International Journal Of Computational Engineering Research||Vol, 03||Issue, 6||

A Novel Design for a Scooter Radiator Using Minichannel

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ABSTRACT

The study was presented a novel design for a scooter radiator using minichannel. The minichannel heat exchanger size is about 64% the size of the scooter radiator which made from manufacturer; however, the heat transfer rate obtained from the minichannel heat exchanger is higher than or equal to that obtained from the scooter radiator. In addition, the experimental method also shows that the heat transfer efficiency obtained from the heat exchangers with water as the working fluid is higher than that obtained from the heat exchanger with ethylene solution as the working fluid. The results are in good agreements with the relevant research.

KEYWORDS: *radiator, minichannel heat exchanger, experimental method, heat transfer rate, temperature.*

Nomenclature

A	heat transfer area	m^2
A_c	cross-sectional area	m^2
c	specific heat at constant pressure	J/(kgK)
f	Fanning friction factor	
k	overall heat transfer coefficient	$W/(m^2K)$
L	length of substrate	m
m	mass flow rate	kg/s
P	wetted perimeter	m
q	heat flux	W/m^2
Q_a	heat transfer rate of air side	W
Q_l	heat transfer rate of liquid side	W
Re	Reynolds number	
T	temperature	ºC
Greek symbols		
ρ	density	kg/m^3
μ	dynamic viscosity	kg/(ms)
ε	effectiveness (NTU method)	
Δp	pressure drop	Pa
ΔT_{lm}	log mean temperature difference	ºC.

I. INTRODUCTION

Most motor scooters are using the step-less transmission. Compared with the chain gear of the motorcycles, the engine of scooter generates more heat. The manufacturers often choose one of two methods: use cooling air on the engine or cooling system with a solution so called radiator. Meanwhile, the engine with cooling solution has an ability to control the combustion process as well as has better performance and higher reliability than the cooling air. In fact, conventional scooter radiator still has some disadvantages such as: the fins are thin, easy to be warped and dirty. Besides, the fins are welded to a channel, the heat transfer area at the welded position is small, so the heat transfers from the channel to fins is not ideal, it is smaller than the monolithic fins. Moreover, the conventional radiators are manufactured with the macro construction, leading to the size of radiator is still bulky. So the technology for mini/micro heat transfer has demonstrated its primacy in this case. Regarding to the micro/mini heat transfer, Xie et al. [1] studied laminar heat transfer and pressure drop characteristics in a water-cooled minichannel heat sink.

A minichannel can be used in heat sink with a quite high heat flux and a mild pressure loss. However, the study mentioned with numerical method. Dang and Teng [2, 3] studied the effects of configurations on performance of the microchannel and minichannel heat exchangers. However, their study ignored the effects of gravity on the performance index of microchannel heat exchangers.The effect of inlet configuration on the refrigerant distribution in a parallel flow minichannel heat exchanger was presented by Kim et al. [4]. Tests were conducted with downward flow for mass flux from 70 to 130 $kg.m^{-2}.s^{-1}$ and quality from 0.2 to 0.6. As mass flux or quality increased, better results were obtained for normal inlet configuration. Oliet et al. [5] presented a set of parametric studies on automotive radiators by means of a detailed rating and design heat exchanger model. In the study, the numerical method was applied to verify and validate using a wide experimental data bank. The results show the utility of this numerical model as a rating and design tool for heat exchangers manufacturers, being a reasonable compromise between classic $\varepsilon-$NTU methods and CFD. An experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators was done by Peyghambarzadeh et al. [6]. In this paper, the heat transfer performance of pure water and pure EG was compared with their binary mixtures; different amounts of Al_2O_3 nanoparticle were added into these base fluids and its effects on the heat transfer performance of the car radiator were determined experimentally. The results demonstrated that nanofluids clearly enhance heat transfer compared to their own base fluid.

