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An Experimental Study on the Convection Heat Transfer of Al-Mg/water Micro Fluid in a Circular Tube with Swirl

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Abstract : In the past decades, extensive studies on convection heat transfer on internal flow have been conducted by using high specific surface area, by increasing heat transfer coefficient and swirl flow, and by improving the transport properties. In this study, we applied a tangential slot swirl generator to improve heat transfer in a horizontal circular copper tube. The Al-Mg particles (approximately 100μm to 130μm) were employed for this experimental work. The copper tube was heated uniformly by winding a heating coil with a resistance of 9 ohm per meter for heat transfer. Using Al-Mg particles, experiments were performed in the Reynolds number range of 5,000 to 13,130, with and without swirl. Experimental data transfers or comparisons between Nusselt numbers with and without swirl along the test tube and Reynolds numbers are presented. The Nusselt number is improved by increasing Reynolds numbers or swirl intensities along the test tube.

Key words : Micro fluid, Swirl, Tangential slot, Bulk temperature, Nusselt number

NOMENCLATURE

C_f : Specific heat of base fluid(J/kg ℃)
Pr : Prandtl number
C_{nf} : pecific heat of macroparticle(J/kg ℃)
μ : Dynamic viscosity(kg/m·s)
C_p : specific heat of particle(J/kg ℃)
ρ : Density(kg/m^3)
h : Convective heat transfer coefficient(W/m^{2}K)
ϕ : Volume concentration of microparticles(%)
k_{nf} : Thermal conductivity of microparticle(W/m℃)
b_f : Base fluid
k_{bf} : Thermal conductivity of base fluids(W/m℃)
n_f : Micro-fluid
k_p : Thermal conductivity of microparticles(W/m℃)
w : Water
$\dot{m}$: Mass flow rate of fluids(kg/s)
p : Microparticles

1. INTRODUCTION

The characteristics of turbulent swirl flow have been studied extensively because of its great technological and scientific importance. Swirl flow improves heat in pipe flow. Recently, Saidur et al. [1] reviewed applications and challenges of nanofluids, and found that the improved thermal conductivities of nanofluids increased by up to 150% with an increase in temperature. Depsite studies on the topic, the exact mechanism of enhanced heat transfer for nanofluids remains unclear. Moreover, many challenges must be

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identified and overcome to ensure the success of different applications.

Ravikanth et al. [2] analyzed the influence of temperature and concentration of nanofluid on thermophical properties and found that the addition of nanoparticles to any liquid significantly increases viscosity while moderately increasing thermal conductivity. Specific heat and density also changed slightly. Zoubidaet et al. [3] studied the natural convective heat transfer of nanofluids, and concluded that these have great potential for heat transfer enhancement and are highly suitable for various applications.

For forced convection heat transfer, Mohammed et al. [4] and Sohelet et al. [5] studied convective heat transfer with fluid flow and boiling with nanofluid. Mohammedet et al. [4] also studied the fluid flow and heat transfer behaviors of different types of single-phase fluid flow over backward facing step; they found that Nusselt number increases along with an increase in velocity, Prandtl number, and aspect ratio. Sohelet et al. [5] studied boiling heat transfer with nanofluids in carbon tubes, and found that it is possible to enhance boiling heat flux depending on the concentration of surfactants.

Much attention has been paid in recent years to swirl flow with energy problems. The problem has practical importance given that swirl atomizers, dust extractors, and enhancement of heat transfer coefficient are widely applied. In using swirling flow, Govarthan et et al. [6] conducted CFD simulation of the heat transfer of nanofluids in a circular tube fitted with twisted inserts under constant heat flux, which is explained using Fluent version 6.326 in laminar flow. The heat transfer increased with Reynolds number and decreased with twist ratio with maximum of 2.93 for the twist ratio.

Using numerical and experimental methods, Adrian et al. [7] used a micro fluid channel consisting of two T-Junctions with vibration. Svetlanaet et al. [8] employed twisted tape as turbulence promoters in the microfiltration of milk. Using the twisted tapes, both reversible and irreversible fouling are reduced and the permeate fluxes are remarkably increased. Syam et al. [9] also measured heat transfer and friction factor of Al_2O_3 nanofluid in circular tubes with twisted tape. The heat transfer coefficient and friction factor of 0.5% and volume concentration of Al_2O_3 nanofluid are 33.51% and 1.096 times higher, respectively, compared with theflow of water in a tube.

