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Experimental Studies on Waste Heat Recovery Using Household Electric Generator

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ABSTRACT
Waste heat is heat that is produced by a machine, or other process that uses energy, as a byproduct of doing work according to the laws of thermodynamics. Recovering this waste heat will help to provide valuable energy sources, increase the efficiency of machines and reduce overall energy consumption. This study examines waste heat recovery from the electric generator for the purpose of boiling water.

The research was carried out by fabricating a heat recovery system consisting of a steel, insulated water tank attached to the exhaust pipe of a 3.5 KVA, Elepaq generator through copper pipe. The copper pipe carried water from the tank and was wound round the exhaust pipe of the generator and then carried water back into the tank. Heat recovery was attained through the process of conduction of heat from the exhaust pipe of the generator to the water flowing through the copper pipe. The temperature of the water was measured using a single probe digital thermometer. Another single probe digital thermometer was used to measure the body temperature of the outlet and inlet pipe, and the time was recorded by a stopwatch.

The result from the study showed that 107 J of heat was gained by 9.48 kg of water per second of the experiment. The water temperature in the tank rose from 26˚c to 62.3˚c within 225 minutes.

As shown by this study, recovering waste heat from the household electric generator can be achieved for the purpose of domestic work such as water boiling for bathing, tea making, washing, cleaning, baking etc. It can therefore be deduced that waste heat recovery from household and industrial devices is achievable.

KEYWORDS: *Waste heat, Heat recovery, Waste heat recovery, Electric generator, Waste energy.*

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I. INTRODUCTION

Nigerian population is facing erratic power supply having about 40% of the population connected to national grid and over 70% of the population living in rural areas, using electric generator as major alternative source of electricity generation is a necessity (Oyedepo, 2014). The present per capita power capacity (28.57 W) and per capita consumption of electricity (145) in the country is obviously inadequate even for domestic consumption (Oyedepo, 2014). Due to low level of development, residential areas account for almost 65% of energy use in the country (Ley *et al*., 2015). The main energy-consuming activities in Nigeria's households are cooking (91%), lighting (6%), and use of electrical appliances (3%) (Oyedepo, 2012). Gasoline and diesel consumption in standby electricity generators are responsible for half of the energy consumed in the residential sector. The extensive use of generators in the country has positioned her as the leading importer of generators in Africa and one of the highest importers globally (Ley *et al*., 2015).

Power production devices, regardless of conventional or renewable always face heat loss problems, which decrease the energy efficiency. The heat loss also includes the heat energy that is rejected to the environment with lower temperature, also known as waste heat. Recently, instead of dumping waste heat into the environment, many efforts are being done to reuse the lower grade energy into useful energy (Mustafa *et al* 2017). Internal combustion engine (ICE) as a power produce device also produce waste heat as byproducts, and the fact is the contribution of waste heat from ICE are not negligible. Severe environment pollution, entropy rise and greenhouse effect are conveyed when almost 60 – 70% of energy from internal combustion is released as waste heat.

Even a highly efficient combustion engine converts only about one-third of the energy in the fuel into mechanical power serving to actually drive the car. The rest is lost through heat discharged into the surroundings or, quite simply, leaves the vehicle as “waste heat”. Clearly, this offers a great potential for the further reduction of CO_2 emissions which the BMW Group’s engineers are seeking to use through new concepts and solutions. The generation of electric power in the motor vehicle is a process chain subject to significant losses.

Nearly three-quarters of all the energy produced by humanity is squandered as waste heat. The main sources of wasted heat in residential applications are chimney, cook stoves and electric generator (Buczynski *et al.* 2016; Kolasinska and Kolasinski 2016). Now, large businesses, high-tech operations such as data centers, and governments are exploring innovative technologies to capture and reuse this vast renewable energy source. (BCS, 2008) Waste heat is everywhere. Industrial heat sources are classified according to temperature range and the examples of classifications are: Liquid streams 50°C – 300°C, Flue gases 150°C – 1650°C, Steam 100°C – 250°C and Process gases and vapors 80°C -500°C. Every time an engine runs, a machine clunks away, or any work is done by anything, heat is generated. That’s a law of thermodynamics. Waste heat recovery is indispensable in saving energy and lowering energy consumption (Hong-kui *et al.*, 2011; El Hage *et al.*, 2019). It is defined as the re-usage of dissipated thermal energy. Power generation, heating, cooling and heat storage systems are among the main applications of heat recovery (Khaled *et al*., 2016). Waste heat utilization holds great potential for improving energy efficiency, reducing energy usage and enhancing engineering functionality (Muhammad *et al*., 2016).

