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Design of a helical coil dehumidifier for a novel gravity-driven solar distillation unit

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Abstract

Solar distillation is a widely researched option for producing potable water in water-starved regions of the globe. Despite its technical simplicity and easiness-to-use, its efficiency has not sufficiently improved to promote its widespread use. The reasons for relative inefficiency of solar distillation are poor energy harvest at solar collectors, poor utilization of the harvested energy for evaporation of the water and suboptimum condensation of the humidified air in the condenser. A novel concept of solar still attempts to optimize the humidification-dehumidification cycle of a solar distillation unit to address these issues related to solar distillation units. The system works in a closed air open water humidification-dehumidification cycle. The energy source is solar irradiation, which heats up an air-water mixture. The driving force in the system is a small suction pressure induced in the system due to an aerator attached to the water inlet. A helical coil dehumidifier achieves efficient dehumidification in the system. The current paper describes experiments conducted to improve the efficiency of the dehumidifier attached to the novel solar distillation unit by optimizing the design parameters. The dehumidifier has the shape of a helical coil heat exchanger, which is cooled by the relatively cold water from a reservoir, which conversely, is heated by the heat of condensation. Even though there are sufficient studies on the design parameters of general helical coil condensers in literature, few studies are done to study their use in a humidification-dehumidification cycle involving non-condensable air. Further, a detailed parameter study of the helical coil dehumidifier is not yet done. The current paper discusses the various design parameters of a helical coil dehumidifier working in conjunction with a solar distillation unit as described above. Different design parameters of a helical coil dehumidifier discussed in this paper are pitch and diameter of the helical dehumidifier. Design insights for helical coil dehumidifier are thus obtained. The study reveals that the overall efficiency of a solar humidification-dehumidification cycle of a solar distillation unit could be considerably improved by optimizing the design of the helical coil dehumidifier used therein.

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Keywords: Helical coil dehumidifier; Solar Distillation, Humidification-dehumidification cycle

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1. Introduction

There are a large number of studies describing methods of producing potable water from saline water. Generally, the relation between water scarcity and solar insolation is such that the regions that have abundance in the latter are those that are affected by the former. Such water-energy nexus is the reason why solar humidification-dehumidification (HDH) is one of the most actively researched areas today. Solar HDH makes efficient use of alternative sources of energy to produce potable water.

A dehumidifier exploits reduction in the humidity of the air with reduction of temperature to condense the vapor content in the air as observed in its psychometric chart. The system is essentially a heat exchanger, used to remove the specific heat of vaporization to facilitate the dehumidification process. However, unlike a usual condenser, a dehumidifier deals with a mixture of air and water vapor. In order to optimize a HDH system, it is essential to enhance the performance of the dehumidifier, which is the subject matter of the current study.

A number of studies on the operating characteristics of dehumidifiers of various shapes and sizes are found in literature. A review of many of these studies is available in [1]. Müller-Holst et al. used a flat plate heat exchanger in his HDH system [2]. Farid et al., reports comparison of different dehumidifier designs attached to a HDH cycle in [3] and [4]. For example, they study the effects of different flow conditions on the functioning of an HDH. In one of their designs, the dehumidifier was made from a long copper pipe mechanically formed into a helical coil fixed around a PVC pipe. We use a similar approach to design a helical dehumidifier in the current study. In another design, a copper tube is bent around a galvanized plate in the shape of a helix and welded to it. Excepting these two papers, few authors have reported on helical dehumidifiers. Some papers discuss finned straight tubes or similar designs [5], [6], and [7]. Use of helical coils in condensers is already established. However, their use in a dehumidifier is yet to be explored.

There are three main reasons to opt for a helical coil construction over other designs as reported in [8]. First, helical design is compact, second, it supports higher heat transfer rates and third, it is used where pressure drop of one of the heat transfer fluids is small. Different papers dealing with helical coil dehumidifier focus on the flow parameters instead of their design parameters. Hence, we attempt a study on the design parameters of a helical coil dehumidifier, especially the effect of pitch of the helical coil and the diameter of tubes as described in Fig 1. Panthalookaran et al has proposed a HDH system in [9]. Dehumidifier detailed in this paper is designed to work in conjunction with the HDH proposed there.

Nomenclature

α	helical angle
A	area of heat transfer surfaces
d	outer diameter of tube
h_1	enthalpy of inlet vapour
h_2	enthalpy of outlet vapour
l	condenser height
L	length of condenser tube
m	mass flow rate
N	number of turns of coil
P	pitch of coil
Q	net energy
r	major radius of coil
t_i	coolant inlet temperature
T_i	vapour inlet temperature
t_o	coolant outlet temperature
T_o	vapour outlet temperature
t_s	saturation temperature at condenser pressure
U	overall heat transfer coefficient