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An Experimental Study of the Waste Heat Recovery for the Absorption Type Transport Airconditioning System

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Abstract− This paper deals with the study of heat exchange between the exhaust manifold and refrigerant for the absorption refrigeration system. This type of heat exchanger is called the Absorption Type Transport Airconditioning System(ATTAS) The exhaust gas from the internal combustion engines is used to heat the refrigerant in order to create a temperature difference needed for the cooling of circulated air inside the passenger bus compartment. The ATTAS collects the combustion gases from the internal combustion engine's exhaust manifold and boils the refrigerants composed primarily water. This study also deals with the effectiveness of the exhaust gas heat exchanger in collecting the heat from the combustion chamber of the internal combustion engine and used it to vaporize the molecules of the refrigerant contained in the heat exchanger. The application of the ATTAS heat exchanger significantly changed the engine exhaust temperature and amount of gas emission. The exhaust gas temperature from the bus engines without ATTAS and without load is 108 ^{o}C and with the attachment of the ATTAS heat exchanger without load, the exhaust gas temperature is 88 ^{o}C or with an average of exhaust gas temperature reduction of 20.0 ^{o}C. The exhaust gas temperature from the bus engines without ATTAS and with load is 127.1 ^{o}C and with the attachment of the ATTAS heat exchanger with load, the exhaust gas temperature is 105 5 ^{o}C or with an average exhaust gas temperature reduction of 21.6 ^{o}C. The composition of the exhaust gases was greatly affected by the installation of ATTAS heat exchanger to the bus engine. With the attachment of the ATTAS heat exchanger, the amount of carbon monoxide increases from 191.9 ppm to 225.7 ppm, the amount of oxygen increases from 16.41 % to 17.8 % while the amount of NOx decreases from 96.4 ppm to 80.4 ppm.

Index Terms− absorption refrigeration system, gas emissions, lithium bromide, waste heat recovery

1 Introduction

THIS paper deals about the study of a new car air-conditioning system that will give a better performance over the conventional car air-conditioning system.

Heat exhaust from the tail pipe contains a vast amount of heat energy that would be useful as a source of energy for other heat consuming devices. One such heat consuming device is the Absorption Type Transport Airconditioning System(ATTAS). This type of device utilizes the waste energy from the exhaust pipe of the passenger buses and serve it as the source of energy to boil the lithium bromide of an absorption refrigeration system.

The application of the exhaust gas heat exchanger is expected to affect the combustion engine's exhaust system. **First**, it will reduce the exhaust gas temperature and thus reduces the internal combustion engine's contribution to global warming. **Second**, it has the capability of changing the amount of pollutants generated by the exhaust gases. The exhaust gases in which most people considered them harmful to both human lives and the environment are generated inside the engine during combustion and can be affected by the change in temperature due to the water inside the exhaust gas heat exchanger. The application of the exhaust gas heat exchanger in the engine's exhaust system can be advantageous in such a way that it can reduced the exit temperature of the

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exhaust system but the change in temperature may affect the magnitudes of the exhaust gases.

This study therefore focuses on the testing of the designed exhaust gas heat exchanger called ATTAS in the mechanical engineering laboratory. The performance of the designed heat exchanger in the generation of vapor and steam at elevated temperature will be observed. The designed heat exchanger's effects to the amount of the internal combustion engines exhaust gases emission such as Oxides of Nitrogen, Carbon Monoxide, and Oxygen will be investigated. The study will also prove the capability of the designed heat exchanger in reducing the temperature of the engine's exhaust system. The effects of the heat exchanger to the internal combustion engine's fuel consumption will also be observed.

In the total system design of the ATTAS, the design of the exhaust gas heat exchanger is considered critical and basic for the success of this study. The answer to the following questions will help the researcher decides whether or not the designed exhaust gas heat exchanger is effective and is capable of supporting the operation of the ATTAS:

1. Does the designed exhaust gas heat exchanger capable of delivering an output temperature of 100 ^{0}C?
2. Does the designed exhaust gas heat exchanger reduce the temperature of the exhaust gases released by the exhaust system's pipe?
3. Does the designed exhaust gas heat exchanger reduce the amount of NO_x and CO? Does the device also improve the O_2 level?

