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Heat Transfer Analysis in Automotive Exhaust System using Liquid Jet Cooling

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ABSTRACT: Heat transfer affects the performance, emission and durability of the engine as well as the design, material choice and fatigue life of vehicle components. Automotive exhaust system and engine cooling is necessary for improvement of engine performance. Liquid jet cooling device is designed for automotive exhaust system based on heat transfer analysis of exhaust system of two wheeler auto bike. It is used to control and regulate the temperature of automotive exhaust system by means of liquid jet in liquid jet cooling device. This device can be fitted with exhaust pipe near manifold to control the temperature of exhaust system. Water is used as a coolant and it is a primary fluid for experimental investigation. Heat transfer analysis of automotive exhaust pipe is carried out using liquid jet cooling device. The experimental investigation is carried out for superficial liquid coolant velocity in the range between 0.016 m/s to 0.032 m/s for the engine speed of 1500, 2000 and 2200 RPM. It has been investigated from the experimental research that using liquid jet cooling device, higher heat transfer coefficient between exhaust pipe and cooling water is obtained for increasing the superficial liquid coolant velocity for each run of the engine which controls the exhaust system temperature. It is also reported that liquid jet cooling device control the temperature of engine and exhaust gases.

KEYWORDS: Heat transfer, Liquid jet cooling device, Automotive exhaust system, Engine performance, Emission..

I. INTRODUCTION

The automotive exhaust system is exposed to high temperature as the hot gases passes through it. The uniform distribution of heat is needed to enhance life of exhaust system components. Controlling the exhaust gas temperature, higher performance of the engine can be achieved. Measuring the exhaust gas temperature from automotive exhaust system is useful to understand the engine processes. The exhaust gases coming out from engine are at very high speed and at high temperature. Exhaust system of an automobile from which exhaust gases coming out from combustion chamber have silencer which is integral part of exhaust system. High temperature in exhaust system leads to thermal, vibration and fatigue failures causing the cracks in silencer. So it is necessary to study the heat transfer analysis for hot section of exhaust system for better performance of automobile.

Thermal mass and external insulation to exhaust system is main factor which affects the inlet gas temperature of catalytic converters. Under normal operating conditions, catalytic converters are most effective to reduce air pollution from internal combustion engines. The exhaust gases flowing through the exhaust system need to be cooled before reaching the catalytic converter to increase performance of catalytic converter. The heat transfer analysis in automotive exhaust system is necessary because their importance in the design and optimization phases of exhaust after-treatment system. Heat loss between the engine out and before the catalyst converter will determine the energy gain of the catalyst thus affect the temperature rise of the catalyst which affect catalyst life time.

A significant number of researches have been done for cooling of exhaust manifold, exhaust piping and catalytic converter for automotive exhaust system to improve performance based on heat transfer analysis of exhaust system.

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Robert Wassmur [14] investigated the method and arrangement for cooling an exhaust system of a vehicle having an internal combustion engine. The arrangement includes a controller for detecting an elevated temperature condition of the exhaust system and detecting a predetermined engine operating status. Bradley J. Shaffer [1] proposed the design for an exhaust manifold cooling for an internal combustion engine having a turbocharger, an exhaust manifold and heat exchanger. Ghazikhani et al. [5] have been researched the exergy recovery from a direct injection diesel engine. Investigation performed for turbocharged diesel engine at various engine speeds and torques. For this, a double pipe heat exchanger with counter current flow is used in the exhaust of engine. As an important outcome, by increasing the load and engine speed, the recovered exergy increased..

II. MATERIALS AND METHODS

Experiments were carried out using liquid jet cooling device which was fitted with the existing exhaust system. Liquid jet cooling device is an exhaust system cooling device which includes a nozzle, bubble generator and a cylindrical housing to hold a quantity of cooling medium. The present cooling device has advantages of simple in construction, less costly and effective cooling to exhaust system. This device is more efficient and more economical to use as it cooling down entire exhaust system and so heat related stress due to mechanical expansion and contraction of mechanical parts can be minimized.

