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The glazing temperature measurement in solar stills – Errors and implications on performance evaluation

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ABSTRACT

Although the brine temperature measurement in solar stills would be more or less conventional, the precise condensing surface temperature measurement, appears to present a significant difficulty to measure. In the present investigation, an analysis is developed aiming to underline the parameters affecting the glazing surface temperature measurement and a series of field measurements are presented, aiming to identify and evaluate the errors associated to the measurement of this crucial physical quantity. It is derived that among other reasons the surface temperature measurement accuracy may strongly be degraded owing to the sensor tip overheating due to the radiation absorption, as well as to the development of poor bond conductance between sensor bead and glazing surface. It may also be degraded owing to the temperature drop across the glazing thickness and the non-uniform temperature distribution over the entire condensing surface area, something that makes the selection of the appropriate location of the particular temperature transducer necessary. Based on the derived measurements, an order of magnitude analysis is employed for the approximate evaluation of error range in the condensing surface temperature measurement. This, which depending on specific conditions was found to vary between about 1 and 2 °C, was employed to demonstrate the implications and approximate conditions under which its effect could become excessively high in ordinary solar still investigations.

1. Introduction

Solar stills are shallow bodies of saline water enclosed in a thermally insulated container glazed at the top. In principle, the incoming solar radiation after partial reflection and absorption at the top glazing surface is admitted in the still and it is finally absorbed by the liquid layer of brine and its dark bottom container surface, causing heating and evaporation of water from its free surface. Owing to the thermally driven convective circulation inside the solar still enclosure, the water vapor in the saturated mixture condenses at the inner top glazing surface, rejecting the heat of condensation in the environment and the condensed liquid is collected and stored outside the device.

A substantial amount of research efforts has already been devoted towards developing theoretical analyses and modeling, allowing the quantification of the internal heat and mass transport processes, improving the level of scientific knowledge and insight on various fundamental transport processes in these systems [1–7].

The experimental validation investigations as well as heat balance and performance evaluations are based on the accurate brine and condenser surface temperature measurements. These are usually derived using conventional calibrated, thin wired welded tip junction thermocouples, which are tough, reliable and widely available low cost devices allowing reliable temperature measurements.

In contrast to the brine temperature which does not generally present significant difficulties to measure, the same is not the case for the accurate glazing surface temperature measurement, which is exposed under the intense solar radiation. This measurement is usually based on the direct top glazing surface temperature recordings, assuming negligible temperature drop across the glazing thickness. However, the accuracy of the so measured temperature may be poor and the measurement results strongly misleading, owing to the temperature drop across the glazing thickness, unless empirical steady state temperature corrections are applied to refer the measured quantity at the inner glazing surface as reported by Tiwari et al. [8]. The problem has also been previously noticed by Tiwari et al. [9], who presented comparable results of the internal convective heat transfer coefficients based on inner and outer glazing surface temperature measurements.

Except of the significant attention that should be devoted on the appropriate selection of the temperature sensor location aiming to derive a representative inner average condensing temperature over the entire glazing area, this accuracy degradation may also be attributed to other factors, like the junction overheating owing to radiation absorption as well as the lack of perfect thermal contact between thermocouple bead and glazing surface. This should in any case be avoided as imposed by the generally accepted rules

