Heat transfer enhancement of Al_2O_3 -EG nanofluid in a car radiator with wire coil inserts

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7 **A B S T R A C T**

8 In this experimental study, Aluminum Oxide (Al_2O_3) in Ethylene Glycol (EG) as nanofluid was
9 used for heat transfer enhancement in car radiator together with wire coil inserts. Two wire coils
10 inserts with different geometry and nanofluids with volume concentrations of 0.08%, 0.5% and
11 1% were investigated. The results indicated that the use of coils inserts enhanced heat transfer
12 rates up to 9 %. In addition, the simultaneous use of the coils inserts with the nanofluid with
13 concentration of 0.08%, 0.5% and 1% resulted the thermal performance enhancement up to 5%
14 as compared to the use of coils inserts alone.

15 **Keywords:** Heat transfer enhancement, Car radiator, wire coil inserts, nanofluid

17 **1. Introduction:**

18 Cooling system in engines is very important part because a lot of energy (about one third) is
19 wasted by this system. Therefore, if even for a short time the cooling system cause the problem
20 or it unable to perform his work well, it can lead to increase fuel consumption, evaporation of

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21 fuel, increase pollution and this could cause irreparable damages to the vehicle engine
 22 components. Due to the reduction of fuel consumption and power consumption in cooling
 23 system, performance improvements and optimization of the cooling system is necessary.
 24 Therefore, researchers have forced to think about the different ways to enhance heat transfer and
 25 cooling performance in the engine. There are several methods to improve the performance of the
 26 cooling system. These methods can be divided into active and passive methods. The active
 27 techniques require additional external power such as surface vibration and fluid injection. The
 28 passive techniques do not require direct input of external power [1].
 29 Taymaz et al. [2] conducted an experimental study of heat loss in a diesel engine with ceramic
 30 coating. They attempted to increase the efficiency of the internal combustion engine in recent
 31 years by reducing energy loss in the engine coolant during the cycle. The main purpose of their
 32 study was to determine heat losses in many different engine speeds, with or without ceramic

Nomenclature

A_s	Surface area of the Radiator (m^2)
W	Length of the Radiator (m)
L	Height of the Radiator (m)
D	inner diameter of the pipe (m)
V	Volume (m^3)
C_p	Heat capacity ($J/kg\ K$)
g	Gravitational acceleration (m/s^2)
h	Heat transfer coefficient ($W/m^2\ K$)
k	Thermal conductivity (W/m K)

$\dot{m}$	Mass flow rate of fluid (kg/s)
$\dot{Q}$	Volumetric flow rate (m^3/s)
Nu	Nusselt number
Re	Reynolds Number
$\mathcal{F}$	Friction factor
U	Velocity (m/s)
T	Temperature ($^{\circ}C$)
T_{∞}	Ambient temperature ($^{\circ}C$)
T_b	The average temperature inlet and outlet ($^{\circ}C$)
T_w	Wall temperature of the Radiator ($^{\circ}C$)

Greek symbols

μ	Dynamic viscosity ($kg/m^2 s$)
φ	Volume concentration of nanoparticles (%)
ρ	Density (kg/m^3)
ΔP	Pressure drop across the Radiator (pa)

Subscripts

EG	Ethylene glycol
H	Hydraulic Diameter
I	Inlet
O	Outlet
bf	Base fluid

<i>nf</i>	Nano fluid
<i>np</i>	Nano particle

coating. The results showed that using the 0.5 mm thickness of the insulating coating on the piston crown and cylinder head, 5 to 25 percent reduction in heat loss occurs. David Huang et al. [3] experimentally investigated the effects of anti-freeze concentration in the engine coolant on the cavitation temperature of a water pump. They examined the cavitation temperature of the water pump in an engine-cooling system using three different coolants contains 100% pure water, 50% EG/ 50% pure water and 100% EG at various rotational speeds. Three major factors such as the quality of the coolant, the inlet temperature and the inlet pressure of the water pump controlled the cavitation of the water pump. The results showed that engines have a higher tolerance to air bubbles at lower rates of rotation. At a given fixed rotational speed, the tolerable cavitation temperature of an engine's water pump will fall slowly as the amount of air bubbles increases. Ganga Charyulu et al. [4] presented an experimental study of performance evaluation of a radiator mounted on a turbo-charged diesel engine with and without fouling factor. The characteristics of the radiator analyzed for deferent tube rows with varying air mass velocities to enable the design engineer to select the size depending upon the requirement and application. They also examined the effect of deferent materials of construction of fins and tubes.