Experimental investigation done by the method mentioned in the research by Petkovic et al. [13]. Temperature at various locations of exhaust system is measured by 'K' type thermocouple which is fitted with exhaust system at location '3' and '4' and at location '1' and '2' of cooling device. Water in cooling device is provided from storage tank by pump and flow rate is adjusted by rotameter. Pressure drop in liquid jet cooling device is measured by 'U' tube manometer. Before starting the engine, water is pumped from the storage tank and allowed to emerge from the device. Water jet is created by means of providing nozzle in the entrance of the device. The purpose of the jet is to create turbulence in water so higher heat transfer rate between exhaust pipe and cooling water could be achieved. The axial temperature distribution was measured for cooling device and exhaust pipe as steady state flow of water is maintained in the device for specified amount of fuel consumption. For the specific speed of an engine the temperature at the location '1' and '2' of cooling device and the location '3' and '4' of exhaust pipe is noted at the specific time. Same experiment was carried out for various flow rate of water in the cooling device. Experiments were carried out at room temperature and exhaust gas temperature was also being measured during the experiments.

Gas holdup is measured by pressure drop measurement technique. Manometer ports are provided to measure pressure drop between two ports. This pressure drop is used to measure local gas hold up. Temperature distributions in cooling device and in exhaust pipe at axial locations T_1 , T_2 , T_3 and T_4 were investigated for the different coolant velocity at different speed of two wheeler engine of single cylinder type, 99.35 cm³ displacement having compression ratio 9.3:1 and heat transfer analysis of cooling device and automotive exhaust pipe near manifold has been studied.

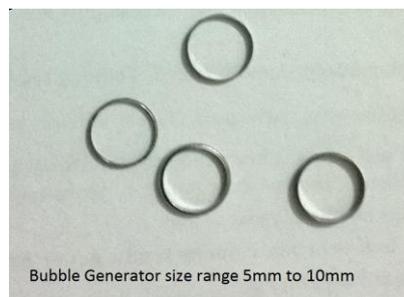


Fig. 1 Bubble generators

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Figure 1 show the bubble generator which was used to create turbulence in liquid jet cooling device. Figure 2 and figure 3 shows the schematic view of experimental set up and liquid jet cooling device which was used in experimental analysis. Liquid jet cooling device has provided a bypass tube to avoid overflow and choking situation which can be arise during operation in cooling device.