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Nomenclature

C	heat capacity (J/kg)	ci	convective inner
e	temperature measurement error, absolute (°C)	co	convective outer
$e_{\Delta T}$	temperature difference measurement error (°C)	e	exposed
$e\%$	percentage yield prediction error (–)	g	glazing
h	convective heat transfer coefficient (w/m^2 K)	go	glazing outer surface
k	thermal conductivity (w/m K)	gi	glazing inner surface
$\dot{m}$	per unit area mass flow rate (kg/m^2 s)	gie	glazing inner surface exposed
P	pressure (Pa)	gip	glazing inner surface padded
q	heat flux (w/m^2)	gis	glazing inner surface shaded
R	thermal resistance (m^2 K/w)	gop	glazing outer surface padded
T	temperature (°C)	goe	glazing outer surface exposed
		gos	glazing outer surface shaded
Greek letters		i	inner
δ	thickness (m)	id	ideal, correct
Δ	difference	m	evaporative
ε	total hemispherical emissivity (-)	oe	outer effective
		p	padded
Subscripts		pr	parallel resistance
bi	bond inner surface	ri	radiative inner
bie	bond inner surface exposed	ro	radiative outer
bip	bond inner surface padded	s	shaded
bis	bond inner surface shaded	sky	sky
bo	bond outer surface	$sky\infty$	equivalent ambient air-sky temperature
boe	bond outer surface exposed	t	total
bop	bond outer surface padded	w	brine
bos	bond outer surface shaded	∞	ambient

of good practice [10]. Aiming to eliminate these phenomena which are strongly associated with the temperature measurement accuracy degradation, the condensing temperature evaluation in certain investigations like those by Farid and Hamad [11] and Shawaqfeh and Farid [12], was alternatively based on the direct condensate flow temperature measurement. However, under certain conditions, this temperature, even measured at the close proximity of the glazing surface, may considerably deviate from the actual condensing temperature as it was also confirmed during the present experimental investigation, due to the strongly non isothermal flow of condensate owing to the low distillate mass flow rates and relatively high heat losses from the condensate channels.

Aiming to minimize phenomena related to the poor thermal contact and development of significant bond conductances between junction beads and glazing surface, there is always the possibility of employing special purpose surface mount thermocouples of extremely low thermal inertia made of very thin (0.0005″ or 0.0125 mm) thermocouple foil alloy junctions as reported by Childs [13]. However, these thermocouples, being special and not easily accessible devices, they are far more expensive than ordinary thermocouples, while being extremely fragile, they cannot provide long-term reliability for operation under the harsh environmental conditions these measurements are usually carried out.

Definitely the precise condensing surface temperature measurement under typical field conditions is not easy, requiring the incorporation of special low thermal inertia sensors with close to condensing surface radiative properties, ensuring perfect thermal contact without disturbing the existing temperature field, while the direct use of non invasive infrared sensors cannot easily be tolerated, mainly owing to their lower accuracy and stringent humidity and temperature operational specifications. The situation may be even more confounded taking into consideration the deviation from the condensing surface temperature uniformity assumption which is not always negligible, as well as two dimensional heat flow effects. This probably explains the relatively limited attention that has already been devoted on this issue and its implications, although an extensive amount of research work has already been published in almost every aspect in solar distillation systems.

2. The theory of condensing surface temperature measurement

Although in the following investigation a reference is explicitly made to thermocouples, the presented analysis can directly be applied to any other temperature sensors like platinum resistance thermometers (PRT), negative temperature coefficient (NTC) thermistor beads or integrated temperature sensor devices, the installation of which always involves phenomena like the possibility of imperfect glazing surface thermal contact and the development of bond conductances.

The simultaneous comparative temperature recording at both glazing surfaces requires the installation of two thermocouple junctions, attached at the opposite inner and outer surfaces of the glazing pane. Assuming thermal equilibrium conditions, the simplified thermal network which also determines the precise outer and inner glazing surface temperatures T_{go} and T_{gi} respectively is shown in Fig. 1a.

The measurement of these surface temperatures usually involves the use of thin wired thermocouple beads attached on the glass surface. Owing to the lack of possibility to embed these junctions by drilling holes or surface grooves in the glass, they are usually glued using high temperature epoxy adhesives under pressure to ensure good thermal contact between glass surface and thermocouple bead. However, owing to the limited direct contact area between glazing surface and junction beads and the small thermal conductivity of epoxy adhesive material (in the order of 0.2 w/m K) these junctions, instead of measuring the precise inner and outer nodal temperature T_{gi} and T_{go} respectively, are recording the inner nodal temperature T_{bi} which is usually slightly higher