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Experimental Study of Alternative Minichannel Heat Exchanger for Scooter Radiator

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Abstract—

This paper presents the experimental study on innovative liquid cooling system of scooter using minichannel heat exchanger. The experiments were carried out to determine heat transfer efficiency and engine power with variation of operating conditions. The results show that the heat transfer efficiency obtained from the minichannel heat exchanger higher than or equal to that obtained from the original radiator. In addition, the engine power can be increased by using minichannel radiator together with removing the cooling fan that driven from engine crankshaft. The obtained results are in good agreement with relevant studies. The size of alternative minichannel radiator is reduced the by 30%, made it easy to manufacture, and cut down its cost approximately 40% compared to the original one. The study also illustrated the feasibility of the alternative minichannel heat exchanger for the conventional radiator of scooters.

***Keywords** — Scooter, liquid cooling system, minichannel heat exchanger, radiator, heat transfer*

I. INTRODUCTION

Recently motorcycle population has grown rapidly in many urban areas of Asia, such as Vietnam, because of small size, short daily trip distances, easy operation, and maintenance. They are very convenient and cater to a large group of people including students and commuters. A popular mode of scooter is continuously variable transmission (CVT) that can change seamlessly through a continuous range of effective gear ratios. A belt-driven offers approximately 88% efficiency, which lower than that of a manual transmission that can be increased more heat engine. Air cooled engines are gradually phased out and are being replaced by water cooled engines which are far more efficient in dissipating heat. In liquid cooled engines, hot coolant flows out from hot spots in the cylinder head and passed to the radiator. This is better for detonation control and for emissions. The combustion chamber surfaces can be kept hot enough to encourage more complete combustion, but not so hot to promote detonation or high NOx emissions.

Liquid-cooled motorcycles have a radiator which is an important component to disperse the engine heat. Its cooling effect is good enough to prevent the engine overheating in most conditions. There are some disadvantages of conventional radiator such as thin fins, easy warp, dust, large dimension, it can also be expensive and could break in an accident. Since the fins are welded to a channel so the heat transfers from the channel to fins is not ideal. They are manufactured with the macro construction leading to bulky size. The technology of minichannel heat transfer has been develop over 10 years, recently that is emerging as one of the promising alternative to improve the heat transfer of machine parts in limited space. Laminar heat transfer and pressure drop characteristics in a water-cooled minichannel heat sink were studied in [1]. A minichannel can be used in heat sink with a quite high heat flux and mild pressure loss. However, the study mentioned with numerical method. Preliminary experimental results were studied on Nouvo LX scooter using minichannel heat exchanger by Trung and Trang [2, 10]. Dixit and Ghosh [3] investigated cross flow minichannel heat exchanger subjected to external heat ingress. In this study, external heating may decrease and increase the effectiveness of the hot and cold fluids, respectively. Comparison between the heat transfer and pressure drop of the microchannel and minichannel heat exchangers were described by Dang and Teng [4], both numerically and experimentally. The results showed that the microchannel heat exchanger should be selected for the systems where high heat transfer rates are needed. In addition of this study, the effectiveness obtained from the microchannel heat exchanger was 1.2–1.53 times of that obtained from the minichannel heat exchanger.

The experimental and parametric study of extended fins provided in the optimization of internal combustion engine cooling using CFD [5]. In this experiment, the single cylinder air cooled engines was assumed to be a set of annular fins mounted on a cylinder. Numerical simulations were carried out to determine the heat transfer characteristics of different fin parameters namely, number of fins, fin thickness at varying air velocities. A cylinder with a single fin mounted on it was tested experimentally. The numerical simulation of the same setup was done using computational fluid dynamics method. The results validated with close accuracy with the experimental results. Cylinders with fins of 4 mm and 6 mm thickness were simulated for 1, 3, 4 & 6 fin configurations. Byun and Kim [6] studied a parallel flow minichannel heat exchanger having two row/four pass configuration by experimental method. The results of this study showed that the optimum inlet diameter was 4.0 mm. Studies [7, 8] showed that when the pass number increased from three to five, the heat transfer rate of the heat exchanger increased. However, these studies did not investigate optimum for the pass number as well as pressure drop in these heat exchangers.

For this study, the minichannel heat exchanger has applied on Yamaha Nouvo LX motorcycle. The experimental results were demonstrated the effects of mass flow rate and inlet temperature of alternative radiator. Because of thermal conductivity, the original cooling fan was driven by the crankshaft engine has replaced by 12-Volt/5 Watt power electric fan that was controlled by coolant temperature. When the engine is hot the electric fan blows air through the radiator. Conversely, it will be not working. Therefore, the engine can improve power. Experimental results were conducted under different conditions to demonstrate the heat transfer efficiency and feasibility of alternative minichannel radiator.

