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# An Experimental Study of Heating Recovery from Engines Exhaust based on Hydrogen Storage System

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**Abstract:** In this research, a heating recovery is used for thermal energy storage from exhaust gas of the internal combustion engines for the purpose of storing hydrogen fuel. Inside the heat recovery, it is designed with multiple flaky layers that are arranged evenly with 60-degree angle to create the exhaust vortex flow as well as store the largest amount of heat for saving energy. The experiment is carried out with three different engine speeds through the corresponding load is the largest, smallest, medium mode and the flow rates of water heated in the fuel storage system are up to 2 LPM. After carrying out and analysis of the results obtained from the heat recovery, we found that the storage process is influenced significantly by the exhaust temperature as well as the motor speed and the rate of water flow; which also shows that the heat recovery served for heating and hydrogen fuel storage has high energy efficiency and good heat transfer capability of the entire system thanks to its special structure.

***Keywords:*** *Heat Recovery, Internal Combustion Engine, Thermal Energy Storage, Saving Energy, Energy Efficiency, Heat Transfer*

**Introduction:**

The internal combustion engines using traditional fuels such as diesel, gasoline emit exhaust gases which content a huge amount of waste heat. The heat from the exhaust gases not only cause environmental pollution and climate change but also consume a big quantity of temperature in supplying the fuel after combustion. Currently, some developed countries have studied and applied the cogeneration system including a combination of waste heat energy from the internal combustion engines to save energy and reduce the exhaust caused environmental pollution that leads to the greenhouse effect.

Much research has been undertaken to study of different exhaust heat exchangers which consists of a cylindrical shell with helical coils placed inside it. On the tube side the flow is forced by a pump through the coils while buoyancy forces are the cause of flow on the shell side, Hatami et al. [1]. Some studies have indicated that vortex generator heat exchangers are superior to straight tubes when employed in heat transfer applications, Gorij-Bandpy et al. [2]. Moreover, these systems have lower initial cost and less maintenance than the alternatives. M. Hatami et al. [3] performed experiments on a delta winglet vortex generator heat exchanger in the case where the buoyancy driven flow occurs in the shell. Other works include those of Tagliafico and Tanda [4] and Parent et al. [5], which involve shell and tube natural convection heat exchangers where buoyancy driven flow occurred inside the tubes. Dravid et al. [6] numerically investigated the effect of secondary flow on laminar flow heat exchanger in coiled tubes both in the fully developed and in the thermal entrance regions. Besides, Parakar et al. [7] discussed the effect of Dean Number on friction factor and heat transfer in the developing and fully developed region of coiled pipes. Besides, the development and research of the thermal energy recovery are necessary to be used in many different purposes including the water heating before electrolysis to save energy. The previous study, as the authors Saiful Bari and Shekh N. Hossain [8] has shown that the heat recovery system is necessary to improve energy efficiency as well as save waste heat source after the operation of engines. With these devices using internal combustion engines, waste heat source is a big amount and the energy source accounting after its combustion.

In Vietnam, there are many studies about this subject. They have provided empirical proof of energy efficiency in using the waste heat is essential and it has a scientific significance, as the authors Pham Minh Son et al. [9]. Although this approach has not been used much, because it depends on subjective and objective factors in the manufacturing industries of internal combustion engines and policies concerning the standards for waste heat in environmental pollutants. Therefore, within this paper, we study about utilizing the thermal energy from the exhaust gases of the engine to heat the water before the archiving process and electrolysis to obtain hydrogen fuel. On the contrary, other studies have also focused on developing the heat recovery under different structures in order to maintain heat exchange capacity and improve its working efficiency as the thermal energy absorption. The heat exchanger which has many structures and different arrangements from the internal components to enhance heat transfer. However, these studies have just focused on simulation or optimization on the exchange process through different shapes and structures, then compared and given conclusions on the theoretical basis of mathematical model or on thermodynamic analysis of the exhaust gases.

