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Desalination via Waste Heat Recovery from Diesel Engine

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Abstract: *The aim of this work is to utilize the heat energy wasted in exhaust gas and jacket water of an internal combustion engine for desalination using a modified single slope solar sill. The heat recovered from the diesel engine was simulated by using a heater and a thermostat adjusted at 90 ^{o}C. In this work a horizontal pipe and a vapor trap is used with a single slope solar still to increase the condensation of the water vapor in the still. Four main cases at three different temperatures were applied to determine the best modification for the still. In all cases the still was filled with 7 cm of raw water. The minimum productivity reached was 4 L/day. While the maximum productivity was 5.9 L/day. Both economic and enviro-economic analysis was performed for the solar still. The cost of the desalinated water is estimated to be 1.1 L.E/Liter and the carbon credit earned is nearly 1800 L.E.*

Keywords: *Desalination, waste heat recovery, Solar still, Economic analysis, Co_2 credit*

I. INTRODUCTION

The modern world rely on Diesel Engines in several applications such as transportation, construction, water pumping, power generation and agricultural sectors [1]. Generally, during engine run time, there are three typical sources of waste heat with significant potential; the released exhaust gases, the cooling system, and the driving auxiliaries [2-6]. The increase of population and human agricultural and industrial activities make the availability of fresh water in arid and semiarid regions a problem of great importance all over the world [2]. Moreover, it energy plays a vital role in the provision of portable water for both household and industrial use. Desalination using Waste heat recovery from exhaust gas and jacket water could be an effective approach that can be used to establish a solution for the above two issues.

K.S. Maheswari and others in their study used a submerged horizontal tube straight pass evaporator and a condensing unit to utilize the waste heat energy from exhaust gases of low capacity for desalination. They were able to collect a maximum of 1.8 l/hr using the air cooled condenser [3]. Hitesh Panchal in his work used a low capacity desalination system integrated with evaporator and condenser unit to employ the waste heat from exhaust gases for potable water production. They were able to produce potable water from this setup up to 4.2 Liter and increasing depending on load application [4]. Fengming Zhang and others have introduced a medium-size low-temperature multi-effect desalination (LT-MED) system. Powered by the cooling water of a 1000 kW diesel power generator set, the system was able to produce 60 tons of fresh water per day[5]. K.S. Maheswari and others in their paper have designed and fabricated a horizontal tube straight pass evaporator (SHTE) and water cooled condenser for condensing the evaporated steam. A 5 hp diesel engine was employed in the analysis under various load conditions. 3.0 l/h of saline water was desalinated from the engine exhaust gas, without affecting the performance of the engine[6]. T.C. Hung and others utilized the waste heat streams from diesel engine both jacket water and exhaust gases as heat sources in seawater desalination. Exhaust gases had the higher temperature and was introduced to further heat this preheated seawater to a saturated state. Thereafter, throttling and heat exchange processes were alternately employed for generation of fresh water. The study successfully demonstrated the feasibility of waste heat recovery from combustion engines in the desalination of seawater [7]. In the present study heat rejected from both jacket water and exhaust gas of a diesel engine were utilized for desalination. An electric heater is used to simulate the heat recovered from the diesel engine. A modified single slope solar still was designed and fabricated for the purpose of desalination.

II. EXPERIMENTAL SETUP

The experimental setup consists of a modified single slope solar still connected to two tanks. The first tank contains raw water which in case of opening the control valves allows the raw water from tank (1) to flow through both the vapor trap and the horizontal pipe in the solar still to tank (2). Tank (2) contains the heater which is used to simulate the heat recovered by raw water from exhaust gas and jacket water of diesel engine. The system was constructed from a large variety of local materials to reduce the overall cost and ease of construction. A schematic diagram of the system is shown in fig. (2.1). The actually fabricated system is shown in fig. (2.2).