II. METHODOLOGY

A. Structure design

Minichannel in minitechnology is a channel with a hydraulic diameter below 4 mm that was designed as in Fig. 1. It consists of four passes minichannel and manifolds. The coolant firstly from the inlet manifold flows through minichannels, then going out of the system by outlet manifold. During its journey, it transfers amount of heat through substrate into the air.

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

The heat balance equation:

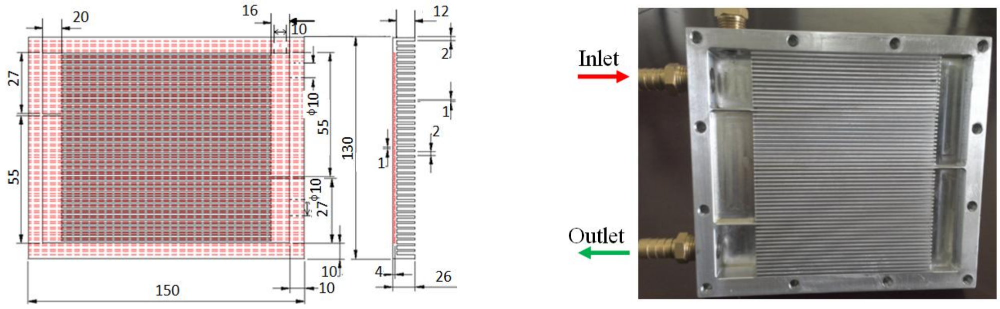
$Q_l = Q_a = Q$ (1)

where: Q_l, Q_a are heat transfer rate of liquid and air, respectively

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

$Q_{max} = (mc)_{min}(T_{l,i} – T_{a,i})$ (2)

where $T_{l,i}$, $T_{a,i}$ are inlet temperatures of liquid and air, respectively.



a) Dimension of minichannel radiator b) Inside a minichannel radiator

Fig. 1 Rectangular minichannel heat exchanger

Heat flux is determined by: $q = Q/A$ (3)

Reynolds number: $R_e = (\rho.w.D_h)/\mu$ (4)

The pressure drop: $\Delta p= 2.f.R_e.L.w.\mu/D^2_h$ (5)

where A is heat transfer area, k is overall heat transfer coefficient, w is velocity in the z direction, μ= is dynamic viscosity, ρ is density, L is channel length, and f is fanning friction factor. The hydraulic diameter is $D_h = (4.A_c/P)$, where A_c is cross-section area, and P is wetted perimeter. Based on the equation above, a minichannel heat exchanger was design in this study as in Fig. 1. The material used for the substrate of heat exchangers is Aluminum, with the thermal conductivity of 237 W/mK, density of 2,700 kg/m^3, and specific heat at constant pressure of 904 J/kgK. There are four passes of channels their length is 90 mm and the depth is 4.0 mm. The distance between two minichannels is 2.0 mm. All channels are connected to manifold of each inlet and outlet of hot liquid and cool air, respectively. There is a manifold to put radiator cap on.

B. Heat transfer laboratory experiments

Fig. 2 shows a test loop used to conduct the heat transfer measurement for nimichannel heat exchanger. The loop is composed of several components such as water storage reservoir, pump, air fan, heater, thermometer, and minichannel heat exchanger or the conventional radiator. Water is circulated through the test section. The flow rate of the loop is measured by a flow meter in the loop. The experiments were performed at atmospheric pressure and temperature condition 34–35 ^{o}C with stationary system.

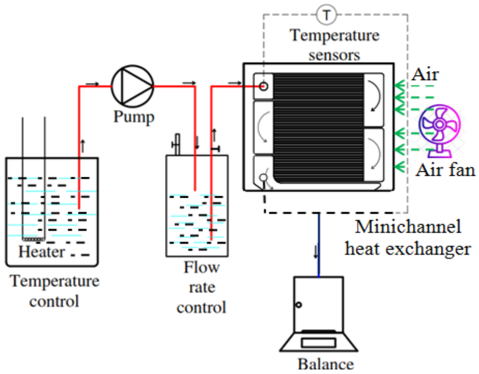


Fig. 2 Schematic diagram of the test loop

In this study, ethylene glycon was used as the woorking fuid. Each inlet and outlet of radiator/minichnally heat exchanger has two thermocoules embedded to record temperature valuses. The accuracy of the testing apparatuses is listed in Table1.