In this paper, the heat is collected from the exhaust of engines is the method of storing thermal energy and then evaluating an experimental process served for heating water before electrolysis process in hydrogen fuel storage. With three different engines, the determination of traffic, speed, pressure and temperature exhaust gas after combustion by passing through the heat recovery that has a swirling structure by the flakes inside the recovery. The experiment is controlled during several days with different environmental conditions of temperature. Besides, the motors can be controlled with different speeds through the corresponding load is the largest, smallest, medium and intermediate mode when it is necessary. In addition, the heating process is performed by the new heat recovery which can increase potentially the efficiency of energy saving corresponding to the controlling level of water flow that goes inside…..The necessary work is also presented in this paper such as: firstly we introduce the process of testing and technical characteristics in the analysis and implementation of the experimental method of heat recovery on the nature of heat transfer and heat exchangers. Secondly, we perform modelling the heat system served for the hydrogen fuel storage after the electrolysis process. Moreover, we also analysed the heat recovery by comparing the experimental results of the engine type and heat transfer condition of the solvent inside. Finally, the results of the experimental process are evaluated through efficient of heat exchanger to save the heat energy.

**Experimental apparatus and procedure:**

Along with the exhaust emitted, the amount of heat carried in the exhaust gas after engine combustion is very large. Degree of heat emissions is stored and measured at both ends of the heat recovery during experiments. The exhaust gas will exchange the heat with water inside the twisted copper coil to heat up water.

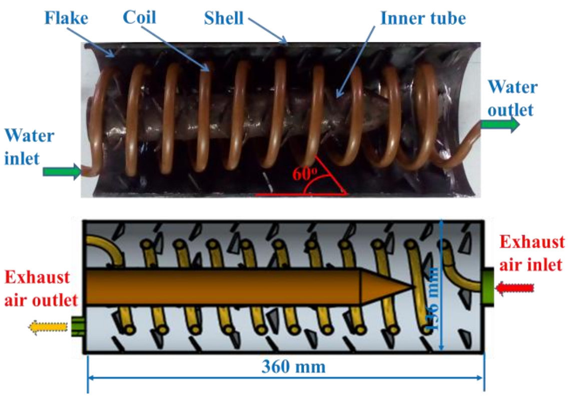


*Figure 1: Details structure assembling into the heat recovery.*

The thermal equilibrium between the cold water and the hot gas stream is formed after the process of heat transfer in convection conditions of the two lines and the turbulence of the air flow inside the tube created by the flakes. According to experiments, the exhaust inside the pipe of heat recovery moves at the speed corresponding to the speed of the engine operation, the rate of mixing air and fuel after combustion. The air flow is turbulent due to the flakes inside combined with twisted copper coil around. Corresponding to the velocity of the gases allowed to go into the heat recovery, the water flow goes in the opposite direction to form convection currents and the temperature difference according to water flow during the control process of experiment.

The heat recovery is designed, calculated and manufactured by different materials such as: copper tube, the flakes made of carbon steel material , the outer shell and the inner cylinder made of carbon steel too that has size and weight are described in Table 1.

Table 1: Dimension of the heat recovery

| **Dimension** | **Average of the measured values** | |
|---|---|---|
| Internal diameter of the coil | 9 ± 1.1 | mm |
| External coil diameter | 10 ± 1.1 | mm |
| The number of internal flakes | 70 | |
| The number of external flakes | 36 | |
| Coil pitch | 30 ± 0.01 | mm |
| The number of coil turns | 10.0 | turns |
| Inner diameter of the shell | 136 ± 1.5 | mm |
| Outer diameter of the shell | 140 ± 2.1 | mm |

