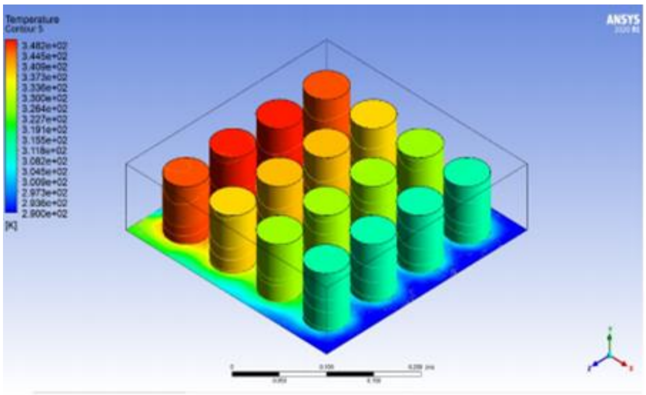

Figure 2a. Temperature Contour of Model 1a

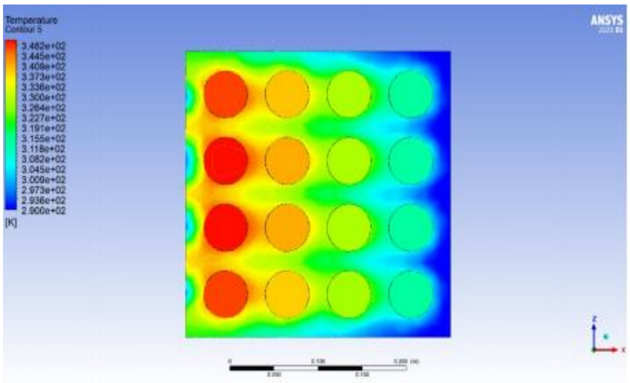

Figure 2b. Temperature Contour of Isometric View of Model 1a

b) v=0.015 m/s

In case 2 of Model 1, the package was analyzed in the same dimensions and order. The inlet air flow was determined as 0.015 m / s. Looking at the results, it was seen that the maximum temperature was in 4 cells at the air outlet.

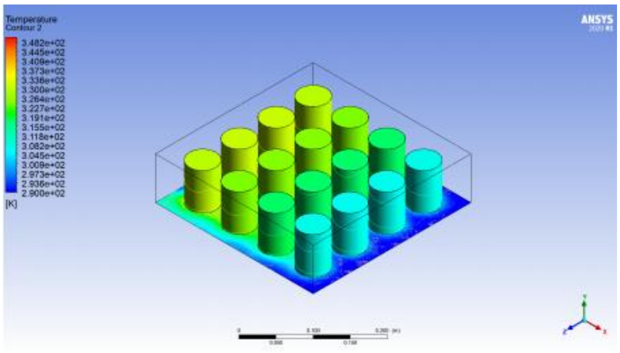

Figure 3a. Temperature Contour of Model 1b

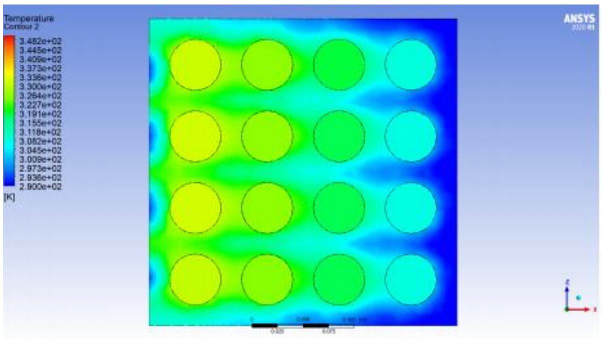

Figure 3b. Temperature Contour of Isometric View of Model 1b

Looking at the Model 1b results, it was seen that the maximum temperature in the outlet cells decreased compared to Model 1a as the inlet air flow increased.

c) v=0.02 m/s

In the 3rd case of Model 1, the package has the same size and order as the 1st and 2nd case.

