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NUMERICAL DETERMINATION OF THE COEFFICIENT OF HEAT TRANSFER BY CONVECTION BETWEEN COVERAGE AND EXTERNAL ENVIRONMENT IN A SMALL SOLAR CHIMNEY

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Abstract. *The growing world demand for energy and concerns about the environmental impacts of energy production has motivated research into alternative sources of energy. In this context, the solar chimney uses a solar radiation to generate a flow of heated air that can be used for a generation of electric energy for a drying of products. An important factor without performance of solar chimneys is a loss of heat to cover the external environment, in this work are proposed two expressions obtained numerically for the coefficient of heat transfer by convection between a cover and the external environment. A small model is used to evaluate the impact of the crosswind (0 to 25m / s) on the performance of solar chimneys.*

Keywords: *Solar chimney, Small scaling, CFD, Energetic efficiency, Coefficient of heat transfer by convection*

1. INTRODUCTION

The updraft solar tower, Fig.1, is a device which combines the concepts of solar collectors and chimneys to induce an air flow that can be used to power wind turbines and generate electricity or for drying of agricultural products. In the solar collector, a portion of solar radiation exceeding the transparent collector and is received by the absorbent, i.e., the floor or an additional absorbent placed on the ground, and thus the indoor air is heated. Heat is stored in the absorber during the day when solar radiation is strong. It is released from the absorber when solar radiation is low (at night or on cloudy days). The difference in density between the hot air inside the solar updraft tower and the ambient air creates buoyancy that acts as the driving force and is also called pressure potential. Buoyancy drives the air floating in the sink toward the base of the tower, manifold air suctioning to the chimney and inhaling cold air arriving from the outside perimeter (SCHLAICH; 1995).

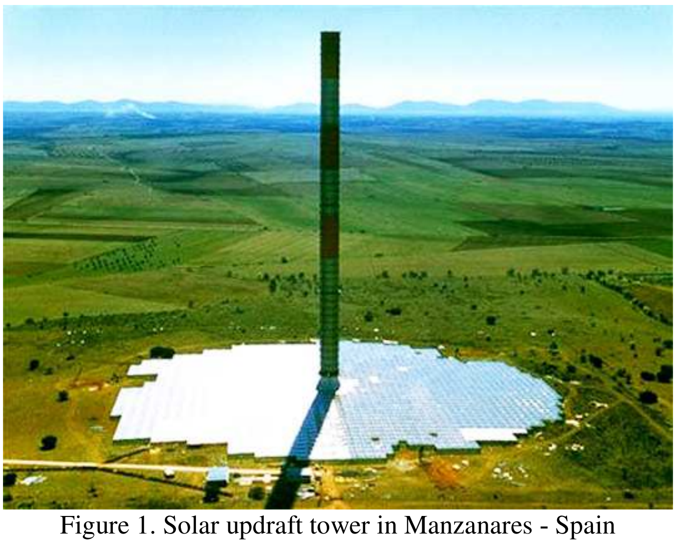

Figure 1. Solar updraft tower in Manzanares - Spain

Maia et al. (2009) conducted a numerical analysis of transient flow in a small prototype, using the technique of finite volume in generalized coordinates. The temperature at the ground surface was used as a boundary condition, and approximated as a function of incident solar radiation and thermal properties of the ground. The results were compared with experimental data, still being investigated the influence of geometric parameters in mass flow, average temperature output and the velocity profiles and temperature throughout the device. The analysis showed that the height and diameter of the tower are the most important parameters. Xu et al. (2011) evaluated the characteristics of air flow, heat transfer and power generated in a two-dimensional model with an energy storage layer and a turbine with similar dimensions to the prototype Manzanares. The influences of the solar radiation on pressure drop and heat transfer in the output power were analyzed. Sangi et al. (2011) described a detailed numerical analysis of a solar updraft tower, using the software FLUENT® to simulate a two-dimensional model of axial symmetry, with the turbulence model k-ε. The model was validated from Manzanares prototype data. The authors also developed a static expression for the pressure inside the collector. Tingzhen et al. (2008) performed numerical simulations using CFD techniques (Computational Fluid Dynamics). The influence of solar radiation in the turbine pressure drop, the heat transfer in the output power and the energy loss power of the solar updraft tower were evaluated. The results showed that for the solar updraft tower with a height chimney of 400m and with a collector radius of 1500m and a turbine with blades of 5m, the maximum power is about 10 MW and the turbine efficiency is 50%.

