

Study on the Basic Properties of Hexagonal Boron Nitride Nano-coolant

Yeou-Feng Lue, Yu-Kai Hung, Yi-Ni Jiang, Jessica Christiana Salim*

Department of Industrial Education, National Taiwan Normal University

*Email: chika.salim@gmail.com

Abstract

In this study, nano-hexagonal boron nitride (hBN), dispersant gum arabic (GA) and dispersant cetyltrimethylammonium bromide (CTAB) were added in different proportions and concentrations in cooling water (coolant). The fixed concentration of nano-hexagonal boron nitride is 0.75 wt.%, and the weight ratio of nano-hexagonal boron nitride to dispersant CTAB is 3:2 to make S_1 , the weight ratio to dispersant GA is 1:1 to make S_2 , and the weight ratio to dispersant GA is 2:1 to make S_3 , as well as three hexagonal boron nitride nano-coolants (hBNNC) with different concentrations were compared with the coolant for basic tests. The basic tests can be divided into: settlement, heat conduction, viscosity, specific heat and friction tests. The performance of the coolant is optimized by adding nano-hBN and dispersant, and then the cooling state of the actual application of electric motorcycles is simulated through the heat exchange platform to verify the optimization results.

According to the results, in the basic test, S_2 showed better results compared to the coolant, S_1 and S_3 . In the heat exchange platform test, compared to the coolant, S_2 had a patent effect and could quickly drop to room temperature at high temperatures.

Keywords: hexagonal boron nitride, nano-coolant, dispersant, heat conduction, heat exchange platform

1. Introduction

In 2001, the United States launched the National Nano-technology Initiative (NNI Program). The funds required for research are shared by seven federal departments and agencies including the Department of Commerce, Department of Defense, and Department of Energy, of which about 70% is directly introduced into the research projects of various universities, and the rest is allocated to national laboratories and various subsidy research projects supervised by various bureaus. In 2004, the President of the United States signed the "21st Century Nano-Research and Development Act", which completes the country's nano-technology research and development [1]. Following the United States, Taiwan also implemented the Taiwan Nano-technology National Technology Plan from 2003 to 2014 to establish and promote the development of Taiwan's technology and industrial competition in the 21st century. The key areas are: "Nano-biotechnology medical treatment", "Nano-energy and environment", "Nano-electronics and optoelectronics" and "Nano-detection and manufacturing process" [2].

The energy report of the Energy Bureau of the Ministry of Economic Affairs mentioned that adding nano-materials to nano-fluids can effectively solve problems such as traditional industrial wear [3]. Plenty of outstanding research results have also been shown in the application of heat exchange, including: solar energy, heat dissipation and heat recovery of heat collectors, automobile cooling systems, diesel generators, etc. All of the mentioned processes use nano-materials to improve fluid heat transfer performance and improve overall system heat exchange efficiency to save energy.

Murshed et al. studied the thermal physics of nano-fluids by adding nano-silica (SiC) and nano-boron nitride (BN) to the base liquid of ethylene glycol plus deionized water and the thermophysical properties of nano-fluids with a volume concentration of 0.01% to 0.05% [4]. It was found that as the concentration increases, the thermal conductivity and thermal diffusivity increases as well. Compared with the basic liquid, the fluid containing nano-SiC increases by about 4.4%, the maximum increase of the fluid containing nano-BN is about 7%, and the conductivity of the nano-SiC fluid increases by about 7%. SiC fluid increased by 3.2 times, and nano-BN fluid increased by approximately 2.8%, indicating that nanofluids have strong development potential in heat transfer applications.

1.1 Research Motivation and Purpose

The number of electric vehicles listed in Taiwan has grown significantly in recent years. In order to respond to the growth trend of electric vehicles in advance, the Ministry of Transportation estimates that there will be nearly 60,000 electric vehicles in the country by 2024. Therefore, the Ministry of Transportation expects to install 4,400 new charging stations. So far, there have been a total of 8,780 charging stations. In the future, it is initially planned to have 7,200 slow charging stations and about 600 fast charging stations to cope with the rapidly growing charging demand for electric vehicles on the road. The first electric vehicle fast charging station on the national highway will be installed at the Beishang gas station parking lot in the National 1 Xiluo Service Area in September 2021, and will provide electric vehicle fast charging services. As charging systems have gradually improved, the issue of electricity storage capacity has gradually come to the fore in the modern era when electric trains have become more popular. The purpose of this research is to improve the efficiency of the electric motor water cooling system and stabilize the temperature of the electric motor to achieve stable performance output.

