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The influence of flow tube vibrations over the efficiency of solar water heating collectors

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Abstract

The effect of vibrations over a flow tube from a solar water heating collector was studied in order to enhance the heat exchange. First, a hydrodynamic model for the internal flow of the tube was proposed, in order to obtain the pattern for the relative motion of the liquid. The results highlighted a strong exchange of liquid volumes between the upper and the lower part of the pipe over the transversal section of the tube for a vertical displacement of the flow. In order to validate the positive effect of the internal motion over the heat transfer between the pipe and the water flow, an experiment was accomplished. The flow tube filled with liquid was introduced in a water recipient and vibrated at several frequencies. The water temperatures inside and outside the tube were recorded. The values for water temperatures measured during the warming and cooling intervals confirm that by vibration, the time for heat exchange is decreasing if the vibrating frequencies near the resonance frequency are considered.

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Keywords: solar water heating; fluid-structure interaction; pipe vibration;

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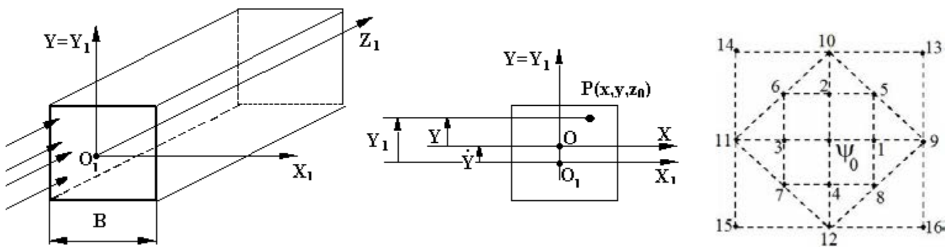
1. Introduction

A large number of studies on solar water heating systems are available in the literature aiming to provide solutions for increasing the thermal efficiency of the collectors. Some research concerning the influence of the tube arrangement and collector position over flow distribution [1-3] had revealed that turbulent flow model had to be extended to laminar flow. Other research propose methods to study the flow distribution inside the collector tubes by using the correlation for pressure losses [4,5]. Most of the recent research is focused on collector system modeling in order to solve energy and flow equations [6-8] or assess the effect of using new materials and technologies, e.g. nanofluids on thermal efficiency of the collector [9-14]. In the present work the influence of vibrations of a flow tube over the heat exchange is studied in order to assess the effect on the thermal efficiency of a solar heat collector. A mathematical model for the internal flow was derived and flow pattern was obtained. For validation of the theoretical results concerning the effect of internal flow on the heat exchange, experiments were accomplished. One pipe of 16.4 mm external diameter was selected and filled with water. The vibrated tube was introduced in a water recipient at various temperatures. The temperatures of water, both inside and outside the tube were measured for the selected vibrating frequencies. Higher values for heat transfer were recorded when near resonance frequency was used for vibrating the flow tube, in comparison with other case studies.

2. Theoretical model for the internal flow of the tube

In order to deriving the model for the internal flow of the pipe, one considers the motion of an incompressible liquid of constant density ρ and viscosity η. A square shape is considered for the pipe cross section. The pipe is vibrated on the O_1Y_1 direction, transverse on the flow, as presented in Figure. 1 a,b.



a. b.

Fig. 1. (a) Internal flow of the pipe; (b) numerical integration network

The Navier-Stokes equations and the continuity equation were written for the relative motion of the liquid considering the relations between velocities - $\dot{V}$ is the velocity of the tube axis - for an ordinary point $P(x,y,z_a)$ placed in section "a" of the tubeas follows:

$$U_1 = U;\ V = V+\dot{V};\ W = W_1.$$

$$\begin{aligned} &UU'_x + \left(V + \dot{V}\right)U'_y = \nu \underset{x,y}{\Delta} U - \frac{1}{\rho}P'_x \\ &UV'_x + \left(V + \dot{V}\right)V'_y = \nu \underset{x,y}{\Delta} V - \frac{1}{\rho}P'_y \\ &U'_x + V'_y = 0 \end{aligned} \tag{1}$$

In order to obtain the solution for the flow pattern inside the tube a numerical method of finite differences was considered [15,16]. By eliminating the pressure variation between the first two relations, one obtains a single partial differential equation of third order. For a more general numerical solution, the equation must be dimensionless, therefore some characteristic values of the geometry and velocities are selected (e.g. the side *B* of the square section