Table I The accuracy of instruments

Testing apparatus	Tolerance	Range
Laser thermometer	± 0.1 °C	0 ~ 600 °C
Precision balance	± 0.1 mg	0 ~ 210 g
Flow meter	± 0.1 %	0 ~ 50 m/s

C. Internal combustion engine laboratory experiments

The experiments were conducted using Yamaha Nouvo LX motorcycle in internal combustion engine laboratory (ICE-Lab), faculty of Transportation Engineering, Ho Chi Minh City University of Technology. Test-cell for motorcycles consists of a dynamometer and an emission measuring system. It is able to implement vehicle performance tests for power, traction force, and fuel consumption following European, US, and Japanese driving cycles. The schematic diagram of the experimental installation is shown in Fig. 3. In this work, the experiment was tested with varying engine speed to obtain heat transfer characteristics of radiator, fuel consumption, and engine power by data acquisition system.

Fig. 3 Schematic diagram of the experiment using Yamaha Nouvo LX in Internal Combustion Engine Laboratory

III. RESULT AND DISCUSSION

A. Heat transfer characteristics

To obtain heat transfer characteristics of radiator, experiments have done with different operating conditions. Figs. 4, 5 show a relationship between outlet temperature and testing time.

Case 1: At idle engine speed, air fan of cooling system was removed during testing period. The results of this experiment showed that the outlet temperature of minichannel radiator is lower than that obtained with original radiator without air cooling fan as in Fig. 4.

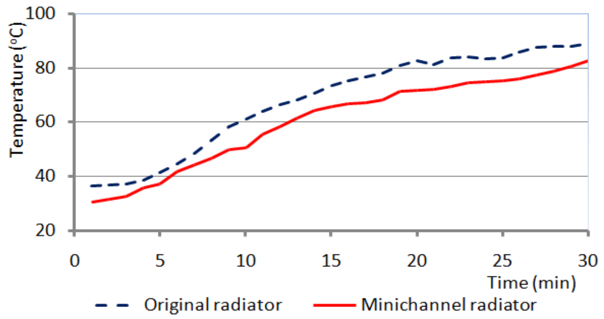


Fig. 4 Coolant outlet temperature without air fan

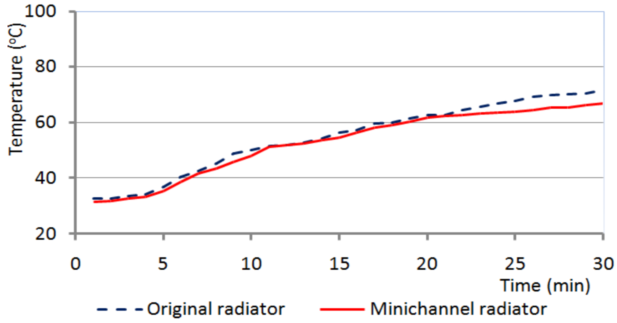


Fig. 5 Coolant outlet temperature with air fan

Case 2: At idle engine speed, the motorcycle was tested with air cooling fan. The experimental results showed that the outlet temperature of engine coolant after through minichannel radiator is lower or equal to that obtained with original radiator as in Fig. 5.

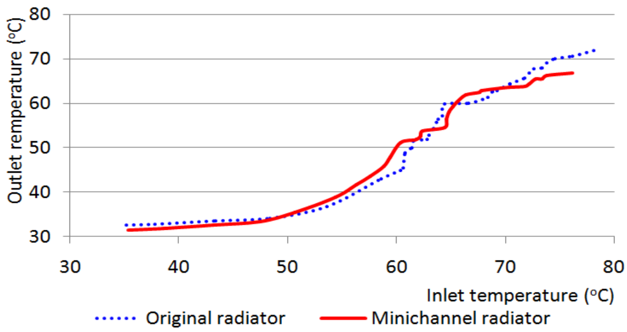


Fig. 6 Comparison outlet temperature between of minichannel and original radiators

Fig. 6 shows the outlet temperature of original radiator and minichannel heat exchanger with air fan. It can be seen that the heat transfer rate of minichannel heat exchanger is better or equal to that of original radiator. It is in good agreement with Service Manual 2005 [9] by Yamaha Motor Co., Ltd. The experimental results can be concluded that the minichannel heat exchanger offer the possibility to increase the heat transfer performance in liquid cooling system.