According to the research motivation, the specific research methods are:

- (1) Preparation of hexagonal boron nitride nano-coolant (hBNNC).
- (2) Measurement and analysis of the basic properties of hBNNC, including settlement test, viscosity test, specific heat test, heat conduction test and friction test.
- (3) hBNNC is compared based on basic test results to determine the optimal concentration.
- (4) The optimal concentration of hBNNC is applied to the heat exchange platform to simulate the cooling performance analysis of electric locomotives.

1.2 Research Methods

The research content is mainly divided into three parts: literature discussion, theoretical analysis, and entity verification. The literature will discuss heat conduction, nanofluid and motorcycle cooling system, and use a comprehensive ranking method to determine the optimal concentration of hBNNC. The optimal concentration of hBNNC will be applied to the heat exchange platform of the simulated electric motorcycle to test the effect of the fluid on the motorcycle. The heat dissipation situation at the temperature points of 60°C and 80°C will be analyzed through the previously mentioned test results to evaluate the feasibility of hBNNC being used in electric motorcycles.

2. Related theories and analysis

Transportation accounts for about 28% of the world's CO₂ emissions [5]. The emissions of traditional cars are about 4 to 5 times to that of electric cars. In 2020, countries in Europe have launched policies and incentive systems, such as: the electric vehicle subsidy in Germany was increased from 3,000 euros to 6,000 euros, and the Spanish government invested 550 million euros to encourage people to replace old cars with new ones, and replace old cars more than 10 years old with low-carbon emission vehicles, etc., making Europe the largest electric car market in the world [6], it can be seen that various parts of the world have begun to design electric vehicles to reduce greenhouse gas emissions.

2.1 Vehicle energy consumption

Nabi mentioned in the study that the thermal efficiency of traditional car engines is about 20% to 25%. If the thermal efficiency is changed, the performance of the engine can be improved. Changes in thermal efficiency can start from the cooling system of the vehicle. As mentioned before, by improving the cooling system's performance, the thermal efficiency can be improved which indirectly improves engine performance [7]. With the development of technology, electric vehicles have

gradually become more popular in the market in recent years, which represent the increase in the number of people purchasing them. Liñeira et al. mentioned that compared with traditional cars, the parts of electric vehicles need to operate in higher load, temperature, electromagnetic field and other high conditions [8], and their energy loss from friction loss is close to 20%. Although the energy consumption is reduced by half compared to traditional cars, the energy loss will definitely become a huge challenge in the future.

2.2 Heat Transfer Properties

With the advancement of science and technology, nano-technology has become increasingly sophisticated, such that nano-technology research has investments in its application and design all around the world. Many studies have pointed out that nano-fluid has a positive and significant impact on heat dissipation and friction performance, and its research is gradually used in the application design of electric vehicles. Esfe et al. used the KD2-Pro thermal conductivity characteristic instrument to measure the thermal conductivity of nano-Al₂O₃ in ethylene glycol [9] and discovered that as the concentration and temperature increased, its thermal conductivity increased as well. The use of nano-materials can effectively improve the heat transfer capabilities of fluids commonly used in cooling systems.

The structure of hBN is similar to graphite, and its appearance is white, making it also capable of being called white graphene. In engineering application research, Nagarajan et al. prepared 0.05 wt.% nano-meter hBN lubricating oil and compared it with SAE20W40 base oil [10]. In addition to effectively reducing friction and wear, it also improves thermal conductivity, effectively improving engine performance and durability.

2.3 Vehicle Cooling Application

Using a coolant which base liquid is ethylene glycol plus water, Kumar et al. used two nano-materials: multi-wall carbon nanotube (MWCNT) and silicon dioxide (SiO₂) to make a nano-coolant. It is then compared to a basic liquid without the addition of any nano-materials. Both were applied to a fin radiator [11]. It was discovered that as the wind speed increased, the temperature decreased; as the flow speed decreased, the temperature decreased, confirming the effect of adding nano-materials. In comparison with the coolant without any nano-materials added, the coolant with nano-materials can improve cooling efficiency and reduce heat loss of the vehicle.