2 Experimental

The research design is experimental in nature. The proponent implemented the experimentation and testing using a stationary engine (Toyota 2C-TE Model - 1.975L of volume displacement). The expected temperature release from the exhaust manifold of the unloaded engine is low since engine temperature is relative to the load of the engine. To replicate the loading of the engine, braking equipment was installed on the flywheel; this allowed the proponent to adjust the friction and raised the exhaust temperature of the engine to the desired engine rpm of 2000. The ability of the heat exchanger in utilizing the available heat from the exhaust system of the internal combustion engine is therefore very critical. This would command the success in the whole study of the ATTAS.

2.1 Experimentation and Testing

Using the exhaust gas analyzer, the proponent measured the following exhaust gases with and without the designed exhaust gas heat exchanger: Nitrogen Oxide, Carbon Monoxide, and Oxygen gases. The temperature release of the exhaust pipe and the heat of the vapor produced by the heat exchanger were also measured using the digital thermometer.

2.2 Standardizing Measurement Procedure

To standardize the measurement, the proponent considered the following procedure. Water of the exhaust gas heat exchange was preheated up to 80 ^oC. With all the measurements and the other accessories set, the engine is run for eight minutes setting the rpm to about 2000 at the instant the engine was started; ten readings of the above mentioned gases were taken at an interval of two minutes; and after the last measurement was taken the engine was allowed to run for two minutes before it was shut down.

The weight difference of the fuel before and after running the engine for ten minutes determines the fuel consumption. This procedure allowed the proponent to observe the effect to the fuel consumption of the designed exhaust gas heat exchanger.

2.3 Bacharach Exhaust Gas Analyzing Setting

The Bacharach instruments comes with standard operating procedure: In turning on the power all numerical LCD segments are tested for 5–15 seconds; after which, the LCD shows the detected CO, NO_x, SO_2, and O_2 level. A minus sign may appear during power up as the sensor stabilizes. After turning on, the instrument the instrument is allowed to warm up for approximately one minute after which the display is zeroed using the kit screwdriver before the gas sample is taken.

2.4 Quantification of Variables

Carbon Monoxide, CO forms when there is insufficient oxygen to fully oxidize the carbon from the carbon-containing compounds of the fuel input a condition that is called rich air/fuel ratio. In high temperature products, even with lean mixtures, dissociation ensures that there are quite significant levels of CO.

Oxygen, (O_2) is important in the combustion process. CO level is expected to go higher when the oxygen content is insufficient for complete oxidation. This situation occurs upon starting the engine when a high air/fuel mixture is necessary, during idling and during acceleration, when the temperature is low or reaction time is short during flame spread in air/fuel mixture on the lean fuel side.

Oxygen (O_2) readings provide a good indication of lean running engine, since O_2 increases with leaner air/fuel mixtures. Generally, O_2 is the opposite of CO; that is O_2 indicates leaner air/fuel mixtures while CO indicates richer air/fuel mixtures. Lean air/fuel mixtures and misfires typically cause high O_2 output from the engine.

The oxide of nitrogen is represented as by the chemical compound as NO_x and can be considered as the most harmful component from the exhaust gases. This compound is generated by combining nitrogen with an excess amount of oxygen.