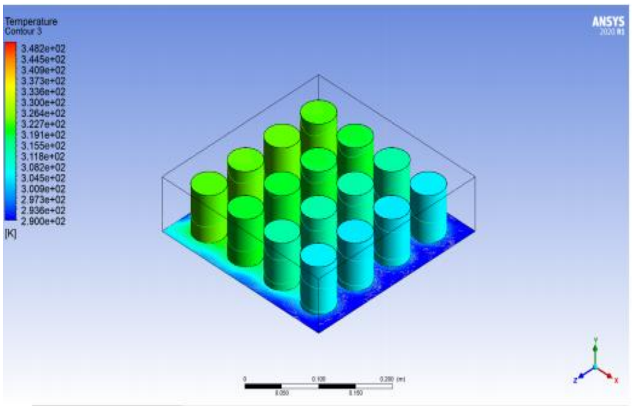

Figure 4a. Temperature Contour of Model 1c

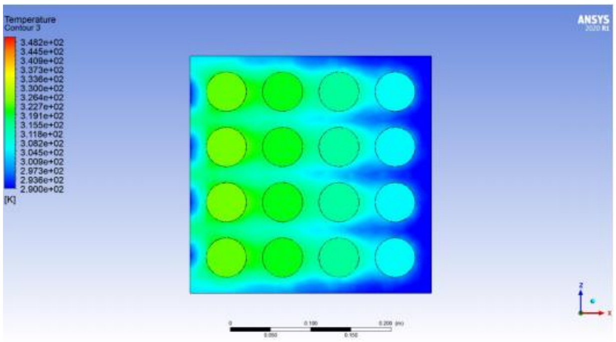

Figure 4b. Temperature Contour of Isometric View of Model 1c

Looking at the results of Model 1c, it was seen that the maximum temperature was in the outlet cells as in Models 1a and 1b. Furthermore, compared to Model 1a and 1b, Model 1c is said to give the best results with increased inlet air flow.

While 1c> 1b> 1a for inlet air flow rates, it was concluded that 1a> 1b> 1c for the maximum temperature in the battery cells.

3.1.2. Model 2

Geometry properties are given below. For the first 3 different flow rates, the given dimensions are used.

Diameter	45 mm
Height	70 mm
Element Size	0.02

a) v=0.01 m/s

The determined diameter for Model 2 is 45 mm, and the inlet air flow rate in the first casing was determined as 0.01 m / s.

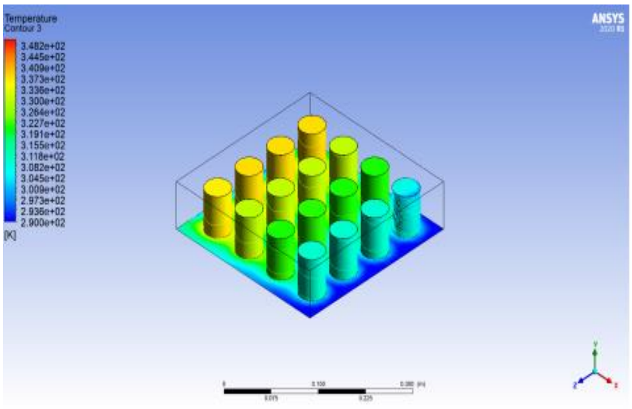

Figure 5a. Temperature Contour of Model 2a

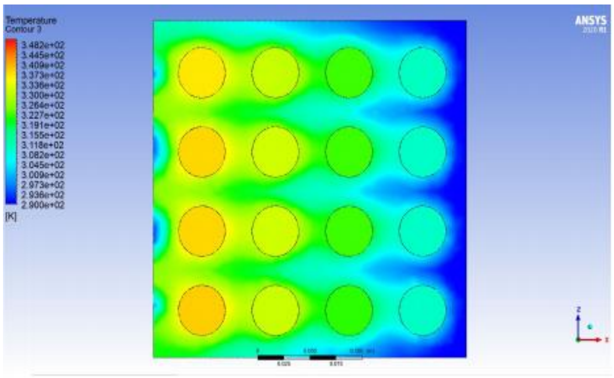

Figure 5b. Temperature Contour of Isometric View of Model 2a

It can be said that reducing the diameter in Model 2a facilitates the cooling of the cells. This is because, in Model 1a, it was concluded that the maximum temperature was higher despite having the same inlet air flow. However, as in the 3 case of the first model, the maximum temperature was seen in the outlet cells.

b) v=0.015 m/s

Model 2b is the same as Model 2a in terms of size and order. Only the inlet air flow was increased from 0.01 to 0.015 and the results were examined.

