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Research Article

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Enhanced Thermal Properties of TiC Nano-powders through Deep Cryogenic Treatment: A Comparative Study of Conductivity and Diffusion

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Abstract

In this investigation, deep cryogenic treatment (DCT), which may be used on materials below to temperatures ranging as -199 °C, is used to cool TiC nanopowder (n-TiCp). To evaluate the differences between cryo treated and untreated TiC in thermal diffusion, scientists can use the flash technique. The thermal conductivity of n-TiCp is also being studied quantitatively. DCT significantly improves n-TiCp thermal conduction by 47% and its thermal diffusion by 34%. The thermal conduction of TiC/water nanofluid (WNF) is also computed. Both untreated and cryogenically treated TiC nano powder benefit from being dispersed in water, as shown by the results. Rapid Brownian motion makes tiny particles great heat conductors.

Keywords

Nanofluid, Thermal diffusivity, Water, Temperature, Cryogenic treatment

Introduction

Finding strategies to cut energy usage is more important than ever before for maintaining the global economy [1]. Everyone needs to do their part to help lower energy use. Academics have put forth a lot of time and effort to find new, innovative ways to increase machinery efficiency without increasing expenses. Increasing the nanofluid's thermal conduction has been found to improve heat transfer performance in thermal management systems. As a result, both energy consumption and operating expenses are decreased [2]. Efficiency gains can be seen in the use of heat exchangers, refrigerators, cold storage, and heating, ventilation, and air conditioning systems. It is essential for industrial cooling and heating systems that the working fluid's thermal conductivity be improved [3]. Now, nano powders are used to make nanofluid, which has potential uses in heat transmission. This is because of how well it conducts heat. For improved heat transfer, it is essential that nanofluids be made from a solid nano powder material. The authors [4, 5] investigated what would happen if you mixed zinc oxide (ZnO) particles with ethylene glycol. Temperatures between 24 and 50 °C are used for the experiments. ZnO concentrations can be anything from 0% by volume to 5%. Increasing the thermal conductivity of a solution of ethylene glycol by adding ZnO nano powder has been demonstrated. Nano powder, a solid, reportedly has a greater thermal conductivity than liquids [6]. Because of this, heat conductivity can be enhanced by distributing the solid nano powder in liquid. Because of this, nanofluids are superior heat conductors compared to other fluids. There has been a rise in interest in nanofluids in the field of science because of their enhanced heat-carrying properties compared to more conventional fluids [7]. Gr-water nanofluid's heat-conducting capacities were compared to those of water by researchers [8]. When graphene (at a concentration of 0.5% by weight) was added to water, the thermal conductivity increased by 38.5%. This investigation is considering the usage of TiC nano powder because of its potential utility in the fields of refrigeration, air conditioning, and heat exchange [9]. Nano particles including TiO and Al_2O_3 are also under study.

Steels of all kinds can benefit from cryogenic treatment to improve their mechanical qualities. The authors [10] explained how to rapidly cool steels to 199 °C for treatment. EN 19 steel, stainless steel, and a few others benefit from cryo treatment since it increases their thermal conductivity, hardness, and resistance to wear. Cryo treatment has recently garnered interest from scientists looking to broaden its application [11]. The outcomes of DCT on TiC nanopowder are of most interest to us. TiC nanopowder can be employed in heat exchangers after undergoing this treatment to increase its thermal conductivity [12]. Previous studies [13, 14] reported on the thermophy TiCal properties of n-TiCp and cryo TiC, including their viscosity and heat transmission. According to the author's knowledge, no research has been conducted into how DCT affects the thermal characteristics (specific heat capacity, diffusivity, and conduction) of TiC nanopowder or TiC/water nanofluid. Neither of these qualities has been the subject of any previously published research [15]. In the most recent study, scientists used a nano flash instrument to compare the heat resistance of untreated n-TiCp to that of n-TiCp that had been cooled to extremely low temperatures. We then compare the thermal conductivity of the TiC/WNF to that of baTiC fluid (plain water). The heat conductance of cryogenic TiC/WNF is also used to evaluate the impact of cryogenic n-TiCp on water.

Nano Material and Techniques

When there is an abrupt shift in the way temperatures are distributed, this phenomenon, known as a transient, arises as a heat transfer issue. The thermal diffusivity was essential when heat transport is unstable. The steady-state thermal conductivity equation is related to thermal diffusivity as shown in equation 1 [16].

$$D = \lambda / CP \quad (1)$$

where

D = thermal diffusivity,

λ = thermal conductivity,

ρ = density, and

Cp = as specific heat.

