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Improving a Diffusion Absorption Refrigeration Cycle Supplied with the Exhaust Waste Heat of an Automobile at Low Engine Speeds

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ABSTRACT: A diffusion absorption refrigeration cycle as a car refrigerator, which uses the car exhaust waste heat as a heat source of the cycle has been simulated in this study. An internal combustion engine with a volume of 1.3 liters at different engine speeds and throttle openings was examined experimentally and exhaust conditions such as flow rate and temperature were used as the input of the cycle. For engine speeds above 2000 rpm, there was no trouble and the evaporator temperature ranged from -0.4oC to -7.1oC. For 1500 rpm and 1000 rpm, the evaporator temperature did not reach the desired range of variations, which is the case in other reported researches. There is no available solution for the situations where the engine is running at low speed such as in traffic jam or idle condition. Therefore, a new generator was designed and simulated to solve this problem. The simulation results show that by using the modified generator, the heat transfer to the generator improves by 16.8% on average. Consequently, the cooling capacity increases by 4.7%. Therefore, the current diffusion absorption cycle is capable of performing well at the low engine speeds.

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1- Introduction

The majority of conventional cooling systems of the cars are based on compression refrigeration cycles. To avoid the extra load on the engine, save the energy and protect a more eco-friendly system, the compression refrigeration cycle is to be replaced by an absorption cooling system in which the driving force of the cycle is provided by the restored heat from the car exhaust.

By achieving the required cooling temperature, many investigators suggested that the recovered heat from the exhaust can be adequate to run the cycle [1-3]. The experiments and simulation results of Koehler et al. [4] showed that once the vehicle is in a traffic jam or running idle, the cycle performance was degraded. Further evidences showing that heat recovery from the exhaust is insufficient at low speed engines were provided by Horuz [5], Ramanathan et al. [6] and AlQdah [7]. In an empirical study conducted by Rêgo et al. [8], a diffusion absorption refrigeration cycle was examined at high engine speeds. Nonetheless, the problem remaining unsolved was with the insufficient heat transfer to the generator at the engine speeds below 1500 rpm.

In order to explore the performance of a diffusion absorption cycle as a vehicle refrigerator with the driving force of exhaust waste heat, the current study is planned. According to the literature, the absorption cycles usually do not operate properly at engine speeds below 1500 rpm which correspond to the conditions where the car is in traffic jam or the engine runs idle. To overcome such major shortcoming of Diffusion Absorption Refrigeration (DAR) cycles, the present study aims to improve the driving force of the cycle and provide higher rate of heat transfer to the generator. The improvement of heat transfer from the thermal source of the cycle is planned to be done by modifying the structure of the generator of refrigerator.

2- The Cycle Analysis

The cycle under study is a DAR cycle in which the exhaust waste heat is used as the source of thermal energy generator. To obtain the rate of transferred heat to generator, first exhaust smoke and mixture of water and ammonia heat transfer coefficients and then total heat transfer coefficient must be calculated. The heat transfer coefficient within the hot tube (ho) can be calculated by Eq. (1) [9].

$$h_o = \frac{Nu_o K}{D} \tag{1}$$

To calculate the heat transfer coefficient inside the tube (water and ammonia solution part-), Shah Equation is used [10].

$$\varphi = \frac{h_{TP}}{h_l} \tag{2}$$

3- Experiment and Simulation

A commercial diffusion absorption refrigerator (Electrolux 27A1) and the exhaust flow from a compact car engine (X100

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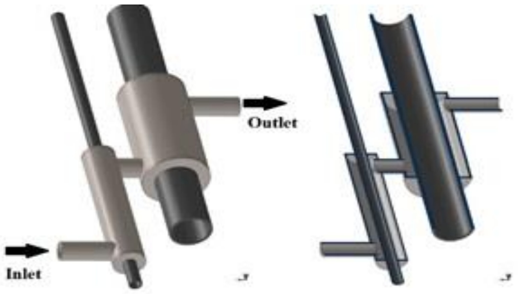

Fig. 1. The modified generator

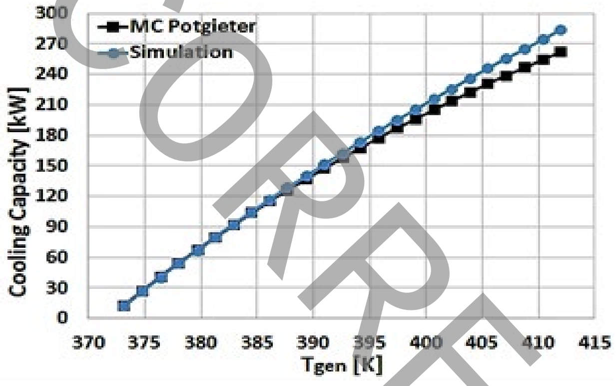

Fig. 2. Validation of simulation results

KIA) are used. The purpose of the engine test is to obtain smoke condition at exhaust outlet, so the engine was tested in laboratory condition from engine speed of 1000 rpm to 3500 rpm with three amounts of 25%, 50% and 100% open throttle.