Vithayasai et al. [5] conducted an experimental research on the effects of the electric field on the car radiator heat transfer performance when the air speed of the front radiator is low. Results showed that the unit with electric field pronounced better heat transfer rate, especially at low frontal velocity of air. Peyghambarzadeh et al. [6] conducted an experimental research to

improve vehicle radiator cooling performance using nanofluid , Al_2O_3 / water compared to pure water. Nanofluid at different volume concentrations of 5%, 1% and 0.1% are used in conducting experiments. The results showed that nanofluids enhance heat transfer compared to their own base fluid. In the best conditions, the heat transfer enhancement of about 40% compared to the base fluids obtained. Naraki et al. [7] experimentally studied the overall heat transfer coefficient of CuO/water nanofluids under laminar flow regime ($100 < \text{Re} < 1000$) in a car radiator. The results showed that the overall heat transfer coefficient with nanofluid is more than the base fluid. The overall heat transfer coefficient increased with the enhancement in the nanofluid concentration from 0 to 0.4 % concentration. They also observed that the overall heat transfer coefficient decreases with increasing the nanofluid inlet temperature from 50 to 80 °C. Peyghambarzadeh et al. [8] presented an experimental investigation of forced convective heat transfer in a water based nanofluid compared to that of pure water in an automobile radiator with 0.1-1 % concentration. They showed that increasing the fluid circulating rate can improve the heat transfer performance while the fluid inlet temperature to the radiator has inconsiderable effects. Peyghambarzadeh et al. [9] experimentally studied the overall heat transfer coefficient in the application of dilute nanofluids (Copper oxide (CuO) and Iron oxide (Fe_2O_3) nanoparticles are added to the water at three concentrations 0.15, 0.4, and 0.65 vol.%) in the car radiator. They evaluated the heat transfer performance of the automobile radiator by calculating the overall heat transfer coefficient (U) according to the conventional ϵ -NTU technique. Results demonstrated that both nanofluids show greater overall heat transfer coefficient in comparison with water up to 9%. They also observed that increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient. Ravikant et al. [10] presented a numerical study of fluid dynamic and heat transfer performance of Al_2O_3 and CuO nanofluids in

the flat tubes of a radiator. A three-dimensional laminar flow and heat transfer with two different nanofluids, Al_2O_3 and CuO , in an Ethylene Glycol and water mixture circulating through the flat tubes of an automobile radiator numerically studied to evaluate their advantage over the base fluid. Results for the local and the average friction factor and convective heat transfer coefficient showed an increase with increasing particle volumetric concentration of the nanofluids.

Most studies have been concerned with passive methods. Recent interests in the use of tube insert [11] and nanofluids [12] for possible heat transfer intensification have attracted the attention of many investigators. Also some researchers have focused on improving heat transfer by nanofluid and twisted and wire coiled inserts [13-16]. Syam Sundar et al. [17] experimentally studied Heat transfer and friction factor of multi-walled carbon nanotubes- Fe_3O_4 nanocomposite nanofluids flow in a tube with/without longitudinal strip inserts. They showed that the Nusselt number enhancement for 0.3% nanofluid flow in a tube without inserts is 32.72% and with inserts of aspect ratio 1 is 50.99% at a Reynolds number of 22,000. Chougule et al. [18] presented a experiment study of heat transfer enhancements of low volume concentration CNT/water nanofluid and wire coil inserts in a circular tube. They also observed that the use of nanofluids increases the heat transfer rate with negligible increase in friction factor in the plain tube and the tube fitted with wire coil inserts. Also, experimental investigation on heat transfer enhancement of a tube with coiled-wire inserts installed with a separation from the tube wall is done by Keklikcioglu and Ozceyhan [19].

From the above literature review, it can be noted that many of the investigations found in the literature described above did not focused on both passive technique of nanofluid and wire coiled inserts. Hence, the aim of the present study is to study both the heat transfer coefficient and friction factor in the turbulent flow of $\text{Al}_2\text{O}_3/\text{EG}$ nanofluid in car radiator with and without wire

coil insert, because the thermo-hydraulic behavior of wire coil inserts with and without nanofluids in car radiator has not been investigated.