In this work are proposed two expressions obtained numerically for the coefficient of heat transfer by convection between a cover and the external environment

2. NUMERICAL MODEL

The governing equations of the problem are the mass, linear momentum and energy conservation equations, as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \cdot \vec{v}) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \cdot \vec{v}) + \nabla \cdot (\rho \cdot \vec{v} \cdot \vec{v}) = -\nabla p + \nabla \cdot \left(\mu \left[\left(\nabla \vec{v} + \nabla \vec{v}^{T} \right) - \frac{2}{3} \nabla \cdot \vec{v} I \right] \right) + \rho \{\vec{g}\} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot \left(k_{eff} \nabla T - h\vec{J} + \left(\mu \left[\left(\nabla \vec{v} + \nabla \vec{v}^{T} \right) - \frac{2}{3} \nabla \cdot \vec{v} I \right] \cdot \vec{v} \right) \right) \tag{3}$$

The flow inside the solar updraft tower is turbulent. The k-ε turbulence model was used, in which the turbulent viscosity is given by:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{4}$$

According to Versteeg and Malalasekera (2007), $k-\varepsilon$ model allows the transport effects of turbulent properties to be assessed by transport equations for the turbulent kinetic energy, k , and the dissipation of the turbulent kinetic energy, ε.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k}(G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} + S_\varepsilon \tag{6}$$

According to Nizetic et al (2008) the energy efficiency of solar updraft towers, disregarding the performance of the turbine is given by:

$$\eta = \frac{\int \dot{m} \cdot Cp \cdot (Tao - Tai)}{Ac \cdot Ho} \cdot \frac{Ht \cdot g}{Cp \cdot Tai} \tag{7}$$

3. METHODOLOGY AND BOUNDARY CONDITIONS

The geometrical dimensions of the solar updraft tower used in this study are based on a previous work, Ferreira (2004) and Maia (2005). It has a 12.30 m tower height with a diameter of 1 m, the collector diameter is 25 m and the height ranges from 0.05 m to 0.10 m.

The atmosphere around the device is represented by a parallelepiped that surrounds the entire device (Fig. 2). In the upper and lower surfaces of the parallelepiped were considered adiabatic walls. In three parallelepiped edges, an opening condition was assumed, allowing the fluid to both enter and leave the system. The bottom surface was considered as a wall, and the remaining surface belonging to the YZ plane was considered as input for wind speeds ranging between 0 and 25 m/s. For the boundary conditions of the solar updraft tower, interface input and device output were considered. The collector was assumed as a wall, with an interface (only allowing the heat flux to leave the boundary), and the tower of the device was considered adiabatic wall.

The commercial software ANSYS- CFX 14.5 was used to solve the governing equations of the problem. The results obtained for simulation default, it is considered crosswind equal zero, ambient temperature of 32°C (305.15K) and heat flux on the ground of 565 W/m² were validated with experimental data from Ferreira (2004) and Maia (2005). The results presented correspond to a mesh with approximately 2 million elements, solved for residue of the conservation and transport equations of 10^{-6}.

Figure 3 shows the comparison of the numerical results with the experimental data for ambient temperature (Tai), coverage temperature (Tcov), outlet tower temperature (Tchi) and ground temperature (Tgro). It is observed that for all the points observed numerical values were within or very close to experimental uncertainty.