Trivedi and Vasava [7] analysed the fluid flow and heat transfer behaviours of an automotive radiator by numerical simulation using software ANSYS version 12.1. The results shown that as the pitch of tube is either decreased or increased, the heat transfer rate decreases; the optimum efficiency has a pitch of 12 mm. Yadav and Singh [8] presented a comparative analysis between different coolants. One of the coolants was used as water and other as mixture of water in propylene glycol in a ratio of 40:60. It therefore can be concluded that the water is still the best coolant; however, its limitation is corrosive and contains dissolved salts. Khot and Satre [9] used the CFD tool to evaluate and compare performance of two different cooling jacket of the 6-cylinder in-line diesel engine. The results shown that flow and heat transfer analyses both are equally important to analyze cooling jacket of an IC engine. In the study, model 2 has advantage of improved velocity in head jacket due to source of flow directly coming from sideways instead of cylinder block to head block. One more advantage of model 2 over model 1 is pressure drop: pressure drop is also reduced due to reduced resistance.

Yoshida et al. [10] studied effects of the number fins, fin pitch, and air velocity on cylinder for an air – cooled engine by the experimental method. The results shown that the optimized fin pitches the greatest the effective cooling are at 20 mm for non-moving and 8 mm for moving. Heat transfer simulation for fins of an air cooled motorcycle engine under varying climatic conditions was done by Agarwal [11]. The heat transfer surface of the engine was modeled in GAMBIT and simulated in FLUENT software. It was observed that when the ambient temperature reduces to a very low value, resulting in overcooling and poor efficiency of the engine. Paul et al. [12] presented experimental and parametric studies of extended fins in the optimization of internal combustion engine cooling using CFD. The heat transfer from 6mm fins is found to be the higher at high velocities. For high speed vehicles, thicker fins provide better efficiency. When fin thickness was increased, the reduced gap between the fins resulted in swirls being created which helped in increasing the heat transfer. From the relevant literatures above, the mini/microchannel heat transfer technology indicates its preeminence in this case. The mini/microchannel heat exchangers have high heat transfer rate and small dimensions. In this study, a novel design for radiator will be invested using minichannel and UV light technology. In the following section, the heat transfer characteristics of the new radiator (the minichannel heat exchanger) will be compared with those of the conventional radiator. The working fluids were used are water and 11% ethylene solution.

II. METHODOLOGY

A. Design and fabrication

The governing equations used to design the minichannel heat exchanger as follows:

The heat balance equation:

$$Q_l = Q_a = Q \qquad (1)$$

Or $$m_l c_l (T_{l,i} - T_{l,o}) = m_a c_a (T_{a,o} - T_{a,i}) \qquad (2)$$

where Q_l is heat transfer rate of liquid (water or ethylene), Q_a is heat transfer rate of air, m is mass flow rate (subscripts l and a stand for liquid and air side, respectively), c is specific heat, $T_{l,i}$, $T_{l,o}$, $T_{a,i}$ and $T_{a,o}$ are inlet and outlet temperatures of liquid and air side, respectively.

The maximum heat transfer rate, Q_{max} is evaluated by

$$Q_{max} = (mc)_{min}(T_{l,i} - T_{a,i}) \qquad (3)$$

The effectiveness (NTU method) is determined by

$$\varepsilon = \frac{Q}{Q_{\max}} \tag{4}$$

Heat flux is calculated by

$$q = \frac{Q}{A} \tag{5}$$

Or $q = k\Delta T_{lm}$ (6)

where q is heat flux, A is heat transfer area, k is overall heat transfer coefficient, and ΔT_{lm} is log mean temperature difference.

The log mean temperature difference is calculated by

$$\Delta T_{lm} = \frac{\Delta T_{\max} - \Delta T_{\min}}{\ln \dfrac{\Delta T_{\max}}{\Delta T_{\min}}} \tag{7}$$

Reynolds number is calculated by

$$\mathrm{Re} = \frac{\rho w \times D_h}{\mu} \tag{8}$$

The pressure drop due to friction is determined by

$$\Delta p = 2 f \rho w^2 \frac{L}{D_h} = 2 f \,\mathrm{Re} \frac{L}{D_h^2} w \mu \tag{9}$$

where $D_h = \dfrac{4A_c}{P}$ is the hydraulic diameter, w is velocity in the z-direction, μ is dynamic viscosity, ρ is density, A_c is cross-sectional area, P is wetted perimeter, L is channel length, and f is Fanning friction factor.