In this study, Al-Mg/water micro fluid is used to measure bulk temperatures and then Nusselt numbers are calculated with and without swirl flow in a horizontal circular copper tube.

2. Experimental Apparatus

2.1 Swirl generator

We use a swirl generator with two parts, namely, the swirl chamber and the swirl generator. The swirl generator has 30 holes with a diameter of 2.5mm each along the generator tube, allowing the sequential circulation of the working fluid through the swirl chamber. The swirl intensities are adjusted by L/D in the swirl chamber. Where L and D are the length of swirl generator and the dia metre of the test tube, respectively.

2.2 The test tube

Figure 1 is a schematic diagram of experimental test tube, which is manufactured by copper tube, which has 7.7mm in diameter, 1,000mm in length and 0.8mm in thickness. The wall of test tube is uniformly heated by electrical power to 0.36kW(120 voltage, 3 Amp). The heating coil is uniformly wound 7mm distance along the test tube. In addition, voltage regular is employed to adjuster heat flux. K-type thermocouples are employed to measure bulk and wall temperatures with 32 channel LaView system.0.36kW (120 voltage, 3 Amp). Two becraite flanges are used the end of test tube to protect the loss of electric power. A water pump is used to circulate microfluid this system using rpm control which has 1,600c.c per miniature pumping capacity. The mass flow are measured the pump exhaust port and then the mean velocities are calculated to decide for the Reynolds number. Al-Mg particles are dispersed some refined water in a beaker with an agitator and then pour it into the mixing water tank.

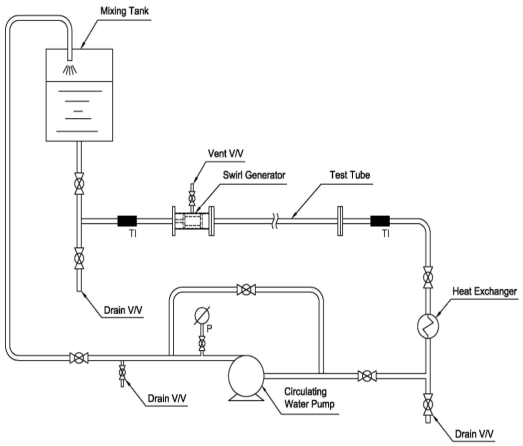

Figure 1: Experimental rig

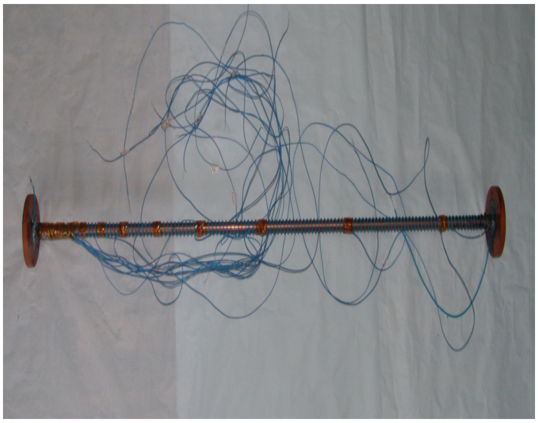

Figure 2: Heating coil winding on the test tube

2.3 Evolution of the thermo-physical properties of micro fluid

Al-Mg microparticles (approximately 100μm to 130μm) are supplied by a Korean company. Distilled water is used to disperse these particles with 0.25% volume concentration. The properties of micro fluid, such as viscosity, specific heat and thermal conductivity, are measured using VISCOMRETER (DV-II+Pro, BROOKFIELD), differential scanning calorimeter (DSC) (Q2000, TAInstruments) and TPA-501 (Hot Disk Company, Sweden), respectively.

