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Experimental Performance Evaluation of Absorption Refrigeration System Driven by Waste Heat of Engine Exhaust

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ABSTRACT

This work presents an experimental study of an absorption refrigeration system (aqua-ammonia) using Internal combustion engine exhaust as a power source. The effect of the absorption refrigeration system on engine performance and exhaust emissions will be evaluated using the available exhaust gas energy. a generator model (TG3700) (with the exhaust pipe) has been tested with an absorption refrigeration system with the exhaust pipe. The generator was tested in four different cases according to the load (no-load, 25% load, 50% load, and load75%). The refrigerator reached different temperatures, depending on the load and the time the experiment was carried out. The availability of exhaust gas indicates that the cooling performance of a customized system can be greatly improved to save electricity usage and save cost as well. The results showed that the best case obtained was 75% load, because the temperature of the freezer decreased significantly, unlike in the rest of the cases, and it reached -13.5°C after it was 29.9°C, and this experiment was done at 75% load For 3 hours of operation.

1. Introduction

The need for energy is growing every day throughout the world as a result of the rising population, changing lifestyles, industrialization, and other factors. Energy demand may be met by two different sources: fossil fuels, which have a finite supply in nature, and Renewable energy (RE), which is plentiful and can be replenished at a rapid rate[1].RE technologies are regarded to be clean energy sources, and their best application reduced environmental concerns. Moreover, RE technologies offer a great way to reduce greenhouse gas emissions and global warming by replacing traditional energy sources [2] . A basic Absorption refrigeration system (ARS) consisting of an absorber, a pump, a generator, and a pressure reduction valve to replace the compressor in a vapour compression refrigeration system (VCRS). The system's other component is the same (condenser, evaporator and expansion valve). The refrigerant in this system is NH3, and the absorbent is water. The low-pressure ammonia vapor refrigerant from the evaporator enters the absorber, where it is absorbed by the cold water. The aqua ammonia solution is generated when water absorbs a considerable amount of ammonia vapor [3]. The main advantage of installing an ARS over a compression refrigeration system is the ability to use multiple heat sources. Solar heat, geothermal heat, or waste heat sources are a few examples. In addition to the traditional heat source of directly burning fossil fuels or using electric heaters, solar collectors have been designed and installed, and they have a great potential for use [4].In recent decades, there has been a growing interest in utilizing RE resources. Since known

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fossil resources (oil, natural gasses, and others) are nearly depleted, renewable resources are the only hope for humanity's survival in the near future. Even if governments implement dynamic strategies to reduce energy use, demand continues to rise [5].(Miraflor et al. 2019)[6]was investigated The heat exchange between the exhaust manifold and the refrigerant for the ARS. This research also looks at how well the exhaust gas heat exchanger collects heat from the internal combustion engine's combustion chamber and uses it to evaporate the refrigerant molecules housed in the heat exchanger. (Wang et al. 2012)[7] looked at a two-stage absorption system that used NH3/water as the source and has a nominal refrigeration power of 2 kW. The average system coefficient of performance (COP) was 0.21 with a maximum value of 0.25 according to the authors. (Kurtulmuş et al., 2019)[8] modeled and studied the air conditioning of an intercity bus interior using a vapour absorption refrigeration system (VARS) driven by exhaust gas waste heat obtained from the internal combustion (IC) engine. In the beginning, the intercity bus's hourly comfort cooling load was calculated for a cooling season in Turkey that lasts five months, from May to October. After calculating the capacity of the heat source for air conditioning the intercity bus, the VARS was constructed and compared to the VCRS in terms of fuel usage. The results suggest that employing the VARS in an intercity bus powered by exhaust gas waste heat may save roughly 4,489 kg of fuel per year. At 5 a.m. in May, the VAR system's maximum COP was 0.78, while the greatest total exergy destruction for the VARS was 15.25 kW at 4 p.m. in July. Finally, a specified time was chosen to evaluate how operational and environmental conditions affect the VAR system.