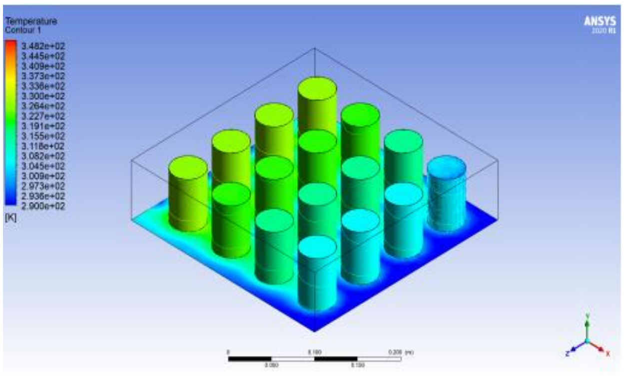

Figure 6a. Temperature Contour of Model 2b

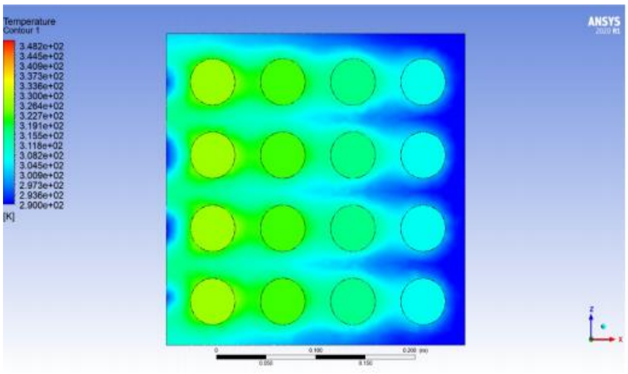

Figure 6b. Temperature Contour of Isometric View of Model 2b

When the analysis results are examined, the increase in the inlet air flow decreased the maximum temperature in the outlet cells compared to Model 1a. However, the outlet cells are the same as the cells with the highest temperature in the 4x4 order.

c) v=0.02 m/s

In the last case of Model 2, the inlet air flow was increased to 0.02 m / s without changing the size and order.

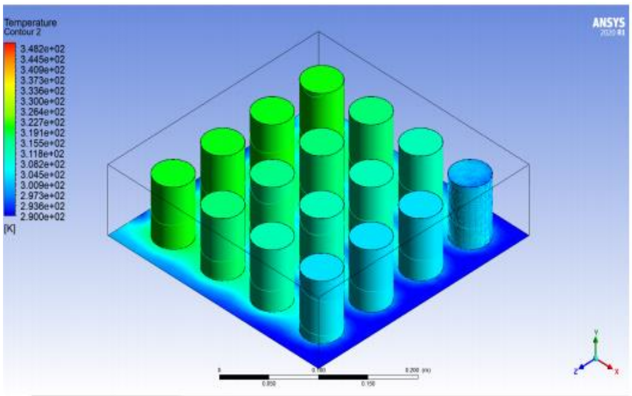

Figure 7a. Temperature Contour of Model 2c

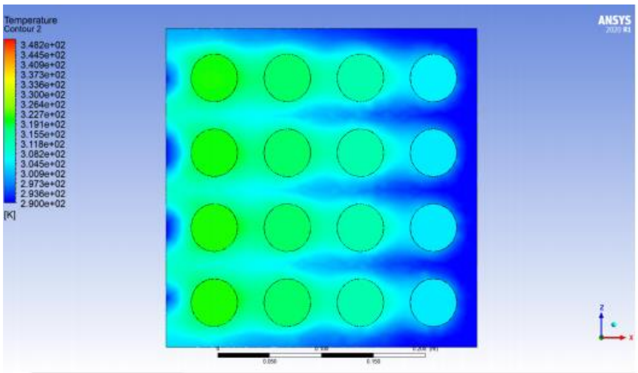

Figure 7b. Temperature Contour of Isometric View of Model 2c

Looking at the analysis results of Model 2 at three different flow rates, it was seen that Model 2c gave the best result. This is because it can be said that the inlet air flow is at the highest level, which affects the cooling of the battery more positively. When Model 1 and Model 2 are compared, it can be seen that decreasing the cell diameter gives more positive results for all 3 flow rates.