A material's thermal conductivity at a given temperature and pressure can be easily determined using the fourier formula. Traditional methods, such as the secured hot plate and rod methodology [17], have been utilized to determine the thermal conductivity for steady heat flow. It could be inaccurate and time-consuming to apply this method to stable research or to make assumptions about the boundary conditions. These issues aren't encountered when using the flash method [18], which measures temperatures in relation to one another. One way to get a temperature reading is to rapidly heat up one side of the specimens while monitoring the other. Thermal diffusivity and thermal conductivity, two properties directly related to temperature, can be measured with these methods. The thermal conductivity can be calculated when the mass and heat capacity have been measured. The thermal capacity of a substance is defined as the amount of energy needed to increase its temperature by 1 °C at a static pressure per unit mass. Bulk density is determined by weighing and measuring powder samples.

Once a nano powder of TiC has been obtained, it is subjected to a cryogenic cool at 199 °C. Titanium carbide micro powder samples are initially heated to 199 °C and then cooled to ambient temperature over the course of 24 h. Nano flash apparatus was used to measure thermal diffusivity, heat capacity, and conductivity by researchers [19, 20]. The test was conducted at temperatures of 40 and 360 °C, as required by ASTM standard E1461-07. It has been shown that a flash technique can be used to assess thermal diffusivity [21]. Water (the fundamental fluid), cryo TiC/water (the cryo nanofluid), and TiC/water (the fluid) are compared for their thermal conductivity (nanofluid). The method of data collection shown in figure 1 was adopted for this article.

Nanofluid and approaches

To be useful as a working fluid, a nanofluid must first dissolve the pure water entirely in its nanoparticles. The addition of a surfactant, modification of the pH mixtures, and the application of ultrasonic vibration can all be employed to create a more cohesive whole. The investigation began with ultrasonic vibrations performed without the use of surfactants. An accurate electronic mass scale makes it simple to measure out the right proportions of base fluid and nanoparticles for making nanofluid. After that, an ultrasonic homogenizer would be used to shake the mixture for a further 60 min at a steady energy flow of 60 Watts. The ultrasonic homogenizer can be broken down into the individual components depicted in figure 2. The source of the ultrasonic waves, the sonotrode, the housing, and the cooling systems all belong here. After waiting 10, 15, 30, 60, and 120 min, the nanofluid is photographed to record the sedimentation. Figure 3 shows that after 120 min of mixing water and nanoparticles without a surfactant, the nanoparticles begin to precipitate. It is possible that titanium

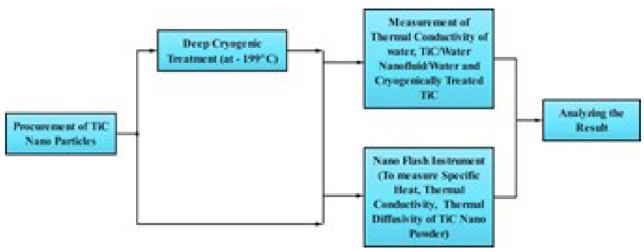

Figure 1: Research methodology map.

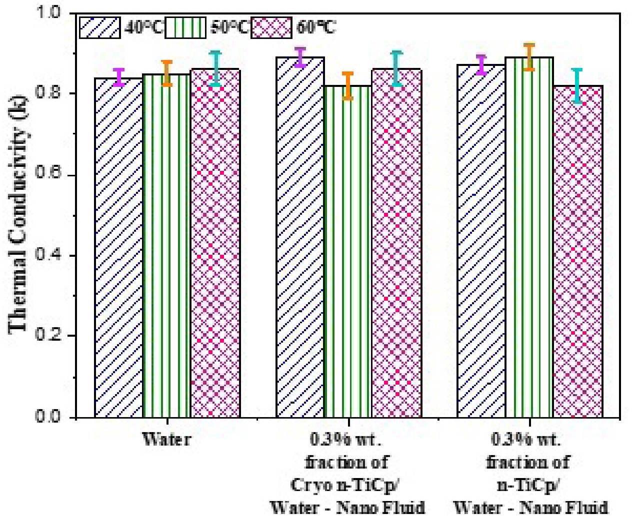

Figure 2: Thermal conductivity of water, cryo n-TiCp/water nanofluid, and n-TiCp/water nanofluid at 0.3% wt. fraction.