The coolant commonly used in traditional automobile radiators is mainly composed of water and ethylene glycol. Although it is commonly used, it is still limited in terms of heat transfer capacity. Kumar et al. conducted fluid analysis to study the improvement of heat transfer capacity [12], the concentration of nano-Al₂O₃, nano-CuO₂ and nano-ZnO was added from

0.05% to 5% respectively, and a cooling liquid composed of 60% ethylene glycol plus 40% water was used as the base liquid. Studying the impact of different concentrations of nano-particles on the thermal conductivity coefficient, it was concluded that the thermal conductivity coefficient gradually increased as the concentration of nano-materials increased. It is speculated that the main reason is that the Brownian motion of nano-particles enhances fluid heat conduction.

3. Research Design and Implementation

Add Kuo-Kuang brand cooling water coolant to nano-hBN, and mix it with different proportions of cetyltrimethylammonium bromide (CTAB) and gum arabic (GA) to make three hBNNC samples, with S_1 hBN:CTAB in a weight ratio of 3:2, S_2 hBN:GA in a weight ratio of 1:1 and S_3 hBN:GA in a weight ratio of 2:1. After uniformly mixing the nanofluid through the six-connected heating electromagnetic stirrer and the ultrasonic vibrator, five basic tests are conducted, namely: sedimentation, heat conduction, viscosity, grinding and specific heat tests. Select the best and optimal sample from three samples through basic testing.

The best hBNNC samples were subjected to heat exchange tests with the coolant to evaluate the performance changes after using hBNNC fluid. The Gogoro 3 electric motorcycle water cooling system is equipped as a simulation platform for testing, observing the temperature values of hBNNC at various monitoring points, and thereby evaluating the addition of hBNNC; whether it has the expected effect and feasibility in actual vehicles.

3.1 hBNNC Basic Quality Test

(1) Settlement test

Prepare three different concentration ratios of hBNNC, mix and disperse them evenly, then put the sample into a colorimetric tank and conduct the test. Through the sedimentation test, the sedimentation of the nanoparticles of the sample can be observed. After storing for 1, 15 and 30 days, take a photograph of the precipitation every 14 days to observe the stability of the nano-fluid.

(2) Thermal conductivity test

The samples were heated to the test temperature using an electromagnetic heating stirrer, and the samples were evenly mixed, and then a thermal conductivity analyzer (KD2, METER Group, Inc., USA) was used to measure the heat transfer coefficient. The temperature measurement range is 30~90°C. Each temperature point is measured 10 times, and the average value of the thermal conductivity coefficient data at that temperature is taken as the final heat conduction value at that temperature point.

(3) Viscosity test

Use an electromagnetic heating stirrer to evenly stir the three samples and heat them to the measurement temperature, its range being 30~90°C with every 10°C as a unit. Measure 10 pieces of data at each temperature point and combine the measurement data with each other. By calculating the average of all the obtained data, the average viscosity value at a specific temperature point is obtained, and it is used as the final viscosity value at that specific temperature point.

(4) Specific heat test

Place the test sample into the aluminum sample box, then conduct the test through the thermal differential measuring instrument (DSC-Q20, TA, USA) and the mechanical cooling system (RCS-40, TA, USA) in conjunction. For the specific calorimetry test of hBNNC at different concentrations, set the temperature measurement range to 30~90°C, with every 10°C as a unit. Measure 10 pieces of data at each temperature point and combine the measurement data with each other. By calculating the average of all the obtained data, the final value of the temperature point is obtained, which can be used to record the specific heat value of the sample at different temperatures.

(5) Grinding test

The grinding test uses a three-ball rotary grinding machine. To determine whether hBNNC has great anti-friction properties, the grinding test requires hBNNC to be placed on a smooth test piece, then have the test piece placed into the parameter setting. In a platform with a rotation speed of 500 rpm, a pressure of 150 N and a rotation number of 500 revolutions. Lastly, the wear results are recorded.

3.2 Heat Exchange Platform Test

The heat exchange platform test is a front-end simulation of the Gogoro Taiwan Limited 3 ordinary heavy-duty electric vehicle equipped in subsequent actual vehicle experiments. This test uses the same type of radiator as Gogoro3, and a heated water tank is installed on the platform to simulate the temperature changes of an electric motorcycle. A water pump is then used to simulate the water flow changes of an electric motorcycle to simulate the actual driving situation as a whole.