3.1.3. Model 3

Geometry properties are given below. For the first 3 different flow rates, the given dimensions are used.

Diameter	40 mm
Height	70 mm
Element Size	0.02

a) v=0.01 m/s

In Model 3, the latest model in cylinder geometry, the diameter was changed to 40 mm. As in the other 2 models, the first inlet air flow was analyzed as 0.01 m / s.

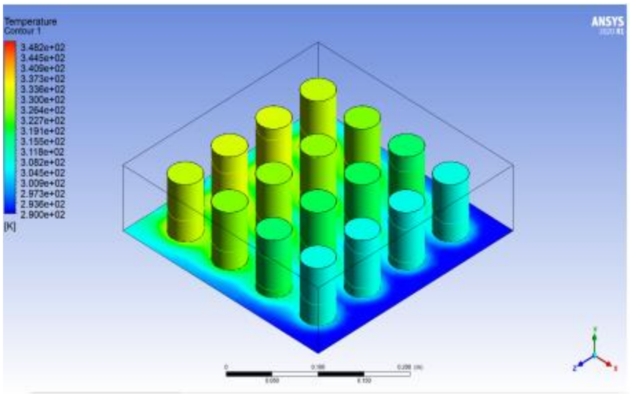

Figure 8a. Temperature Contour of Model 3a

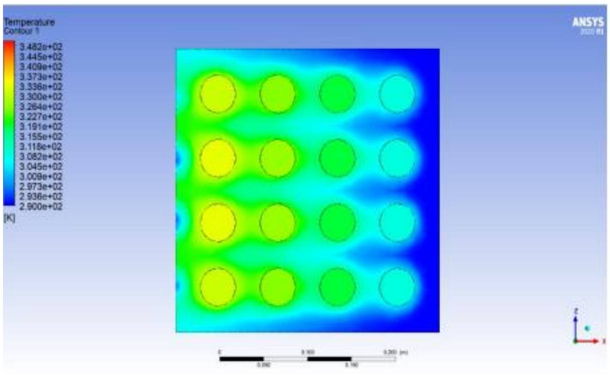

Figure 8b. Temperature Contour of Isometric View of Model 3a

When the first case of Model 3 was examined, it was seen that the temperature in the outlet cells was the cells that formed the maximum temperature of the pack, similar to the 6 cases examined so far. However, the reduction of the diameter in this model also affected the results more positively in parallel with the model 2.

b) v=0.015 m/s

The second case of the Model 3 has the same dimensions and features as the first and the flow rate is increased.

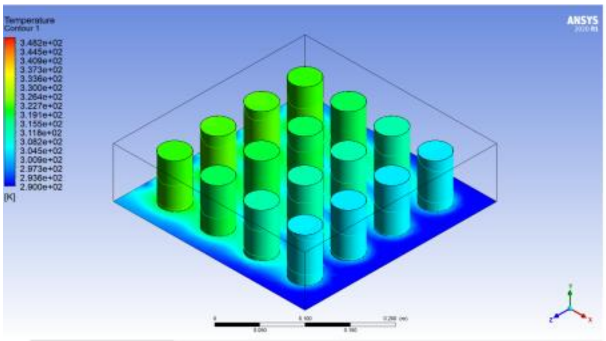

Figure 9a. Temperature Contour of Model 3b

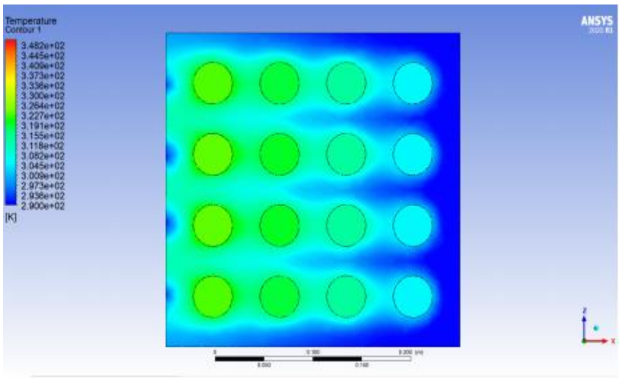

Figure 9b. Temperature Contour of Isometric View of Model 3b

As can be seen from the results, the model gave values that match with the other analysis results in 3b. In addition, the increase in the flow rate caused the maximum temperature to decrease and a result that could be considered closer to the ideal was found.

c) v=0.02 m/s

The analysis values found for both model 3 and the last of all analyzes are given below.