2. Experimental setup and description

2.1. Experimental setup

The experimental setup is shown in Fig.1. Also, the experimental setup is shown schematically in Fig. 2. This experimental setup includes:

(1) Tank: the reservoir has a capacity of about 18 liters of cooling fluid that the coolant is placed in it. 6 heat electrical elements used in the tank to raise the temperature of the coolant fluid, similar to engine temperature rises during operation, which is about 80 °C. (2) Pump: a pump with Diamond QB-60 model used, which has a $Q_{max}=35$ lit/min, $H_{max}=35$ m, 0.5 hp power and is around 2850 rpm. This pump is one step and using a tap placed on the pump output can be different to the flow rate adjusted. (3) Radiator: the radiator used in this article belongs to the Peugeot 405 vehicle. This radiator as the heat exchanger is a compact heat exchanger which contains 40 channels with dimensions of 24*1.5 mm. (4) Fan: According to the vehicle structure (Peugeot 405) fans are used behind the radiator. The fan with C78/22/4SO model and with specifications PH:1, HZ:50. V: 220 used. Fan speed is adjustable in the trial of three low, medium and high. (5) Controller device: This device contains fuses regarding a thermal element and pump, digital displayer, temperature sensor connected to the radiator inlet and screws to adjust fan speed. By the fluid inlet temperature to the radiator temperature sensor shows and according to the desired temperature of the fluid control device is set on it, electric heating elements off, and if the temperature is set lower, connected. Digital displayer shows the inlet temperature of the fluid to the radiator. (6) Rotameter: Flowmeter used in this study is rotameter

with LIQID-SP.GR.1.O model. This flowmeter installed at the entrance to the radiator. (7)
Pressure gauges: In the Experimental setup of the two pressure gauges with EN-837-3 models in
the pressure range from 0-160 mbar is used. It installed at the input and output of radiator. (8)
Thermocouples: Two thermocouples (type K) are used to measure the fluid temperature in the
input and output of radiator. Other thermocouples are used for measuring the temperature on the
radiator body wall. By connecting all the thermocouple to the data logger with model TES 1384,
temperature measured and recorded.

2.2. Nanofluids preparation

In this study, Al_2O_3 nanoparticles with an average size of 40 nm are used. EG is used as the base
fluid. A small quantity of sodium dodecylbenzene sulfonate (SDBS) is used as dispersant.
The physical properties of nanoparticles are listed in Table 1. The SEM (scanning electron
microscope) micrograph of the prepared sample is shown in Figs. 3. There are three techniques
for the preparation of nano-fluids with the final stability of dispersions [20]; (1) changing the pH
value of suspensions; (2) adding the surface activators to the suspensions; (3) putting in an
ultrasonic apparatus. In this study, ultrasonic apparatus is used for the preparation of nano-fluid.
The first stage is to mix nanoparticles in Ethylene glycol and the second stage is to homogenize
the mixture using ultrasonic vibration (UP-400S model), which is depicted in Fig. 4 with
working frequency of 24 kHz and useful output power of 400 W. After sonification for
approximately 1 h, the dispersion of the nanoparticles is established by visual observation for
nanoparticle sedimentation. Since the sonication time is an important factor for breaking down
agglomerates, uniform dispersion and stable suspension of nanoparticles in liquid this time was
selected 30 min after several tests. In present work, three volume concentrations contains 0.08%,
0.5% and 1% is used.

The tube inserts are made of copper strip from 0.3 mm thick and 0.013 m width in the Energy Research Laboratory (Yasouj University). Two used configurations in the present work are shown in Fig. 5. Also, wire coil inserts having pitch ratios of 2 are used in present work. Specifications of tube inserts are shown in Table. 2.

3. Results and discussion

In this study, by measuring the temperature and pressure in certain areas such as, input and output radiator, radiator wall temperature and ambient temperature at different flow rate; the heat transfer coefficient and friction factor are determined. Also, the effect of parameters such as mass flow rate, fan speed, tube insert geometry and concentration of the nano-fluid studied.