B. Fuel consumption and engine power

The experiments were performed in ICE-Lab by several components such as motorcycle Test-cell, Yamaha Nouvo LX motorcycle, minichannel heat exchanger as in Fig. 3. In this study, the Test-cell for motorcycles is able to implement vehicle power and fuel consumption in different operating conditions.

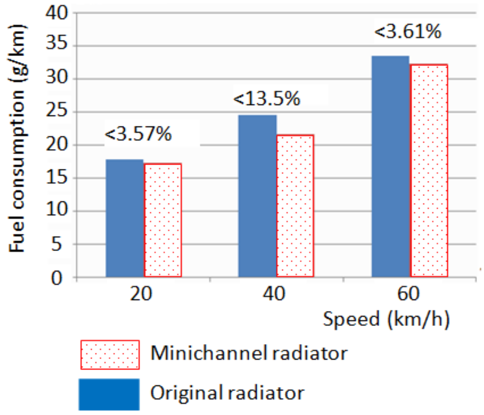


Fig. 7 Fuel consumption

In engine test, fuel consumption can be measured as mass flow rate. It is given how much fuel to consume per unit of time or distance. The experimental results showed slight reduction of engine fuel consumption as in Fig. 7. However, the engine fuel consumption was significant decrease in vehicle speed range from 30 to 60 km/h. This is also the commonly speed range in many urban areas of Vietnam.

In this work, the experiments were conducted to obtain relation between engine power, moment and vehicle speed by data acquisition system as in Fig 8, 9. The results indicated that it was slight increase moment and engine power for minichannel heat exchanger with compared to original radiator. The main reason can be explained for those results is that by removing air cooling fan, instead of that was driven by engine crankshaft, the alternative electric cooling fan was operated by battery. Comparing the alternative minichannel heat exchanger and original radiator which applies same operating condition. It was obvious that the minichannel heat exchanger was more potential to decrease fuel consumption and increase engine power.

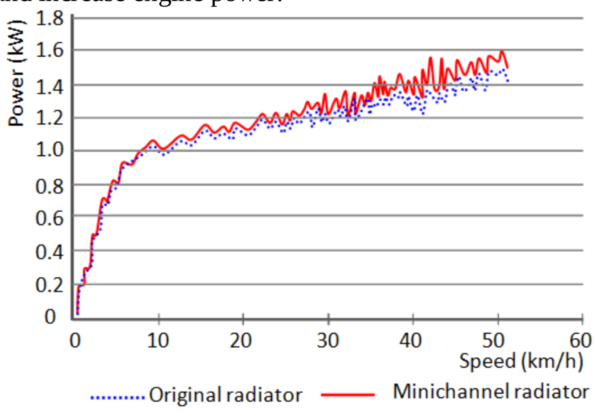


Fig. 8 Power and vehicle speed

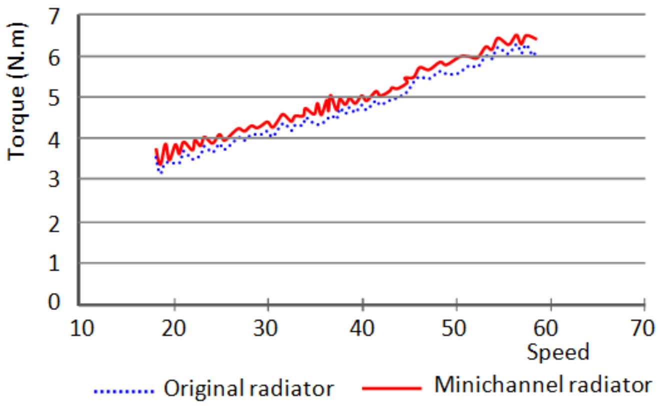


Fig. 9 Torque and vehicle speed

IV. CONCLUSIONS

In this research work, the experimental study been done to find out the heat transfer characteristic of minichanel heat exchanger. It was indicated that the temperature of engine coolant, after going through minichannel heat exchanger is compatible with operating condition as in original radiator at different operating conditions. To use alternative minichannel radiator, the engine power was slight increase and fuel consumption was slight reduction as well. The main reason can be explained for those results is that by increasing heat transfer performance, instead of air cooling was driven by engine crankshaft, the alternative electric cooling fan was operated by battery. In addition, the minichannel heat exchanger is reduced the size by 30% and cut down its cost by approximately 40% compared to the original radiator of liquid cooling system.

Besides, minichannel heat exchanger has more feature than original radiator such as the production cost can be lowered at large quantity, domestic production, and low maintenance. This approach was illustrated the feasibility of the alternative minichannel radiater that can be replaced for the conventional scooter radiator.

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