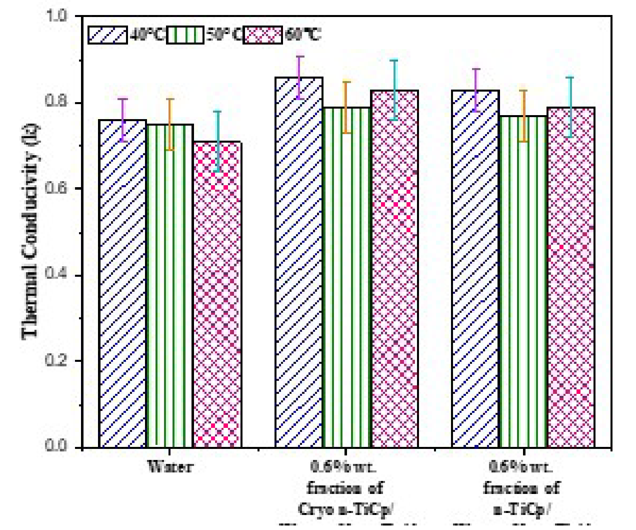

Figure 3: Thermal conductivity of water, cryo n-TiCp/water nanofluid, and n-TiCp/water nanofluid at 0.6% wt. fraction.

carbide and the titanium carbide/water nanofluid created by cryogenic processing would not mix without the inclusion of a surfactant.

The two types of surfactants were used in this investigation. Even after vigorous shaking in an ultrasonic homogenizer, bubbles formed in the resulting nanofluids containing 10% by weight of particles treated with cetyltrimethylammonium bromide as a surfactant. Nanofluids made with a 10% weight concentration of Gum Arabic as a surfactant were shown to be superior in several respects, including delivery of the intended content, sedimentation after nearly a week of storage, and, most importantly, the absence of bubbles. This has led us to decide to use Gum Arabic as a surfactant in our next experiment.

Our research is centered on these two categories of nanofluids. Each is a cryo version of the other; the first is a titanium carbide and water nanofluid. Nanofluid thermal conduction was measured at 0, 0.3, and 0.6% by weight. The atmosphere was monitored by a thermometer, and a condenser/heater device maintained a constant temperature in the bath.

The fluid's target temperature must be reached in the constant temperature bath as the first stage. Once the KD2 probe has been placed within the container and its temperature has been kept at a constant ratio to that of the water in the constant temperature bath, the test is allowed to run for a long period of time. This is the standard method for gauging thermal conductivity. Once the target temperature of the nanofluid has been achieved, the heat transfer to the pure water can be determined. Experimental data are compared to a standard to establish the instrument's precision. The thermal conduction was then calculated using a battery of experiments in which the load and temperature were carefully controlled. Each experiment was repeated five times to ensure the highest degree of accuracy.

Results and Discussion

Analysis of n-TiCp

These two powders both have a lot going for them. The thermal properties of raw n-TiCp and n-TiCp that have undergone a DCT (Cryo n-TiCp) can be compared with flash devices. The trials take place in both cold (40 °C) and hot (360 °C) temperatures.

Specific thermal capacity

Table 1 displays the specific thermal capabilities of nano

Table 1: Cryogenic TiC and n-TiCp thermal capability (J/g K^{-1}).

S. no	Temperature (°C)	Cryo n-TiCp		n-TiCp		(%) Change
		Specific thermal capacity	Average	Specific thermal capacity	Average	
1	40 °C	0.711	0.711	0.741	0.741	3.9 decrease
2		0.711		0.741		
3		0.711		0.741		
4		0.711		0.741		
5	360 °C	0.799	0.799	0.741	0.8085	3.64 decrease
6		0.799		0.831		
7		0.799		0.831		
8		0.799		0.831		

powders at temperatures of 40 and 360 °C. The specific thermal capacity of n-TiCp is 0.752 and 0.842 J/g K^{-1} at 40 and 360 °C. Nanoscale TiC nanopowder has an average thermal capacity of 0.82 and 0.89 J/g K^{-1} at 40 and 360 °C. At 40 °C, the thermal capacity of DCTnp is 3.9% lower than that of untreated n-TiCp. When nano powder was exposed to extremely cold temperatures, its thermal capacity dropped by 3.64%. This physical property is crucial in determining the necessary heating energy for the material. One way to lower the cost of a thermal item is to increase its specific thermal capacity [22]. Consequently, the specific thermal capacity is reduced, and the thermal conductivity and diffusivity are enhanced.

