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Experimental results of a seawater distiller utilizing waste heat of a portable electric generator

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ABSTRACT

We have designed an evaporation-type seawater distiller using waste heat of exhaust gas from a portable electric generator. Waste gas from the small generator commonly used in islands has not been utilized because of its low energy density, which may be used as heating source of a small-capacity distiller as well as an additional heat source for solar stills. The proposed distiller of a multiple-effect diffusion still type consists of a series of closely-spaced parallel partitions in contact with saline-soaked wicks. In the distiller, evaporation and condensation processes are repeated as much as its effect number to recycle the thermal energy, resulting in increasing the system thermal efficiency. Experimental results show that the proposed distiller can produce at least 6.7 kg/d of distilled water only with a one-effect still and is expected to produce 43 kg/d with a ten-effect still. This amount of distillate is 4 times larger than the maximum daily productivity of solar stills obtained by outdoor experiments.

Keywords: Electric generator; Waste heat; Evaporation chamber; Desalination; Multi-effect

1. Introduction

Seawater desalination technology can be classified mainly as two categories; phase change (evaporation, freezing) and membrane separation methods. Evaporation is represented by multi-stage flash distillation (MSF), multi-effect distillation (MED), and vapor compression (VC). Of membrane separation methods, there are reverse osmosis (RO), electrodialysis (ED), and forward osmosis (FO) highlighted recently. However, these kinds of desalination technologies have been developed almost only for large-scale plants, so there are difficulties to apply them as small capacity of stand-alone desalination units. Moreover, these conventional desalinating methods depend on the high quality energy as their energy sources, such as oil and electricity, inevitably causing environmental pollution and natural resource depletion.

Even at present time, there is a number of arid areas which do not have enough potable water and electric grid at the same time, such as remote areas, islands, and developing countries. The pollution and decrease of water sources like rivers, lakes, and wells become more severe due to industrial and agricultural waste, resulting in health problems like diseases caused by using this non-treated water as drinking water in the developing countries. Unfortunately, these kinds of regions do not have social (water and electricity) infrastructure so that large-scale desalination plants are not available due to initial high construction cost, operation and maintenance cost and/or skills. Therefore, stand-alone small scale desalination units are necessary for supplying fresh water to these remote areas.

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Technology for small-scale desalination may consider vapor compression, reverse osmosis, and solar distillation [1]. Vapor compression and reverse osmosis may not be suitable for islands in the long run because of shortage of energy sources and maintenance for membranes. Solar distillation is evaporating saline water directly or indirectly by exchanging heat obtained from a solar thermal collector, and then condensing the evaporated water vapor. A solar still has a simple structure and has been widely studied (reviewed by Tiwari et al. [2]). However, solar distillation has disadvantages of climate-affected features by intermittence of energy sources and does not have enough amount of distillate productivity per unit area installed due to low energy density. Moreover, a solar thermal desalination system may not serve as a stand-alone device because extra electricity such as pump power to feed seawater and to supply fresh water is necessary.

In this research, we try to design and develop a stand-alone small-scale desalination unit by using waste heat from a small diesel electric generator which is used in various places such as islands and remote areas. In general, the waste gas from the portable electric generators is just exhausted to the surroundings because thermal energy of the exhausted gas from the engine is too low to be effectively utilized. However, we have been convinced from our previous research on heat balance calculation [3] that this diesel generator can serve not only to provide electricity necessary for both habitants and desalination unit, but also thermal energy for evaporating seawater or brackish water to make fresh water. Further, the hourly distillate productivity of a distiller utilizing energy from waste gas may be greater than that of the same distiller under solar insolation, since the energy density of the waste gas may be greater than that of solar insolation. Therefore, in this paper, we have tried to investigate applicability of our designed distiller heated by waste gas of a portable diesel generator to a small-scale desalination unit by presenting experimental results.

2. Experiment with a single-effect distiller

The desalination system suggested in this study is mainly focused on the use in islands and remote areas where there is lack of an electric and water supply grid. Therefore, the distiller system should be of stand-alone type; electricity for operating feeding pumps and control system in the desalination system should be supplied by an electric generator or self-generating electric unit using renewable energy. We have designed a multi-effect distillation (MED) distiller with a small electric diesel generator. Vacuum devices widely used in MED distillers are not adopted for structural simplification of the system, considering maintenance characteristics in island areas.

