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WASTE HEAT RECOVERY USING A HOUSEHOLD ELECTRIC GENERATOR

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Abstract - **Waste heat is heat produced by a machine or other process that uses energy as a byproduct of doing work according to the laws of thermodynamics. The recovery of this waste energy helps to provide valuable energy sources, increase the efficiency of machines and reduce overall energy consumption. This research examines waste heat recovery from an electric generator for hot water supply for domestic uses in homes and offices. A fabricated heat recovery system consisting of an insulated steel water tank was attached to the exhaust pipe of a 3.5KVA, Elepaq generator by a copper pipe. The copper pipe carries water from the tank, winds around the generator's exhaust pipe, and then carries water back into the tank.**

The result from the study shows that 107J of heat is gained by 9.48kg of water per second of the experiment. The water temperature in the tank rises 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 domestic work such as water boiling for bathing, tea making, washing, cleaning, and baking.

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

I. INTRODUCTION

Energy recovery from thermal processes plays a pivotal role in achieving environmental sustainability by mitigating the negative impacts of energy consumption and waste generation. As societies strive for a greener future, minimizing resource depletion and reducing greenhouse gas emissions becomes increasingly vital. Waste energy recovery offers a viable solution by capturing and utilizing energy that would otherwise be lost or discarded during various processes. Waste heat is everywhere. According to the law of thermodynamics, heat is produced whenever anything works, whether it's an engine, a machine, or anything else. Most of the time, that heat is lost and dribbles into the atmosphere. Waste energy accounts for almost 70% of all the energy humans create.[1].

To save energy, reduce energy use, and lessen pollution, waste heat recovery is essential [2]. Waste heat recovery is described as using thermal energy that has once been lost to do work. The main uses of heat recovery include power generating, heating, cooling, and heat storage systems [3]. Utilizing waste heat has tremendous potential to increase engineering functionality, reduce energy use, and improve energy efficiency [4]. The building sector produces the second-highest CO_2 emissions, with residential emissions making up 10.9%. [5]

The electric generator is one of the highest waste heat-releasing household devices, widely used in homes and business centers in Nigeria. The use of off-grid Power generators, commonly called "backup generators," have increased steadily over the years, from just over 60% in 2002 to about 84% in 2020. Urban households rely on gasoline or diesel generators for their electrical needs revealing Nigeria's dysfunctional power infrastructure [6]. Researchers have recently become quite interested in recovering some of this lost energy. While certain waste heat losses are unavoidable, losses can be minimized by upgrading equipment efficiency or installing waste recovery systems. [7]. Homes in nations with frequent power outages often use electric generators. Approximately 65% of the energy released during fuel combustion is lost through various means, including exhaust gases, cooling water, friction, sound, and others. Exhaust gases carry around 40% of the thermal energy dissipated while cooling liquid carries about 25%. Researchers have become increasingly interested in recovering some lost energy in recent years. In general, the method of power transition can be used to categorize the waste energy in an electrical generator. About 40% of the fuel input energy is found in exhaust gasses [8]. The temperature of the exhaust gas changes depending on the generator's size and the load.[9]. Utilizing low-grade waste thermal energy can significantly reduce the consumption of fossil fuels and advance society's transition to carbon neutrality. Recovered heat can be used as an energy source to produce more heat or electrical and mechanical power [10].

II. MATERIALS AND METHODS

2.1 Equipment and materials

The materials used in this work were: heat source; generator exhaust pipe (Petrol generator; ELEPAQ gasoline generator

SV4800E2), Water Tank (Galvanized steel, Mild steel), water tap, copper pipe, digital thermometer (TES 1310 type-k), paper tape.