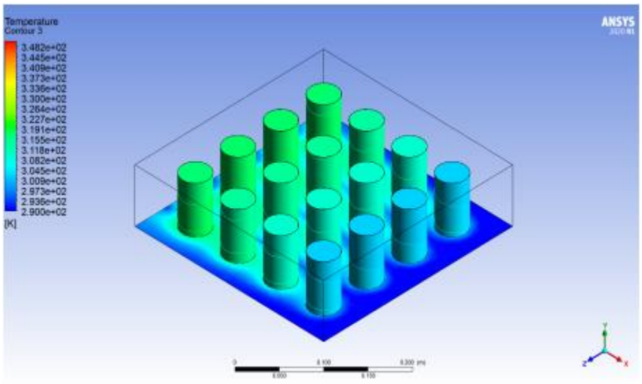

Figure 10a. Temperature Contour of Model 3c

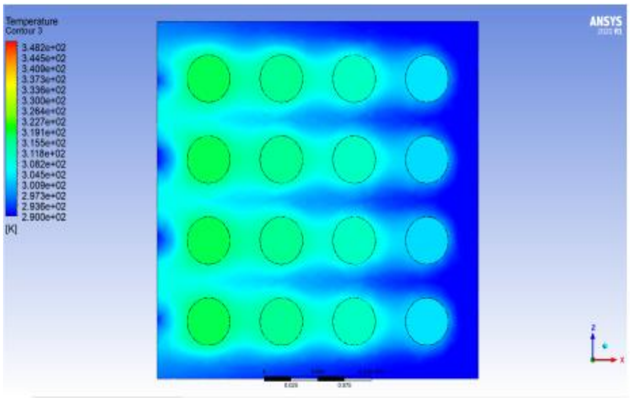

Figure 10b. Temperature Contour of Isometric View of Model 3c

It has been observed how different air inlet flow rates affect the thermal performance in 3 models with the same geometry. It has been observed that the higher the inlet air flow rates, the higher the thermal performance. The increase in flow caused the temperature rise of the cells to decrease. Looking at the model with the lowest flow, it was seen that the cells at the outlet level were overheated. However, as the inlet flow increased, it was observed that the thermal performance of the cells at the outlet level was almost as good as the cells at the inlet. When the cylinder cells were examined in terms of diameter, it was seen that the thermal performance was negatively affected as the diameter increased. When the same flow rates are compared, it can be said that the cells of the larger diameter model are more heated.

4. Conclusions and Recommendations

Different inlet air flow velocities have been investigated in different battery geometries in electric vehicles. For this purpose, a cylinder geometry design was made and the diameter of this geometry was changed and 3 different diameters were investigated. In the simulation modeling, thermal performance evaluation was made for 3 different models for 3 different air inlet flow rates. In this case, a total of 9 different results were found. When the results are examined, it is seen that the increase in inlet air flow rates has a positive impact on thermal performance. It is concluded that the lower the inlet air flow, the higher the outlet temperature and the less cooling the cells.

In addition to the main purpose of the study, it was possible to discuss how diameters affect thermal performance at similar flow rates. Since the increase in diameters increases the thickness of the cells, it can be said that the thickest cell at the same flow rate has the lowest thermal performance with the least cooling. Similarly, it was observed that the battery with the lowest diameter, that is, the thinnest battery, had higher thermal performance at equal flow rates.

As a result, it can be seen how important the inlet air flow is for the cells, regardless of geometry or size. The inlet air flow is one of the most important factors in cooling the cells in the battery pack. As the flow rate decreases, the cells get hotter and this affects the thermal performance negatively. However, determining the ideal inlet air flow rate keeps thermal management in balance and extends battery life.

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