The equations below are used to calculate these properties. The density of the micro fluid is derived using the following equation (1):

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_f \tag{1}$$

The following Einstein equation is used to determine viscosity of this micro fluid:

$$\mu_{nf} = (1+2.5\phi)\mu_f \tag{2}$$

where μ_f is the viscosity of the base liquid, and ϕ is the volume fraction of the micro fluid (0.25%). The following equation proposed by Hamilton et al. [16] is used to calculate thermal conductivity:

$$\frac{K_{nf}}{K_{bf}} = \frac{K_p + (n-1)K_{bf} - (n-1)\phi(K_{bf} - K_p)}{K_P + (n-1)K_{bf} + \phi(K_{bf} - K_p)} \tag{3}$$

where K_{nf}, K_{bf}, and K_p the thermal conductivities of the micro fluid, the base fluids and the microparticles, respectively. Here, n is the space factor of the micro fluid, and 3 refers to spherical micro fluid. The following more accurate equation is modified by Buongiorno [15]:

$$C_{pnf} = (1-\phi)\rho_f C_f + \phi\rho_p C_p)/\rho_{nf} \tag{4}$$

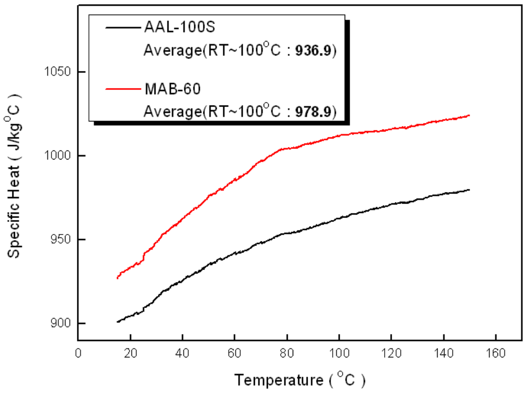

Figure 3: Specific heat of Al-Mg(MAB-60) and Al_2O_3(AAL-100S) particles

Figure 3 shows the specific heat of Al-Mg and Al_2O_3 particles measured by DSC. These values are chosen in order to decide the specific heat of micro fluid for each temperature. **Table 1** depicts the experimental conditions for this work

Table 1: Experimental conditions

1	Room temperature	25℃
2	Particles	Al/Mg
3	Volume concentration	0.25%
4	Basic fluid	Pure water
5	Heat flux	360W/120V
6	Thermocouples	k-type
7	Test tube diameter	7.7mm ID ×1000mm
8	Swirl generator	Tangential slot
9	Re number	5,000~13,130

3. Results and Discussion

The wall and fluid temperatures are measured along the test tube using k-type thermocouples. Then, the bulk temperatures and Nusselt numbers are calculated with and without swirl flow using the following equations:

$$Q = \dot{m} \times C_p \times (T_w - T_b) \tag{5}$$

$$h = \frac{Q}{A_s(T_w - T_b)} \tag{6}$$

where Nu is the Nusselt number, h is the heat transfer coefficient, and Re and Pr are the Reynolds and Prantl numbers, respectively. As and Tw are indicate the surface area and the wall temperature.

$$\mathrm{Nu} = \frac{hD}{k} \tag{7}$$

Equation (7) below is the Dittus-Boelter equation [10] given as follows:

$$\mathrm{Nu} = 0.23\mathrm{Re}^n\mathrm{Pr}^m. \tag{8}$$

Figure 4 shows the comparisons of the bulk temperatures with and without swirl for Re=5,000–13,130. The bulk temperatures with swirl are 7.3% to 9.7% higher than those without swirl flow. Where, Tb is the bulk temperature and Tr room temperature (25℃) for the test section.

The bulk temperatures are decreased with the decline in Reynolds number and swirl intensity. These occurrences could be attributed to strong tangential velocities.

Using these bulk temperatures and the wall temperatures, the Nusselt numbers are calculated for several Reynolds numbers with and without swirl.

