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Modeling and testing of a dew collection system

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Abstract

In this paper a renewable method of obtaining fresh water from the atmospheric air in the form of dew is proposed. This study deals with the dew formation on radiatively cooled pigmented polyethylene foils. Since a large number of variables are involved in the formation of dew, a steady-state mathematical model is formulated using the energy balance equations and the computer program is developed using the iterative procedure to find the mass rate of condensation of dew from the atmospheric air. Experiments are conducted in Dhahran, Saudi Arabia, with 1 m × 1 m dew collecting panel and about 0.22 L/m^2 of water is collected during a single night of operation. Further, the model predictions are compared against the experimental results, with very good agreement. It is found that for maximum possible dew collection, a clear sky with a high degree of atmospheric humidity is needed. The effects of relative humidity of air, the ambient temperature, and the wind speed on the dew collection rate are studied and the results are presented in this paper.

Keywords: Atmospheric humidity; Dew collection; Modeling; Radiative cooling; Water

1. Introduction

In recent years the problem of obtaining fresh water from the atmosphere has received more attention and this source of fresh water can be recovered for general domestic use. Fog and dew are some important sources of water for arid regions. Dew is common in relatively humid climates with clear sky conditions whereas fog is common in locations like mountainous and coastal areas. Generally the fresh water obtained from the atmosphere is expected to be soft, neutral water of a good quality with a very low content of minerals and metals. The formation of dew requires a cold surface and cloudiness, surface temperature, air humidity, and wind speed influence the dew formation. This research seeks an endless source of fresh water as dew from the atmosphere.

2. Dew collection studies

Rajvanshi [1] proposed a scheme for large-scale dew collection as a source of fresh water supply by passing the 500 m deep cold sea cold water at 5°C through a heat exchanger field area of 1.29 × 10^5 m^2, where it condenses 643 m^3 of

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dew over a period of 24 h. However, the author concluded that the scheme was not feasible economically. Nikolayev et al. [2] investigated the history and functioning of dew collection methods. It is reported that approximately 1 L/m^2 is possible under ideal conditions. It has also been suggested that a light sheet that is thermally isolated from the ground would be ideal to collect the dew. Using different dew collection configurations, several measurements were made by Beysens et al. in Tunisia and France [3] and they found that some of these configurations produce an equivalent rainfall of the order of 0.1–0.5 mm/d. Nilsson [4] described the field tests of condensation of moisture in the air as dew on cold pigmented polymer foils in Sweden and an arid location in the inland of Tanzania. It was found that in arid places, water was condensed during the last few hours before sunrise and the volume/m^2 was low.

Experiments were conducted by Alnaser and Barakat [5] in Bahrain with three different small condensation surfaces made of aluminum, glass and polyethylene foil and it was found that the most favorable conditions for dew collection were at dawn. Muselli et al. [6] tested a dew collecting foil in Ajaccio, France, made of TiO_2 and $BaSO_4$ microspheres embedded in polyethylene and reported that the maximum yield in the period was 11.4 L/d. They found that except for a weak acidity (average pH $\approx$ 6) and high concentration of suspended solids, dew water met the requirements for potable water. It should be pointed out that no attempt has been made in the Kingdom of Saudi Arabia to study the feasibility of collecting water from dew.

3. Mathematical model

Consider a radiatively cooled pigmented polyethylene foil is placed horizontally and exposed to a clear night sky. The bottom of the foil is well insulated. The following energy balance equation can be written at steady state/unit area basis:

$$q_c + q_m + q_{cond} - q_r = 0 \tag{1}$$

It is assumed that no heat is accumulated in the foil. The heat exchange between the foil and the surrounding air by convection is given by:

$$q_c = h_c(T_\infty - T_f) \tag{2}$$

Depending upon the flow, the convective heat transfer coefficient can be evaluated. The radiative heat exchange with the sky is given by:

$$q_r = \varepsilon_f \sigma (T_f^{\,4} - T_{sky}^{\,4})(1 - CC) \tag{3}$$

For clear skies, $CC = 0$; and for overcast skies, $CC = 1$. The energy gain due to the latent heat of condensation is given by:

$$q_m = \beta(P_\infty - P_f)\, h_{fg} \tag{4}$$

The analogy between heat and mass transfer is used to calculate the convective mass transfer coefficient. It may be assumed that the latent heat of condensation is constant. It is to be noted that if $P_\infty < P_f$, then there will not be any condensation. Conduction through the back insulation is given by:

$$q_{cond} = \frac{k_i}{x_i}(T_\infty - T_f) \tag{5}$$

The mass rate of dew condensed as fresh water/h is given by:

$$m = \left(\frac{q_m}{h_{fg}}\right) \times 3600 \tag{6}$$

The computer program is developed using the iterative procedure to find the mass rate of condensation of dew from the atmospheric air on a foil radiating heat from its surface.

4. Experimental set-up

In order to use the above model with confidence for predicting the mass rate of dew collected from the atmosphere, experiments are conducted in Dhahran (26.3°N, 50.1°E) during