ISSN 1027-5495. Functional Materials, 29, No.3 (2022), p. 451-455.
doi:https://doi.org/10.15407/fm29.02.451

Investigation of the effect of graphene nanofluid on heat transfer and cooling capacity of refrigerants

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Received June 12, 2022

The heat transfer of a graphene nanofluid has been studied. Graphene nanofluid samples of various concentrations were prepared as coolants, and the efficiency of their heat transfer (cooling) was calculated and measured. It was found that the cooling stability gradually decreases as the concentration of the additive increases; at a fixed inlet temperature, the heat transfer coefficient increased as the additive concentration and flow rate increased. On the example of a sample of 0.4 wt.%, it is shown that the heat transfer coefficient reaches 15537 $W/(m^2 \cdot K)$ at a flow rate of 1.0 m/s. It is shown that at a fixed flow rate, with an increase in the concentration of the additive and the temperature at the inlet, the heat transfer coefficient increases significantly. Experimental results confirm that graphene nanofluids can optimize heat transfer and cooling performance. Graphene nanofluids can be used in car radiators.
Keywords:

Дослідження впливу графенової нанорідини на теплопередачу та охолоджувальну здатність холодоагентів. *Bo Fu*

Досліджено теплопередачу графенової нанорідини. Зразки графенової нанорідини різної концентрації були приготовлені як холодоагенти, розрахована та виміряна ефективність їх теплопередачі (охолодження). Виявлено, що стабільність охолодження поступово знижується зі збільшенням концентрації добавки; при фіксованій температурі на вході коефіцієнт теплопередачі збільшувався зі збільшенням концентрації добавки і швидкості потоку. На прикладі зразка 0,4 мас.% показано, що коефіцієнт теплопередачі досягає 15537 Вт/(м²·К) при швидкості потоку 1,0 м/с. Показано, що коли швидкість потоку фіксована, зі збільшенням концентрації добавки та температури на вході коефіцієнт теплопередачі значно збільшується. Експериментальні результати підтверджують, що графенові нанорідини можуть оптимізувати характеристики теплопередачі та охолодження. Графенові нанорідини можуть бути використані в автомобільних радіаторах.

Introduction

Humans and society cannot develop without energy. Since energy is mainly utilized in the form of thermal energy, improving the thermal management of energy is a good way to utilize and save energy better. The energy consumption of cars is very high, and the optimization of energy consumption of cars has received much attention from researchers. The radiator performance of a car is closely related to the engines overall performance [1], and improving the heat transfer cooling performance of the radiator plays a vital role in reducing energy consumption. At present, the optimization of radiators is often done by optimizing the structure [2], and research on coolant is relatively rare. Nanofluid [3] refers to a new type of medium obtained by adding metal and non-metal particles to a traditional base fluid in a certain ratio, which has advantages in terms of specific heat and heat transfer capacity and has been applied in many fields. In [4], the heat transfer performance of CuO-water nanofluid was analyzed by numerical methods and it was found that nanofluid at higher concentrations enhanced heat transfer. In [5], the performance of graphene/water nanofluids was analyzed to replace deionized water in solar gravity heat pipes and it was found that the use of 0.05 wt% nanofluid instead of water reduced the start-up time by more than 10 % and improved the thermal efficiency for solar collection. Authors of [6] studied Fe_3O_4–H_2O nanofluids, considered the effect of the shape factor, and found that the highest Nusselt number was obtained with nanoparticles of platelet shape. In [7] the graphene oxide nanofluid was studied to improve thermal performance of pulsating heat pipe (PHP) and it was found from the comparative analysis of nanofluids of different concentrations that graphene addition improved the thermal conductivity and viscosity and reduced the thermal resistance, but the addition of nanofluids of high concentration led to worsened thermal performance.