A two-stage absorption–compression combined refrigeration system was subjected to an energy and exergy study by(Dixit et al. 2017)[9] and The results suggest that by lowering the condensation temperature and raising the evaporation temperature, the exergy destruction rate may be reduced and the COP improved. (Jawahar et al. 2010)[10] studied an NH_3/H_2O absorption cooling system in order to recover as much internal heat as possible from the streams and improve system performance. The system was tested at 120°C to 150°C for the generator, 25°C to 45°C for the sink, and -10°C to 10°C for the evaporator. The traditional cycle was adjusted without the requirement for rectification and its performance was compared, based on the greatest internal heat that could be created using this technique. With respect to the operating conditions investigated, the suggested cycle was determined to be 17 to 56 % higher than a conventional cycle. (Manzela et al. 2010)[11]used an IC engine's exhaust as the source of energy. The purpose of the study is to investigate the feasibility and potential of using exhaust gas from IC engines as a source of energy for an ARS. The ARS was applied to the exhaust pipe of a production car engine in a bench test dynamometer. The engine was put through its paces at 25%, 50%, 75%, and full open throttle. Depending on the engine throttle valve opening, the refrigerator attained a steady-state temperature of 4 to 13°C about 3 hours after system startup. The results showed when the exhaust gas was inserted in the absorption refrigerator, carbon monoxide emissions reduced, while hydrocarbon emissions increased and carbon dioxide concentration remained virtually unchanged. (Mathapati et al. 2014)[12] utilized the energy from an IC engine's exhaust to power an ARS that cools a typical passenger vehicle. A feasibility study was conducted to determine the amount of energy available from a vehicle's exhaust gas. The cooling load for the car had been calculated. In addition, the system was mathematically modeled using EES software, and the impacts on the COP of the system with changes in several parameters were investigated. Therefore, Results showed a 2-kW system can offer air conditioning in a car based on the estimates of heat load and heat availability derived from the vehicle. According to the results of the system study, the COP of the system increases as the generator and evaporator temperatures rise, but decreases as the condenser and absorber temperatures rise. There is an ideal temperature for the generator over which the COP decreases, and the COP also rises as the mass flow rate of water increases. (Oza et al. 2018)[13] focused on the thermodynamics of an ammonia-water combination ejector-absorption refrigeration system. Moreover, a thermodynamic study was performed for various combinations of 45°C and 35°C condenser temperatures and 15°C and 5°C evaporator temperatures. Moreover, the influence of generator temperature on system performance had been investigated for various entrainment ratios in a combined ejector absorber system. When compared to the conventional cycle. As a result, the combined cycle's COP had increased by 14.98 %to 33.47%. (Vazhappilly et al. 2013)[14] designed a breadboard prototype of an absorption system for refrigeration that used heat from exhaust emissions. A heating coil generator system had been used to evaporate the ammonia refrigerant in commercial VARS. The ARS heating coil generator system had been replaced by a plate frame type heat exchanger, which made use of the IC engine's exhaust emissions. In addition, based on actual IC Engine operating cycles, the available heat in the exhaust gases must be evaluated.

The research aims to shed light decisively on the evolution of waste heat in aqua ammonia absorption refrigeration system (AARS). In addition, conducting theoretical studies on converting RE sources into a cooling system, using the ARS.

2. Experimental work

Refrigerator model V170KE was selected with a power of 325 watts as shown in Figure 1 and their general specification is listed in Table 1.