Based on the equations above, a minichannel heat exchanger was designed in this study. The heat exchanger has the same total cross-sectional area of 52 mm^2 for all channels involved. That implies that the average velocity in the channels is the same. This heat exchanger can be used to replace the scooter radiator which made by the manufacturer. The heat transfer process of this device is carried out between two fluids which are hot water and cool air. Fig. 1 shows the dimensions of the test section. The material for the heat exchanger is aluminum, used as a substrate with thermal conductivity of 237 W/(mK), density of 2,700 kg/m^3, and specific heat at constant pressure of 904 J/(kgK). The thickness of the substrates is 12 mm. With the minichannel heat exchanger, the liquid side has 52 minichannels; the length of each minichannel is 114 mm, and the distance between two adjacent minichannels is 1 mm. For these 52 minichannels, the liquid flows through with three pass: the first pass has 18 minichannels; the second pass has 17 minichannels and the last one has 17 minichannels. The minichannels have rectangular cross-section with a width of 1 mm and a depth 1 mm. All channels are connected with a manifold for each inlet and outlet of hot liquid and cool air, respectively. The manifolds of the minichannel heat exchanger are rectangular in shape, with the width of 9 mm and the depth of 1 mm, as shown in Fig. 1. The air side has 40 fins; the length of each minichannel is 150 mm, and the distance between two adjacent fins is 2 mm. The cross-section of fins is rectangular in shape, with a width of 1 mm and a height of 10 mm, as shown in Fig. 1. However, with the two outermost fins, they have a width of 2 mm.

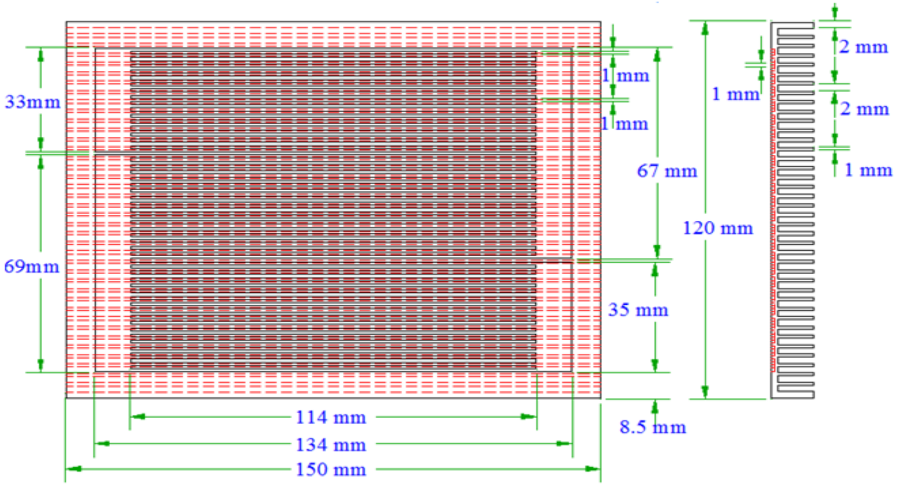

Fig. 1. Dimensions of the test sample

The test section was manufactured by precision machining. Each inlet or outlet of the heat exchanger has cross-sectional area of 19.6 mm^2. To seal the minichannels, a layer of PMMA (polymethyl methacrylate) was bonded on the fluid side of the substrate by UV (ultraviolet) light process, as indicated in Fig. 2. After cleaning the surfaces of Aluminum and PMMA, a special-purpose gel was used to paste. Then, it was joined and solidified using UV Light. The Fig. 3 shows a photo of the minichannel heat exchanger. With the bonding technology, the minichannel heat exchanger can stand with the working temperature up to 105 °C and absolute pressure up to 1.8 bar, this condition can allow the minichannel heat exchanger to operate as a scooter radiator. With a length of 150 mm and a width of 120 mm, the size of the minichannel heat exchanger is equal 64 percent of the conventional radiator, as shown in Fig. 4.