The household electric generator is one of the highest waste heat releasing household devices. Heat is released along exhaust gas which is a by-product of the incomplete combustion of fuel in the engine. Recovering and reuse energy waste that is coming from generator will improve the condition of living of majority of people in rural area and reduce the effect on the environment. This is why this study was carried out on using waste heat to boil water that can be used in the house.

II. MATERIALS AND METHODS

2.1 Equipment and materials

The materials used in this work were: heat source - generator exhaust silencer (Petrol generator; ELEPAQ gasoline generator SV4800E2), water Tank (Galvanized steel, Mild steel), water tap, copper pipe, digital thermometer (TES 1310 type-k), and paper tape. The dimensions of the copper pipe that was used are: inner diameter, d = 38.1mm, outer diameter, D = 40.8mm and thickness 2.7mm.

A cylindrical shape water tank was chosen because it is suitable and aids the flow of water for the heat recovery process. The following are the dimensions of water tank: inner and outer height is Height = 450mm, inner and outer diameter are 160mm and 200 mm respectively, mild steel was used for the inner tank and galvanized steel for the outer tank (Volume 9.04896 liter or 0.00904896 m^3). The tap and lid opening were welded to the tank using electric welding. The space between the inner tank and the outer covering was insulated using fiberglass to prevent heat loss.

2.4 Experimental Procedure

Waste heat was harvested by allowing water to flow from tank through copper pipe that was wound round the silencer of the 3.5 KVA generator and back to the tank. Initial temperature at the inlet pipe, the outlet pipe and that of the water in the tank were measured using two different single point thermometers. The Generator was put on and the starting time was recorded. The silencer of the generator being made of mild steel conducts heat from the exhaust gas passing through it and the heat is transferred to copper pipe and was harvested to raise the temperature of water through the principle of conduction. The copper pipe wound around the Generator silencer conducted heat and transferred the heat to the water flowing inside it from the tank and therefore carried the heated water to outlet end of the outlet pipe. The temperature of water flowing inside the copper pipe continued to increase as the running time of the generator increased. Temperatures of the water and at the outlet and inlet pipes were recorded at intervals of 15 minutes.

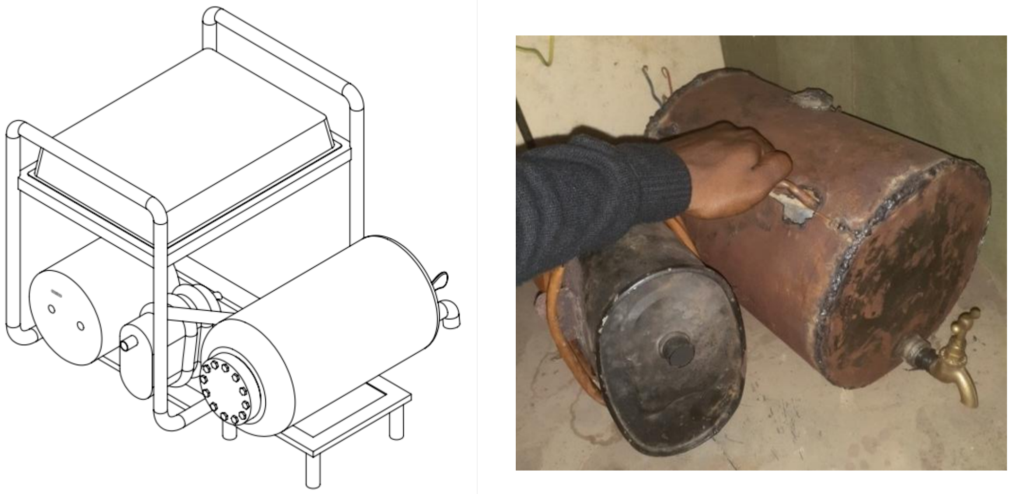

Plate 1: Fabricated heat recovery System

III. RESULTS AND DISCUSSION

3.1 Results

The results of the tests carried out were recorded and entered in a table. Two different single probe thermometers were used to take the temperature reading. One was used for the water temperature and one to measure the inlet and outlet pipe body temperature. The temperature reading was taken at an interval of 15 minutes for a total of 225 minutes.

