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Experimental Analysis of Flash Evaporation Desalination with Solar Energy

Uyung Dinata, Jaya Kurniawan, Adly Havendry

Andalas University, Mechanical Engineering Department, Energy Conversion Laboratory, Padang, Indonesia
e-mail: uyung@gmx.de

Abstract
A seawater desalination system with flash evaporation using solar energy was tested in producing fresh water from seawater. The system can effectively evaporate seawater with throttling and flashing processes in a flash tank. In the system, the cooling fluid from the seawater itself condenses water vapor, therefore, no additional cooling system is required. Parameters influencing on the fresh water capacity are heater outlet temperature and feed seawater capacity. The higher heater outlet temperature can increase the mass transfer rate of water vapor in the tank. Also, the higher the feed seawater capacity, the higher the vapor product rate. But in a critical condition, if the feed seawater capacity in the collector heater is increased, the flash tank temperature decreases, therefore, the fresh water capacity could also decrease. For that, the optimal feed seawater capacity should be determined in order to operate the desalination system at a maximal fresh water capacity. This was obtained via experiments conducted on a typical flash evaporation desalination system with a solar collector water heater.

Keywords
Desalination, flash evaporation, flash tank, solar collector, seawater, fresh water

Nomenclature
A_p=pipe cross section area, m^2
c_p=specific heat of seawater, kJ/kg
E_{glob}=solar radiation intensity, W/m^2
h_4=enthalpy at throttling outlet, kJ/kg
h_5=enthalpy at flash tank, kJ/kg
h_{f5}=saturated water enthalpy, kJ/kg
h_{g5}=saturated water vapor enthalpy, kJ/kg
m_c=fresh water condensate capacity, kg/s
m_g=water vapor capacity, kg/s
m_w=seawater capacity, kg/s
M_t=total amount of condensate, kg
q_{col}=heating power of collector, W
q_{con}=condenser preheating power, W
q_t=total heating power of seawater, W
q_{use}=used heating power of seawater, W
T_3=collector outlet temperature, °C
T_0=feed seawater temperature, °C
V_4=flow velocity at throttling valve outlet, m/s
w_p=pumping power, W
x_5=vapor quality at flash tank, -
ρ_w=specific mass of seawater, kg/m^3

Introduction

Currently, the demand of fresh water for domestic and industrial uses is very high, but the nature resources provide water in limited amounts. Even drinking water is more expensive than benzene fuel in some places. For some tropical regions or cities near beach, seawater and solar energy is available in a large amount. A desalination system is desired to produce fresh water from seawater with free and renewable energy.

An evaporation desalination system with solar energy can be used to produce fresh water for small islands, agricultural plantations near coast, ships with additional heating energy from exhaust gas, off-shore oil rigs, and industries requiring fresh water in high capacity (Dinata [1]). The other product of a desalination installation is brine (high salt-content water), which can, then, be processed for crystal salt (Dinata [1,2], Havendry [3]).

This research aim is to obtain the characteristics of a desalination system with a flash evaporation using a solar collector water heater that operates with various feed seawater capacity. With various seawater capacities, an optimal performance of the system could be obtained based on the ratio of fresh water condensate product and heating energy. At such an optimal ratio, the installation could operate in an optimal capacity, which produces maximal fresh water capacity with minimal heating power.

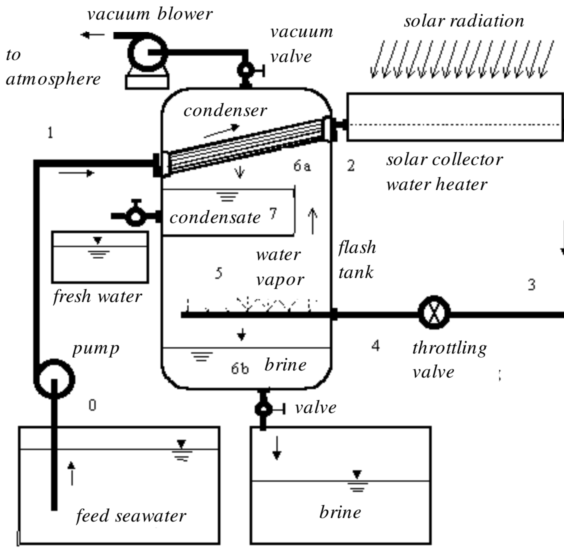

Figure 1: Desalination system with flash evaporator (Dinata, [1])

Flash Evaporation Desalination with Solar Energy

One of the desalination system is a flash evaporation (Stocker [4]) as shown in Figure 1. The system has a seawater heater of solar collector (Dinata [1]). The feed seawater flows through a condenser for condensing water vapor to make fresh water. After this preheating, the seawater is heated by a heater to increase its temperature. This hotter seawater flows through a throttling valve so some of the salt water is vaporized and then, condensed on condenser pipes to be fresh water and drops into a container.