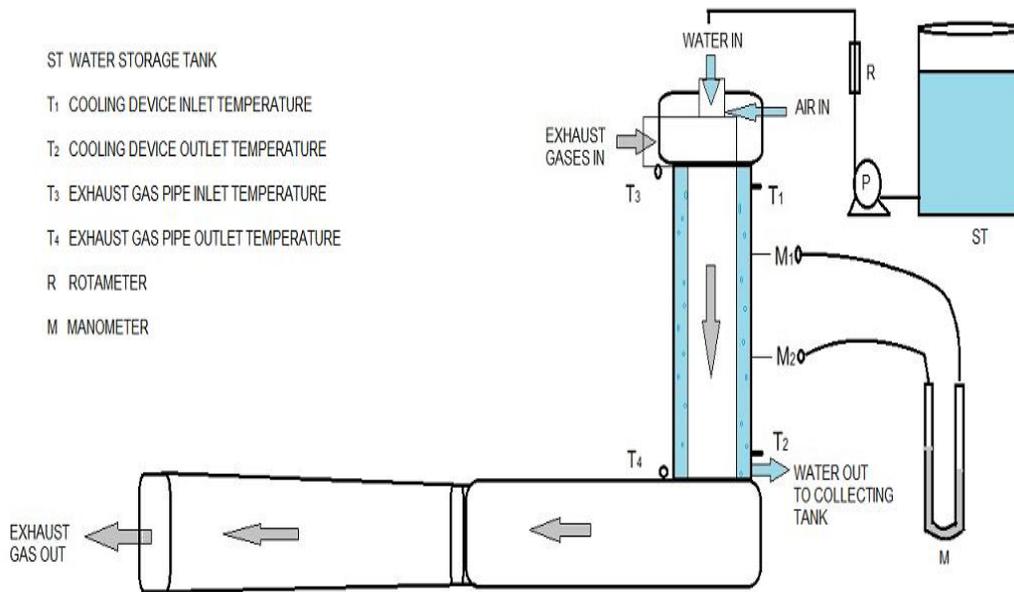


Fig. 2 Schematic diagram of experimental set up

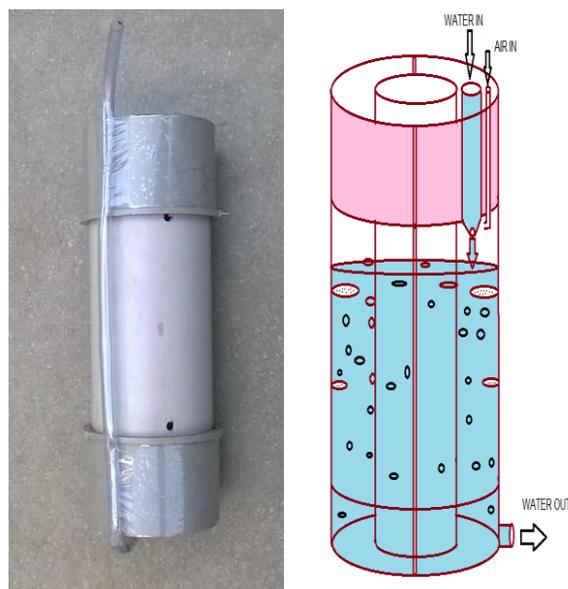


Fig. 3 Schematic view of liquid jet cooling device

III. RESULTS AND DISCUSSION

1. VARIATION OF TEMPERATURE WITH TIME

Figures show the experimental result of temperature variation at inlet and outlet section of the exhaust pipe with and without cooling device. Figs. 4 show the experimental variation of temperature with time for 100 ml of fuel consumption for 1500 rpm engine speed with and without liquid jet cooling device at inlet section of the exhaust pipe. It is found that increase in liquid coolant flow rate, exhaust pipe inlet and outlet temperature decreases sufficiently.

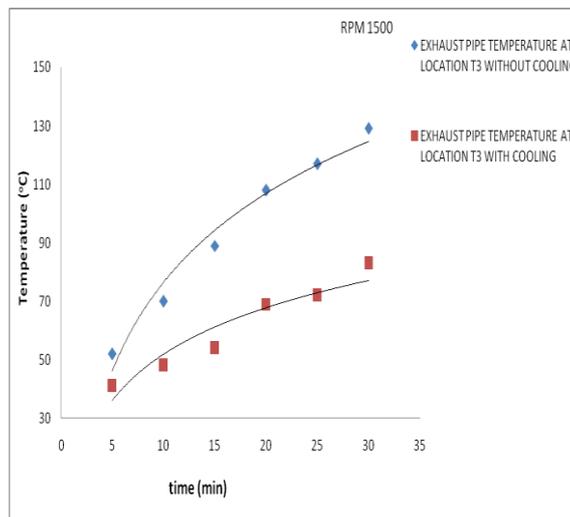


Fig. 4 Exhaust pipe temperature variation at location T₃ with and without cooling

Figs. 5 show the experimental variation of temperature with time for 100 ml of fuel consumption for 1500 rpm engine speed with and without liquid jet cooling device at outlet section of the exhaust pipe.

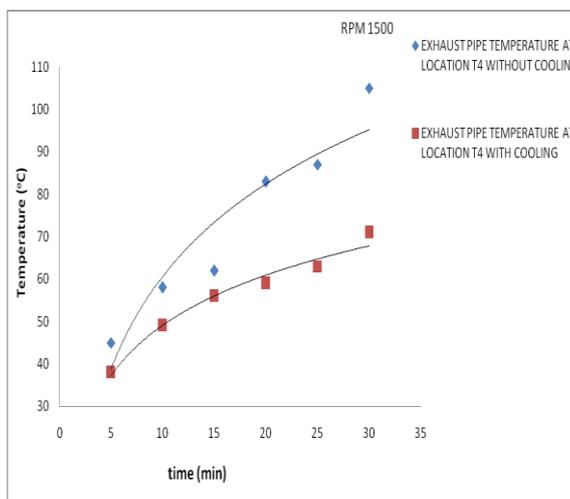


Fig. 5 Exhaust pipe temperature variation at location T₄ with and without cooling

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2. VARIATION OF HEAT TRANSFER COEFFICIENT WITH SUPERFICIAL LIQUID VELOCITY

Figures show the experimental result of heat transfer coefficient variation with superficial liquid velocity for exhaust pipe and cooling device at inlet and outlet section. Figs. 6, 7 and 8 shows the experimental variation of heat transfer coefficient with superficial liquid velocity for 100 ml of fuel consumption for 1500 rpm, 2000 rpm and 2200 rpm engine speed.