At present, a mixture of glycol and water is the liquid used most frequently as a coolant in car radiators [8]. Compared with water, ethylene glycol has better physical properties. The heat transfer cooling performance of the coolant is the most important. As the heat transfer performance of liquid medium is inferior to that of solid, the addition of solid particles to a liquid medium is increasingly used to improve the heat transfer characteristics during cooling. Nanoparticles have a larger specific surface area and a better effect on heat transfer cooling. The superior performance of nanoparticles has received wide attention from researchers [9], and they have been well used in the cooling of electronic components and nuclear energy reactors [10].

Graphene is a two-dimensional layered planar material (Fig. 1) with a very stable structure and has advantages in electrical and mechanical aspects. With good thermal and electrical conductivity, it has broad application prospects in microelectronics and optical drives [11]. Graphene production methods have now been developed, including chemical vapor deposition (CVD) and the epitaxial silicon carbide method [12], which contributed a lot to the application and development of graphene.

This paper mainly studied graphene nanofluid; samples were prepared with different concentrations; parameters such as heat transfer have been calculated and analyzed to understand the effect of graphene nanofluid optimization on the cooling capacity of automotive radiators, in order to provide some theoretical support and foundations for a better application of nanofluids in automotive radiators.

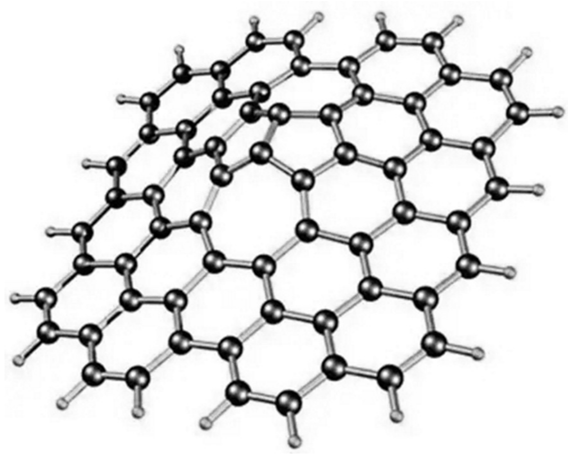

Fig. 1. The structure diagram of graphene.

2. Experimental

2.1 Graphene nanofluid

Currently, there are two main methods for the preparation of nanofluids. The one-step method: nanoparticles are directly dispersed into the base fluid to obtain fluids with favorable dispersion and stability, but the high cost required for preparation and low yield limit their application in practice.

The two-step method: the prepared nanoparticles are dispersed into the base solution, and the preparation and dispersion are done in different steps, as shown in Fig. 1. This method is simpler in operation and less expensive, so it has more applications in practice.

In this paper, the two-step method was used for the preparation. The specific process is as follows. The nanoparticles were mixed with the base fluid according in the certain ratio. PVP K-30 was added as a dispersant (the ratio of PVP K-30:nanoparticles is 1:2.). The mixture was shaken by ultrasonic for 2 h and stirred for 0.5 h. The obtained fluids were graphene nanofluids with different concentrations. The designed mass fractions of nanoparticles were 0.05 wt%, 0.1 wt%, 0.15 wt%, 0.2 wt%, 0.3 wt%, and 0.4 wt%.

The stability of the samples was analyzed using zeta potential. After preheating the instrument for 15 min, samples were taken

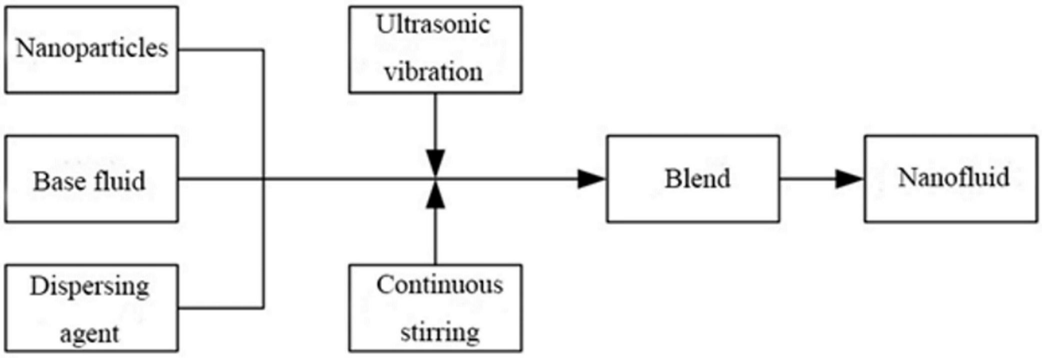

Fig. 2. The two-step method.