Samples are added to the water tank and heated to 60°C and 80°C to simulate the temperature changes when the electric motorcycle is running. The circulation system of the electric motorcycle is simulated through the operation of the water pump. A single unit is installed on the platform. The flow rate in the pipe is controlled by the valve, and temperature points are buried at the inlet and outlet of the water tank to observe the temperature changes of the inlet and outlet water, while the temperature changes of the radiator are read and stored

through a data logger.

4. Results and Discussion

This chapter will analyze and compare the test results. The content in this chapter can be divided into five basic experiments: settlement test, thermal conductivity test, viscosity test, specific heat test, grinding test and heat exchange platform test, therefore totaling six parts.

4.1 Settlement test results

The settlement test on the first day is shown in Figure 1. It can be observed that the three samples are uniformly turbid and there is no obvious sedimentation condition. The settlement conditions on the 15th day are shown in Figure 2. It can be found that the S_1 sample using CTAB as the dispersant is compared with the S_2 and S_3 using GA as the dispersant. There is obvious sedimentation, while the S_1 sample is only slightly suspended compared to the coolant. The sedimentation on the 30th day is shown in Figure 3. None of the three samples are suspended like the sedimentation on the 1st day. The degree of suspension is: $S_2 > S_3 > S_1$. It can be seen that S_2 on the 30th day shows better stability.

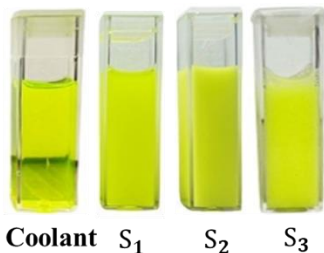


Fig. 1 hBNNC sedimentation test day 1

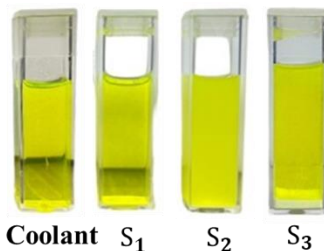


Fig. 2 hBNNC sedimentation test day 15

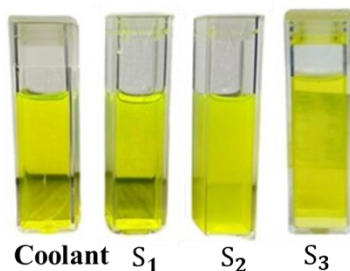


Fig. 3 hBNNC sedimentation test day 30

4.2 Thermal conductivity test results

Use the thermal conductivity characteristic meter KD2 to analyze the thermal conductivity of hBNNC. During measurement, start measuring the value after the measurement temperature point has stabilized for about 10 minutes to avoid errors caused by ambient temperature. The experimental results are shown in Figure 4. The measured samples are uniform. As the temperature increases, the thermal conductivity coefficient increases as well. Among them, S_2 shows a higher thermal conductivity coefficient, while S_1 is better than the coolant at 30~50°C and lower than the coolant after 50°C. S_3 is slightly higher than the coolant. The test shows that the heat transfer properties are: $S_2 > S_3 > S_1$. The heat conduction of the sample using GA as the dispersant is better than that of the dispersant CTAB.

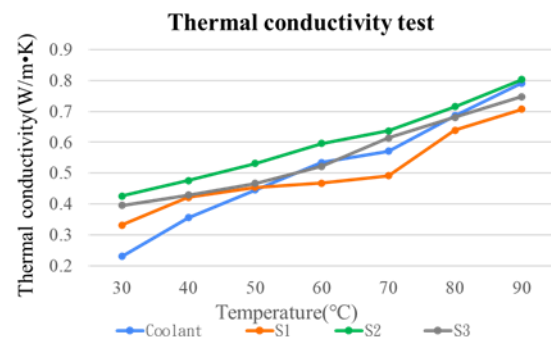


Fig. 4 Thermal conductivity test

4.3 Viscosity Test Results

The test results are shown in Figure 5. It can be observed that the three samples containing 0.75 wt.% nano-hBN have higher viscosity than the coolant. Among them, S_1 has a lower viscosity, whereas S_2 and S_3 have similar viscosities, and the added GA amount in S_2 is slightly higher than S_3 . Therefore, the viscosity of S_2 is slightly higher than that of S_3 .