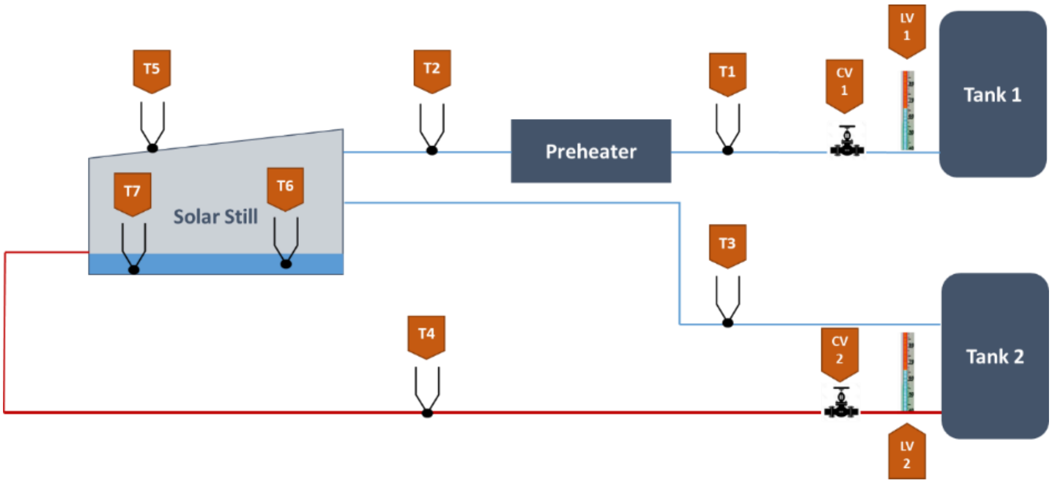

Figure 1. Schematic Diagram of the Designed System

Figure 2.The Front and Back Sides for the Actual Fabricated System

The basin area of the still is 0.54 m2, fabricated using galvanized steel sheet of 2 mm thickness. The bottom and sides of the basin are insulated by 1 cm thick rock steel sheet. The surface of the basin is coated with a black cloth to absorb maximum solar radiations. The cover of the still is made up of 6 mm thick glass, making an angle of 32 with horizontal, optimized for 32.2 N latitude of Alexandria [8]. The fresh water is collected in a galvanized iron channel fixed at the lower end of the glass cover and is taken out through an outlet nozzle. A stainless steel pipe with 2 mm slope, with a basin below, is installed between the two sides of the solar still. The still is made vapor-tight using silicone rubber as sealant.

Four cases were investigated in the present work. In the first case, the heater is turned off, the solar still is filled with 7 cm height of raw water, the two control valves are closed so there is no water flow through both the vapor trap and the pipe in the solar still, and the fan attached to the vapor trap is turned off. In the second case, the heater is turned on to increase the temperature of the raw water to 90C. In the third case, the two control valves are opened so the water flow through both the vapor trap and the pipe in the solar still, and the fan attached to the vapor trap is turned on. Finally, in case four, the two control valves are opened so the water flow through both the vapor trap and the pipe in the solar still, and the fan attached to the vapor trap is turned off. All cases were repeated at three different ambient temperatures; 31 ^oC, 36 ^oC, and 40 ^oC.

III. RESULTS AND DISCUSSION

3.1 Temperatures

The temporal distribution of the temperatures measured by the different thermocouples installed at the seven locations; T1, T2, T3, T4, T5, T6, and T7 were investigated throughout the day cycle (24 hours) for all cases. The ambient temperature was also monitored in addition to the previous locations. For all cases investigated, the ambient temperature starts to increase gradually from nearly 9:00 am till reaching its maximum value at 3:00 pm. Then it starts to decrease till reaching its minimum value at 4:00 am (curves are not shown for brevity). In both cases 1, and 2, the curves representing the temperatures measured at the first four thermocouples (T1, T2, T3, T4) are almost typical to the ambient temperature curve. This is apparently because there is no flow in the pipes as they are already full of air. While, in both cases 3, and 4, the curves representing the temperatures measured at these thermocouples are almost typical to the ambient temperature curve with one hour lag. This is apparently because there is water flow in the pipes. As the specific heat of water is higher than that of air, the water loses its temperature slower than the air. For the temperatures of water, the solar still basin, and the glass cover, represented by the thermocouples T5, T6, and T7 respectively. In case 1, their curves increased till reaching the maximum values at the time between 2:00 - 3:00 pm. Then they are decreased gradually till reaching values nearly close to the ambient temperature from midnight till 8:00 am next day. The maximum temperature values of both water and glass, represented by T5 and T7 respectively, are higher than the maximum temperature values measured by the thermocouples T1, T2, T3, and T4. Due to the solar still orientation, both thermocouples (T5, and T7) are exposed to sun radiation more than the other four thermocouples. Finally, the maximum temperature value of the solar still basin is noticed to be higher than both water and glass cover temperature values, as the specific heat of galvanized steel is higher than that of water and glass. In cases 2, 3 , and 4, the temperatures represented by the thermocouples T5, T6, and T7 respectively, are decreased gradually till reaching values nearly close to the ambient temperature from midnight till 8:00 am next day.