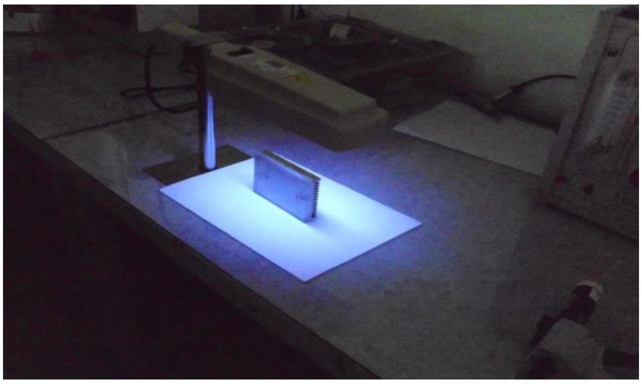

Fig. 2. A photo of bonding substrate and PMMA using UV Light

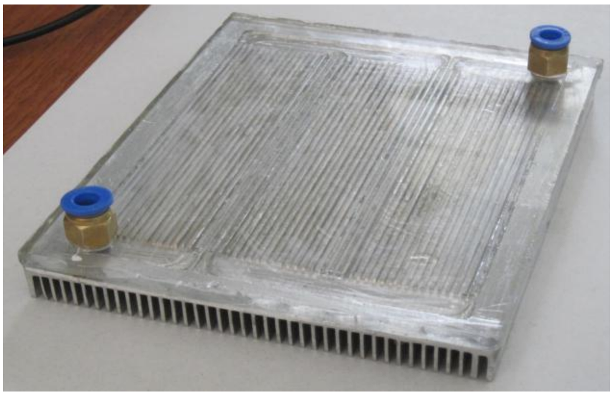

Fig. 3. A photo of the minichannel heat exchanger

Fig. 4. Comparison between the minichannel heat exchanger and scooter radiator

B. Experimental setup

The experimental system consists of the test section (the minichannel heat exchanger or the conventional radiator), syringe system, and overall testing loop, as shown in Fig. 5. Experimental data obtained from the microchannel heat exchanger/scooter radiator are under the constant room temperature condition of 34~35 °C.

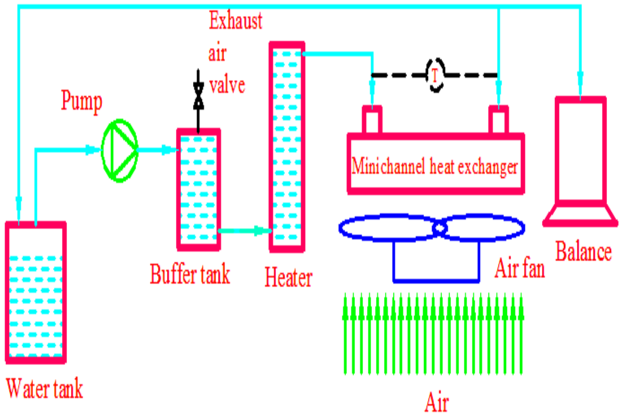

Fig. 5. Schematic of the test loop

For this study, the water and the ethylene solution were used as the working fluid. Each inlet or outlet of the radiator/minichannel heat exchanger has two thermocouples embedded to record temperature values. Accuracies and ranges of testing apparatus are listed in Table 1.

Table 1. Accuracies and ranges of testing apparatuses

Testing apparatus	Accuracy	Range
Thermocouples	± 0.1 °C	0 ~100 °C
Precision balance	± 0.1 mg	0.0000 ~ 210g
Flow meter	± 1 %	0 ~ 50 m/s

The equipments used for the experiments are listed as follows:

1. Thermocouples, Model PT-100, made by Omega
2. Pump, Model YS-1200
3. Pump, VSP-1200, made by Tokyo Rikakikai
4. Heater, Model AXW-8, made by Medilab
5. Micro electronic balance, Model TP – 214, made by Denver.
6. Flow meter.

III. RESULTS AND DISCUSSION

A. The water as the working fluid

Varying mass flow rate of water

For this study, the experimental data obtained under the atmospheric temperature of 35 °C; the air inlet velocity was 3 m/s; the mass flow rate of water was varying from 1.64 to 4.1 g/s, and the water inlet temperature was kept around 62°C. Fig. 6 shows a relationship between the outlet temperature and mass flow rate of water. When mass flow rate of water increases, the temperature difference between the inlet and outlet of water decreases, leading to the outlet temperature increases, as shown in Fig. 6. Besides, the water inlet temperatures obtained from the minichannel heat exchanger are less or equal to those obtained from the conventional radiator. As a result, the temperature difference of the minichannel heat exchanger is higher or equal to the radiator, leading to the heat transfer of minichannel heat exchanger is the better one.