Fig. 1 shows a schematic diagram of the experimental apparatus depicted as four-effect distillation for convenience sake. It consists mainly of an evaporation chamber, a feeding distributor and a distillation part. The distillation part consists of closely-spaced vertical parallel plates as many as the number of effect, wicks, and water pockets at its bottom. Each plate of the distillation part is a thin stainless plate with a wick attached on its back side, which is cotton flannel absorbing by capillary force and feeding by gravity the seawater. Exhaust gas from the diesel engine flows into the copper tubes in the evaporation chamber in which water is heated to evaporate. The evaporated vapor is condensed on the front side of the first plate. This condensation latent heat is conducted through the plate and transfers heat to seawater flowing along the wick. The vapor evaporated from the first wick is diffused across a thin air layer between the plates and condensed on the front side of the second plate. This condensate flows down to be gathered in a water pocket installed at the bottom of each plate. These processes of evaporation, vapor diffusion, condensation, and conduction are repeated by an optimum number of the effects, which is an important design parameter of this distiller. The distance between plates determining vapor-diffusing length through the air layer is set as 5 mm that is considered to be the optimum spacing length in this system, though Tanaka et al. [4] have suggested a theoretical minimum distance of 3 mm.

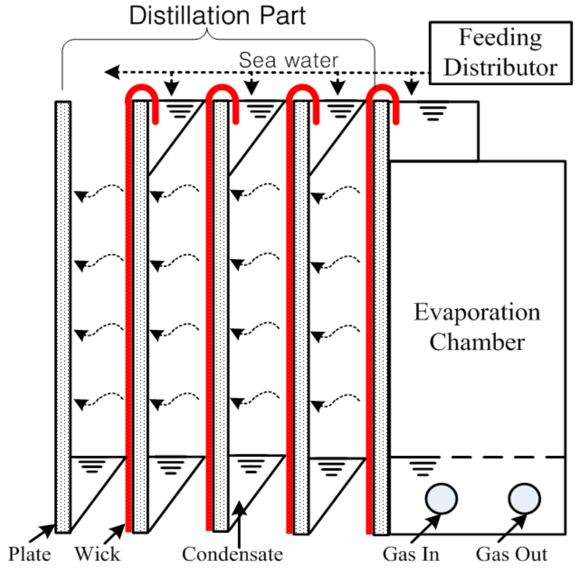

Fig. 1 Schematics of a multiple-effect distillation system.

Temperature and flow rates of the exhaust gas from the diesel engine significantly affect the system performance, which depends on the capacity of the engine employed and its operation conditions. Table 1 shows the specifications of the diesel electric generator selected in this experiment, which is a general model used in domestic islands.

The evaporation chamber is an isolated container with 19.42 kg of tap water. The water at the bottom of the

Table 1
Specifications of the diesel electric generator

Model		Honda SG6500DX
Generator	Rated AC power	5.6 kVA
	Rated DC power	6.5 kVA
Engine	Model	GX340
	Type	Forced air-cooled, 4-stroke, single cylinder
	Displacement	337 cc
	Net horse power output	11.0 PS (8.2 kW)/3600 rpm
	Starting system	Recoil
	Fuel tank capacity	28 ℓ
	Continuous operation times	9.0 h
Dimensions	Length × width × height	690 × 580 × 525 mm
	Exhaust pipe inner diameter	23 mm
	Dry mass	78 kg

chamber is heated by the exhaust gas and is evaporated to condense on the first plate. Exhaust gas from the engine diverges into two tubes and flows into the chamber in order to perform the experiment with variation of the heat exchange area and gas flow rate. The heat exchange tubes have diameter of 23 mm and 2 m length for each inside the evaporation chamber. Nine T-type thermocouples are attached on the inner wall of the evaporator chamber and two flow meters measure the flow rate of the gas.

3. Experimental results

The experiment was performed for 3 h from the operation start of the diesel generator. Fig. 2 shows the measured temperatures of the exhaust gas at the gas inlet and outlet of the evaporation chamber. The inlet temperatures of the gas increased to 356°C and 378°C, and reached steady-state after approximately 15 min. The outlet gas was exhausted at 66°C and 73°C after heat exchange with the water inside the chamber. The temperature difference between the diverge tubes is attributed to the different flow rates and flow path lengths in each tubes as shown in Fig. 3. Thus, total heat energy obtained by water inside the chamber from the exhaust gas was calculated at 2,973 kJ/h (0.83 kW).

Fig. 4 shows the temperature variation of the inner wall and space inside the evaporation chamber with operation time of the generator. All temperatures increase with the time to be 85.0°C of the water temperature at the bottom of the chamber. It is noted that the temperature difference between the inner space (steam) and the wall is negligible (0.6°C) at the top and middle areas of the chamber, but the temperatures of the wall and the inner space (water) at the bottom area are 80.3°C and 85.0°C, respectively, due to temperature gradient by heat conduction at the wall. It is important that even the first plate

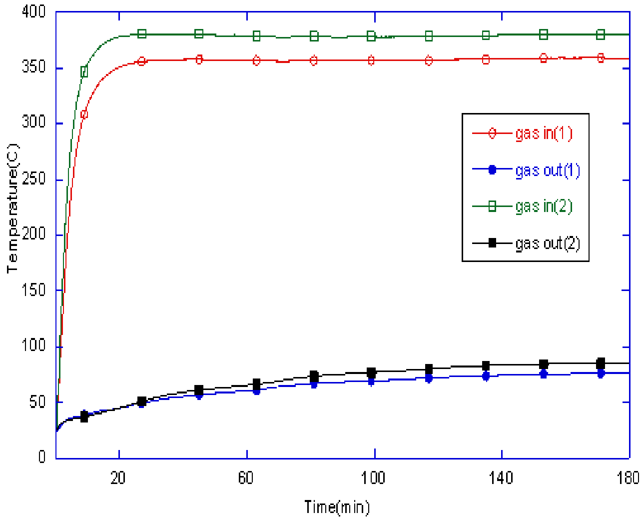

Fig. 2. Inlet and outlet temperatures of exhaust gas.