3.2 Solar irradiance

The solar irradiance starts to increase at 9:00 am until it reaches its maximum value at 1:00 pm. Then it starts to decrease till 7 pm where no more solar energy is available. It is found that the maximum solar irradiance leads the maximum ambient temperature by two hours.

3.3 Productivity

The following figure shows the productivity for the whole 12 cases studied. It is apparent that the productivity increases with the increase in the ambient temperature for each case. In addition, the productivity increases as the raw water temperature increases. Therefore, the maximum productivity is noticed to be at case (4-C) which represents the use of preheated raw water along with highest ambient temperature.

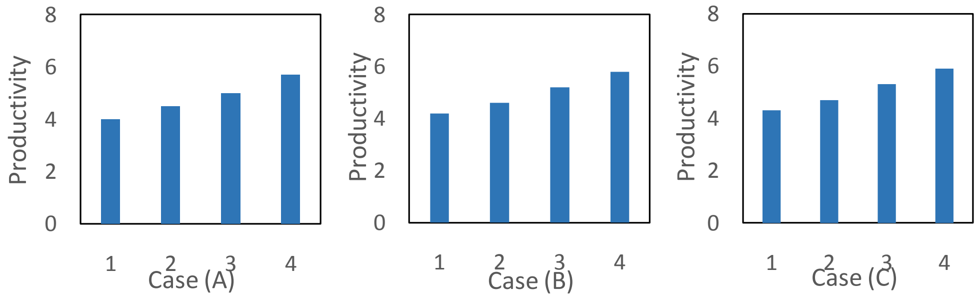

Figure 3. Productivity for the Present 12 Cases

IV. COST ANALYSIS

The initial capital investment for solar stills manufacturing varies with design, size and materials of construction. The better economic return on the investment depends on the production cost of the distilled water and its applicability. Factors affecting the cost of the distilled water from solar stills were taken from [14].The cost of the desalinated water per liter is calculated using the equations in [14-16]. It is estimated to be 1.1 L.E/Liter which is considered reasonable compared with the values encountered in the literature.

V. CARBON DIOXIDE MITIGATION AND CREDIT ANALYSIS

This analysis is used to evaluate the CO_2 mitigated by the solar still on the environment during the operational period and energy payback time of the solar still. The average CO_2 equivalent intensity for electricity generation from coal based power plants in Egypt is approximately 0.98 kg of CO_2 per kWh at the source [17]. The transmission and distribution losses are taken as 40% and domestic appliance losses are approximately 20%. By considering this, the figure 0.98 is taken as 1.58 [17-19]. Table (1) Shows the embodied energy of different components in solar still calculated using the equations from [17-19].

Table2. Embodied Energy of Different Components in Solar Still

Component	Materials	Total weight (kg)	Embodied energy (MJ/kg) [17-19]	Total embodied energy (MJ)	Total embodied energy (KW.hr)
Transparent cover	Glass	3.8	15	57	15.83
Basin	Galvanized steel	20	20.1	402	111.67
insulation	Rockwool	0.2	16.8	3.36	0.93
Tanks and drain pipes	PVC	9	77.2	694.8	193
Horizontal pipe	Stainless steel	0.4	56.7	22.68	6.3
Total embodied energy				1554.84	431.9

CO_2 emitted annually during the manufacturing of the previous components is calculated to be 245.66 kg/year. The CO_2 mitigated over the lifetime of the solar still as a result of using solar energy is estimated to be 14.79 tons. The share of CO_2 equivalent to this saved amount of CO_2 can be sold with a profit of nearly 1800 L.E for the lifetime of the solar still.

VI. CONCLUSION

The aim of this work is to utilize the heat energy wasted in the exhaust gas and the jacket water of IC engine to get potable water from the saline water. The experimental setup consists of a modified single slope solar still connected to a heater to simulate the heat extracted from the exhaust and the jacket water. It was designed, fabricated and tested to desalinate the raw water. Four main cases at three different ambient temperatures for each case was operated to determine the best modification for the solar still. It was concluded that

- The maximum and minimum productivity of the desalinated water was 5.9 L/day and4 L/dayrespectively.
- The maximum productivity is noticed to be at case (4-C) which represents the use of preheated raw water along with highest ambient temperature.
- The cost of the desalinated water per liter is estimated to be 1.1 L.E/Liter.
- The CO_2 mitigated over the lifetime of the solar still as a result of using solar energy is estimated to be 14.79 tons.
- The share of CO_2 equivalent to this saved amount of CO_2 can be sold with a profit of nearly 1800 L.E for the lifetime of the solar still.

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