To simulate the current absorption refrigeration cycle, Engineering Equation Solver (EES) software is used due to the extensive library functions for different fluids. The simulation process is such that momentum, mass and energy conservations equations are coupled with each other for different equipment, then the heat transfer equations are added to them in generator in order to calculate the rate of transferred heat to generator. Then, the process of solving by repetitive solutions continues until the convergence to a certain condition is reached.

4- Modified Generator

For the engine speeds below 1500 rpm, it is observed in the preliminary simulations of the current study as well as in the previous studies that the exhaust flow cannot provide the sufficient heat transferred to the generator.

The original generator delivers heat by just conduction mode of heat transfer through the welding lines to the flow of ammonia water solution. Nevertheless, the designed convertor in the modified generator, as shown in Fig. 1, enables the convection mode of heat transfer and greatly improves the rate of heat transfer. Furthermore, applying the modified generator provides a three times larger surface for heat transfer compared to the original generator.

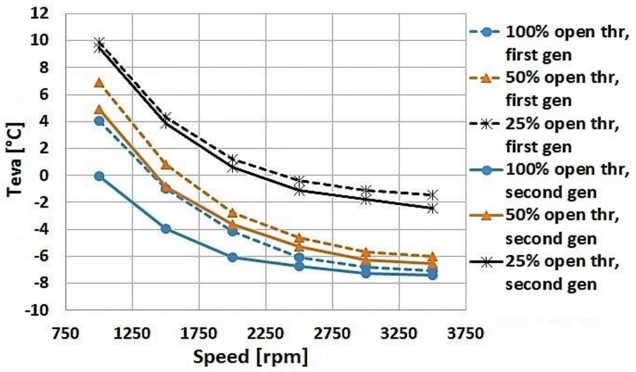

Fig. 3. The evaporator temperature in different engine speeds and throttle openings for original and modified generator

5- Results and Discussion

In order to validate the modeling, simulation results of Potgieter [11] are taken into consideration. In Fig. 2, by using inputs of Potgieter [11] model, it is shown that the highest difference at 413 K is 8.54%.

The most important target in the cycle analysis is to see how the cycle performs at various engine speeds and throttle openings. One of the major factors in analysis of the refrigerator performance is the evaporator temperature which is shown in Fig. 3. As it can be seen in this figure, increasing at engine speed and the extent of the throttle openness, causes a decrease in the evaporator temperature. Also, by using the modified generator, the evaporator temperature decreases at all the engine speeds and the minimum temperature reaches to -7.41 °C at the engine speed of 3500 rpm and full-throttle opening which matches with the results of Rego [8] research. For engine speeds lower than 2000 rpm, using modified generator can fix a lot of problems. For instance, the evaporator temperature at the engine speed of 1500 rpm and 1000 rpm decreases 4.08°C and 2.97°C respectively at full-throttle opening.

Increasing the engine speed and the amount of openness of the throttle, causes an increase in cooling capacity. By using original generator, the highest value of cooling capacity is 22.78W and the lowest value is 14.08W. By replacing the modified generator, these values are improved to 2.28% and 2.85% respectively. Using modified generator has a positive effect on the cooling capacity at all the engine speeds and various openings. For example, in 25% throttle opening it improves cooling capacity 3.1% averagely.

By increasing the cooling capacity in terms of the engine speed, it is expected that the Coefficient Of Performance (COP) follows the same trend, but the COP decreases with increasing the engine speed. The reason is that the rate of increase in the amount of heat transferred to the generator is greater and this reduces the COP. Replacing the generator also lowers the COP. It should be noted that given the fact that the propulsion energy of the cycle is completely provided with the exhaust waste heat, the low COP of the cycle is justifiable.

6- Conclusions

•By using original generator, at engine speeds of 2000 rpm and higher there is no problem and the evaporator temperature reduces up to the desired value of -7°C, but at the low engine speeds of 1000 and 1500 rpm heat transmission to the generator is inadequate. It causes the evaporator to hardly reach the freezing temperature.

•Using the modified generator improves heat transmission averagely by 16.8%. Consequently, the cooling capacity increases averagely by 4.7%.

•By using the modified generator, it is possible to reach -0.05°C and -7.41°C at the evaporator at the car engine speed of 1000 rpm and 3500 rpm respectively. Thus, the range of applicable engine speeds to run the diffusion absorption refrigeration system extends to as low as 1000 rpm.

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