Thermal diffusivity

The rate of thermal transfer as a function of time is calculated using the thermal diffusing factor. This transport feature is employed in the study of dynamic heat transfer. The rate at which heat is transmitted increases together with the thermal diffusivity. Table 2 displays the thermal diffusivity of n-TiCp and cryo n-TiCp at temperatures of 40 and 360 °C. There were four different measurements collected for each of the experimental conditions. At 30 °C, the thermal diffusivity of n-TiCp is 0.166 m^2s^{-1}, but at 360 °C, it drops to 0.156 m^2s^{-1}. At 30 °C, DCT has a thermal conductivity of 0.0169 m^2s^{-1} at 360 °C and n-TiCp has a thermal diffusivity of 0.253 m^2s^{-1}. The thermal diffusivity is improved by 57.41% at 30 °C and by 11% at 360 °C. The thermal diffusivities of n-TiCp were found to rise when subjected to a DCT at 199 °C. TiC nano powder benefits from thorough cryogenic processing, which increases its thermal diffusivity and thus its ability to transport heat quickly. Cryogenically treated TiC nano particles allow for rapid heat transfer. This is helpful for businesses that deal with thermal transfer.

Thermal conductivity

As diffusivity increases, there is a linear relationship between thermal conductivity and thermal diffusivity. TiC nano powder and cryo TiC nano powder are compared in table 3 for their thermal conductivity at 40 and 360 °C. At 360 °C, n-TiCp has an average thermal conductivity of 0.0058 W mK^{-1}, while at 40 °C, it is 0.0067 W mK^{-1}. The thermal conductivity of n-TiCp that has been subjected to a DCT is 0.0094 and 0.008 W mK^{-1} at 40 and 360 °C. When compared to untreated n-TiCp, deep cryo n-TiCp has a thermal conductivity gain of 60% at 40 °C and 34% at 360 °C. Cryogenic treatment improves n-TiCp's thermal conductivity and diffusivity. As the researchers show, as thermal diffusivity increases, both thermal capacity and thermal conductivity decrease. Better thermal conductivity is required due to rising energy expenditures and demand. The best technique to increase the thermal conductivity of a material at the lowest possible cost is through cryogenic treatment [23].

Table 2: The cryogenic TiC and n-TiCp thermal diffusivity (m^2 s^{-1}).

S. no	Temperature	Cryo n-TiCp		n-TiCp		Percentage of improvement (%)
		Thermal diffusivity	Average	Thermal diffusivity	Average	
1	40 °C	0.207	0.2397	0.035	0.1565	55.28
2		0.287		0.265		
3		0.226		0.232		
4		0.239		0.094		
5	360 °C	0.235	0.1563	0.125	0.1455	
6		0.176		0.155		
7		0.089		0.157		
8		0.125		0.145		

Table 3: Cryogenic TiC and n-TiCp thermal conductivity (W mK^{-1}).

S. no	Temperature	Cryo n-TiCp		n-TiCp		(%) Change
		Thermal conductivity	Average	Thermal conductivity	Mean	
1	40 °C	0.008	0.009	0	0.0058	55
2		0.01		0.01		
3		0.009		0.009		
4		0.009		0.004		
5	360 °C	0.01	0.007	0.005	0.0055	34
6		0.008		0.006		
7		0.004		0.006		
8		0.006		0.005		

Analysis of thermal conductivity on TiC/water nanofluid

Between 40 and 60 °C, the thermal conductivity of water is 0.3% by wt. that of TiC/WNF is 0.6% by wt., and that of cryogenic TiC/WNF is 0.9% by wt.

Thermal conductivity increases with increasing temperature for static wt. percentage

Cryogenic dilution of TiC Nano powder in water to 0.3% wt is compared to pure water and TiC Nano powder in water in figure 2. At 40 °C, the thermal conductivity of the TiC/WNF is 6.7% higher than that of water, while the thermal conductivity of the cryo TiC/WNF is 5.6% higher than that of water. The thermal conduction of a TiC/WNF at 50 °C and 0.4 wt. % is 6.91, while that of a base fluid is 9.563. At 60 °C and a weight percentage of 0.3%, the conductivity of untreated TiC/WNF was found to rise by 10.5%, whereas that of cryogenic TiC/WNF increased by 16.6%.