2.2 Design Calculation

2.2.1 Copper Pipe

The dimension of the copper pipe

- Inner diameter, d = 38.1mm (1.5 inches)

We chose an inner diameter of 38.1mm because it helps to maintain a laminar flow based on the Reynold number calculation. Also, a small diameter is needed to minimize the flow area, thereby increasing the flow pressure for an efficient flow

- Outer diameter, D = 40. 8mm

We chose a small outer diameter of 40.8mm because a small diameter is needed to minimize the flow area, thereby increasing the flow pressure for an efficient flow

- Thickness: Outer diameter – Inner diameter

Thickness = D – d
40.8mm – 38.1mm = 2.7mm

2.2.2 Water Tank

We chose a cylindrical shape because it is suitable and aids the movement and flow of water for heat recovery.
The water tank is a cylindrical tank with the following dimensions;
Inner Dimension

- Height = 450mm

We chose a height of 450mm because we need depth for increased pressure flow.

- Inner diameter, d = 160mm.
- Inner radius = 80mm

A diameter relatively minor to the height is needed to increase pressure flow at the bottom side of the tank where water flows out.
Outer Dimension

- Height = 450mm

A height of 450mm to create space for insulation

- Outer diameter, D = 200 mm

We used an outer diameter of 200mm to create space for insulation

- Outer radius = outer diameter ÷ 2

Outer radius = 100mm

- Volume = Height x (inner radius) ² x π

$V = \pi r^2 h$(1)
Volume = 450mm x $(80mm)^2$x 3.142
Volume = 9048960mm³

III. THE OPERATIONAL SYSTEM

This system functions as a heat recovery mechanism for water heating, utilizing the heat from the body of the exhaust pipe from a generator as its heat source and employing conduction and convection as heat transfer. The tank is lying horizontally, filled with water, and slightly elevated to increase the pressure in the inlet pipe, ensuring consistent flow. (e.g., P = pgh, where P represents pressure, p denotes density, g signifies gravitational acceleration, and h indicates height.)
Using a gas or liquid to capture and transmit waste heat from a process back into the system as an additional energy source is one waste heat recovery approach [11].Water circulates through a copper pipe that surrounds the generator's exhaust. By direct contact with the exhaust pipe, the copper pipe effectively conducts heat from the generator to the water flowing through it. Direct contact is achieved by tightly winding the copper pipe around the exhaust pipe, ensuring a metal-to-metal connection that facilitates efficient heat transfer. Water flows to the inlet pipe from the tank around the generator exhaust pipe, and this pipe transports the heated water back into the reservoir through the outlet pipe. The tank is insulated using fiberglass, a commonly employed insulation material to minimize heat loss. The continuous flow of water within the system enables efficient heat exchange. Heated water molecules in the tank expand, gain more kinetic energy and move faster to flow out of through the inlet pipe to ensure circulation. This process is maintained by consistently transferring water from the reservoir to the insulated tank. A tap is affixed to the tank through welding for water discharge.

IV. EXPERIMENTAL PROCEDURE

The recycling tank unit, which consists of a copper pipe wound around an exhaust pipe, was fixed to a 3.5kVa electric generator. We filled the tank with water, and the initial temperature at the inlet pipe, the outlet pipe, and the water in the tank were measured using two different single-point thermometers; one for the water temperature and the other for the temperature at the inlet and outlet pipe. We put on the generator and the starting recorded the starting time. With water circulating through the copper pipe lying around the exhaust pipe, the heat was conducted to the water through conduction as the generator continued to operate. The temperature of water flowing around the copper pipe continued to increase as the generator's running time increased. We recorded the temperature of the water and the temperature at the outlet and inlet pipes at intervals of 15 minutes.
As the generator remained in operation and burned fuel, the electric generator built up heat. The combustion process generated heat, part of which passed out through the generator's exhaust pipe as hot gas. The exhaust pipe of the generator, made of mild steel, conducted this heat and transferred it to the copper pipe around it, which, in turn, transferred it to the water in the pipe through the principle of conduction. The heated water molecules move to the end of the outlet from the pipe into the water tank. The heated

water molecules were continuously delivered back to the tank from the top. The water flowed from the tank into the inlet of the copper pipe again, ensuring a continuous heating process. This continuous flow process ensured the rise of temperature in the water.