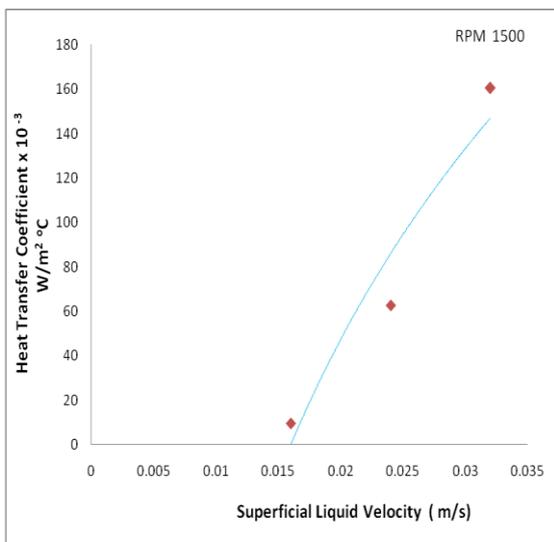


Fig. 6 Heat transfer coefficient variation for 100 ml fuel consumption 1500 RPM

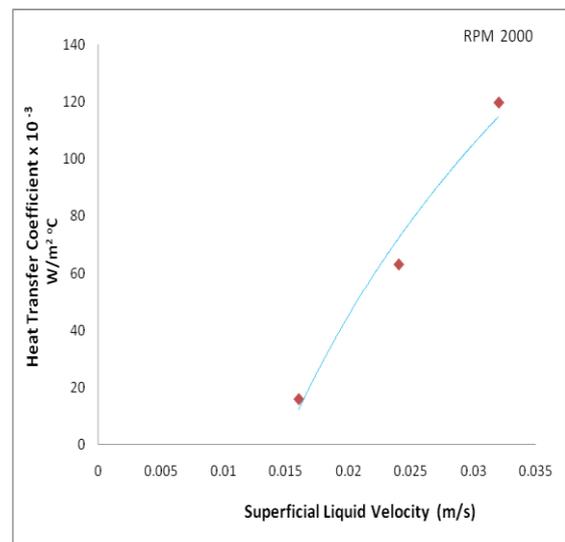


Fig. 7 Heat transfer coefficient variation for 100 ml fuel consumption 2000 RPM

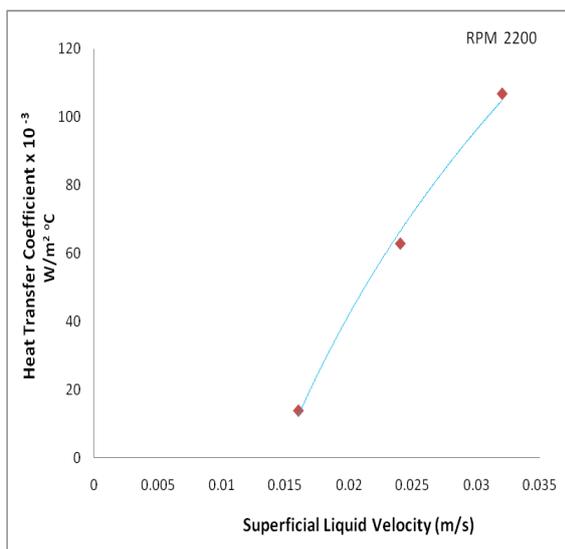


Fig. 8 Heat transfer coefficient variation for 100 ml fuel consumption at 2200 RPM

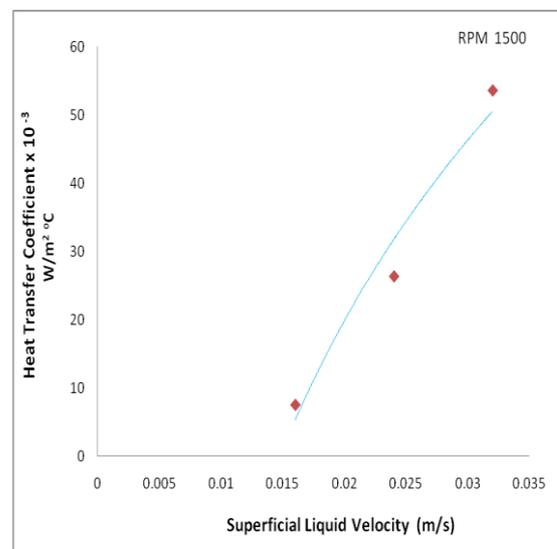


Fig. 9 Heat transfer coefficient variation for 200 ml fuel consumption at 1500 RPM