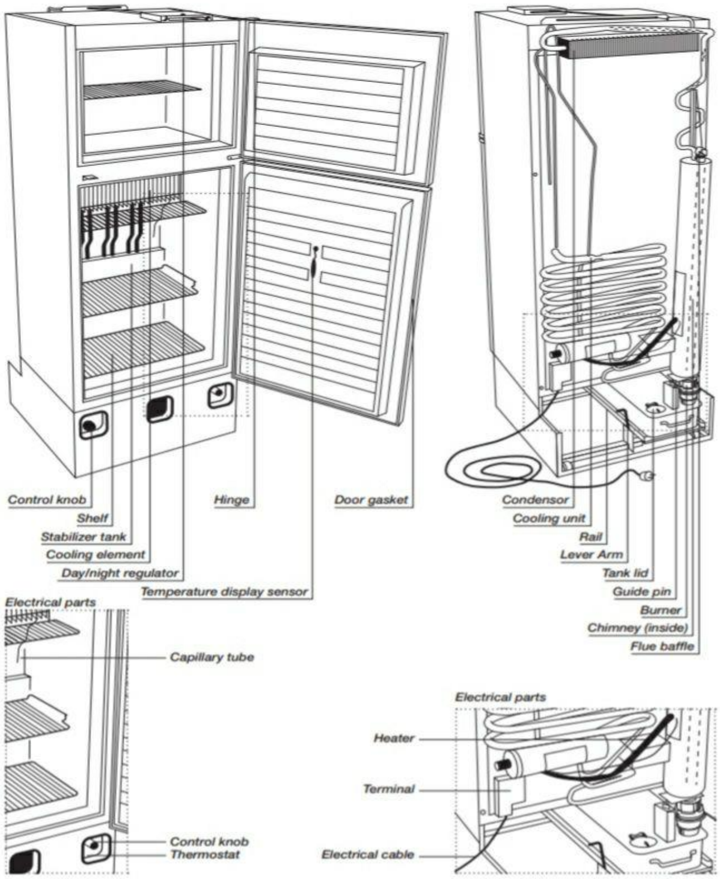

Figure 1. The refrigerator's front and back [15]

Table 1: The specification of Refrigerator model V170KE

power	325 watts
voltage	220 volts
current	1.5 Amp
volume	0.17 m^3/170 L

The experiment was prepared by connecting 8 sensors of type (TPM-10) on each part of the system for the purpose of measuring the temperature. Where the sensors were installed on each of the freezer, fridge, condenser inlet, condenser outlet, absorber, rectifier out, generator inlet and the eighth sensor were placed to measure Room temperature. In addition, a thermometer was installed to measure the generator outlet temperature.

In this case, the source of operating the refrigerator is waste heat. a generator model (TG3700) is used and exhaust gas is taken from it to operate the refrigerator by installing an L-shaped tube between the generator (TG3700) and the refrigerator as shown in Figure 2. The tube is flexible, withstands a temperature of 300 degrees Celsius, and has a length of 90cm and a diameter of 1.2cm. The long part is 75 cm fixed to the exhaust gas outlet of the generator (TG3700) and the short part is 15 cm fixed to the generator inlet to the refrigerator. In addition, an insulator model (Glass wool) is placed on the pipe to prevent the exhaust gas heat from leaking, and the Glass wool as shown in Figure 3 is an insulating material comprised of glass fibers that have been organized using a binder into a texture similar to wool. The method traps several microscopic pockets of air between the glass, resulting in exceptional thermal insulation qualities. Glass wool is manufactured in rolls or slabs with varying thermal and mechanical qualities. It can also be manufactured as a substance that can be sprayed or put on the surface to be insulated. The generator is run without load first and then at different loads of 25%, 50%, and 75%.

Figure 2. The process of connecting the pipe between the generator and the refrigerator