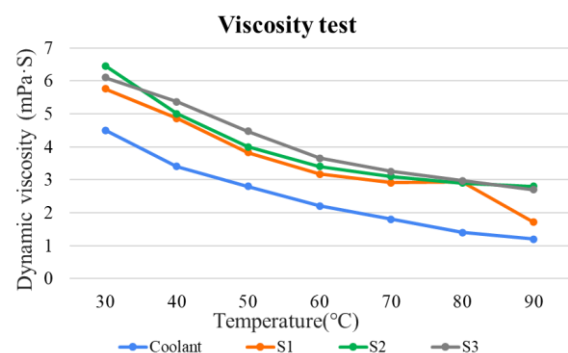


Fig. 5 Viscosity test

4.4 Specific Heat Test Results

The specific heat test results are shown in Figure 6. It can be observed that as the temperature increases, the

measured samples all increase slightly. Compared with the coolant, S_1 , S_2 and S_3 , they all have obviously lower specific heat values, among which S_2 has a lower specific heat. The value shown in S_2 is preferably suitable for equipment in electric vehicle cooling systems. The reason is that when equipped in electric vehicle cooling systems, it assists the system to heat up with shorter time in needs of heating. It assists the system to cool down with shorter time as well in needs of cooling. Therefore, this study requires a sample fluid with a lower specific heat value.

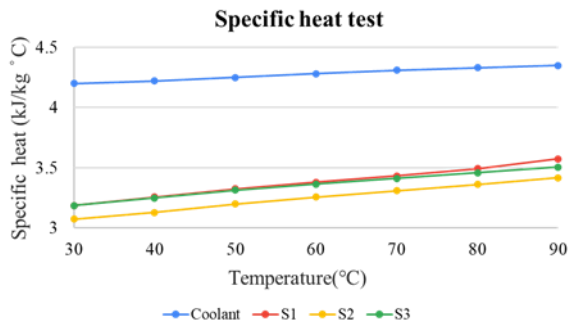


Fig. 6 Specific heat test

4.5 Grinding test results

The grinding test simulates the wear of the sample in the pipeline. It observes the loss reduction after using the sample and the improvement rate after comparing it with the coolant. Therefore, hBNNC with lower loss amount and higher improvement rate in the pipeline can reduce friction and wear, thereby extending the life span of the equipment. The test results are shown in Figure 7. It can be seen that $S_2 > S_1 > S_3$.

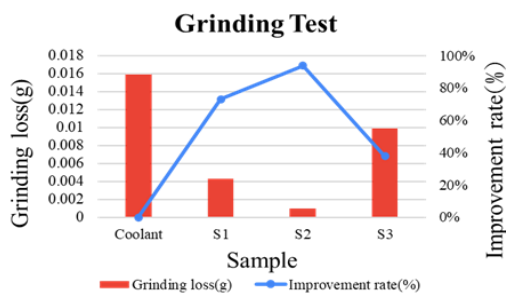


Fig. 7 Grinding test

4.6 Heat exchange platform test results

Based on the above basic test comparison, S_2 was selected as the sample to compare the coolant in the actual vehicle test. Therefore, only the coolant and S_2 were tested in the heat exchange test. S_2 was heated to 60°C and 80°C, and the time required for hBNNC and the coolant to cool down to 35°C was evaluated. The test results are shown in Figure 8-Figure 11.

Figure 8 and Figure 9 show the temperature change results of the inlet and outlet radiator after the heater was heated to 60°C and then cooled to room temperature 35°C.

It can be seen that S_2 cools down to 35 °C faster, about 20 minutes faster than the coolant. Figure 10 and Figure 11 are the temperature change results of the inlet and outlet radiators when the heater is heated to 80°C and then cooled to 35°C. It can be seen that S_2 cools down to 35°C faster, about 15 minutes faster than the coolant.