V. RESULTS AND ANALYSIS

5.1 Presentation of Results

The tests' results were recorded and entered in a table. We used two different single-probe thermometers to take the temperature reading. One was used for the water temperature, and one to measure the inlet and outlet pipe body temperature. We took the temperature reading at an interval of 15 minutes for a total of 225 minutes.

Time(mins)	Inlet Pipe Temperature(˚C)	Outlet Pipe Temperature(˚C)	Water Temperature(˚C)
0	31	32	36
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	46.5
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

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

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 because the generator exhaust always drops the temperature at intervals through cooling systems like the air cooling system. This prevents the Generator from continuing to rise in temperature exponentially during its operating hours. Also, the drop can be associated with some heat loss to the environment in the process of circulating and transferring water from the reservoir to the insulated water tank.

The temperature began to rise again between 165 minutes to 225 minutes. This is because the generator builds up heat again from the continued burning of fuel.

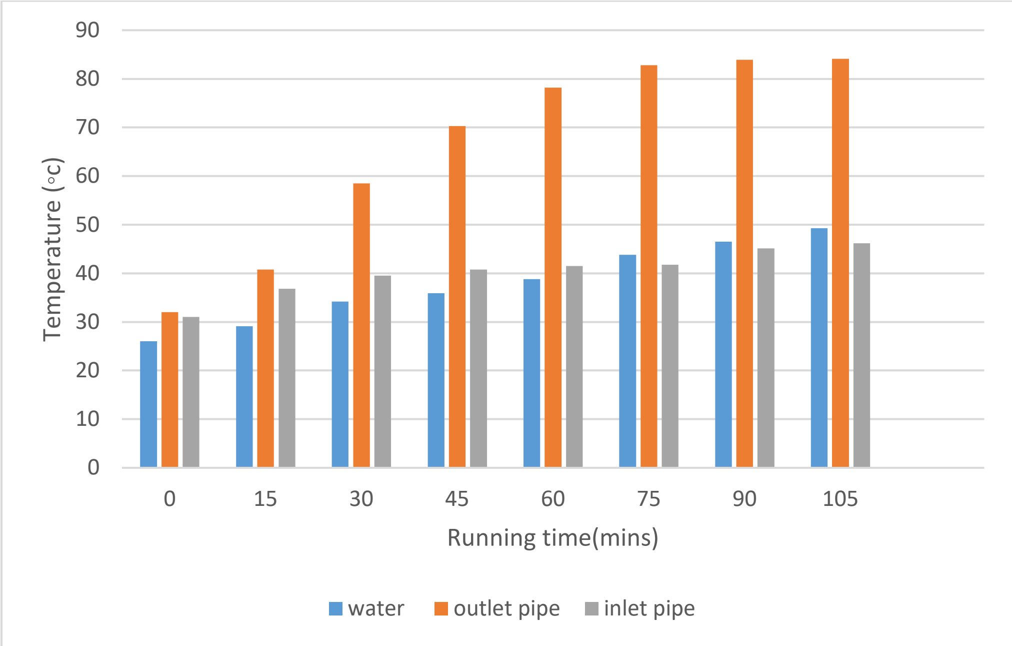

Figure 1: Shows the relationship between the temperature of the water, the body of the inlet pipe, the body of the outlet pipe, and the running time of the generator (between 0 minutes and 105 minutes)