Figure 3. Glass wool

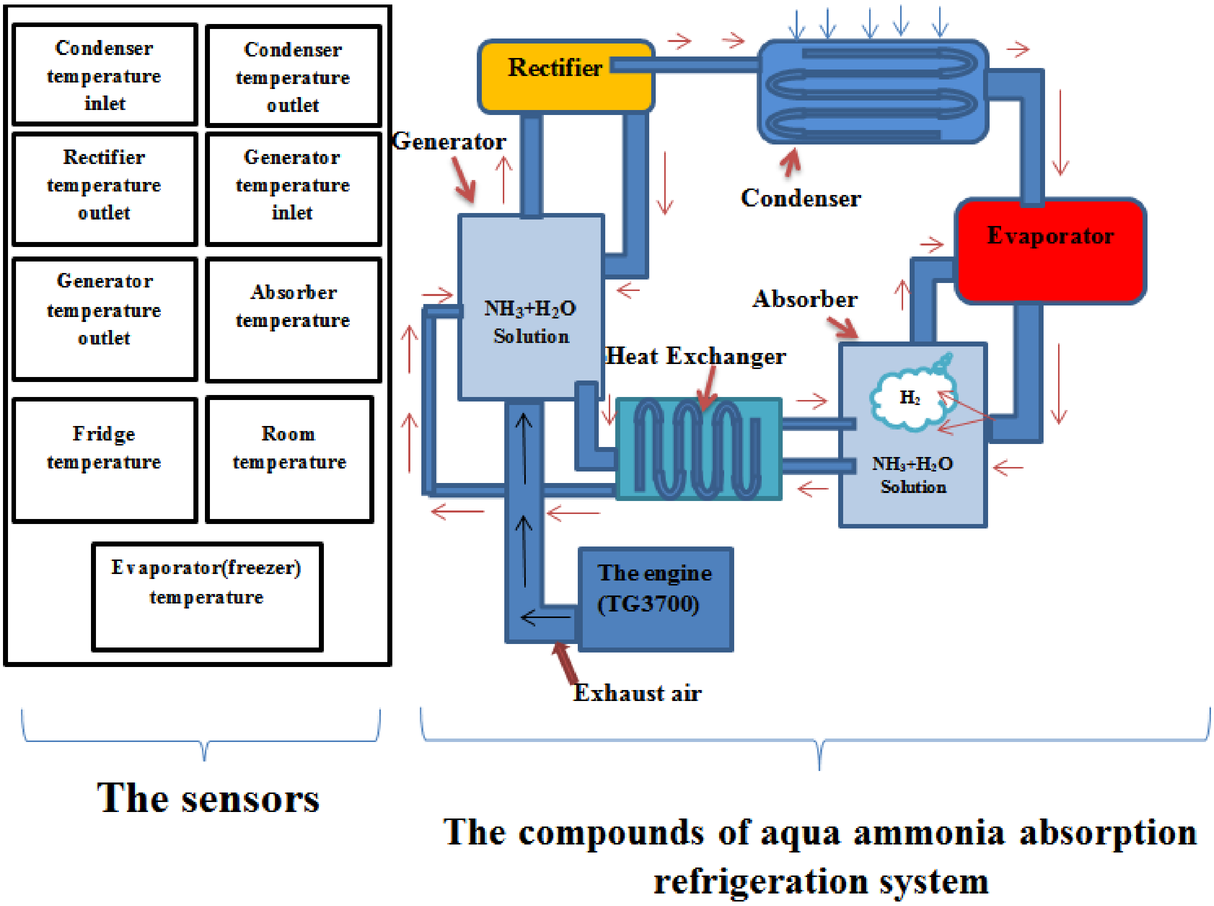

Figure 4. Schematic diagram of the working part with sensors

2.1calculations

The mass flow rate can be estimated by Equation

$$\dot{m}=\rho VA \tag{1}$$

The waste heat rate from engine can be estimated by Equation

$$q = \dot{m}c_p\Delta t \tag{2}$$

3. Results and discussion

This part explains the use of the engine's waste heat source in 4 cases. The first case is the use of engine exhaust gas without load, which means the amount of current is zero, the second case is the use of engine exhaust gas at 25% load, which means the amount of current is 2.2 amps, the third case is the use of engine exhaust gas at 50% load, which means the amount of current is 4.4amps, and the fourth case is the use of engine exhaust gas at 75% load, which means the amount of current is 6.6 amps. Exhaust air temperature and mass flow rate per load were also used.

3.1 Exhaust at engine no load

The experiment was carried out on 23rd February, and the parameter studied was temperature. The output data was plotted every 5 minutes between 10:45 AM and 1:15 PM, while the room temperature ranged from 15°C to 17.5°C. From 10:45 AM to 12:05 PM, the pipe connecting the generator to the refrigerator was not insulated, and it had a negative effect on the results of the refrigerator, at 12:10 PM an insulator was placed on the pipe. and at 12:30 a sticker was placed on the exhaust gas outlet to prevent its leakage, so the temperature of the chimney and generator began to rise. and also, at 12:45 PM, Changing the location of the sensor to the generator out, there was a jump in readings that rose dramatically. Additionally, in this case, were the exhaust air temperature 302°C and mass flow rate 0.0009 kg/s.

