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Waste to water: a low energy water distillation method

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Abstract

This paper describes a new water distillation method and apparatus. It is a low-cost system operating at low temperature and sub-atmospheric pressure that can produce water at different scales, for large cities or remote rural communities, thus suitable for the First World or the Third. The system may be configured to use waste heat from power plants, allowing co-generation of fresh water and with electricity. Though using waste heat allows for water production efficiency which is better than the current leading technologies, the process can also be made to run with other sources of low quality heat and alternative energy sources.

Keywords: Distillation; Low pressure; Vacuum; Waste heat; Effluent

1. Introduction

Energy requirements of traditional water distillation systems make this technology less than desirable for the generation of drinking water. If a similar process is done under low pressure, the to-be-distilled water will boil at lower temperatures allowing the use of waste heat or naturally available energy sources. The distillation process as described in this paper reduces the need for costly “prime” energy.

2. Theory

Throughout this paper it will be assumed that the heat of vaporization of water is 2276 J (544 cal) and that is takes 4.2 J (1 cal) to heat 1 g of water 1°C. These values do change slightly with temperature of the water, but this minor effect does not change the outcome of the following analysis by much.

This paper describes a new water distillation process that uses sub-atmospheric pressure, and hence low temperature to boil water. This new system uses the concept of the Torricelli column, also known as a barometric leg. Atmospheric pressure can support a column of water 10 m high. Any open space located above the level of the water column will be at very low pressure.

Fig. 1 illustrates a new distillation process that applies Torricelli’s observation. This process consists of two connected identical Torricelli columns, i.e. columns of water roughly 10 m in

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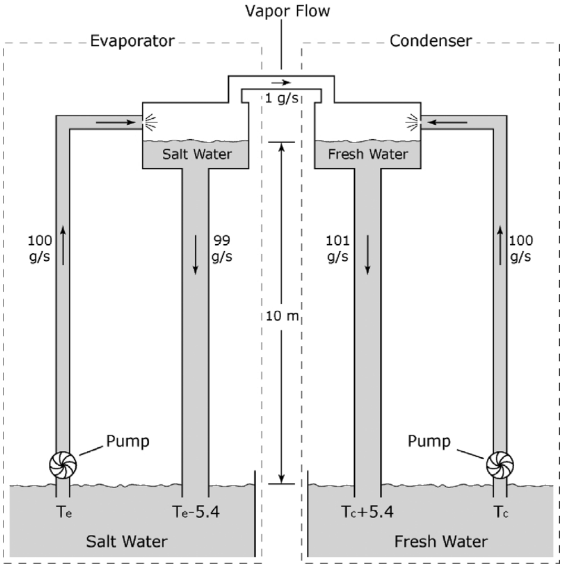

Fig. 1. This model of the system illustrates two connected columns and an example of a 100 to 1 pumping ratio.

height inside sealed tubes with near vacuum at their top; these are the system's evaporator (on the left) and condenser (on the right). The only difference between the two columns is that the to-be-distilled water, e.g., salt water, in the evaporator is hotter than the fresh water in the condenser. Since the top of each column is at low pressure, the evaporator water vaporizes first. Vapor flows through a pipe on top to the condenser where it contacts cold water and changes phase to liquid. However, the vapor transfers heat from evaporator to condenser, so eventually the two chambers will reach thermal equilibrium and distillation will cease.

We solve the problem of temperature maintenance by pumping large amounts of hot salt water into the evaporator and cold fresh water into the condenser. It requires 544 cal to vaporize a single gram of water and each calorie can change the temperature of 1 g of water by 1°C; therefore, if the system were to pump in 100 g for each gram vaporized, the output water temperature from the evaporator would be (544/100≅) 5.4 degrees cooler than the input to the evaporator. The reverse is also true for the condenser, where for 100:1 ratio water exits the system 5.4 degrees hotter. Fig. 1 illustrates the system producing 1 g of water per second, but the unit could be anything — 1 g, 1 L, 1000 gallons, provided that 100 times the desired water production rate is pumped into the chambers. This is based upon the relationship in Eq. 1, where K_{PR} is the pumping ratio. In the shown example, K_{PR} is 100. Note that the 100:1 is used here for illustration purposes only.

$$\frac{544}{K_{PR}} \cong \Delta C \tag{1}$$

3. Experimentation and results

A proof of concept was constructed and tested by the co-authors (Fig. 2). It is a "low-tech" machine constructed mostly from common plumbing components such as PVC pipes and installed in a university building between the fourth and second floors to obtain the 10 m height necessary for the barometric columns. Since large bodies of water were not available for testing, 150 L drums were used to simulate the bodies of water. The to-be-distilled water drum was warmed using

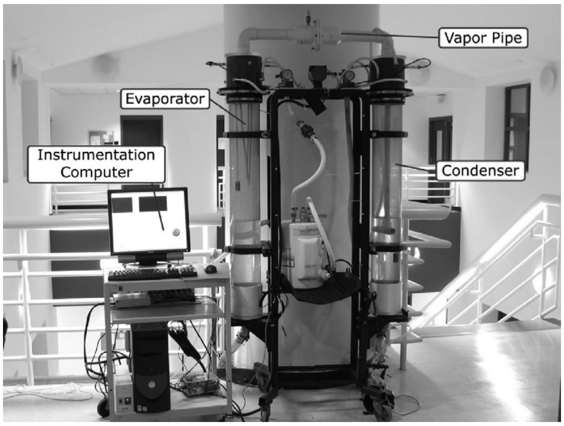

Fig. 2. Fourth floor portion of the proof of concept. Hoses extend down 10 m to reservoirs on the 2nd floor.