Figure 1 shows the details to be made according to the dimensions in Table 1. The structure of flakes is processed with the angle deviation of 60 degrees compared with “body” (the outer shell) and the tube of the shell (the inner cylinder). Two sides of each flake create an isosceles triangle with the length of 22.5mm. Besides, the outer shell of the heat recovery is tied to 72 flakes spaced equally and this outer shell is associated with the inner tube that has 33 flakes arranged alternately to create turbulent airflow. In particular, the inner tube is placed at a distance of 35 mm from the outer shell and it is sharpened for creating a spiral rule of airflow when meeting the flakes and the copper tube. Interior of copper coil stores water to be heated by the exhaust gas temperature before performing the process of electrolysis to produce hydrogen in the system of hydrogen storage. Copper pipe has also the size and general characteristics are shown in Table 1. The turns of copper tube are arranged with appropriate steps in order to the air flow through the holes (slots) of the flakes and itself creates a turbulent flow. This way can benefit the largest amount of the waste heat.

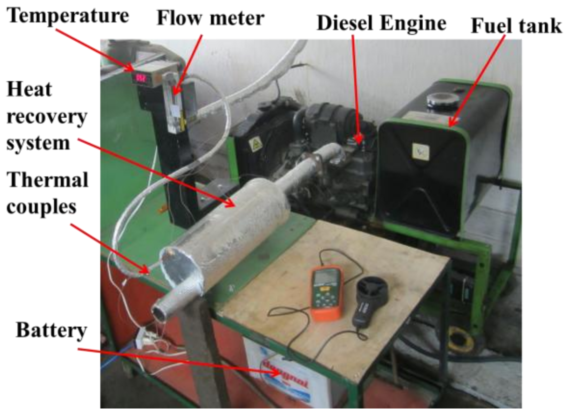


*Figure 2: Experimental set up at automotive workshop in the institute of technology.*

In figure 2, the experiment is performed at automotive workshop in the institute of technology. The experiment is arranged insulated from the sun and other ventilation to ensure the accuracy of measurement and treating process. The operation of heat recovery follows the heat exchanger principle between the exhaust streams after the combustion of engine that works inversely to the water flow inside the copper coil. The amount of exhaust gases during operation of the engine passes through the heat recovery and the outside shell of the heat recovery insulated from the environment around to keep the temperature. Rule of exhaust airflow inside the heat recovery is generated towards the design of Figure 1. In addition, two flows between the air and the water are two convective flows; exhaust gas following the turbulence principle goes through the flakes of inner and outer tube coil. Air flow inside the heat recovery is chaotic vortex with various speed and pressure after discharged from the internal combustion engine.

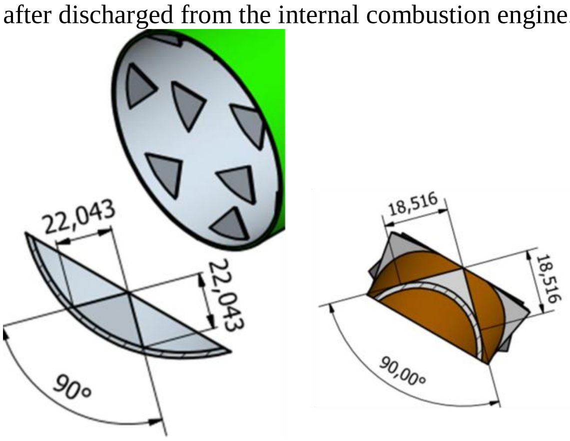


*Figure 3: Structures of flakes in the outer and inner tube with different sizes (a. Arranged outside the tube; b. Arranged inside the tube).*

To create turbulent flow of the exhaust gas after passing combustion engine and then go into the heat recovery, the exhaust with high speed goes inside the outer tube and towards the front of the tube in the heat recovery (the pipe is sharpened, 60-degree bevelled at peak than the surface of the tube, the position of top tube is placed 25mm from the entrance of gas emissions). Air flow after meeting summit of the tube will be diverted the direction, then met the flakes that are arranged alternately and tilted 60 degrees to the direction of airflow (gaps between the flakes are the same and sizes of flakes inside and outside are different as shown in Fig 3). In the process of moving, air flow is also swirled due to the profile of flakes associated with copper coil which is placed between the inner and the outer tube of the heat recovery.