Water, TiC nanopowder in water, and cryogenic TiC nanopowder in water all have different thermal conduction rates, as shown in figure 3. (0.6% wt.) At 40 °C and 0.6% wt. fraction, the TiC/WNF outperforms the base fluid in terms of thermal conductivity. When compared to the plain water, the thermal conduction of cold TiC/WNF was 15.28% maximum at 50 °C and 0.6% wt. percentage. Compared to pure water (60 °C) or a TiC/water nanofluid with a wt. percentage of 0.2%, a cryo TiC/WNF with a weight percentage of 0.6% may conduct heat very efficiently.

Heat conduction comparisons between water, n-TiCp/water nanofluid, and n-TiCp/water nanofluid treated with 0.6% wt. of cryo are shown in figure 4. At a weight of 20%, the thermal conductivity of the TiC /WNF is 17.94% higher than that of the pure water, and at a weight of 0.6 wt.%, it is 21.85% maximum. At 45 °C, the TiC/WNF has a higher thermal conduction than pure water, and at cryogenic temperatures, it has a greater thermal conduction by 26.62%. Thermal conduction was improved by 26.62 and 30.94% for TiC/WNF and cryo TiC/WNF at 60 °C and 0.6% wt. fraction, respectively.

The thermal conduction of water was found to be improved by using nanoparticles of titanium carbide powder (water). Cryogenic treatment enhances the already high thermal conduction of titanium carbide/WNF. Since n-TiCp are present in water, it acts as a superior heat conductor [24]. As predicted by the authors [25, 26] the thermal conductivity of a TiC /WNF increases with temperature.

Changes in mass fraction at a given temperature result in enhanced thermal conduction

Water, n-TiCp in water, and cryo n-TiCp in water, together with their respective temperature dependencies, are shown in figure 5. At 40 °C, the thermal conductivity of the TiC/WNF increasing wt. fractions in comparison to pure water. The thermal conductivities of water, n-TiCp in water, and cryogenic n-TiCp in water at 50 and 60 °C are depicted in figure 6 and figure 7. Cryo TiC/water nanofluid thermal conductivity is found to rise from 0.3 to 0.9% as temperature is raised from 40 to 60 °C. with earlier studies, we determined that increasing the ratio of TiC/water and cryogenic TiC / Water nanofluids from 0.3 to 0.9% increased the thermal conductivity of both fluids in comparison to the baTiC water.

Dispersions of TiC nanoparticles in water have been shown to increase thermal conductivity. TiC's thermal conductivity is further improved with cryogenic treatment [27].

Because of Brownian motion, the nanoparticles in a nanofluid have a higher thermal conductivity. The increased thermal conductivity can be attributed to Brownian motion. Particle movements are typically erratic and wavy. Nanoparticles can share their heat with one another through collisions with other solid particles. Multiple mechanisms contribute to the enhanced heat conduction of the fluids. These include the effect of nanoparticle clustering, the convection of nanoparticles, and the formation of molecular-level layers between fluid particles.

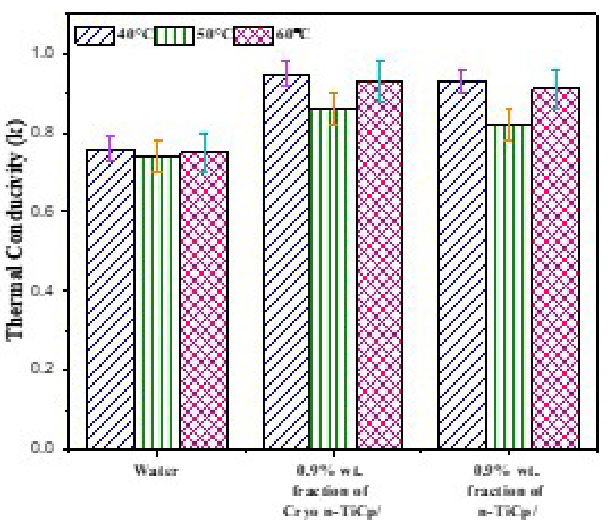

Figure 4: Thermal conductivity of water, cryo n-TiCp/ WNF, and n-TiCp/ WNF at 0.9% wt. fraction.