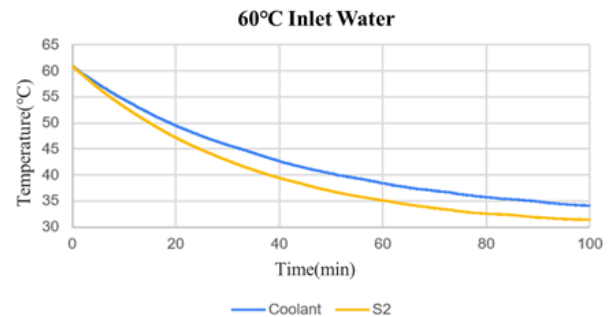


Fig. 8 Heat exchange platform enters water at 60°C

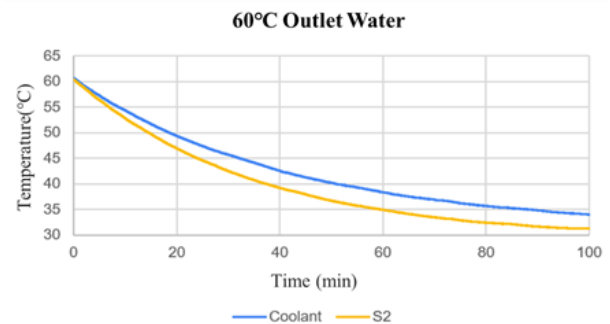


Fig. 9 Water outlet from heat exchange platform at 60°C

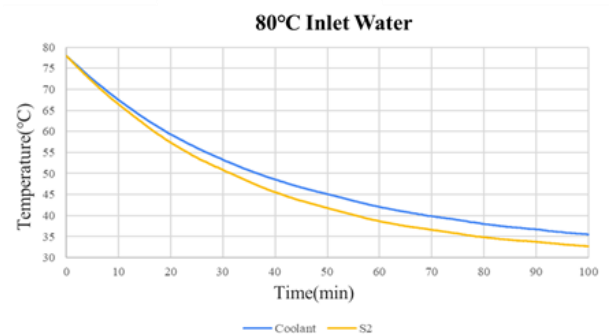


Fig. 10 Heat exchange platform enters water at 80°C

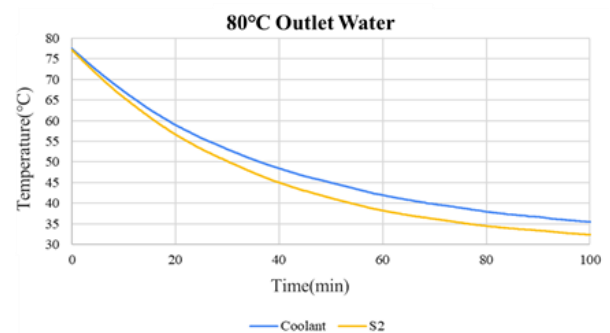


Fig. 11 Water outlet from the heat exchange platform at 80°C

5. Conclusions

This study uses the high thermal conductivity of hBNNC to improve cooling performance, uses five basic tests to select the best samples, and then conducts heat exchange test simulations to confirm that the samples can effectively improve the heat dissipation performance compared with the coolant. Through the results of the above tests, the following conclusions can be summarized:

- (1) After 30 days of observation in the sedimentation test, using the dispersant GA compared to the dispersant CTAB improves the suspension effect of the nano-hBN, and the S_2 sample is able to obtain the best suspension state.
- (2) In the thermal conductivity test, S_2 and S_3 , which used GA as the dispersant, both showed higher thermal conductivity coefficient values than the coolant and had better heat conduction capabilities. Among them, S_2 had a higher thermal conductivity coefficient than S_3 .
- (3) The viscosity test shows that hBNNC is higher than the coolant, and the viscosity of S_1 is lower than that of S_3 and S_2 .
- (4) In the specific heat test, the specific heat value of hBNNC at each temperature point is lower than that of cooling water. Among them, S_2 has a lower specific heat value, which is preferable and in line with the needs of the cooling system.
- (5) It can be seen from the grinding test that the use of hBNNC can effectively reduce the loss of the specimen, with the lowest loss being S_2 , followed by S_1 and S_3 , which confirms that the use of hBNNC can effectively reduce wear.
- (6) Through basic experiments, it can be concluded that S_2 has better characteristics and fulfills the needs of the cooling system. Subsequent heat exchange platform tests and real vehicle experiments will be carried out.
- (7) From the heat exchange test, the heat dissipation capacity of S_2 is significantly better than that of cooling water. From the test results, it is concluded that S_2 can reduce the temperature about 17 minutes faster than the coolant, which proves that hBNNC made by adding nano-hBN to the coolant can effectively improve the heat dissipation properties of the coolant.

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