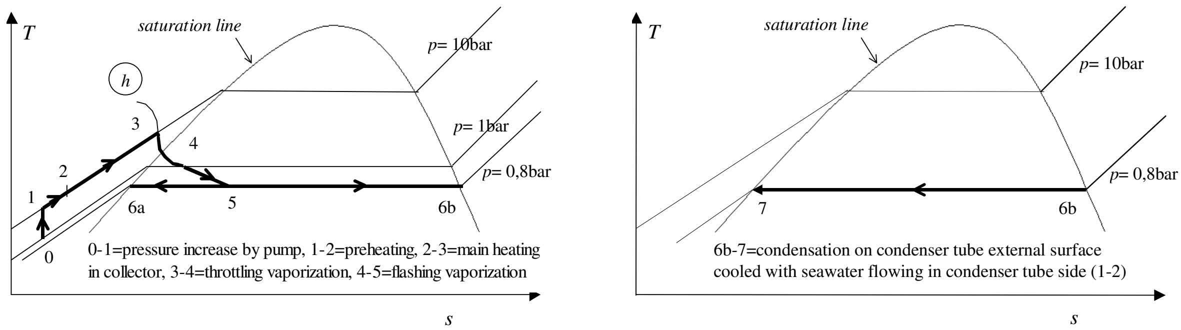

Figure 2: T-s diagram (left) for the evaporation process and (right) for the condensation (Dinata, [1])

This desalination process for one-stage stage is illustrated using a temperature-entropy (*T-s)* diagram in Figure 2. The assumptions for the desalination characteristics analysis include a constant seawater capacity, no heat and mass leakages, negligible pressure drop due to friction loss, neglected kinetic and potential energy changes, a constant seawater specific mass and heat, and thermodynamic properties of seawater approximated with pure water. Therefore, the fresh water condensate capacity for one-stage system is determined (Dinata [1]):

$$m_c = m_g = x_5 m_w = \frac{\left(h_5 - h_{f5}\right)}{h_{fg5}} m_w = \frac{\left(\left(h_4 + V_4^2/2\right) - h_{f5}\right)}{h_{fg5}} m_w = \frac{\left(\left(c_p T_3 + \left(m_w/\left(2\rho_w A_p\right)\right)^2\right) - h_{f5}\right)}{h_{fg5}} m_w \qquad (1)$$

Equation 1 shows $m_c = f(m_w, T_3, p_5)$, which means the condensate capacity is function of seawater capacity, collector outlet temperature and flash tank pressure because $h_{fg5} = (h_{g5} - h_{f5})$ and h_{g5}, $h_{f5} = f(p_5)$. The condensate capacity gets higher (with order 3) if m_w is increased and proportional to T_3, while p_5 is constant due to a vacuum blower, so h_{f5} and h_{g5} are constant. However, at constant collector heating and with constant pumping and preheating effects, the collector outlet temperature is inversely proportional to the seawater capacity (Equation 2).

$$T_3 = \frac{w_p + q_{con} + q_{col}}{m_w \; c_p} + T_0 \qquad (2)$$

The optimal seawater capacity is known at a maximal fresh water capacity determined via experiments and these capacities can be used as an optimal specification of the system.

Experiment

The tested desalination system with flash evaporation using solar collector water heater is already illustrated in Figure 1. The system specifications consisted of flash tank with diameter of 1m and height of 2m, a throttling valve and 10 sprayer nozzles, a brass tube condenser (¼ inches-diameter, 100m-length tube), a water heater of solar flat collector (6m^2), a centrifugal blower (Δp=0.5bar, 1HP) and a centrifugal pump (0.5HP, H=60m and Q=60lt/m). The used measuring devices were a solarimeter to measure radiation intensity, a turbine flowmeter and stopwatch to measure capacity, thermometers for measuring seawater temperatures, and pressure gauges for inlet and outlet pressures of the throttling valve and flash tank.

The experiments were conducted in front of Energy Conversion Laboratory, Mechanical Department of Andalas University from 08.00 until 16.00. The experiment was carried out at various valve opening to change seawater capacity. The measurement was conducted every 5 minutes. Experiment data are graphed to known the system characteristics and then, analyzed to know optimal performance of the system based on seawater capacity in producing maximal fresh water capacity. Characteristics and performance diagrams of experiment result were analyzed so we obtained, i.e.: maximal fresh water condensate capacity, optimal seawater capacity and maximal ratio of condensate capacity to heating power.