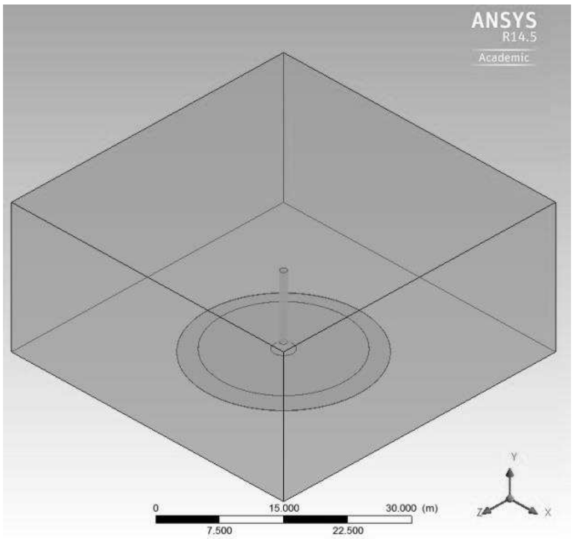

Figure 2. Geometry and boundary condition

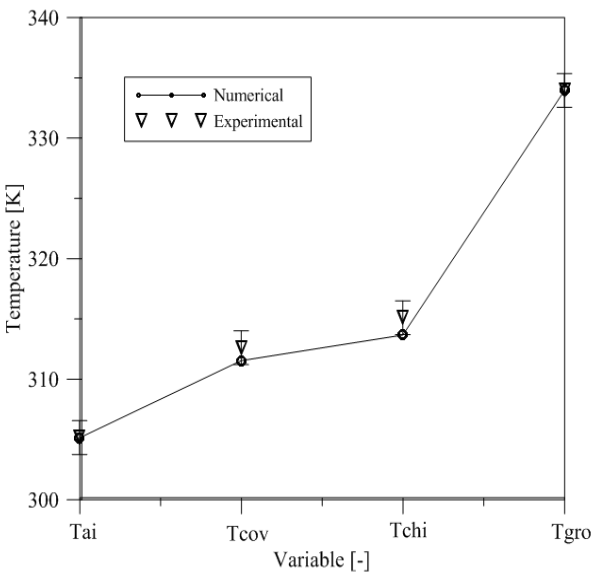

Figure 3. Validation

4. RESULTS AND DISCUSSIONS

After leaving the collector, the air moves to the junction between the collector and the tower. In this region, there is a change of direction of the flow from radial to axial. Furthermore, as the flow area becomes smaller, there is an increase on the velocity at the junction. In the chimney, the flow area is constant. Therefore, the average velocity does not change; small variations are observed in the profile, since the flow is not yet fully developed. For the average speeds obtained Reynolds numbers found are the $1x10^5$ order, characteristics of turbulent flows. For the situation analyzed the Rayleigh number was the $1x10^{12}$ order and Grashof number was the $1x10^{13}$ order, characteristic of flow governed by natural convection.

The crosswinds influence the performance of solar updraft towers by heat loss through convection from the outer surface of the collector to the environment, drag heated air out of the collector, and drag generating a suction effect at the outlet of tower increasing the upward air flow in the tower. The first two processes reduce the collector efficiency, while the latter results in increased efficiency of the tower. In general, heat loss by convection by the first process is included in the energy equation of the most common mathematical models for solar updraft towers. Heat loss of the second process is not included in the common mathematical models, but has been investigated based on environmental wind speed profiles using CFD (Computational Fluid Dynamics) simulations.

The crosswind influence directly on the temperatures causing a decrease in same. The ground temperature is ranging between 369.14 K and 341.69 K, since the outlet temperature of the flow ranges from 345.45 K to 318.86 K. For both reaching its minimum value for the crosswind equal of 25 m / s. The effect of the speed on the temperature is attributed to an increase on the convective heat transfer between the collector and the environment, as shown in Fig 4.

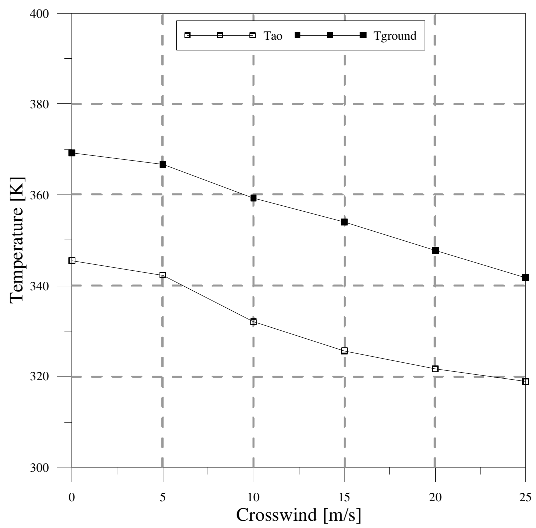

Figure 4. Influence of crosswinds at temperatures

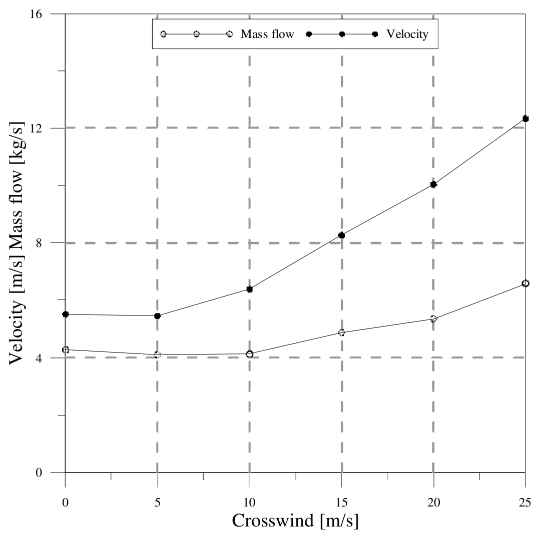

Figure 5. Influence of crosswinds at velocity and mass flow

It is worth mentioning that the magnitude of the maximum velocity reached by the airflow is significantly affected by the crosswind. As the crosswind speed increases, the velocity of the airflow increases. This behavior can be explained by the increase of the mass flow entering the system. As can be seen in Fig. 5, the rate of increase of crosswinds caused an increase of 54.39% on the mass flow, when the speed increases from 0 to 25 m/s.