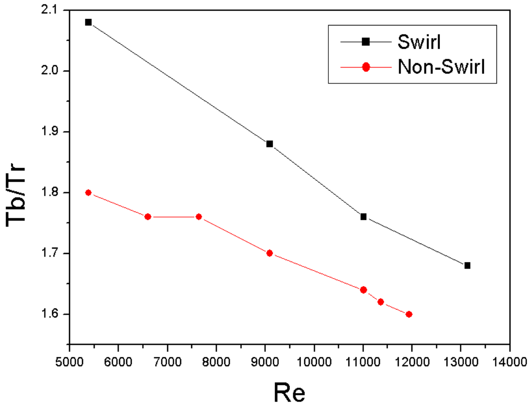

Figure 4: Bulk temperature distributions for the Reynolds numbers with and without swirl flow

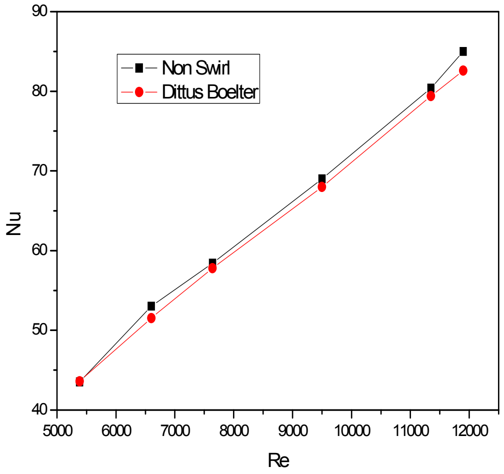

Figure 5: Comparisons of Nusselt numbers without swirl flow and the Dittus-Boelter equation

Figure 5 compares the Nusselt numbers of Al-Mg/water micro fluid without swirl with those obtained using the Dittus-Boelter equation along the test tube for Re=5000 to 12,000. The Nusselt number without swirl is approximately 1.25% to 3.7% higher than that obtained using the Dittus-Boelter equation. The bulk temperature of Al-Mg/water micro fluid is considered based on the particle conductivity.

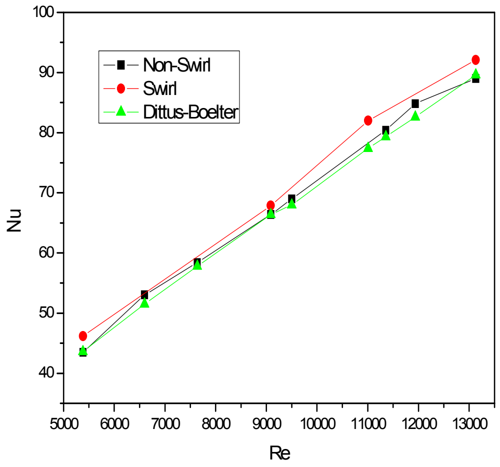

Figure 6: Comparisons of the Nusselt number distributions with and without swirl for Reynolds numbers

However, the Nusselt number at the entry of the test tube is nearly the same with that obtained using the Dittus-Boelter equation. In addition, at the end of the test tube, the Nusselt number is slightly higher than that obtained using the Dittus-Boelter equation. The bulk temperature is increased along the tube.

In **Figure 6**, Nusselt numbers with and without swirl flow are compared with those of Dittus-Boelter for Re=5000 to 13,130. The Nusselt numbers with swirl flow are 2.0% to 2.7% higher than those without swirl flow and 2.1% to 6.2% higher than those obtained using the Dittus-Boelter equation, respectively. These features are considered based on the tangential velocity and the friction of swirling flow. The Nusselt number with swirl flow is not much higher than that without swirl flow and that obtained using the Dittus-Boelter equation. This result is related to the faster decline of swirl flow at 7.7 inside the diameter tube. Therefore, the tangential velocity with swirl flow does not significantly affect the heated wall inside the test tube.

4. CONCLUSION

Al-Mg/water micro-fluid is employs in this work. Bulk and wall temperatures are measured using k-type thermocouples along the test tube under uniform heating condition. Afterwards, Nusselt numbers with and without swirl flow in a horizontal circular tube are calculated for Re=5,000 to 13,130. The conclusions below have been obtained.

1) The bulk temperature with swirl shows 7.3% to 9.7% higher than that of non swirl flow, but the bulk decreases with increasing the Reynolds. This features are considered from the constant heat flux along the test tube.

2) The Nusselt number without swirl is approximately 1.25% to 3.7% higher than that

obtained using the Dittus-Boelter equation. These numbers are considered based on the particle conductivity and the bulk temperature of Al-Mg/water micro fluid.