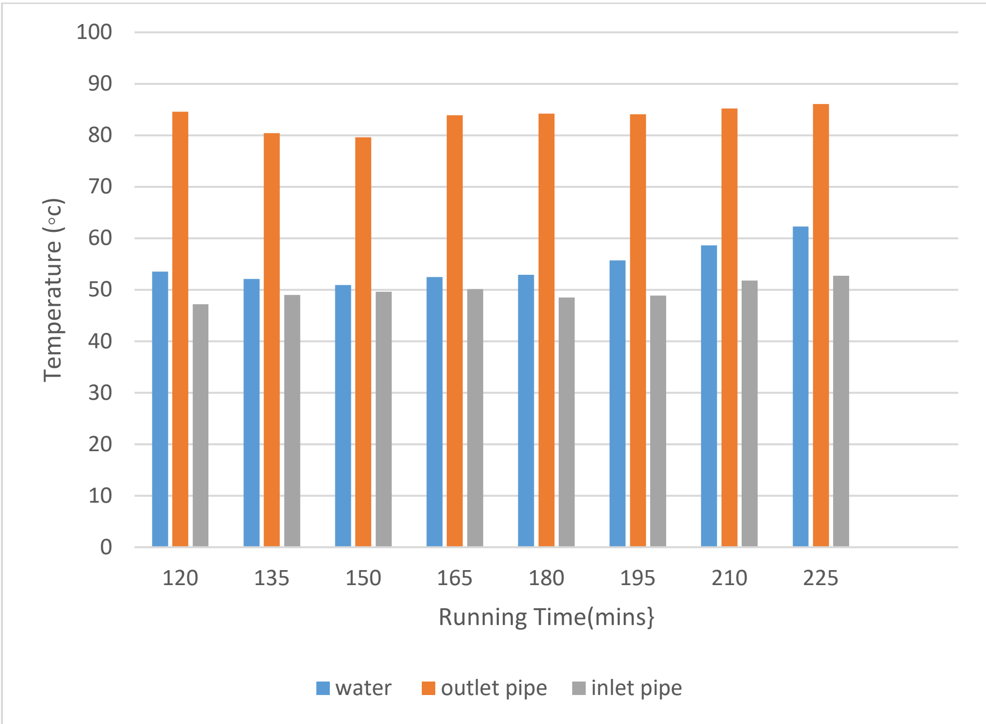

Fig 2: Shows the relationship between the temperature of the water, the body of the inlet pipe, the body of the outlet pipe, and the running time of the generator (between 120 minutes and 225 minutes)

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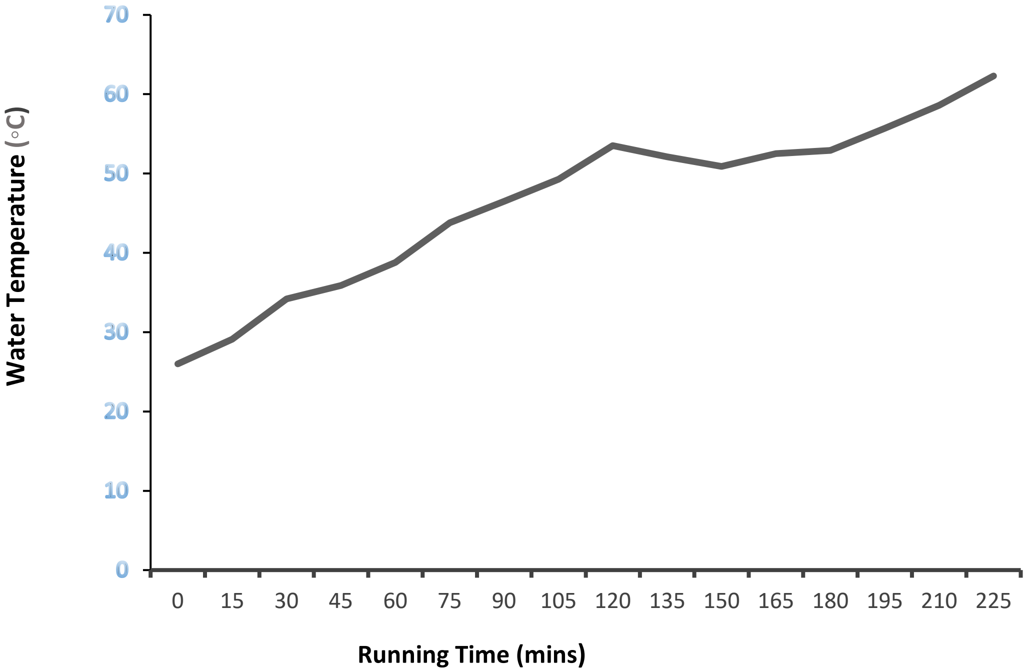