The freezer temperature was recorded at 13.6°C the first moment the refrigerator was turned on and it reached 14.9°C at 1:15 PM as shown in figure 5. While the fridge temperature was recorded at 13.7°C and it reached 15°C at 1:15 PM. In this case, the temperature of the freezer and fridge increases with time. The reason is due to the high room temperature during the experiment period. Therefore, the temperature inside the refrigerator cabinet also increased.

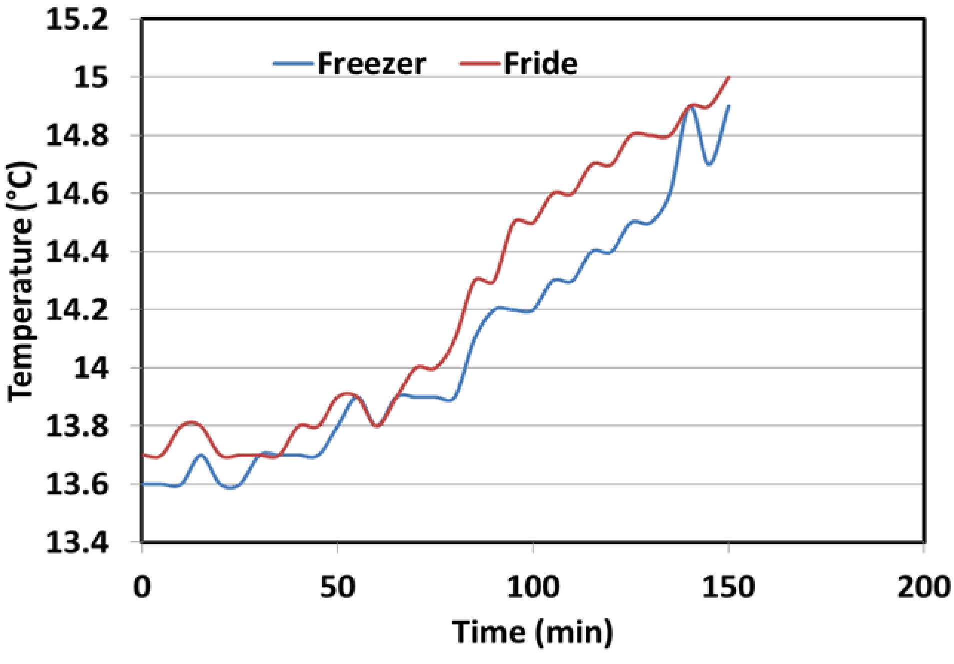

Figure 5. Variation in freezer and fridge temperature with time in no-load case

3.2 Exhaust at engine load 25%

In this section, the temperature at which the refrigerator is operated from exhaust gas was measured, and this procedure was carried out by applying a generator load of 2.2 amperes for both February and May. The experiment was conducted on February 25 for a period between 10:30 AM and 1:30 PM with room temperatures between 15.9°C and 19.3°C. While the experiment was conducted on May 6 for a period between10:20 AM and 12:30 PM Where the room temperature ranged between 30.9°C and 35.5°C. Additionally, in this case, were the exhaust air temperature 324.9°C and mass flow rate 0.0011 kg/s.

In February,the freezer temperature was recorded at 14.2°C the first moment the refrigerator was turned on and it reached -10.2°C at 1:30 PM. While the fridge temperature was recorded at 14.8°C and it reached 16.6°C at 1:30 PM as shown in figure 6. While in May as shown in figure 7, the freezer temperature was recorded at 27.5°C the first moment the refrigerator was turned on and it reached 14°C at 12:30 PM while the fridge temperature was recorded at 28.1◦C and it reached 30.7◦C at 12:30 PM. We conclude that the freezer and fridge perform better in February than in May. As a result of the relationship between room temperature and rate of condenser effectiveness in condensing refrigerant, it is obvious that the temperature around the refrigerator had a significant effect on the rate of temperature decrease inside it.