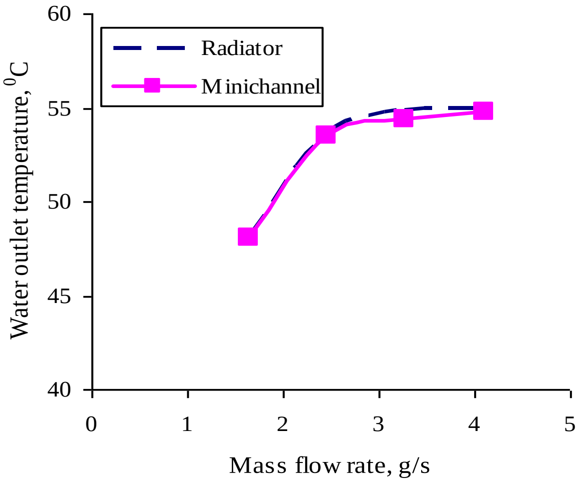

Fig. 6. Outlet temperature versus mass flow rate of water

Varying air velocity

In this study, the mass flow rate of water was 3.8 g/s, the water inlet temperature was 62°C, the air inlet velocity were varying from 0.8 to 3.5 m/s. A comparison of water temperature difference as rising air velocity was shown in Fig. 7. It is observed that the temperature difference of water increases as the air velocity increases. As a result, the heat transfer rate also increases with the air velocity increases. It is also observed that the heat transfer rate obtained from the minichannel heat exchanger is higher that obtained from the radiator as high air velocity (over 1.5 m/s), as shown in Fig. 8. The results indicate that with high air velocity, the heat transfer of the radiator back side is not good because it has many fins and distance of fins is small, leading to the air outlet velocity is small. Meanwhile, the velocity distribution on the surface of the minichannel heat exchanger is better than that of the scooter radiator; it does not have a velocity drop at the surface heat transfer. With the minichannel heat exchanger, the heat transfer rate of 145 W was achieved for hot water of the device having the inlet temperature of 62°C and mass flow rate of 3.8 g/s and for cool air having the inlet velocity of 3.5 m/s and the ambient of 34°C (Fig. 8).

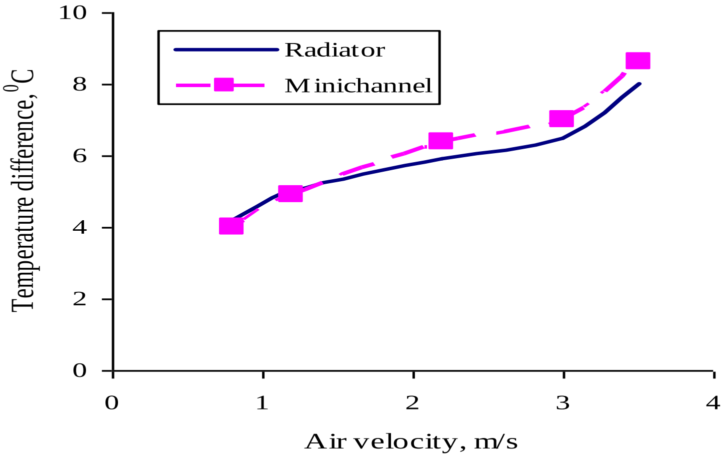

Fig. 7. Water temperature difference versus air inlet velocity

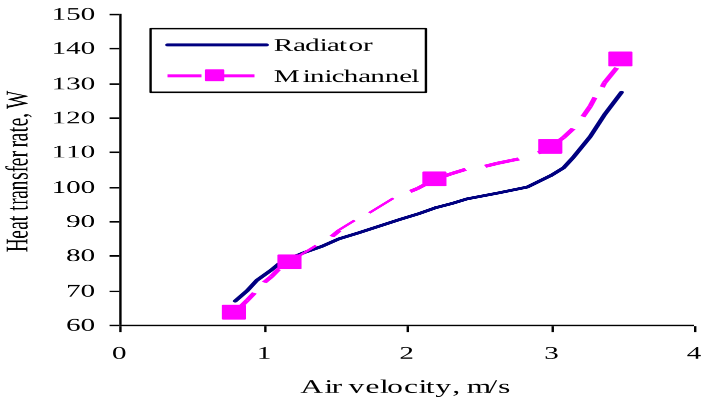

Fig. 8. Heat transfer rate versus air inlet velocity

B. The ethylene solution as the working fluid

For experiments carried out in this study, the mass flow rate of ethylene solution (11% ethylene) was 3.28 g/s and the inlet temperature was 60 °C. The air inlet velocity was from 0.8 to 3.5 m/s with the average ambient temperature of 34 °C. The experimental results shown that at high air velocity (over 1.5 m/s), the temperature differences obtained from the minichannel heat exchanger are higher than those obtained from the scooter radiator, as shown in Fig. 9.

