Flow Characteristics of Nozzle Spray Cooling for Electric Vehicle Motor Using Discrete Phase Modeling

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분산입자 이상유동 모델을 이용한 전기자동차 모터용 노즐 스프레이의 유동특성

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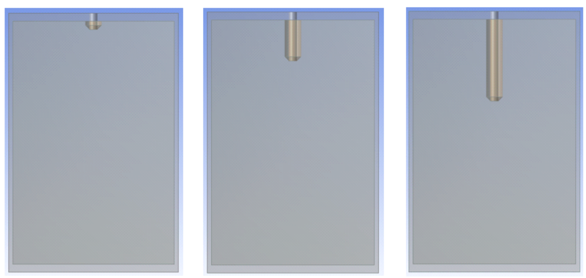
Abstract
The nozzle spray cooling performance is affected by the type of coolant, discharge rate and distance between the nozzle and heating surface. Therefore, in the present study, the flow characteristics of nozzle spray cooling are investigated under the influences of nozzle heights and volume flow rates. The spraying liquids of water and oil are considered with volume flow rates in a range of 2 LPM to 10 LPM. Three nozzle heights of original, 50 mm and 100 mm are considered for the investigation. The transient three-dimensional discrete phase model is developed to simulate the flow characteristics of nozzle spray cooling using ANSYS commercial software. The results reveal that the velocity of oil is superior to water whereas, the volume fraction is better for water compared to oil except at the volume flow rate of 2 LPM. The velocity and volume fraction of water and oil increase with increase in volume flow rate and nozzle height. The maximum velocities of 2.10 m/s and 2.15 m/s and maximum volume fractions of 0.0229 and 0.0218 are evaluated for water and oil, respectively.

1. Introduction

Nozzles atomize the liquid into fine droplets which are impacted on the heated surface to remove the heat through evaporation and convection [1]. Numerous research works have been conducted to remove the heat from high flux density components through spray cooling using different types of nozzles. The heat transfer rate using nozzle spray cooling could be enhanced by changing the flow characteristics such as, discharge rates, flow structures and droplet dynamics [2, 3]. Furthermore, the spray cooling performance is affected by nozzle and coolant types, height of spray between nozzle and applied surface and mass flow rate of coolant [4]. The velocity distribution in nozzle spray cooling is significantly affected by the distance between nozzle to surface [5].

2. Numerical model

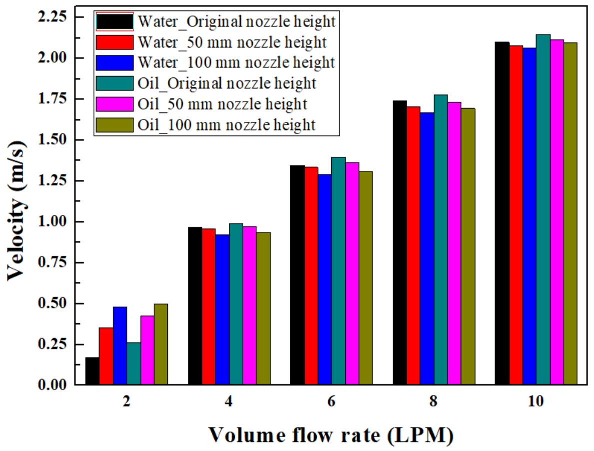
The flow characteristics of nozzle spray cooling are simulated using ANSYS commercial software. The computational geometry for numerical analysis is depicted in Fig. 1. The nozzle is placed at the top center of the spray chamber. Three computational models with original nozzle, nozzle with 50 mm height and nozzle with 100 mm height are considered as shown in Fig. 1. The water and NOVEC7500 mineral oil are investigated as the spraying liquids. The velocity distribution and volume fraction are evaluated as the flow characteristics for nozzle spray cooling. The governing equations describing continuous phase modeling and discrete phase modeling are solved to analyze the nozzle spray flow characteristics. The tetrahedron mesh element is considered as the meshing configuration. The mesh elements number of 286,800 is adopted for simulation. The five volume flow rates of 2 LPM, 4 LPM, 6 LPM, 8 LPM and 10 LPM are considered. The side and top walls are considered as adiabatic and bottom wall is exposed to the ambient.