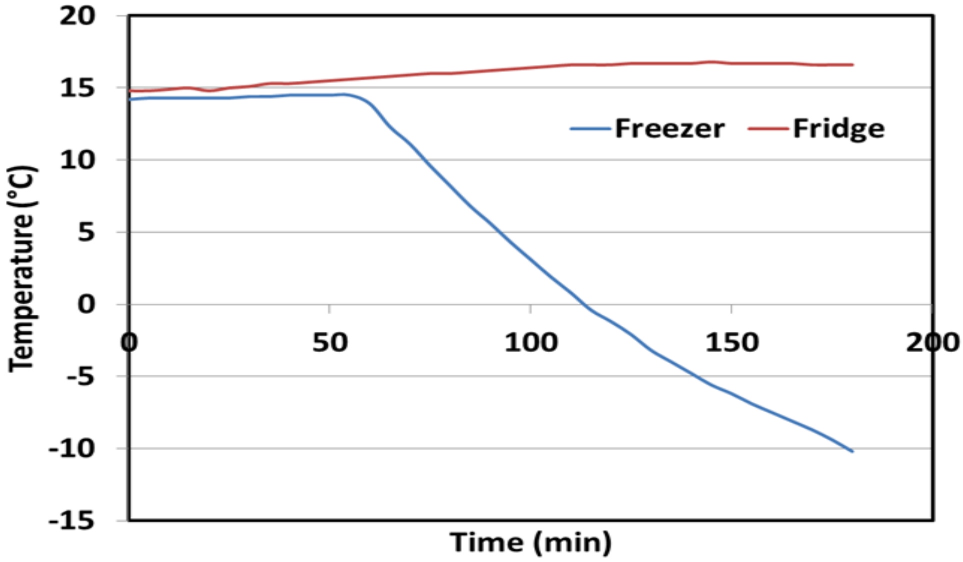

Figure 6. Variation in freezer and fridge temperature with time for 25% load case in February

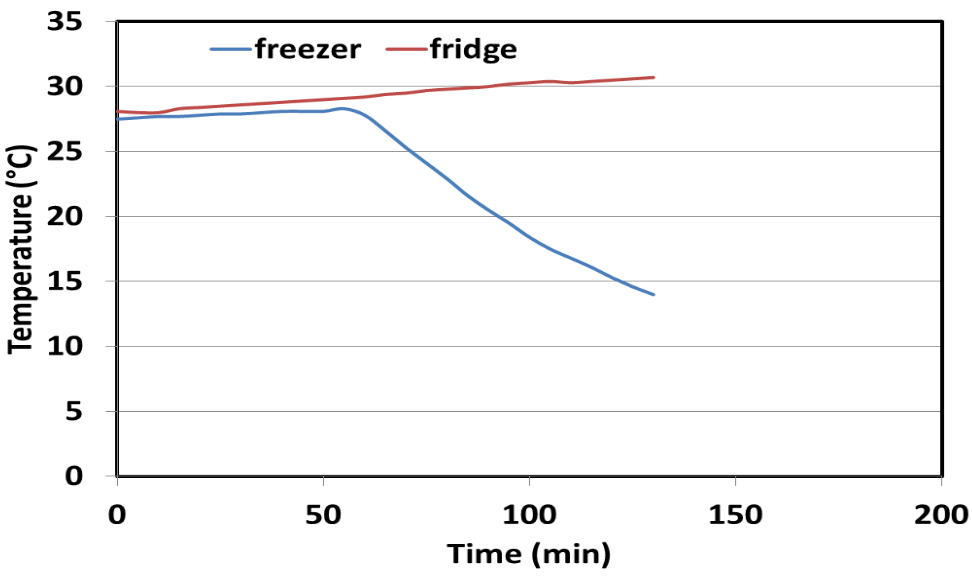

Figure 7. Variation in freezer and fridge temperature with time for 25% load case in May

3.3 Exhaust at engine load 50%

In this section, the temperature at which the refrigerator is operated from exhaust gas was measured, and this procedure was carried out by applying a generator load of 4.4 amperes for May. The experiment was conducted on 9 May for a period between 9:40 AM and 12:40 PM with room temperatures between 29.3°C and 38.5°C. Additionally, in this case, were the exhaust air temperature 384°C and mass flow rate 0.0012 kg/s.

