

# A three-dimensional performance analysis of all-glass vacuum tubes with coaxial fluid conduit <sup>☆</sup>

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## Abstract

The thermal performance of a solar system composed of parallel, all-glass (double skin) vacuum tubes has been investigated by using a three-dimensional analytical model. Each vacuum tube is equipped with a coaxial fluid conduit for water to flow through and collect the sun's thermal energy. The space between the exterior of the fluid conduit and the glass tube is filled with antifreeze solution to facilitate heat transfer from the solar heated absorber surface to water and to prevent the functional problems due to freezing in frigid weather conditions. Different from one-dimensional analytical models, the three-dimensional model considered in the present analysis enables the prediction of spatial variation of water temperatures as it flows through the coaxial conduit. This is quite useful in extracting major variables for the operation of the solar system using all-glass vacuum tubes as considered in the present investigation. © 2008 Elsevier Ltd. All rights reserved.

*Keywords:* Three-dimensional analysis; Solar tubular collectors; Coaxial conduit; Thermal performance

## 1. Introduction

The use of solar water heaters is becoming increasingly widespread for space heating of buildings. Especially, the systems using all-glass vacuum tubes offer energy efficiency and adaptability in any application [1,2]. All-glass vacuum tubes consist of two glass tubes which are fused together at one end. The inner tube is coated with a selective surface that absorbs solar energy well but inhibits radiant heat loss. Air is withdrawn from the space between the two tubes, forming a vacuum. No conductive and convective heat losses take place as there is no air to conduct heat or to circulate and cause convective losses (Fig. 1, [2]).

All-glass vacuum tubes have become the key component of the solar collectors in converting solar energy into hot water. Especially, they proved to be very useful in residential applications that require higher temperatures. Vacuum tube collectors perform well in both direct and diffuse solar radiation because of its circular shape. The sun's rays are always striking the tubes at an angle which is perpendicular to their surface thus reducing

reflection. This feature also maximizes the total amount of solar radiation compared to other types of solar collectors. If the collector surface is flat, the amount of solar radiation striking the collector surface is only at its maximum around noon when the sun is directly above the collector.

There are currently a number of configurations hiring different heat transfer strategies to transform the solar energy into heat, and transfer it to either water or other heat conducting elements (heat transfer medium). Of these, the most popular ones are the direct flow, heat pipe and U pipe configuration [3,4].

Adapting from the direct flow configuration, a solar collector system where each vacuum tube is equipped with a coaxial fluid conduit [2], as shown in Fig. 2, has been investigated for its thermal performance and operational characteristics by a three-dimensional steady state analysis. In our previous work [2], a one-dimensional analysis has been introduced adopting Eberlein's approach [5].

## 2. Analysis

The solar system considered in the present analysis consists of an array of all-glass vacuum tube collectors, a circulating pump, control unit and storage tank as shown in Fig. 3 [2].

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Nomenclature	
$I$	solar radiation, $W/m^2$
$S$	absorbed solar radiation, $W/m^2$ (normal surface)
$S_{eff}$	absorbed solar radiation, $W/m^2$ (tilted surface)
$P$	total absorbed solar radiation, $W$
$L$	length of a tube, $m$
$R$	radius
$G$	nominally absorbed solar radiation, $W/m^2$ (per unit absorber area of tube)
$\rho$	density, $kg/m^3$
$v$	velocity, $m/s$
$h$	enthalpy, $J/kg$
$r, \theta, z$	cylindrical coordinates
<i>Greek symbols</i>	
$\alpha$	absorptivity
$\beta, \gamma$	angle, deg
$\varepsilon$	emissivity
$\mu$	dynamic viscosity, $kg/(m\ s)$
$\tau$	transmissivity
<i>Subscripts</i>	
$r$	radial
$\theta$	angular
$z$	lengthwise
$b$	body force
$ref$	reference

Water continuously circulates between tubular collectors and the storage tank as long as it is driven by the circulation pump directed by the control unit. As the black absorber surface (outer surface of the inner glass tube, Fig. 1) of a tubular collector gets heated by the impinging solar radiation and

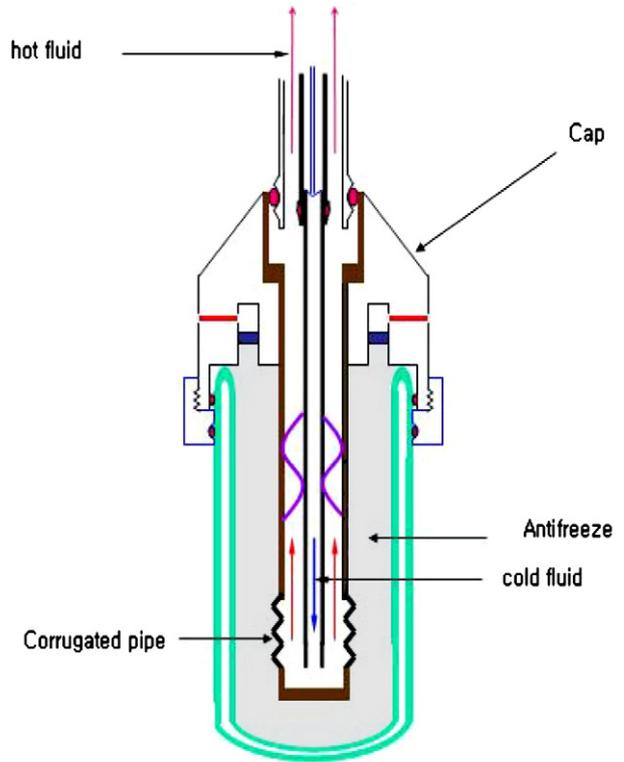


Fig. 2. A tubular solar collector with a coaxial conduit inserted (Korea Patent No. 0449958), [2].

warms up the antifreeze (mixture of ethylene glycol and water) it contains. Here, the antifreeze functions as a thermal buffer enabling uniform and stable heating of the coaxial (fluid) conduit by efficiently absorbing heat from the hot absorber surface and plays a role of liquid fin. The heated antifreeze subsequently transfers heat to the coaxial conduit and finally the water that runs through it.

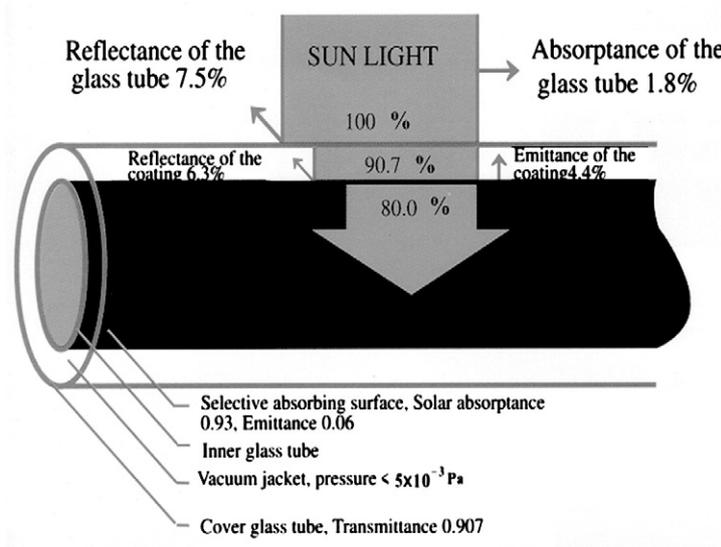


Fig. 1. A typical double skin solar tubular collector, [2].

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