3) The Nusselt numbers with swirl flow are 2.0% to 2.7% higher than those without swirl flow and 2.1% to 6.2% higher than those obtained using the Dittus-Boelter equation, respectively. These particular things are considered based on the tangential velocity and the friction of swirl flow. Nusselt numbers with swirl flow are not much higher than those without swirl flow and those obtained using the Dittus-Boelter equation. This result may be attributed to the faster decline of swirl flow at 7.7mm inside the diameter tube. Therefore, the tangential velocity with swirl flow does not significantly affect the heated wall along the test tube.

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REFERENCES

[1] R. Saidur, K. Y. Leong, and H. A., “Mohammad, A review on applications and challenges of nanofluids,” Renewable and Sustainable Energy Review, vol. 15, pp. 1646-1668, 2011.

[2] Ravikanth S. Vajjha and Debendra K. Das, “A review and analysis on influence of temperature and concentration of anofluids on thermophysical properties, heat transfer and pumping power,” International Journal of Heat and Mass Transfer, vol. 55, pp. 4063-4078, 2012.

[3] Zoubida Haddad, Hakan F. Oztop, Eiyad Abu-Nada, and Amina Mataoui, “A review on natural convective heat transfer of nanofluids”, Renewable and Sustainable Energy Review, vol. 16, pp. 5363-5378, 2012.

[4] H. A. Mohammed, A. A. Al-aswadi, N. H. Shuaib, and R. Saidur, “Convective heat transfer and fluid flow over a step using nanofluids”, Renewable and Sustainable Energy Review, vol. 15, pp. 2921-2939, 2011.

[5] S. M. Sohel Murshed, C. A Nieto de Castro, M. J. V. Lourenco, M. L. M. Lopes, and F. J. V. Santos, “A review of boiling and convective heat transfer with nanofluids”, Renewable and Sustainable Energy Review, vol. 15, pp. 2342-2354, 2011.

[6] Govarthan Pathipakka and P. Sivashanmugam, “Heat transfer behavior of nanofluids in a uniformly heated circular tube fitted with herical inserts in laminar flow,” Supertlattices and Microstructures, vol. 47, pp. 349-360, 2010.

[7] Adrian Neild, Tuck Wah Ng, Gregory J., Sheard, Matthew Powers, and Stefano Oberti, “Swirl mixing at microfluidic junctions due to low frequency side channel fluidic perturbations,” Sensors and Actuators B, vol. 150 pp. 811-818, 2010.

[8] Svetlana Popovic and Miodrag N. Tekic, “Twisted tapes as turbulence promoters in the microfiltration of milk,” Journal Membrane Science, vol. 384, pp. 97-106, 2011.

[9] L. Syam Sundar and K. V. Sharma, “Turbulent heat transfer and friction factor of Al_2O_3 nanofluid in circular tube with twisted tape inserts,” International Journal of Heat and Mass Transfer, vol. 53, pp. 1409-1416, 2010.

[10] Yunus A. Cengel, Heat Transfer, MeGRAW-HILL, Second Edition, pp. 441,

2003.
[11] F. J. Wasp, Solid-liquid pipeline transportation, Trans, Tech, 1977.
[12] R. S. Vajjha, D. K, Das, B. M. Mahagaonkar, "Density measurements of different nanofluids and their comparison with theory," Petro, Sci. Tech, vol. 27, no. 6, pp. 612–624, 2009.
[13] B. C. Pak, Y. J. Cho, "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles," Experimental Heat Transfer, vol. 11, no. 2, pp. 151-170, 1998.
[14] B. C Sahoo, R. S. R. S. Vajjha, R. Ganguli, G. A. Chukwu, and D. K. Das, "Determination of rheological behaviour of aluminium oxides and development of new viscosity correlations," Petro. Sci. Tech., vol. 27, no. 15, pp. 1757-1770, 2009.
[15] J. Buongiorno, "Convective transport in nanofluids," Journal of Heat and Mass Transfer, vol. 128, pp. 240-250, 2006.
[16] R. L. Hamilton and O. K. Crosser, Thermal conductivity of heterogeneous two component system, I and EC, Fundamentals 1 pp. 187-191, 1962.