The solar updraft tower have low energy efficiency, as affirm by Tingzhen et al. (2006), solar updraft tower with structures up to 300m high, maximum energetic efficiency is 1%. As mentioned environmental winds decreased to 7.7% the outlet temperature of the device and increase the output from velocity to 123.86 % for the range of speeds environmental analyzed (0 to 25 m / s). What favors the decrease of energy efficiency which increases 47.51%, Fig. 6.

Therefore, the effects of crosswind interfere with the effects of heat flow in the collector, increasing the convective heat losses from the collector to the environment. Furthermore, the air that enters the lower part of the tower causes distortions on the airflow and resistance on the pressure reduction or temperature difference between the interior and the exterior of the tower, the air non uniform temperature distribution inside the tower.

In figure 7 it is possible to observe a discrepancy between the coefficient of theoretical and numerical heat transfer. The theoretical coefficient for a speed 25 m / s, the value of 90 W/m²K while for the value for the coefficient is obtained numerically is 40 W/m²K. In figure 8 two proposals of new equations are presented starting from the numerical result, the first more simplistic and the second similar to the theoretical equation. The two presented results very close to the numerical curve, the most simplistic equation presented a variation of 2.86% and similar to theoretical variation of 0.91%.

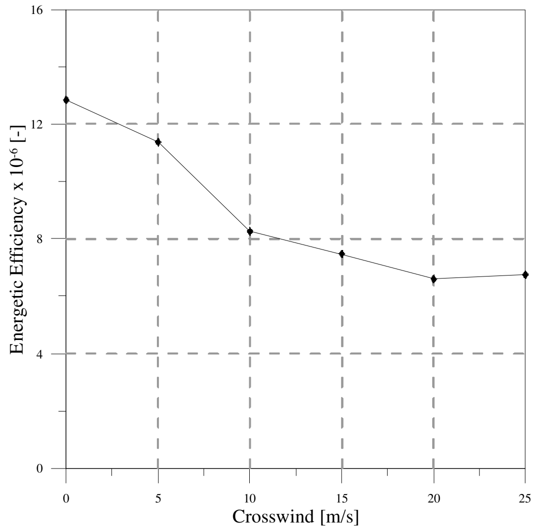

Figure 6. Influence of crosswinds at energetic efficiency

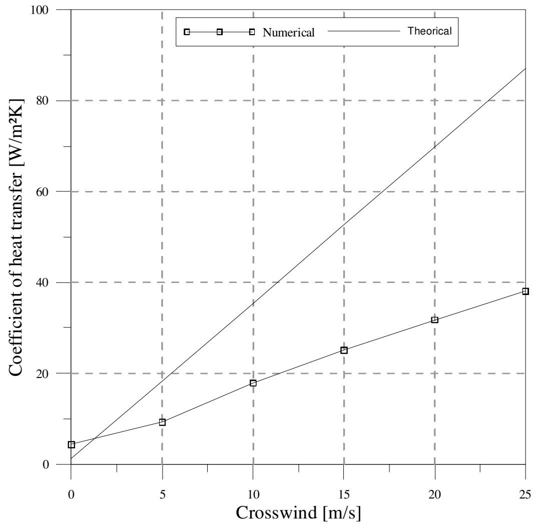

Figure 7. Theorical and Numerical coefficient of heat transfer by convection between coverage and external environment

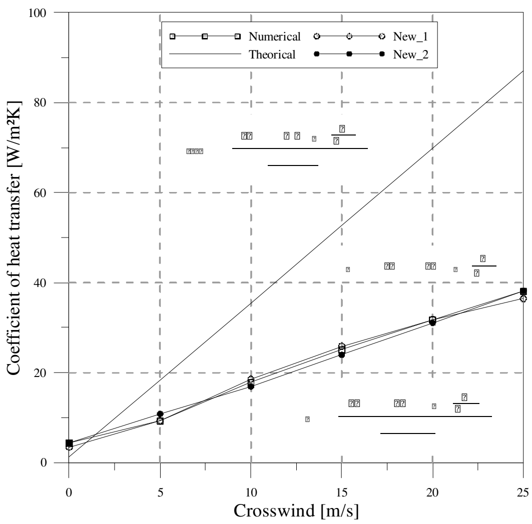

Figure 8. Coefficient of heat transfer by convection between coverage and external environment

5. CONCLUSIONS

The results of numerical simulations have shown that environmental parameters have significant influence on fluid flow and heat transfer, with both positive and negative effects.

- The effects of wind interfere with the effects of heat flow in the collector, increasing the convective heat losses from the collector to the environment;
- The two new equations proposed presented results consistent with the numerical analysis, presenting a variation of less than 3%.

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7. RESPONSIBILITY NOTICE

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