The experimental friction factor is obtained from the relation;

$$f = \frac{D_H}{L} \left(\frac{2\Delta P}{\rho U^2} \right) \quad (1)$$

Where, ΔP is the pressure difference between the inlet fluid and outlet fluid in the radiator. D_H , is hydraulic diameter in the radiator pipes, which of the following equation is obtained [21].

$$D_H = \left(\frac{4V}{\pi L} \right)^{0.5} \quad (2)$$

Where V and L are the volume and height of the radiator, respectively, where V is obtained from this equation.

$$V = 40 A.W \quad (3)$$

Where A and W are cross- sectional area pipe and length of the radiator, respectively. Also, Mean flow velocity in the radiator is calculated from the continuum equation.

The heat transfer coefficient and corresponding Nusselt number can be derived as follows:

The heat transfer rates due to the fluid flowing inside the tube to the outside air flowing in the air flow can be calculated as:

$$Q_{f1} = \dot{m} C_{p,nf}(T_i - T_o) \quad (4)$$

$$Q_{f2} = hA_s(\tilde{T}_w - T_b) \quad (5)$$

Where Q_{f1} and Q_{f2} are the heat transfer rates for the radiator using two different calculation methods. $\dot{m}$ is mass flow rate. A_s , is the surface area of the radiator. T_b is bulk temperature which is assumed to be the average values of inlet (T_i) and outlet (T_o) temperatures of the fluid moving through the radiator, and $\tilde{T}_w$ is tube wall temperature which is the mean value measured by 3 thermocouples. These parameters are obtained by the following equations.

$$\tilde{T}_w = 0.33(T_o + T_i + T_{amb}) \quad (6)$$

$$T_b = \frac{T_o + T_i}{2} \quad (7)$$

Reynolds number is calculated by equation (8) to determine the flow regime.

$$Re = \frac{\rho U D_H}{\mu} \quad (8)$$

Then, The heat transfer coefficient and corresponding Nusselt number is obtained from eq's (9) and (10).

$$h = \frac{\dot{m} C_p (T_o - T_i)}{A_s (\tilde{T}_w - T_b)} \quad (9)$$

$$Nu = \frac{h D_H}{k} \quad (10)$$

Where, k is fluid thermal conductivity. Also all the physical properties were calculated at the fluid bulk temperature.

The thermal performance factor of the radiator with coil wire inserts under same pumping power criteria is given by [1];

$$\eta = \frac{h_{rc}}{h_r} \quad (11)$$

Where h_r and h_{rc} are the heat transfer coefficient for the radiator without inserts and heat transfer coefficient for the radiator with inserts, respectively.

If nanofluid is used as the working fluid, K_{nf} is calculated by [20]:

$$\frac{K_{nf}}{K_{EG}} = \frac{K_{np} + 2 K_{EG} + 2\phi(K_{np} - K_{EG})}{K_{np} + 2 K_{EG} - \phi(K_{np} - K_{EG})} \quad (12)$$

C_p and ρ are the heat capacity and density of nanofluid respectively. These parameters can be calculated by equations (13) and (14) [20]:

$$C_{p,nf} = \frac{\phi \rho_{np} C_{p,np} + (1-\phi) \rho_{EG} C_{p,EG}}{\rho_{nf}} \quad (13)$$

$$\rho_{nf} = (1 - \phi) \rho_{EG} + \phi \rho_{np} \quad (14)$$

where ϕ suggests the volume fraction of nanoparticles. Also, Viscosity of nanofluids was calculated via the general Einstein's formula [21].

$$\mu_{nf} = \mu_{EG}(1 + \eta\phi) \quad , \eta = 2.5 \quad (15)$$

Where $\eta = 2.5$, as recommended for hard spheres [21].

In this study, two tube inserts with various geometries are investigated. Also, from Al_2O_3 nanoparticles to reinforce the thermal properties of the base fluid (EG) used. These experiments in three flow rate of 11, 12.25 and 13.50 lit/min and the Reynolds number in the range of $18500 < Re < 22700$ and three fan speed (rpm) 750, 1100 and 1220(rpm) is investigated. Nanofluid in volume concentrations of 0.08, 0.5 and 1 % was used in this study.