Table 1: Experimental Readings of temperature at the inlet, outlet and water

Time(mins)	Inlet Pipe Temperature(˚C)	Outlet Pipe Temperature(˚C)	Water Temperature(˚C)
0	31.0	32.0	26.0
15	36.8	40.8	29.1
30	39.5	58.5	34.2
45	40.8	70.3	35.9
60	41.5	78.2	38.8
75	41.8	82.8	43.8
90	45.1	83.9	46.5
105	46.2	84.1	49.3
120	47.2	84.6	53.5
135	49.0	80.4	52.1
150	49.6	79.6	50.9
165	50.1	83.9	52.5
180	48.5	84.2	52.9
195	48.9	84.1	55.7
210	51.8	85.2	58.6
225	52.7	86.1	62.3

From table 1, the temperature of water increased steadily for the first 120 minutes but there was a drop in temperature for another between 129 minutes and 165 minutes. This is due to the fact that the generator exhaust is always dropping temperature at intervals through cooling systems like air cooling system in this case. This prevents the Generator from continuing to increase the temperature exponentially during its operating hours. Also the drop can be associated to some heat loss to the environment in the process of circulating and transferring water from the reservoir to the insulated water tank. Temperature began to rise again between 165 minutes to 225 minutes. This is because, the generator builds up heat again from continued burning of fuel.

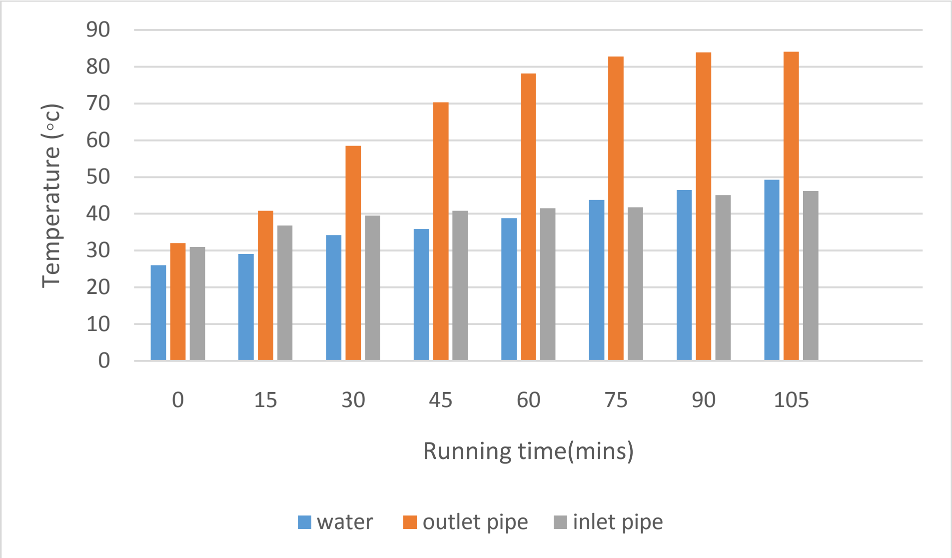

Figure 1: relationship between temperature of water, body of the inlet pipe, body of the outlet pipe and running time of the generator (between 0 minute and 105 minutes)

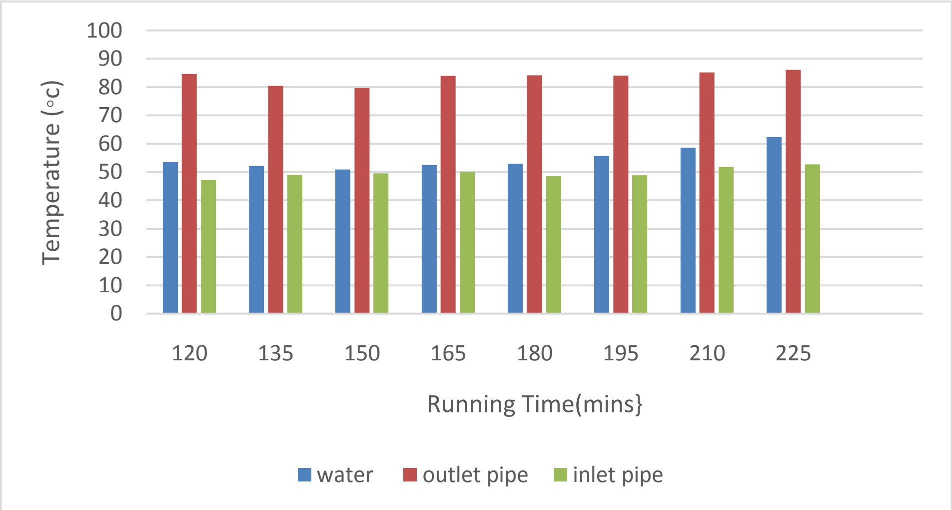

Fig 2: relationship between temperature of water, body of the inlet pipe, body of the outlet pipe and running time of the generator (between 120 minutes and 225 minutes)