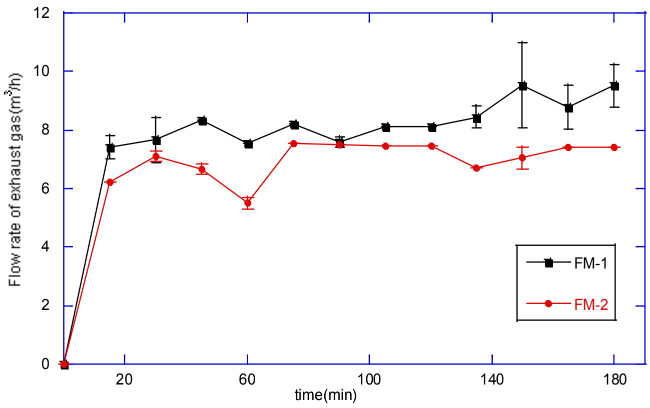

Fig. 3. Measured flow rate of exhaust gas through diverged tubes.

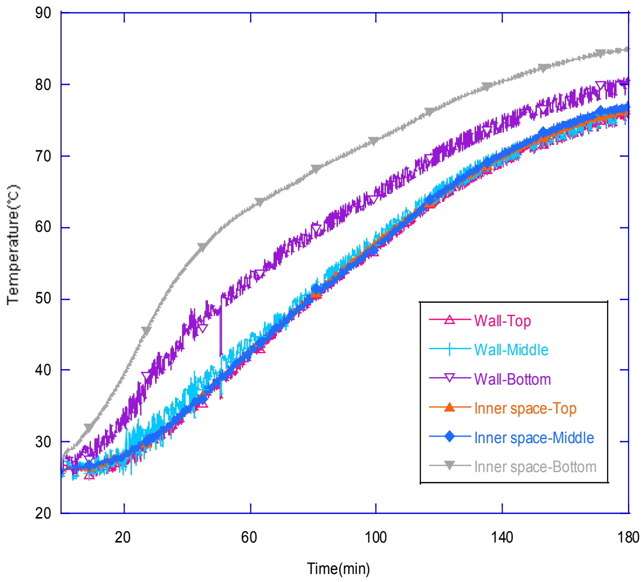

Fig. 4. Temperatures of the wall and inner space inside the evaporation chamber.

Fig. 5. Distillated water on the condensing glass plate.

having the highest evaporating temperature can keep the temperature below 80°C to be able to suppress the scale generation by seawater in the MED system.

In order to observe the condensation phenomena, the glass plate substitutes the first condensation plate in the case of a single-effect experiment. The condensed droplets start to produce on the bottom of the glass plate after about 25 min and on the whole area of the glass plate in 60 min as shown in Fig. 5. The total feeding volume of seawater during 180 min is 2.12 kg (flow rate 11.76 cm^3/min) and produced condensate is 0.84 kg (flow rate 4.67 cm^3/min). Therefore it was found that thermal efficiency of this single-effect distiller is 24.1% and energy recovery rate is 39.6%.

4. Conclusions

A seawater distiller of a multiple-effect diffusion type was designed, utilizing the waste heat of exhaust gas from a portable electric generator which is commonly used in islands, remote areas, and developing countries. The performance test with the single-effect distiller shows that condensate evaporated from seawater flowing down through the wick is produced at the bottom area of the condensation plate in 25 min and at the whole area in 60 min after the generator starts to operate. The produced distillate amounts to 0.84 kg in comparison with feeding seawater of 2.12 kg during diesel engine operation of 3 h. This is equivalent to productivity of 6.72 kg/d with the single-effect distiller, and is expected to produce 35–44 kg/d with the ten-effect distiller, considering results of the previous researches [4,5] which was demonstrated by solar distiller with the distillation part of similar structure. This expected amount of produced fresh water corresponds to at least 4 times larger than the experimental results obtained by a solar thermal distiller.

Therefore the distiller system suggested in this study, which utilizes heat source as waste gas from a portable diesel engine, may be useful for a small-capacity distributed seawater distiller and for various areas where a large desalination plant cannot be constructed and operated. In addition, this system may be constructed as a hybrid distiller with other renewable energy sources such as solar energy and wind power.

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