Figure 3: Shows the relationship between water temperature and the running time of the electric generator

5.2 Experimental Data Analysis
From Figure 1 above, it can be deduced that there is a steady rise in the temperature of the water, the inlet pipe, and the outlet pipe for the first 115 minutes of the running time of the generator
Figure 2 above, the chart shows between 120 minutes and 225 minutes of the experiment. It can be deduced that there is a fluctuation in the temperature level of the water, the inlet pipe, and the outlet pipe. There was a drop in the water temperature and the outlet pipe temperature for the first 30 minutes on the chart (between 120 and 150 minutes). This is due to heat loss through air cooling. The temperature of the water dropped from 53.5 ◦c to 50.9 ◦c while the temperature of the outlet pipe temperature dropped from 84.6 ◦c to 79.6 ◦c. The temperature of the water rose from 50.9 ◦c to 62.3 ◦c for the last 1 hour 15 minutes (between 180 minutes to 225 minutes). 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 counteracting cooling effect of 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 an 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.
The temperature at the inlet pipe continued to increase for 105 minutes but dropped at 180 minutes before rising steadily again till 225 minutes. This is because of the rise in the water flowing through it, the building heat conducted and radiated from the generator. The drop of 50.1 ◦c to 48.5 ◦c at 180 minutes is due to the loss in heat in the water and the surrounding air.
From Figure 3 above, it can be deduced that the temperature of water increases linearly with the 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 and then rising again with an increase in the running time of the electric generator.

5.3 Performance Evaluation
1. Calculations for Increased Rate of Waste Heat Recovery Achieved
Q = Heat Absorbed by Water
Given data;
The volume of water, V = 9048960mm^3
Mass, m = V/ 1000
m = 9.48 kg
Specific heat of water, Cp = 4200 K J/g ˚C
Initial temperature of water = 26 ˚C
Final temperature of water = 62.3°C
Change in temperature ΔT = Final temperature – Initial temperature
$\Delta T = 62.3^{\circ}c - 26^{\circ}c$
$\Delta T = 36.3^{\circ}c$
Time required for reading Δt = 225 min
Heat absorbed by water $Q = m \times c \times \Delta T$ (2)

$Q = 9.48 \times 4200 \times 36.3$
$Q = 1445\ KJ$
Heat rate, $H = Q \div \Delta t$ (3)

$$H = \frac{1445320.8}{225 \times 60}$$

H =107J/s = 107W

5.4 Performance Analysis

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

Researchers presented a parametric study that allows us to measure the heat recovered from an electric generator[12]. The test results showed that we recovered 4.3 kW of heat using a 15KVA electric generator with a mass flow rate of 0.05kg/s. Compared to this study, a smaller electric generator of 3.5KVA was used and a lesser mass flow rate of 0.03kg/s. This comparison suggests that the heat recovery setup for this study has a fairly good performance based on the flow rate and the size of the generator.

VI. CONCLUSION

We can draw the following conclusions can from the results obtained;

1. Effective recovery of waste heat can save energy and reduce the need to burn excess fossil fuels in homes for domestic work.
2. Since it has been shown from this study that the water temperature increases with the increasing running time of the household generator, we deduce that waste heat recovery from household and industrial devices is achievable.
3. The temperature of the water increased and then dropped at some point before rising again. This fluctuation shows that the waste heat recovered will not always increase with the running time of a device because of unpreventable heat loss to the environment and through the cooling process of the system.
4. The temperature at the outlet was constantly higher than the temperature of the water. This shows that only some waste heat from a device can be recovered except for an ideal system that does not occur in reality.
5. We can use the heated water at 62.3˚c for a warm bath, domestic cleaning, washing, coffee, and tea.
6. It shows that if harnessed, the heat lost from domestic appliances are potential energy source in homes.

VII. REFERENCE

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