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Figs. 9, 10 and 11 shows the experimental variation of heat transfer coefficient with superficial liquid velocity for 200 ml of fuel consumption at 1500 rpm, 2000 rpm and 2200 rpm engine speed. It is found from experimental analysis that increases in superficial liquid coolant velocity increases the heat transfer coefficient for exhaust pipe and cooling water.

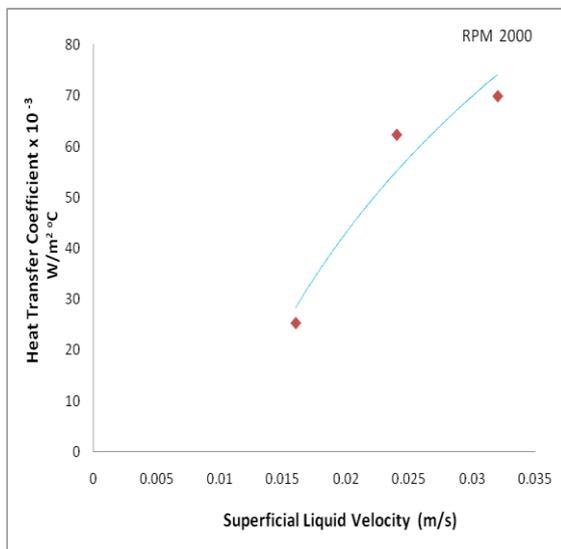


Fig. 10 Heat transfer coefficient variation for 200 ml fuel consumption at 2000 RPM

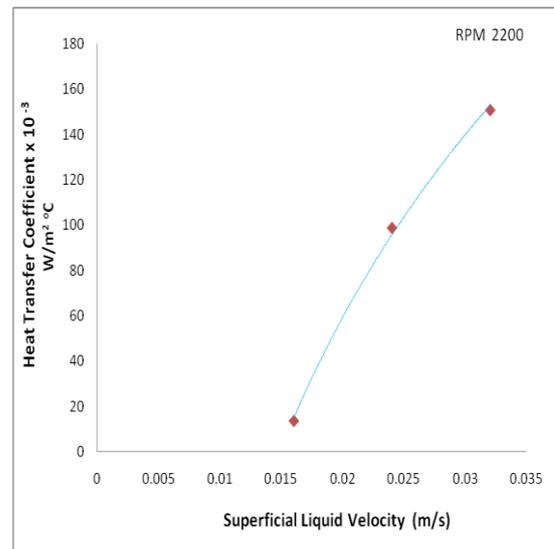


Fig. 11 Heat transfer coefficient variation for 200 ml fuel consumption at 2200 RPM

From experimental analysis it is found that increase in cooling water flow rate would be lower the inlet and outlet exhaust pipe temperature. So increase in liquid coolant velocity in liquid jet cooling device enhanced the heat transfer between exhaust pipe and cooling device. This is due to the more turbulence created in the cooling water which is improved the heat transfer between exhaust systems and cooling water. For a specific quantity of fuel consumption, local temperature of exhaust pipe decreases with increase in liquid flow rate. It is also reported from experimental investigation that the use of liquid jet cooling device lower the temperature of exhaust gases and silencer.

IV. CONCLUSION

The present paper gives the analysis of the heat transfer in automotive exhaust system using designed liquid jet cooling device. It is reported from the experimental investigation increase in superficial liquid coolant velocity increases the heat transfer rate and hence increases the local heat transfer coefficient which is need of automotive exhaust system cooling. It is found that the heat transfer in exhaust system important for the design of exhaust system components. Hot spot and corrosion on exhaust pipe and silencer can be controlled by exhaust system temperature. Back pressure in exhaust pipe can be controlled by limiting exhaust temperature which can be improved the silencer and exhaust pipe efficiency. By controlling the exhaust gas temperature, catalytic converter life span can be improved. Many researchers have concluded that the heat transfer in exhaust system directly affects the performance and the emission characteristics of the internal combustion engine.

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