Nitric oxide or NO forms throughout high temperature burn gases behind the flame through chemical reactions involving the two elements that do not achieve chemical equilibrium. The component forms in larger quantities when combustion temperatures exceed to about 1371 ^{0}C. The higher the temperature of burned gases the higher the rate of nitric acid formation, so when combustion is done in the area closer to the theoretical air/fuel ratio, the Stoichiometric ratio, more nitric oxide is release as it is closer to complete combustion. Oxides of nitrogen are the greatest resultant exhaust gas from spark ignition engines. In high temperature and combustion this reaction occurs to form nitric oxide: $N_2 + O_2 \rightarrow 2NO$. When this oxide cools in the presence of air it is further oxidized to nitrogen dioxide: $2NO + O_2 \rightarrow 2NO_2$ – a high pressure is also necessary for such a reaction.

2.5 Statistical Analysis

The magnitudes of the carbon monoxide, nitrogen oxide, oxygen and exhaust gas temperature before and after the installation of the exhaust gas heat exchanger were to be compared. The statistical method to use in the analysis of the data is the t-Test: Two-Sample Assuming Equal Variances. The null hypothesis being the variances of the variables are equal ($\delta_1^2 = \delta_2^2$), The decision rule is that the neglect of the null hypothesis will mean that there is significant difference in the variables before and after the installation of the exhaust gas heat exchanger: and the acceptance therefore will mean that there is no significant difference in the variables before and after the installation of the exhaust gas heat exchanger.

The statistical test procedure was set at alpha equals 0.05, The decision is confirmed by the $P(T \leq t)$ value for both one-tailed and two-tailed conditions.

3 Findings and Analysis

The operation of the absorption type transport air-conditioning system depends upon the capability of the exhaust gas heat exchanger in collecting the heat of the exhaust gases and uses it to compress the molecules of water that it contains. The molecules of water are compressed by the increase in the temperature of the surrounding environment that turns the water into steam. The change in the state of water into steam occurs at the boiling temperature of about 100 ^{0}C.

3.1 The Exit Steam Temperature of the EGHX

The ATTAS operates primarily through the exhaust gas heat exchanger by absorbing the hot gases from internal combustion engine exhaust manifold and use it in heating the water that the heat exchanger contains. The amount of heat absorbed should be capable of converting the water inside the heat exchanger into vaporize state or steam, such condition can only be attained if the absorbed heat reaches the level to about the boiling of water at about 100 ^{0}C.

The testing of the designed exhaust gas heat exchanger has proved its effectiveness in the production of steam vapor. The temperature of the steam or water vapor is constant at 99 ^{0}C (hence statistical analysis was not performed), a value where water begins to vaporize.

Figure 3.1 Steam at the pipe outlet

Figure 3.1 shows how the steam was generated by the exhaust gas heat exchanger during testing. The steam production as seen in the figure has proven that the water inside the exhaust gas heat exchanger has reached the boiling temperature of 100 ^{0}C.

The measured temperature of 99 ^{o}C was measured near the tip of the exit pipe and would have been a bit higher should the set up allows the proponent to make a few insertion of the digital thermometer prove inside the exit pipe.

Figure 3.2 also shows the effect of the heat transfer between the exhaust gases from the internal combustion engine to the ATTAS where water is tested to absorbed the waste heat generated by the exhaust gases.

Figure 3.2 Visible high pressure steam from the inlet pipe

3.2 Temperature on the Exhaust Pipe

Fuel combustion takes place inside the internal combustion engine, and produces expanding gases that are used to provide mechanical power. For diesel engines the ignition of fuel is caused by compression of air in its cylinders instead of a spark.

Combustion gases forms primarily inside the engine and among others, CO, NOx, and O_2 are combustion gases that give important information outside the internal combustion engine. High CO reading indicates a rich and high O_2 reading indicates a lean running engine. NOx, considered as the most dangerous combustion by-product forms in large quantities when combustion temperatures exceed to about 1371 ^{o}C (Toyota Emission Analysis, p. 8, www.autoshop101.com). Anything that causes combustion temperature to rise will also cause NOx to rise (Toyota Emission Analysis, p. 5, www.autoshop101.com).

The temperature of the exhaust gases from the engine is measured in two cases. First, when there is no attachment of the ATTAS heat exchanger and second, when there is an attachment of the ATTAS heat exchanger.