In present work, to investigate the effect of tube inserts three cases have been examined. In the first case, coil wires (type A) are inserted in the left channels and in the second case, coil wires (type B) are inserted in the right channels (Fig. 6). But in the final case, both coil wire insert are embedded together across all channels. TIT1, TIT2 and TIT3 represents for the first case, second case and third case, respectively. In other words, TIT1 represents first case where coils (type A) located on the left side of radiator. TIT2 represents second case where coils (type B) located on

the right side of radiator. TIT3 represents third case where coils (type A) located on the left side of radiator and coils (type B) located on the right side of radiator.

Also, comparison was made between the experimental data and empirical correlations developed by Gnielinsky [1].

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}}-1\right)} \quad (16)$$

In Eq. (9), f is friction factor and was developed by Filonenko [1].

$$f = (0.79 \ln Re - 1.69)^{-2} \quad (17)$$

Nusselt number of base fluid in radiator with different coil wire inserts is shown in Fig. 7. The experimental results clearly show that the Nusselt number increased by increasing the Reynolds number in all states. In addition, by using coil wire inserts in the radiator the Nu number increased compared to radiator without tube inserts. Results show that An increase of 2% , 4% and 9% in Nusselt number for a Reynolds number of 22672 is observed for wire coil inserts TIT1, TIT2 and TIT3, respectively. The main reason for this increase is the Nusselt number is the use of wire coil inserts which increases the energy exchange rates in the fluid. Also, In Fig. 7 good agreement can be seen between empirical correlations and the results obtained in this study. Fig. 8 shows the Nusselt number of the fluid in radiator at $Re = 22672$ for the different fan speed in the range of $750 < N < 1220$. In all cases, with or without tube inserts, Nusselt number increased with increasing speed of cooling fan. The largest increase in Nusselt number about 7% is related to the third case at $N = 1220$ (approx.).

Fig. 9 shows the effect of concentration of AL_2O_3/EG nanofluid on Nusselt number of the radiator with tube inserts type TIT3. The results show that the Nusselt number increased with increasing AL_2O_3 concentration and all AL_2O_3/EG nanofluids gave higher Nusselt number than

233 EG as the based fluid. The main reasons for this increase are the ability of suspended
 234 nanoparticles enhancing thermal conductivity and movement of nanoparticles carrying energy
 235 exchange. Of course the differences between these concentrations are not very noticeable.
 236 Nusselt number in Fig. 8 shows that the presence of AL_2O_3 at 0.08%, 0.5% and 1% vol.
 237 concentration enhanced Nusselt number by 11%, 12.5% and 13%, respectively, compared to that
 238 of EG as base fluid at $Re = 22672$. Fig. 10 shows the Nusselt number at $Re = 22672$ for the
 239 different speed of cooling fan. Nusselt number increased with increasing the speed of cooling fan
 240 for all concentration. The largest increase in Nusselt number about 7% is related to the third case
 241 at $N = 1220$ (approx.). The minimum and maximum change in Nusslet number by fan speed are
 242 6.5% at $N = 750$ (approx.) and 12.5% at $N = 1220$ (approx.), respectively.
 243 The friction factor of the radiator with tube inserts are represented in Fig. 11. The use of tube
 244 inserts resulted in an increase in friction factor compared to the radiator without tube inserts. As
 245 shown in Fig. 11, the maximum friction factor with tube inserts TIT3 was found. In addition, at
 246 the same Reynolds number, TIT3 caused 2.3-5% higher friction factor than the TIT1 and 18-
 247 33.5% higher friction factor than the radiator without tube inserts. Also, the friction factor of
 248 AL_2O_3 nanofluid is shown in Fig. 12. The friction factor of AL_2O_3 nanofluid is high compared to
 249 the friction factor of EG as base fluid. At the same Reynolds number, nanofluids with different
 250 volume concentration caused 1-11.8% higher friction factor than the radiator with tube insert
 251 TIT3 and 20-47.5% higher friction factor than the radiator without tube inserts. The main reason
 252 for the enhancement of friction factor is solid nanoparticles present in the base fluid.
 253 Although tubes insert increases heat transfer, it leads to more pressure drop. To evaluate the
 254 effects of tube insert on heat transfer and pressure drop, thermal performance factor as regard eq.
 255 11 is defined. The thermal performance factor for all tube inserts increased with an increasing

Reynolds number shown in Fig. 13. With the use of TIT1, TIT2 and TIT3, thermal performance factors were in a range between, 1.0.19–1.021, 1.039–1.043 and 1.079–1.087 respectively. The results show that the values of thermal performance factor are not significantly different for different cases. On the other hand, thermal performance factor is more than 1 in all of cases, and it can be concluded that this technique can be used in car radiators to improve heat transfer.