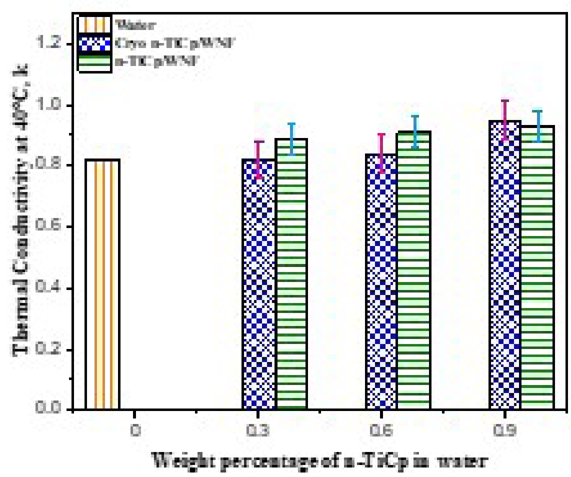

Figure 5: Comparing the thermal conductivity of water, cryo n-TiCp/ WNF, and n-TiCp/ WNF at 40 °C.

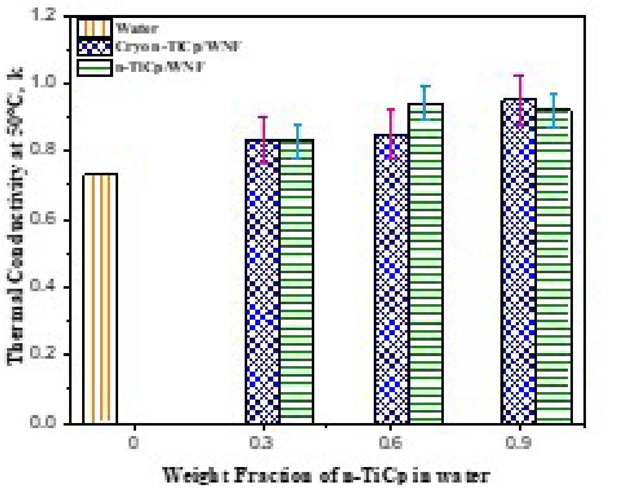

Figure 6: Comparing the thermal conductivity of water, cryo n-TiCp/WNF, and n-TiCp/water nanofluid at 50 °C.

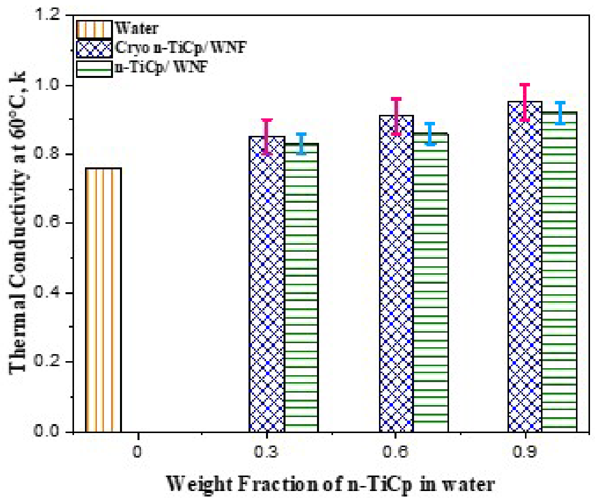

Figure 7: Thermal conductivity of water, cryo n-TiCp/water nanofluid, and n-TiCp/water nanofluid at 60 °C.

Conclusions

The goal of this research is to lessen strain on the power grid by increasing the efficiency of thermal exchange systems using n-TiCp and TiC/water nanofluid. Below, scientists report on their studies with higher thermal conductivity.

Cryogenic processing of TiC nano powder increases its thermal conductivity by 60% at 40 °C and by 34% at 360 °C. The thermal diffusivity of n-TiCp is enhanced by cryo treatment as well, by 56.38 and 11% at temperatures of 40 and 360 °C, respectively.

TiC/water nanofluid has an improved thermal conductivity of 15.28% over the baTiC fluid, and cryogenic TiC/water nanofluid has an increased thermal conductivity of 19.38% over the baTiC fluid. Cryogenically treated or not, the TiC/water nanofluid has more heat conduction than ordinary fluids. The average thermal conductivity as a function of weight rose from 0.3% to 0.9%. This change is due to the particles' Brownian motion.

Acknowledgements

None.

Conflict of Interest

None.

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