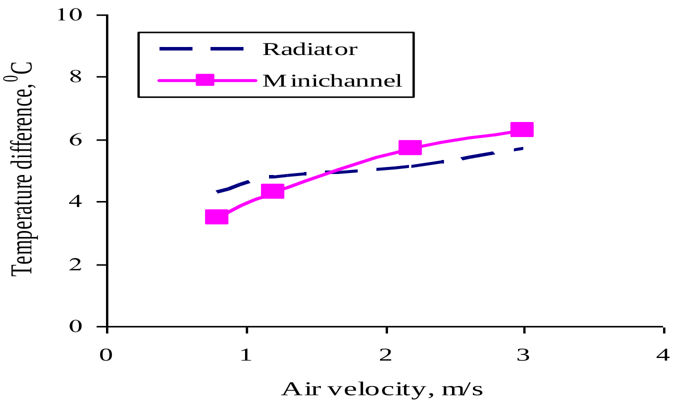

Fig. 9. Comparison between the radiator and the minichannel heat exchanger using ethylene

The results also indicated that with high air velocity, the heat transfer obtained from the minichannel heat exchanger is higher than that obtained from the radiator. The results have the same rule with those in Figs. 7 and 8. At low air velocity (less than 1 m/s), the heat transfer process is backward to the natural convective condition, so the conventional radiator has more preeminent than the minichannel heat exchanger because the radiator has more heat transfer area (more fins). However, this study was also presented to measure the air velocity at head cylinder. With scooter velocity was from 30 to 60 km/h, the air velocity measured at head cylinder from 1.2 to 3.8 m/s. Hence, the results obtained with air velocity over 1.2 m/s are available for real working condition of a scooter.From Figs. 6-9, with air velocity over 1.2 m/s, the heat transfer rate obtained from the minichannel heat exchanger is higher than that obtained from the conventional radiator. So it can be concluded that the minichannel heat exchanger can replace for the conventional radiator.

Comparisons between the ethylene glycol and the water were done in this study. Fig. 10 shows a comparison of the two liquids using in the minichannel heat exchanger. It is observed that the temperature difference obtained with water is higher than that obtained with the ethylene solution. The same condition above, with air velocity from 0.8 to 3.5 m/s, the maximum temperature difference is 0.8 °C. The results are in good agreement with the results in [8]. The comparison in [8] between water with propylene has a conclusion that the water is still the best coolant. In the study, the water is also the best one.

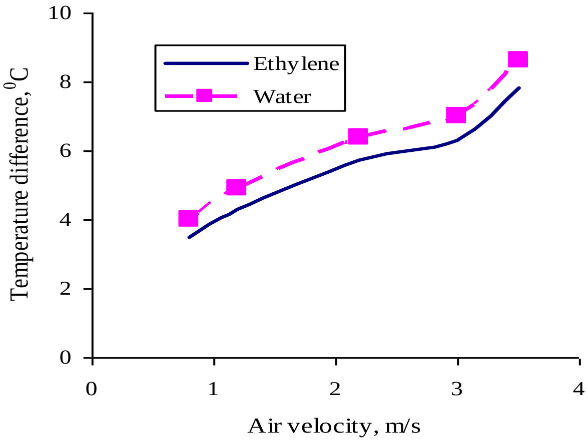

Fig. 10. Comparison between the ethylene and the water

IV. CONCLUSION

Experimental works were done on a scooter radiator and a minichannel heat exchanger to carry out the evaluation of their heat transfer rate. The minichannel heat exchanger size is about 64% the size of the radiator which made from manufacturer; however, the heat transfer rate obtained from the minichannel heat exchanger is higher than or equal to that obtained from the scooter radiator. For the minichannel heat exchanger, the heat transfer rate of 145 W was achieved for hot water of the device having the inlet temperature of 62°C and mass flow rate of 3.8 g/s and for cool air having the inlet velocity of 3.5 m/s and the ambient of 34°C. In addition, the experimental method also shown that the heat transfer efficiency obtained from the heat exchanger with water as the working fluid is higher than that obtained from the heat exchanger with ethylene solution as the working fluid. The results are in good agreements with the relevant research.Based on the results above, it has an ability that the minichannel heat exchanger can replace for the conventional radiator.