and placed into a sample sink. After submerging the electrode, the sample sink was put into the instrument. The zeta potential value was measured. Every sample was measured three times, and the average value was taken as the final result.

2.2 Cooling efficiency test experiment

In this article, experiments were carried out on car radiators Changan Lingmu to evaluate the optimization of nanofluids. Radiator parameters are given in Table 1.

The test process is as follows. The samples were heated, with heating time controlled according to the radiator inlet temperature. The fluid flow rate was controlled through the flow meter valve. The temperature at the radiator outlet, inlet, and wall surface was measured and recorded in real-time. The samples were tested one by one.

2.3 Heat transfer cooling performance calculation

The parameters involved in the calculation and their values are shown in Table 2.

(1) *Physical parameters* [13–15]

Fluid density directly affects the Reynolds number, Nussle number, etc., is describe as follows

$$\rho_{lt} = \varphi\rho_{lz} + (1 - \varphi)\rho_{jy}.$$

Specific heat of fluid:

$$(\rho C_p)_{lt} = \varphi(\rho C_p)_{lz} + (1 - \varphi)(\rho C_p)_{jy}.$$

Reynolds number is the ratio of the inertial force to the viscous force, reflecting the flow property of fluids; $Re < 2300$ indicates laminar flow, and $Re > 4000$ indicates turbulent flow.

- Nanoparticle Reynolds number:

$$\mathrm{Re}_{lz} = \frac{2\rho_{jy}k_b T_{lt}}{\pi\mu_{jy}^2 d_{lz}}.$$

- Fluid Reynolds number:

Table 1. Heat sink parameters

Parameters	Numerical value
Length, width, and height, m^3	0.33×0.016×0.002
Number of pipes, roots	20
Cross-sectional area, m^2	$3.2\cdot10^{-5}$
Perimeter, m	0.036

$$\mathrm{Re} = \frac{\rho v d_t}{\mu},\quad v = \frac{f_v}{A'},\quad d_t = \frac{4A'}{P'}.$$

Prandtl number describes the effect of physical properties of the fluid on heat transfer performance

$$Pr = \mu C_p / k.$$

Fluid viscosity is the fluids internal friction when subjected to external forces, related to heat transfer,

$$\mu_{lt} = \mu_{jy}(1 + 7.3\varphi + 123\varphi_2).$$

(2) *Heat transfer parameters* [16]

Heat flow: heat load,

$$Q = m_v C_p(T_{in} - T_{out}),\quad m_v = \rho f_v.$$

Heat transfer coefficient:

$$h = \frac{m_v C_p(T_{in} - T_{out})}{A(T_a - T_w)},\quad A = 2l(w + h')n.$$

Nussle number is the intensity of convective heat exchange,

$$Nu = \frac{hd_t}{k}.$$

3. Results and discussion

The stability of the samples (zeta potential) is shown in Fig. 3.

Table 2. Parameters of heat transfer cooling performance

Parameter	Meaning
lt	Nanofluid nf
lz	Nanoparticle np
jy	Base fluid bf
ρ	Density, kg/m^3
C_p	Specific heat at constant pressure
φ	Nanoparticle concentration
Re	Reynolds number
k_b	The Boltzmann constant, $k_b \approx 1.38 \cdot 10^{-23}$) J/K T_{lt}
μ	Viscosity, Pa·s
d_{lz}	Nanoparticle diameter
Pr	Prandtl number
υ	Fluid flow rate, m/s
f_υ	Volume flow rate
d_t	Hydraulic diameter, m
h	Heat transfer coefficient, W/(m^2·K)
k	Thermal conductivity, W/(m·K)
A	The surface area of the radiator
A'	The cross-sectional area of the radiating tube
P'	The circumference of the radiator
l	Pipe length
w	Pipe width
h'	Pipe height
n	Number of pipes
T_{in}	Inlet temperature
T_{out}	Outlet temperature
T_a	The average value of inlet and outlet temperatures
T_w	Radiator wall temperature
m_υ	Mass flow rate