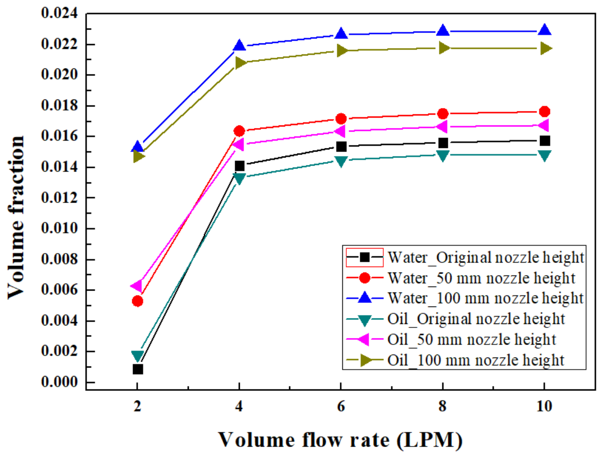
[Fig. 1] Three-dimensional geometry of spray chamber with different nozzle heights

3. Results and discussion

The velocity comparison of water and oil for three different nozzle heights and volume flow rates is shown in Fig. 3. The velocity increases for water and oil with increase in the volume flow rates for all nozzle heights. For all nozzle heights, the oil velocity is superior compared to water velocity. For volume flow rate of 2 LPM, the velocity increases with increase in nozzle height for both water and oil. However, for remaining volume flow rates, the velocity decreases as the nozzle height increases. The water velocity ranges as 0.17~2.10 m/s, 0.35~2.08 m/s and 0.48~2.07 m/s and oil velocity ranges as 0.26~2.15 m/s, 0.43~2.12 m/s and 0.50~2.10 m/s for original, 50 mm and 100 mm models, respectively as volume flow rate varies from 2 LPM to 10 LPM.



[Fig. 3] Comparison of velocity of water and oil for different volume flow rates and nozzle heights



[Fig. 4] Comparison of volume fraction of water and oil for different volume flow rates and nozzle heights

The volume fraction comparison of water and oil for various nozzle heights and volume flow rates is depicted in Fig. 4. The volume fraction is superior for water than oil except at volume flow rate of 2 LPM for all nozzle heights. The volume fraction increases with increase in the nozzle height and volume flow rate for both water and oil. The water volume fraction ranges as 0.0009~0.0158, 0.0053~0.0176 and 0.0153~0.0229 and oil volume fraction ranges as 0.0018~0.0149, 0.0063~0.0167 and 0.0147~0.0218 for original, 50 mm and 100 mm models, respectively as volume flow rate varies from 2 LPM to 10 LPM.

4. Conclusion

The flow characteristics of nozzle spray cooling is investigated and compared for water and oil. The influence of nozzle heights and volume flow rates are evaluated on flow characteristics. The discrete phase modeling using ANSYS has been demonstrated to simulate the flow characteristics. The following key findings are drawn from the present study.

a) The oil velocity is superior compared to water velocity for all volume flow rates and nozzle heights. The velocity of oil and water increases with increase in the volume flow rates for all nozzle heights. The maximum velocities of 2.10 m/s and 2.15 m/s are evaluated for water and oil, respectively at original nozzle height and volume flow rate of 10 LPM.

b) The volume fraction of water is superior compared to that of oil for nozzle heights except at the volume flow rate of 2 LPM. The volume fraction of water and oil increases with increase in the volume flow rate for all nozzle heights. The maximum volume fractions of 0.0229 and 0.0218 are evaluated for water and oil, respectively at nozzle height of 100 mm and volume flow rate of 10 LPM.

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