The attachment and installation of the exhaust gas heat exchanger has reduced the temperature of the exhaust gas through the exhaust pipe. In Table 3.1, the average temperature difference of the ATTAS heat exchanger before and after the installation of the heat exchanger on the unloaded system is 20.0 ^{o}C while 21.6 ^{o}C on the loaded system. Primarily the water in the ATTAS heat exchanger caused the reduction of the temperature of the exhaust gas. The heat exchanger converts a large quantity of heat into a pressurized steam of the heat exchanger.

Exhaust Gas Temperature	Condition	Without ATTAS	With ATTAS	Difference
	No-load	108.0 ^{0}C	88.0 ^{0}C	20.0 ^{0}C
	With-load	127.1 ^{0}C	105.5 ^{0}C	21.6 ^{0}C

Table 3.1 Average temperature of exhaust gas

Statistical analysis result showed that there is a significant difference in the exhaust gas temperature before and after the installation of the exhaust gas heat exchanger. With no attached load condition, the average temperature reduction is 20.0 ^{o}C and when the load is attached, the average temperature reduction is 21.6 ^{o}C.

3.3 Effects on Gas Emissions

Exhaust gases from the internal combustion engines powered by diesel fuel has many components. NOx, CO, CO_2, O_2, sulfur dioxide, water vapor, fly ashes are just few components of the gas emissions. In this study, the gas emission measurements are focused only in NO_x, CO and O_2.

Initial data were taken under no load condition (torque device was not activated). Readings of the exhaust gases were taken before and after the installation of the heat exchanger while running the engine at about 2000 rpm.

Table 3.2 shows the amount of oxides of Nitrogen has decreased from 74 to 48 ppm; the Carbon Monoxide has increased from 218 to 253 ppm; and the O2 has increased from 14.7 to 16.7 %.

When 50 psi is applied as load to the engine through the braking system, the values of the parameters with and without the exhaust gas heat exchanger resulted into a rather similar pattern.

Table 3.2 also shows the oxides of nitrogen has decreased from 96.4 to 80.4 ppm; the carbon monoxide has increased from 191.9 to 225.7 ppm; the amount of oxygen has also increased from 16.4 to 17.8 %. The engine temperature is quite stable when the readings were taken at about 88 to 89 0C.

The t-Test was conducted for the gathered data for two-sample with equal variances proves that there is a significant difference in the variances of the nitrogen oxide, the carbon monoxide, and the oxygen content of the exhaust gases before and after the installation of the exhaust gas heat exchanger.

Exhaust Gas	Condition	Without EGHX	With EGHX	Difference
NO_x	No-load	74.0 ppm	48.0 ppm	-26 ppm
	With-load	96.4 ppm	80.4 ppm	-16 ppm
CO	No-load	218.0 ppm	253.0 ppm	+35 ppm
	With-load	191.9 ppm	225.7 ppm	+33.8 ppm
O_2	No-load	14.7 %	16.7 %	+2 %
	With-load	16.41 %	17.8 %	+1.4 %

Table 3.2 Measured gas emission

3.4 Oxides of Nitrogen inside the ATTAS Heat Exchanger

Nitrogen Oxide is a combustion by-product that is greatly affected by temperature. In the combustion process inside the engine formation of Nitrogen Oxides picks up at temperature above 1371 ^{0}C and reduces in magnitude below 1371 ^{0}C. The main means of the removal of nitrogen oxide is the catalytic “unfixing” back to dinitrogen at temperature below 800 ^{0}C where the oxides of nitrogen becomes thermodynamically unstable yet kinetically extremely stable in the absence of a suitable catalysts (Selective Catalytic Reduction of Nox with N-Free Reductants, pubs.acs.org/cgi-bin/abstract.cgi/cheay/1995/95). The combustion process continues inside the exhaust gas heat exchanger where reduction and oxidation or molecular dissociation occurs and the drop in Nitrogen Oxide can be drawn from the very low temperature (between 105.5 to 127.1 ^{0}C) inside the heat exchanger.