Experimental uncertainties in these parameters including the friction factor and Nusselt number were estimated by the procedure described in [22]. The mean uncertainties are 3.7% in the friction factor, 4.6% in the Nusselt number.

5. Conclusions

Experimental studies of heat transfer, friction factor and thermal performance factor characteristics of car radiator with coil wire inserts and AL_2O_3 nanofluid have been presented. The coil wire inserts with different configuration and AL_2O_3 nanofluid with different volume concentration were tested. The conclusion can be drawn as follows:

1. Nusselt number at Reynolds number in the range of $18500 < Re < 22700$ with coil wire inserts (TIT1, TIT2 and TIT3) is higher compared to EG without tube inserts.
2. Nusselt number at Reynolds number in the range of $18500 < Re < 22700$ with tube inserts (type TIT3) and nanofluids with the volume concentrations of 0.08%, 0.5% and 1% is higher when compared to EG as base fluid.
3. Nusselt number at Reynolds number of 18500 with the coil wire inserts (TIT1, TIT2 and TIT3) and the volume concentrations of 0.08%, 0.5% and 1% for the different fan speed in the range of $750 < N < 1220$ increased with increasing speed of cooling fan.

4. Friction factor at Reynolds number in the range of $18500 < Re < 22700$ with the coil wire inserts (TIT1, TIT2 and TIT3) and the volume concentrations of 0.08%, 0.5% and 1% is higher compared to EG as base fluid.

5. There is no significant difference in thermal performance factor at the different coil wire inserts. In all of cases, thermal performance factor is more than 1, and can be concluded that this technique can be used in car radiators to improve heat transfer.

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Fig.1. The experimental setup

Fig.2. Schematic of the experimental apparatus; (1) tank, (2) pump, (3) radiator, (4) fan, (5) controller device, (6) rotameter, (7) pressure gauge, (8) thermocouple, (9) elements, (10) line valve, (11) data logger.

Fig. 3. SEM photograph AL_2O_3 particle.

Fig. 4. The ultrasonic device, A: the concentrations of 0.08%, B: the concentrations of 0.50%, c: the concentrations of 1.00 %

Fig. 5. Configurations of tube insert located in tube

Fig. 6. Tube insert located in tube; type A is inserted in left channel (TIT1), type B is inserted in right channel (TIT2), The combination of both TIT1 and TIT2 (TIT3)

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378 **Fig. 7.** Experimental Nusselt number of Ethylene glycol with different tube inserts.

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381 **Fig. 8.** Experimental Nusselt number of Ethylene glycol with tube insert for the different speed.

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385 **Fig. 9.** Effect of AL_2O_3/EG nanofluid volume concentration on Nusselt number of nano-fluid
 386 with tube insert (TIT3)

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Fig. 10. Experimental Nusselt number of nano-fluid with tube insert (TIT3) for various speeds.

Fig. 11. Experimental friction factor of EG with different tube inserts

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395 **Fig. 12.** Experimental friction factor of EG and different volume concentrations of AL_2O_3
 396 nanofluid with tube inserts (TIT3)

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400 **Fig. 13.** Thermal performance factor Vs Reynolds number for tube inserts.

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402 Tables:

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Table 1. The specifications of the used nanoparticles in the current study. 404

Nano fluid	Purity (%)	Diameter (nm)	Morphology	Color	Heat capacity (J/kg K)	thermal conductivity (W/m K)	Density (kg/m ³)
Al ₂ O ₃	99	40	Nearly spherical	White	880	40	3890

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Table 2. Specifications of tube inserts. 406

Material tybe Inserts		Purity (%)	Diameter (mm)	Heat capacity (J/kg K)	thermal conductivity (W/m K)	Density (kg/m ³)	Pitch (mm)
Type A	Cu	99,9	0.3	385	401	8940	11.7
Type B	Cu	99,9	0.3	385	401	8940	6

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