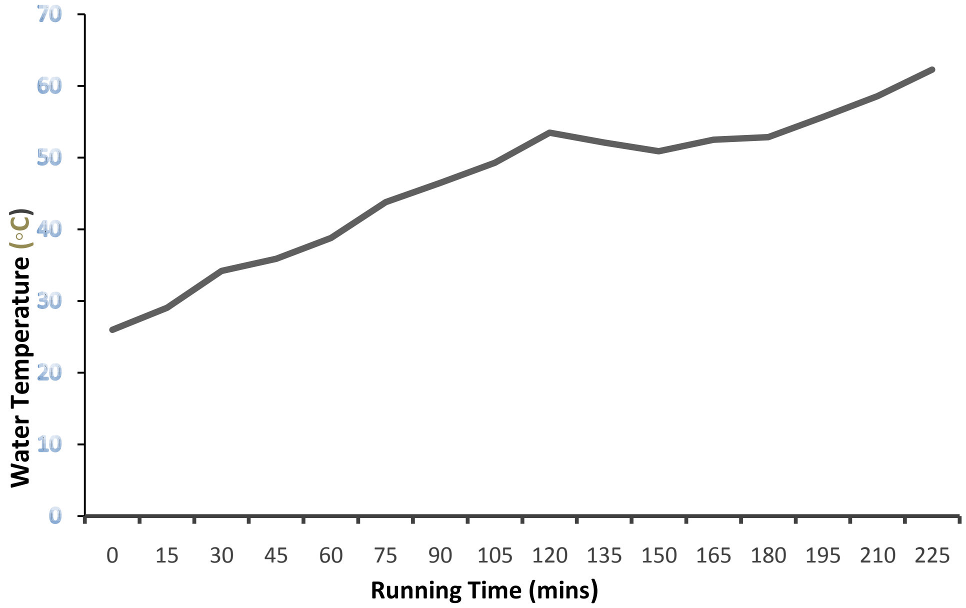

Figure 3: relationship between water temperature and the running time of the electric generator

3.2 Discission

From figure 2, the temperature of the outlet pipe increased steadily from 79.6 ˚C to 86.1˚C, but there was a drop from 84.2 ˚C to 84.1 ˚C (between 180 minutes and 195 minutes). This is due to the counter acting cooling effect the surrounding atmosphere the pipe was exposed to. This is also due to the cooling of the generator by the surrounding air. There is almost equilibrium in the heat gained from the generator by the exhaust pipe and the heat lost to the cooling effect of the surrounding air around the pipe between 180 and 195 minutes.

From figure 3 above, it can be deduced that temperature of water increases linearly with running time of the electric generator if all external factors are neglected. There was a steady rise in the temperature of water for the first 120 minutes before dropping for the next 30 minutes due to heat loss and then rising again with increase in the running time of the electric generator.

Equations 1 and 2 show the expression for calculating heat absorbed by water and heating rate.

$Heat\ absorbed\ by\ water\ Q = \mathrm{m}\ x\ c\ x\ \Delta T$ 1

Heat rate, H = Thermal Energy in/Energy out 2

3.3.2 Results Analysis

The result of the experiments shows that, while raising the temperature of 9.48 kg of water from 26˚c to 62.3˚C, water in the tank gained 1445 KJ of heat from the wasted heat during the whole experiment, which lasted 225 minutes. This means heat recovered from the electric generator was at the rate of 107 Joules per second of the experiment.

Results of the experiment carried out by Khaled *et al.*, 2015; Khaled and Ramadan, 2017, show that allowing exhaust gases to flow through pipes inside the tank increases water temperature by 30 °C compared to what was obtained when exhaust gases just pass beside the bottom side of the tank. Compared to this study, a smaller electric generator of 3.5 KVA was used and a lesser mass flow rate of 0.03 kg/s. This suggests that the heat recovery set up for this study has a fairly good performance based on the flow rate and the size of the generator.

IV. CONCLUSION

The following conclusions can be drawn from the results obtained;

1. Since it has been shown from this study that the water temperature increases with increasing running time of the household generator, it can be deduced that waste heat recovery from household and industrial devices is achievable.
2. The temperature of water increase then drop at some point before rising again. This shows that the waste heat recovered will not always continue to increase with running time of a device because of unpreventable heat loss to the environment and through the cooling process of the system.

3. The temperature at the outlet was constantly higher than the temperature of the water. This shows that not all the waste heat from a device can be actually recovered except for an ideal system which does not occur in reality
4. The heated water at 62.3˚c can be used for warm water bath, domestic cleaning and washing, coffee and tea

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