3.5 Carbon Monoxide inside the ATTAS Heat Exchanger

In the three-way catalytic converter, carbon monoxide varies inversely with the Nitrogen Oxide, the decrease of the magnitude of latter results into the increase of the former and vice versa (Toyota Emission Analysis, p. 4, www.autoshop101.com).

Statistical analysis shows a positive correlation between CO and ΔT, revealing that CO emissions are not independent of temperature (http://www.findarticles.com/p/articles/mi_qa3979/is_200410/ai_n9471589/pg_4).

The proponent would rather justify the behavior of the carbon monoxide gas inside the exhaust gas exchanger as the result of molecular dissociation. The phenomenon allows the collision and the banging of gas molecules (www.iop.org/EJ/abstract/1370-1301/63/3/304/moleculardissociation) inside the exhaust gas heat exchanger. The situation makes it possible for the gases in the active state to change its state by releasing and absorbing other elements such as oxygen. The dissociation of the molecules of the combustion gases was affected by the reduction of the surrounding temperature.

3.6 Oxygen Gas inside the ATTAS Heat Exchanger

Rich and lean combustion condition occurs inside the internal combustion engine. In the result published by Toyota Motors Sales Oxygen and Carbon Monoxide behavior is rather opposite; an increase of one results into the decrease of the other. Rich air-fuel ratio is a result of too much fuel and lesser air in the mixture, while lean air-fuel ratio is a result of lesser fuel and more air in the mixture (Toyota Emission Analysis, p. 2, www.autoshop101.com). The tests that were performed were totally outside the engine therefore lean and rich air-fuel condition is not significant anymore, chemical reaction though possible can never be emphasized because of the absence of the proper catalysts. The behavior of the oxygen gas inside the exhaust gas heat exchanger can be drawn as a result due to dissociation the molecules of the combustion gases. Molecular dissociation allowed some oxygen molecules set free rather than combining to the carbon monoxide atoms and form carbon dioxide.

The magnitude of differences of O_2 before and after the installation of the heat exchanger in both loaded and unloaded system is surprisingly high a possible investigation using compressible flow principle can justify these differences but such procedure is left for further study.

A possibility of a leaky exhaust gas heat exchanger especially at the portion where the inlet pipe of the exhaust gas heat exchanger connects to the exhaust manifold of the engine can never be discounted.

3.7 Other Observable Findings

It is important to note that the average temperature of the exhaust gas consistently reduced to a considerable value (21.6 ^{0}C reduction) when the designed ATTAS heat exchanger was installed.

The effect of ATTAS heat exchanger to the temperature of the exhaust gases is significant (t-Test: Two-Sample Assuming Equal Variances). The application of the heat exchanger significantly changed the engine temperature from 88.7 to 89.8 ^{0}C.

The application of the exhaust gas heat exchanger into the internal combustion engine's exhaust system showed no significant observation in the engine's fuel consumption. The engine consumed 24.5 grams per minute without the EGHX and 25.9 grams per minute with the EGHX can be accounted from the inaccuracy of the setting the rpm to 2000 during the start of the testing operation and the inaccuracy in the application of the braking system and other human factors but further investigation is a welcome endeavor.

4 CONCLUSION

Heat energy is a very expensive commodity and waste heat recovery system is very important component in a successful industrial operation for the modern world. In this study, the amount of heat available in the exhaust gases is so abundant that boiling of tap water is possible. This amount of heat is more than enough to boil the refrigerants needed for the absorption refrigeration system. This study is useful for the operators of passenger buses that spend a lot of money to fuel their engines and being used to operate the air conditioning system of the passenger buses compartment. The waste heat recovery system in the ATTAS device will not only reduce the amount of fuel needed to run the passenger buses but also reduces the amount of NOx in the gas emission system.

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