**Data reduction:**

If the heat loss to the surroundings in the heat exchanger is assumed to be negligible, the heat transfer rate between the hot fluid and cold fluid can be expressed as:

$$Q=\dot{m}_w c_w (T_{iw}-T_{ow}) \cong \dot{m}_a c_a (T_{oa}-T_{ia}) \qquad (1)$$

where $\dot{m}$ is the mass flow rate (kg/s) through the heat exchanger and *c* is the specific heat of the air (kJ/kg°C), where the indices *w* and *a* refer to the coil-side and shell-side flows. $T_{iw}$, $T_{ow}$, $T_{oa}$, and $T_{ia}$ are the temperatures of the fluid inside coil inlet, the fluid inside coil outlet, the fluid inside shell outlet, and the fluid inside shell inlet (°C), respectively.

Since all heat exchanger operated with counter flow, mean logarithmic temperature difference is [10]:

$$LMTD=\Delta T_m=\frac{(T_{ow}-T_{ia})-(T_{iw}-T_{oa})}{\ln\left[(T_{ow}-T_{ia})/(T_{iw}-T_{oa})\right]} \qquad (2)$$

The total heat transfer is determined from the energy absorbed by the water:

$$q=\dot{m}_w c_w \Delta T_m \qquad (3)$$

**Results and discussion:**

Figure 4 shows the difference in temperature between the input and output from the exhaust and the water heated in the controls condition of engine at three different speeds within 30 minutes of each experiment.

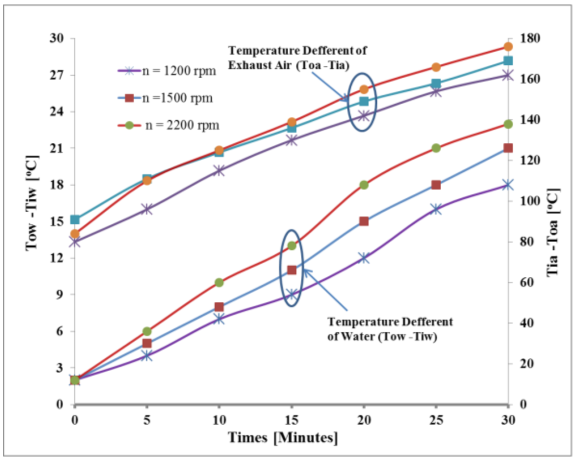


*Figure 4: Graph of different temperatures of exhaust gas and water after passing through the heat recovery with 3 different engine speeds.*

Generally, in terms of 1 LPM-water flow of experiment maintained in three speeds ($n_{min}$, $n_{av}$, $n_{max}$) when the engine operates, the different temperature of heating water is increased with time corresponding to the augmentation of different temperature of exhaust gas.

The figure also shows different temperature of the water heated tends to rise from 2°C to 23°C over a period of 0 to 30 minutes when the engine is running. Although the initial temperature is the same, but with different speeds of the engine, the temperature of heating water varies according to the speed of the engine. Specifically, with the speed $n_{max}$= 2200 rpm, different temperature of the water heated is the largest and reaches 23°C after 30 minutes. Conversely, different temperature with the speed of engine $n_{min}$ reaches 18°C in the same period of time of this operation. This indicates that the heat recovery is designed to carry out experiments have achieved the temperature for heating the water to take advantage of the exhaust heat in terms of time of engine operation with different speeds. In other words, the exhaust heat recovery from the engine has a significant positive impact on the utilization of waste heat from the engine for heating the water to meet the demand before the electrolysis process to create hydrogen fuel.