As shown in figure 8, the freezer temperature was recorded at 27.7°C the first moment the refrigerator was turned on and it reached -5.3°C at 12:40 PM. While the fridge temperature was recorded at 28°C and it reached 29.9°C at 12:40 PM. Despite the increased load than the first case, the freezer did not reach the required level, and the reason is due to the high temperature surrounding the refrigerator.

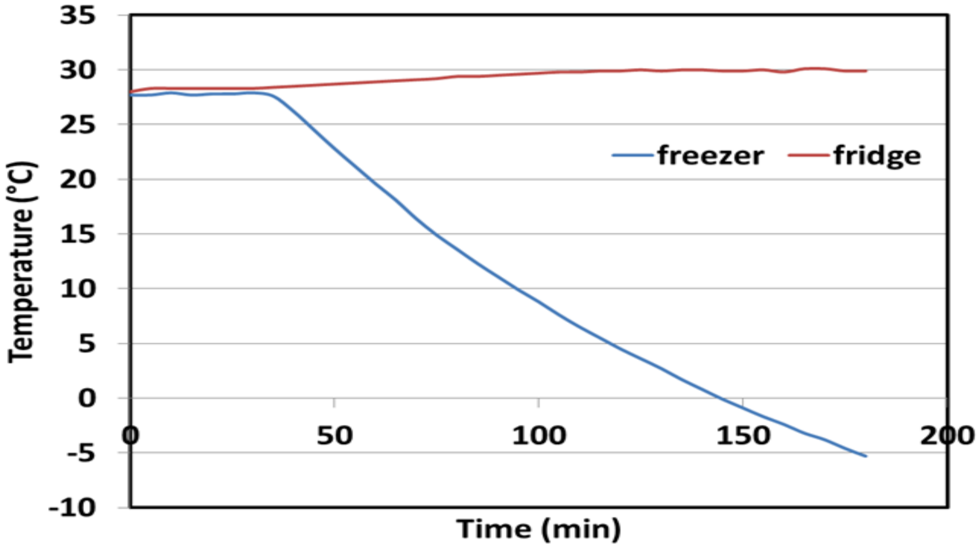

Figure 8. Variation in freezer and fridge temperature with time for 50% load case in May

3.4 Exhaust at engine load 75%

In this section, the procedure was carried out by applying a generator load of 6.6 amperes. The experiment was conducted on 26th May for a period between 9:40 AM and 12:40 PM with room temperatures between 31.8°C and 40.9°C. Additionally, in this case, were the exhaust air temperature 428°C and mass flow rate 0.0018 kg/s.

As shown in figure 9, the freezer temperature was recorded at 29.9◦C the first moment the refrigerator was turned on and it reached -13.5°C at 12:40 PM. While the fridge temperature was recorded at 30.7°C and it reached 25.9°C at 12:40 PM. we conclude that the higher the load, the lower the freezer temperature. Moreover, there are two factors that affect a decrease in the temperature of the freezer, which is the mass flow rate and the exhaust air temperature. the reason for this difference decreasing rate is due to the amount of heat enters to the generator in absorption refrigeration system, when the engine load increased then the fridge performance enhanced.