It was seen from Fig. 3 the zeta potential value of the samples decreased gradually with an increase in the sample concentration, i.e., the zeta potential became less stable. The zeta potential value of the 0.05 wt% sample was 6.43 mV, while the zeta potential value of the 0.4 wt% sample was only 0.42 mV, which decreased by 93.46 % compared to the 0.05 wt% sample. The results indicate that with an increase in the amount of graphene nanoparticles, the samples are more prone to agglomeration and destabilization, showing poor dispersion.

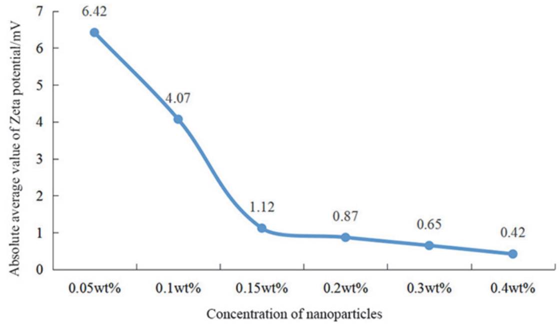

Fig. 3. Sample stability analysis.

The effect of nanoparticle concentration φ on the heat transfer coefficient h is compared for different samples. When the inlet temperature was 75°C, changes in the h value for different samples and different flow rates υ are shown in Table 3.

The general trend of change in Table 3 was that at the same concentration, the higher the flow rate, the larger the h value; with the same flow rate, the larger the concentration of the nanoparticles, the larger the h value. For example, at $\upsilon = 0.6$ m/s, for 0.05 wt% sample, the h value was 7582 W/(m^2·K), and for the 0.4 wt% sample, the h value was 9377 W/(m^2·K), which was 23.67 % larger than that for the 0.05 wt% sample. For the 0.05 wt% sample as an example, the h value was 12879 W/(m^2·K) at $\upsilon = 1.0$ m/s, which was 69.86 % larger than that at $\upsilon = 0.6$ m/s. Then, an increase in the h value was discussed. For example, at $\upsilon = 0.6$ m/s, for the 0.15 wt% sample, the h value was 8233 W/(m^2·K), which was 8.59 % larger than that for the 0.05 wt% sample; for the 0.4 wt% sample, the h value was 9377 W/(m^2·K), which was only 3.8 % larger than that of the 0.3 wt% sample. The same feature was also seen at $\upsilon = 1.0$ m/s. At $\upsilon = 1.0$ m/s, the h value of the 0.15 wt% sample was 14267 W/(m^2·K), which was 10.78 % larger than that of the 0.05 wt% sample; the h value of the 0.4 wt% sample was 15537 W/(m^2·K), which was only 3.68 % larger than that of the 0.3 wt% sample. Table 3 indicated that as the concentration of nanoparticles increased, the effect on the heat transfer coefficient became smaller, and the flow rate was positively correlated to the heat transfer coefficient: the larger the flow rate, the larger the h value.

Table 3. Variation of the h value for different samples and flow rates (unit: W/(m^2·K))

	0.6 m/s	0.7 m/s	0.8 m/s	0.9 m/s	1.0 m/s
0.05wt%	7582	8233	9536	11212	12879
0.1 wt%	8186	9078	9864	12264	13985
0.15 wt%	8233	9236	10325	12563	14267
0.2 wt%	8579	9455	10678	12748	14568
0.3 wt%	9034	9876	10946	13564	14986
0.4 wt%	9377	10276	11216	13892	15537

When the flow rate was fixed at 1.0 m/s, the effect of inlet temperature T_{in} on the h value was studied, and the results are shown in Table 4.