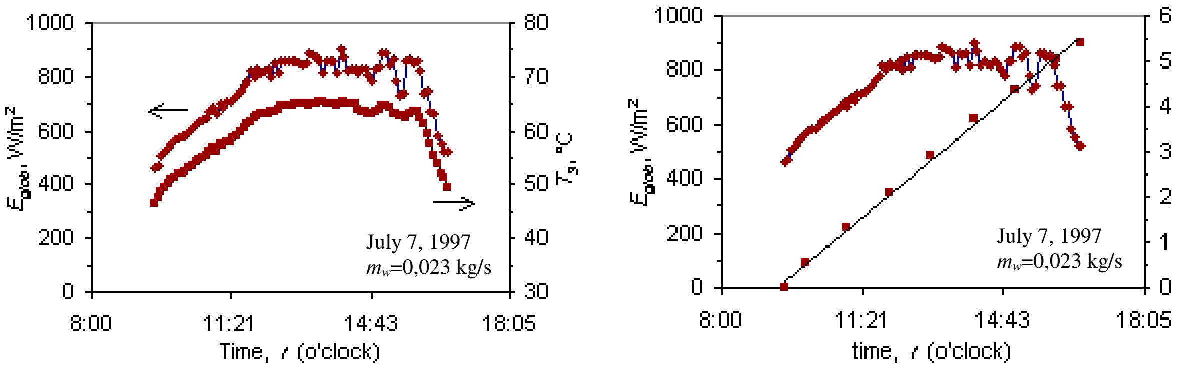

Figure 3: Solar radiation intensity and seawater temperature at collector outlet (left) and cumulative fresh water condensate product (right) against sunlight hours

Result and Discussion

The experimental results of the typical one-stage desalination system with flash evaporation using solar collector water heater are shown in Figure 3. The left diagram shows that if the solar intensity gets higher, so the heat gained by seawater and the collector outlet temperature are increased. The higher outlet temperature can increase fresh water capacity. The right diagram shows the solar intensity and cumulative condensate in sunlight hours. The condensate data curve is almost linear so the fresh water capacity is constant.

The analysis of the experimental results to determine ratio of condensate capacity to heating power are described as followed:

- Used heating power for the sea water:
  $q_{use} = m_w \, c_p \left(T_3 - T_0\right)$ (3)

- Averaged heat (Q_{use}) for Δt=5 minutes:
  $Q_{use} = q_{use} \, \Delta t$ (4)

- Total heat obtained, Q_t
  $Q_t = \Sigma Q_{use}$ (5)

- Characteristics of the system at various seawater capacity is based on the ratio r_t of total amount of condensate and total heating energy determined using:
  $r_t = m_c \,/\, q_{col} = M_t \,/\, Q_t$ (6)

The analyzed result is shown in Figure 4 illustrating the relationship of the seawater capacity against ratio of condensate amount to heating power for various seawater capacities with a parabolic characteristics curve. The system has the maximal ratio of 0.33kg/kJ, which obtained from the optimum seawater capacity of 0.027kg/s, which can produce maximal fresh water capacity. The maximal fresh water capacity was obtained with an amount of 0.81kg/h

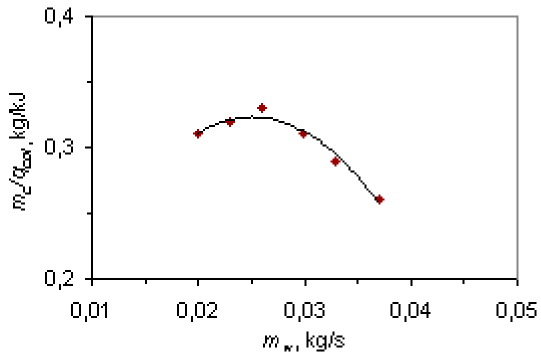

Figure 4: Seawater capacity against ratio of fresh water total amount to total heating energy

Conclusion and Recommendation

The theoretical and experimental analysis result of the flash evaporation desalination system using solar energy suggests that the solar collector outlet temperature and feed seawater capacity influence on the condensate fresh water capacity. But the outlet temperature depends on the feed seawater capacity so there is an optimal condition, where the fresh water capacity is maximal. The typical result of the tested desalination system consists of an optimal seawater capacity of 0.027kg/s and a maximal ratio of condensate fresh water capacity and heating power of 0.33kg/kJ and a maximal fresh water capacity of 0.81kg/h.

Recommendations for next developments i.e.: an increase in water vapor quality in the flash tank can be achieved with decreasing vacuum pressure in the flash tank and increasing solar collector area so the seawater temperature of collector outlet is increased.

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