With the control mode corresponding water flow when operating the system for recovering heat from exhaust gases, different temperature of the water heated is also shown in Figure 5. This figure also shows that when we control at three different speeds of the motor $n_{min}$, $n_{av}$, $n_{max}$, the water flow varies from 0 LPM to 2 LPM, the different temperatures of water also change significantly. Obviously, the bigger the water flow is, the smaller temperature difference is.

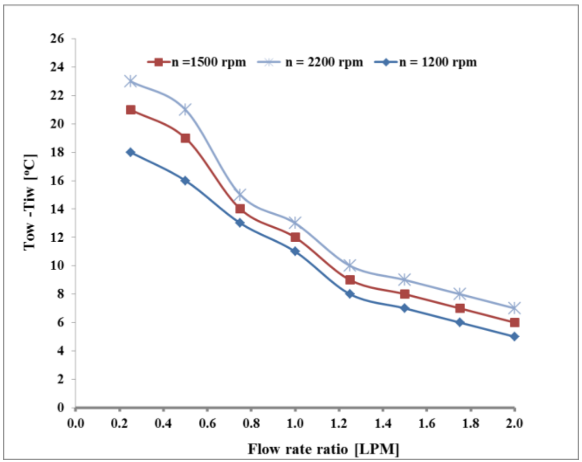


*Figure 5: Graph shows the temperature difference of water after being heated as the function of water flow ratio.*

It is clear that different temperatures of water tend to decline quickly when the flow control is increased. In 30 minutes, the control speed changes respectively, different temperatures of water reach the maximum value at 23°C and down to a minimum value 5°C (corresponding to the water flow is 2LPM). It can be concluded that, when the water flow is increased during the utilization of waste heat from the exhaust to hot up in heat recovery, the water temperature will drop differently. In addition, when controlling with different speeds of engine, the different temperatures of water also gain the values corresponding to the order of speed control to heat during 30 minutes.

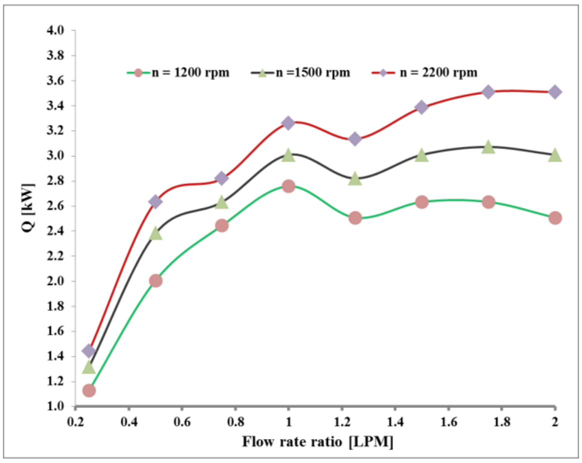


*Figure 6: Graph shows the heat transfer rate under various rates of water flow adjusted in the experiment process.*

Figure 6 shows that the thermal energy to hot up the water is collected in the heat recovery for three engine speeds varying with water flow during the control. Corresponding to the maximum speed of the engine, the waste heat to hot up is the largest as well as the water flow is controlled from 0.25 LPM to 2 LPM. Obviously, when the water flow augments, the heat obtained also increases with the engine speeds $n_{min}$, $n_{av}$ and $n_{max}$. This confirms the heat recovery is useful to take advantage of the waste heat from the engine exhaust.

**Conclusions:**

The theme focuses on the actual experiments on heat recovery from the exhaust of internal combustion engines to store energy with the different speeds of the engines as well as level controls of water flow going inside. To make use of waste heat, the heat recovery is designed with special structure consisting of the triangle flakes to create turbulent flow for emissions and help efficiently the heating of convective water currents inside the copper coil. The experimental results from the engines and heat transfer conditions on the solvent inside are compared and analysed. Obviously, engine speed and water flow going inside the heat recovery greatly affect the heat rate gained as well as the temperature difference of water flow and exhaust gases. This shows realistic about energy efficiency and heat transfer capability to the system of heat recovery.

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