It is seen from Table 4 that at the same flow rate, as the inlet temperature increases, the h value of the sample with the same concentration increases. For the 0.05 wt% sample as an example, when T_{in} = 75°C, h = 12879 W/(m^2·K); at T_{in} = 80°C, h = 14811 W/(m^2·K), which is 15 % larger than at T_{in} = 75°C; at T_{in} = 85°C, h = 18714 W/(m^2·K), which is 26.35 % larger than at T_{in} = 80°C. Similarly, for the 0.4 wt% sample as an example, at T_{in} = 80°C the h value is 15.65 % larger than at T_{in} = 75°C, and the h value at T_{in} = 85°C is 24.86 % larger than at T_{in} = 80°C. These results indicate that the graphene nanofluid is more effective in improving the heat transfer coefficient at high temperatures.

Table 4. Effect of inlet temperature T_{in} on the h value

	75°C	80°C	85°C
0.05 wt%	12879	14811	18714
0.1 wt%	13985	16283	20403
0.15 wt%	14267	16507	20609
0.2 wt%	14568	16653	21042
0.3 wt%	14986	17434	21442
0.4 wt%	15537	17968	22434

Conclusions

In this article, graphene nanofluids of various concentrations were prepared as automotive coolants and their cooling heat transfer capability was analyzed. During the experiments it was found that:

1. An increase in the concentration of graphene nanofluid did not contribute to the stability of the sample.
2. The higher the concentration of the additive, the greater the increase in the heat transfer coefficient
3. Heat transfer coefficient increases with increasing the flow rate;
4. The increase in heat transfer coefficient was more evident when the samples were exposed to high temperatures.

The experimental results demonstrate the advantages of the cooling ability of graphene nanofluids in heat transfer. Graphene nanofluids could be further promoted and optimized in automotive radiators to promote energy savings.

References

1. S.Ruzimov, D.A.Muydinov, *Tech. Sci.*, **5**, 46 (2020).
2. H.Zhou, Y.Zhang, T.Xu et al., *J.Adv.Manuf. Syst.*, **16**, 129 (2017).
3. R.Ramana, V.Sugunamma, N.Sandeep, *J. Phys.Conf.*, **1000**, 1 (2018).
4. M.Sheikholeslami, M.K.Sadoughi, *Int.J.Heat Mass Tran.*, **116**, 909 (2018).
5. S.Zhao, G.Xu, N.Wang et al., *Nanomaterials*, **8**, 1 (2018).
6. M.Sheikholeslami, S.M.Shahzad, *Int.J.Heat Mass Tran.*, **118**, 182 (2018).
7. A.Puia, R.Ghasempour, M.H.Ahmadi et al., *Int.Commun.Heat Mass*, **91**, 90 (2018).
8. A.Tripathi, H.Chandra, in: MATEC Web of Conferences, Singapore (2015), p.1.
9. M.Khan, M.Irfan, W.A.Khan, *Results Phys.*, **9**, 851 (2018).
10. C.F.Ramos-Castaeda, M.A.Olivares-Robles, J.V.Mendez-Mendez, *Processes*, **9**, 1 (2021).
11. J.Li, J.Xia, F.Zhang et al., *Talanta*, **181**, 80 (2018).
12. S.Naghdi, K.Y.Rhee, S.J.Park, *Carbon*, **127**, 1 (2018).
13. B.C.Pak, Y.Cho, *Exp.Heat Transfer*, **11**, 151 (1998).
14. Y.M.Xuan, W.Roetzel, *Int.J.Heat Mass Tran.*, **43**, 3701 (2020).
15. X.Wang, X.Xu, *J.Thermophys.Heat Tr.*, **13**, 474 (1999).
16. R.K.Ravi, R.P.Saini, *Appl.Therm.Eng.*, **129**, 735 (2018).