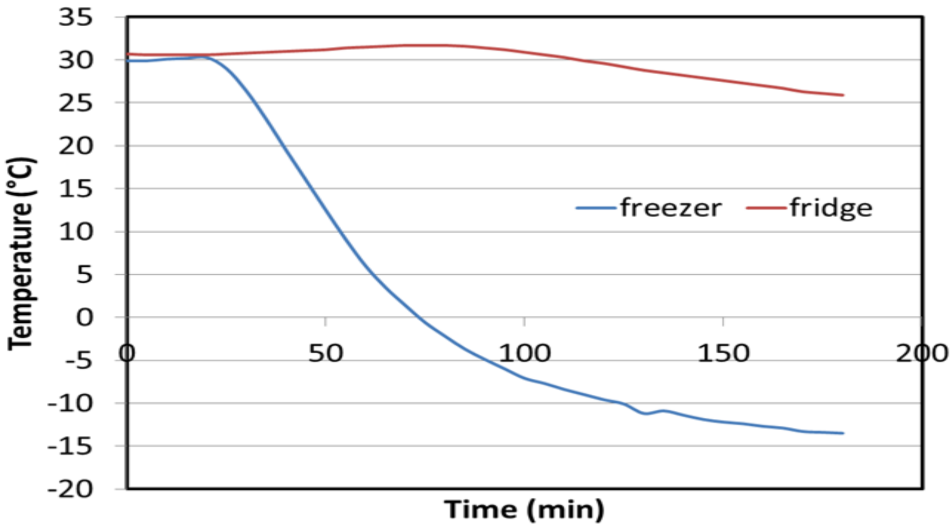

Figure 9. Variation in freezer and fridge temperature with time for 75% load case in May

3.5Waste heat rate from engine

In this part, we explain the waste heat rate from the engine at 4 loads and at different intervals.
as shown in Figure 10, We note that the maximum waste heat rate from engine among the four cases is in the case of 75% load, where it recorded 175.5W at 10:25AM, and the reason is that the temperature of the exhaust gas in this case was higher, which is 428°C and the mass flow rate was higher as it was recorded 0.0018 kg/sec.

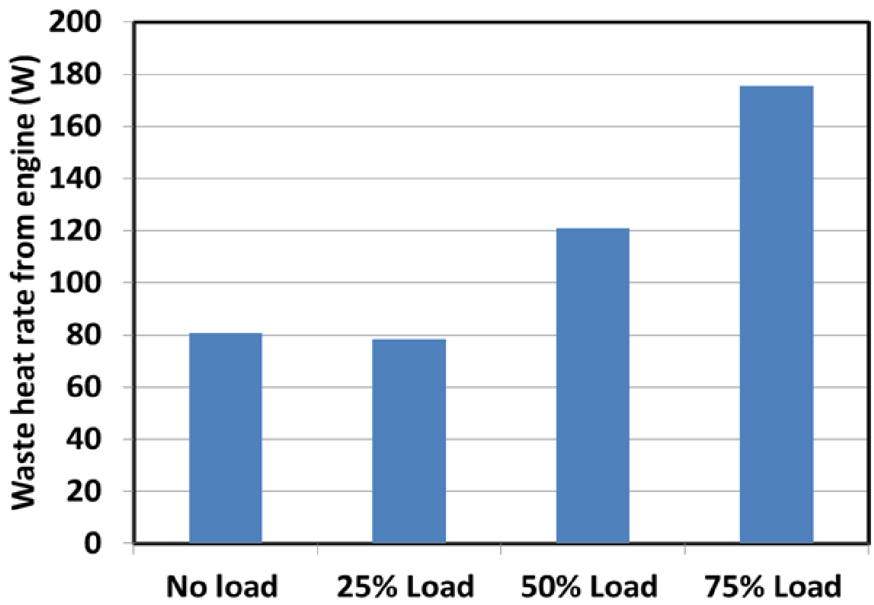

Figure 10. Variation waste heat rate from engine with load

4. Conclusions

The following conclusions can be drawn from this study based on an analysis of the experimental results: -

1- the higher the load, the shorter the time to reach the stabilization state. In addition, there are two factors that lead to a faster cooling process, namely, the temperature of the exhaust gas and the mass flow rate**.**

2- When the exhaust air temperature rises, it leads to a higher mass flow rate in case of exhaust of engine at load 75%. In addition, it will produce the maximum waste heat rate from engine where it recorded 175.5W at 10:25AM.

3- The best freezer temperature among the four cases was recorded at -13.5°C at 12:40 PM in the case of 75% load.

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