ACKNOWLEDGMENT

The supports of this work by (1) the projects (Project Nos. 54-11-CT/HD-CTTB, 38- 12-CT/HD-CTTB, and 11-13-CT/HD-CTTB) sponsored by New Product & Technology Center (NEPTECH) – Hochiminh City Department of Science and Technology of Vietnam and (2) the project (Project Nos. T2012-16TĐ /KHCN –GV and T2013-22TĐ /KHCN-GV) sponsored by the specific research fields at Hochiminh City University of Technical Education, Vietnam, are deeply appreciated.

REFERENCES

[1] X.L Xie, Z.J. Liu, Y.L. He and W.Q. Tao, Numerical study of laminar heat transfer and pressure drop characteristics in a Water – Cooled minichannel heat sink, Applied thermal Engineering, Vol. 29, Issue 1, 2009, PP. 64 – 74

[2] T.T. Dang and J.T. Teng, Comparison on the heat transfer and pressure drop of the microchannel and minichannel heat exchangers, Heat and Mass Transfer, Vol, 47, 2011, pp. 1311-1322

[3] T.T. Dang and J.T. Teng, The effects of configurations on the performance of microchannel counter-flow heat exchangers – An experimental study, Applied Thermal Engineering, Vol. 31, Issue 17-18, 2011, pp. 3946-3955

[4] Nae – Hyun Kim, Do – Young Kim and Ho – Won Byun, Effect of inlet configuration on the refrigerant distribution in a parallel flow minichannel heat exchanger, International journal of refrigeration, Vol. 34, Issue 5, 2011, PP. 1209 – 1221

[5] C. Oliet, A. Oliva, J. Castro and C.D. Pérez – Segarra, Parametric studies on automotive radiators, Applied thermal engineering, 1221Vol. 27, Issues 11 - 12, 2007, PP. 2033 – 2043

[6] S.M. Peyghambarzadeh, S.H. Hashemabadi, S.M. Hoseini and M. Seifi Jamnani, Experimental study of heat transfer enhancement using Water / Ethylene glycol based Nanofluids as a new coolant for car radiators, International communications in Heat and Mass transfer, Vol. 38, Issue 9, 2011, PP. 1283 – 1290

[7] P. K. Trivedi and N. B.Vasava, Effect of Variation in Pitch of Tube on Heat Transfer Rate in Automobile Radiator by CED Analysis, International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-1, Issue-6, August 2012

[8] JP Yadav and Bharat Raj Singh, Study on Performance Evaluation of Automotive Radiator, S-JPSET : ISSN : 2229-7111, Vol. 2, Issue 2, 2011

[9] S. M. Khot and Santosh D. Satre, Comparitive study of cooling jacket models of a diesel Engine using CFD analysis, Proceedings of the NCNTE-2012, Third Biennial National Conference on Nascent Technologies, Navi Mumbai, Feb 24-25, 2012, pp. 69 - 74

[10] Masao Yoshida, Soichi Ishihara, Yoshio Murakami, Kohei Nakashima and Masago Yamaoto, Air – cooling effects of Fins on a Motorcycle Engine, JSME International Juornal, Series B, Vol 49, No 3, 2006, pp. 869-875

[11] Pulkit Agarwal, Mayur Shrikhande and P. Srinivasan, Heat Transfer Simulation by CFD from Fins of an Air Cooled Motorcycle Engine under Varying Climatic Conditions, Proceedings of the World Congress on Engineering 2011 Vol III, WCE 2011, July 6 8, 2011, London, U.K.

[12] J.Ajay Paul, Sagar Chavan Vijay, U.Magarajan, and R.Thundil Karuppa Raj, Experimental and Parametric Study of Extended Fins In The Optimization of Internal Combustion Engine Cooling Using CFD, International Journal of Applied Research in Mechanical Engineering (IJARME) ISSN: 2231 –5950, Volume-2, Issue-1, 2012, pp. 81-90.