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NUMERICAL STUDY OF THE ASPECT RATIO EFFECTS ON THE STRATIFICATION IN WATER STORAGE TANKS

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ABSTRACT

The thermal performance of solar heating systems is highly influenced by the thermal stratification in the heat storage. A good thermal stratification improves the system thermal performances and the collector efficiency. The purpose of this study is to figure out the thermal stratification mechanism inside a water storage tank and to study the influence of the aspect ratio and thereby to determine an optimum design of the tank. The studied system is a horizontal cylindrical cavity with fluid inlet at the bottom and the fluid discharge at the top. Transient, three dimensional, mixed convection flow in the thermal storage tank has been studied by means of computational fluid dynamics (CFD) method. The governing equations are the conservation equations for laminar natural convection flow based on the Boussinesq approximation equation. The CFD simulations have been conducted using a commercial code. The objective of the study is the optimization of the tank aspect ratio for the case of thermosiphon solar hot water system and the analysis of the influence of this factor on the system efficiency.

The commercial code Fluent (2005) [3] has been used for our CFD simulations; it is a general purpose computational fluids dynamics code that solves the governing equations for the conservation of mass, momentum, and energy. The code includes the unsteady and laminar models; both have been used to study the stratification in our storage tank.

The study domain is divided into discrete control volume cells. The influence of type and meshing space are presented in the full paper.

To model the storage tank, the segregated solver using implicit discretization is appropriate and is being used for our studies. The momentum equations are solved, and then a pressure correction is applied to update the pressure field. Calculations are performed for the case of first order implicit discretisation. The unknown value in each cell represented at the cell center is calculated using both existing and unknown values from neighboring cells. The cell properties are updated at each iteration until the convergence criteria is reached.

PRESTO (PREssure Staggering Option), SIMPLEC (Semi Implicit Linked Equation Correction) and second order algorithms for both momentum and energy have been used to solve the governing equations of incompressible fluid flow on a staggered grid.

In order to study the stratification in storage tanks, one situation has been considered: the draw-off process of a horizontal storage tank having a volume V= 0.2m^3. The inlet and the outlet have a diameter equal to 0.03m. A 4 cm thick thermal insulation layer is insulating the tank.

The main purpose of the analysis has been the selection of the best aspect ratio A [4].
With $A = \frac{H}{D}$, H is the height of the tank and the D its diameter.
For the dynamic mode of operation, the stratification number str(t) [5] is defined as the ratio of the mean of the temperature gradients at any time to the mean maximum temperature gradient for the discharging process according to equation 1:

$$\text{str(t)} = \frac{\overline{\left(\frac{\partial T}{\partial x}\right)_t}}{\overline{\left(\frac{\partial T}{\partial x}\right)_{\max}}} \qquad (1)$$

Where:

I Is the number of thermal layer, T_{out} is the outlet temperature and T_{in} is the inlet temperature.

$\overline{\left(\frac{\partial T}{\partial x}\right)_t}$ Is the mean of the transient temperature gradients; it is given by

$$\overline{\left(\frac{\partial T}{\partial x}\right)_t} = \frac{1}{(I-1)}\left[\sum_{i=1}^{i=I-1}\left(\frac{T_{i+1}-T_i}{\Delta x}\right)\right]$$

$\overline{\left(\frac{\partial T}{\partial x}\right)_{\max}}$ Is the mean maximum temperature; it is given by $\overline{\left(\frac{\partial T}{\partial x}\right)_{\max}} = \frac{T_{out}-T_{in}}{(I-1).\Delta x}$

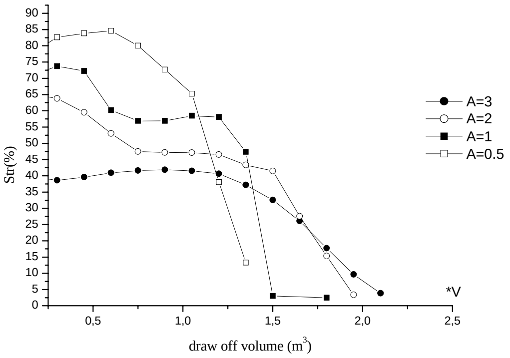

Figure1. Stratification number as a function of the draw off volume for different aspect ratios and for a mass flow rate of 0.1 kg/s.

Figure 1 shows the stratification number as a function of the draw off volume for different aspect ratios of 0.5, 1, 2, 3.

These results show that for an aspect ratio A= 0.5, the thermal stratification is the highest.

For all aspect ratio, the stratification number increases until an optimum value, then the stratification number decreases to reach a constant value.

The stratification number is maximum (value: 0.85) for an aspect ratio equal to 0.5.

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