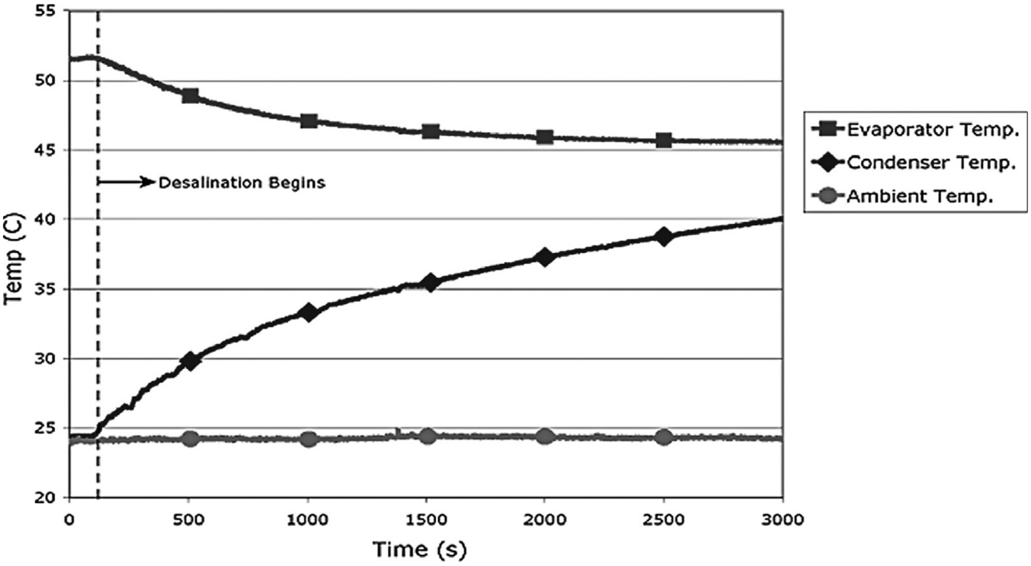

Fig. 3. Temperature sensory data taken during experiments showing convergence of the temperatures in each column.

electric water heaters and the “fresh” water drum was left at room temperature.

Running the experiment revealed that the water in the evaporator column cooled and the water in the condenser warmed. It was also observed that the water level in the drums changed this was a clear evidence that distillation was taken place. Note the fast convergence of the evaporator and condenser temperatures in Fig. 3.

This means that the distillation occurred so fast that temperature difference could not be maintained throughout the process.

Using this data as well as the heat of vaporization, it was determined that this run generated approximately 4.4 L of water before the system reached an equilibrium state. About half of the distilled water was produced during the first two minutes of the experiment when the difference in temperature between the evaporator and the condenser was relatively high. The amount of water produced was calculated using Eq. (2) which relates temperature change to volume change.

$$\Delta V \approx \frac{\Delta T_C V_0}{540°\text{C}} \tag{2}$$

Based on this experimental data a projection for the daily production rate could be established (Fig. 4) dependent upon the temperature difference between the two sources of water

4. Competitive efficiency

As shown in Fig. 1, the low pressure within the system draws the water level to nearly 10 m in

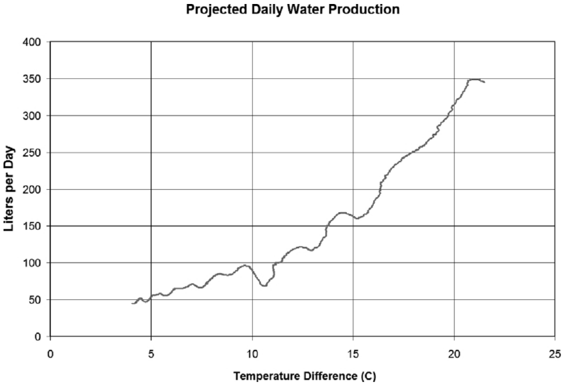

Fig. 4. Based on temperature difference in source waters, proof of concept shows an exponential relationship between distilled product and temperature difference.

the water supply pipe as well as in the barometric column, thus reducing the amount of pressure the pump must overcome in order to circulate the water. A calculation involving pumping efficiency and pressure differences can determine an energy cost per volume of distilled product as shown with Eq. (3).

$$E = \frac{2k}{\eta}(\rho g h)\frac{1\ \mathrm{kW\ h}}{3.6 \times 10^6\ \mathrm{J}} \tag{3}$$

E: energy consumed per unit volume (kW h/m^3)
k: pumping ratio
η: pump efficiency
ρ: density of water (1026 kg/m^3)
g: acceleration due to gravity (9.8 m/s^2)
h: head loss (m)

For these calculations, it was assumed that 3 m of additional pumping must be overcome. This accounts for frictional and nozzle losses. It is also assumed that water is pumped with a 0.85 efficiency and that ocean water has a density of roughly 1026 kg/m^3. In addition it is assumed that water must be pumped at 100 times the quantity of water which is produced.

Using these values, the energy cost is 0.99 kW h/m^3 per water pump placing this technology's 1.98 kW h/m^3 of product almost 40% more efficient than reverse osmosis' 3.5 kW h/m^3 of product [1]. With a smaller pumping ratio, the potential to make product for less than 1 kW h/m^3 is real, placing this technology as a new economical way to generate drinking water.

Acknowledgement

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Reference

[1] M. Taub, "The world's largest SWRO desalination plant", Proc. of Innovations and Applications of Sea-Water and Marginal Water Desalination, in: 8th Annual Conf., in: R. Semiat and D. Hasson (Eds.), Israel Desalination Society, Haifa, 2006.