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Numerical simulation of air flow and temperature distribution in air receiver of solar tower

Aoudjera farida[*], **Djouimaa sihem** [1]
Applied physic energetic Laboratory (LPEA), University of Batna.
Chahid Boukhlouf Mohamed El Hadi, Batna, Algeria
*faridaph89@yahoo.com
[1]*sihem.djouimaa@univ-batna.dz*

***Abstract-- Simulations* are carried out to analyze the temperature distribution of the fluid (air) and solid phases in volumetric solar receiver which is considered as a porous medium. The porous media is ceramic foams and presented by periodic packed tetrakaidecahedron regular structures. The numerical simulations are based on the resolution of the three dimensional instationary Reynolds Averaged equations. The SST Kω model is taken into account to visualize the turbulence effects. Studies were conducted to see the velocity effects, thickness of porous medium and the thermal conductivity on the temperature fields. The structure proposed in this work causes a large variation in the velocity field which generate a high gradients and causes an important heat transfer.**

***Keywords*— Heat transfer, CFD, porous media; volumetric solar receiver; ceramic foams;**

I. INTRODUCTION

The solar tower technology is a promising way to generate large amounts of electricity from concentrated solar energy in high solar resource countries such as North Africa and the Middle East, India, Australia and parts of North and South America, countries known to belong to the so-called "sun belt" of the Earth. As Algeria is a large solar potential, its contribution to develop this technology is very high.The solar potential is estimated at 169, 440 tera-watt hours / year (TWh / year) for solar thermal and 13.9 TWH / year for solar photovoltaics. Boughezoul in the north of algeriais the especially city where the installation of a power plant with a solar tower is expected to produce up to 20 megawatts by 2030.

A volumetric solar receiver receives the concentrated radiation generated by a large Number of heliostats. Heat transfer takes place from the receiver solid phase to the air as it passes through the porous media. Volumetric receivers contain porous structures that absorb solar radiation in depth. The Porous structure may be metallic or ceramic (e.g., silicon carbide SiC) and air can be heated to 850 ° C in the first case and attempts 1000 ° C in the second. Volumetric receivers exhibit excellent performance as they are theoretically possible to capture radiation over the entire depth and thus greatly increase the exchange surfaces, reduce local peak flow and reduce radiation loss. Furthermore the air is in direct contact with the radiative flux and its temperature is very close to the temperature of wall Release absorber. [1].

Studies of the temperature field inside porous media have widely used the local thermal non-equilibrium model (The radiation heat transfer plays a dominant role in the heat transfer when the porous is in a high temperature environment (Zhao et al., 2004) [2]. The working temperature of volumetric solar receiver is very high, generally range from ambient temperature to 1000^{0}C or higher. Thus the radiation heat transfer is important. Volumetric solar receivers have been studied for more than two decenies. Flamant et al. (Flamant et al. 1988) and Variot et a[3].l. (Variaot et al., 1994) investigated the combined heat transfer in a two-slab selective volumetric solar air receiver made of a multilayer packed bed. Pitz-Paal et a[4].l. (Pitz-Paal et al., 1991) numerically investigated the air and wall temperature distribution in a selective solar receiver which consisted of a ceramic foil receiver covered by a matrix of square channels of quartz glass. These volumetric solar receivers used the same selective absorptive concept in which the maximum temperature locates inside of the volumetric solar receiver. However, because of the complexity of the structures, the selective-absorbing volumetric solar receiver has not been studied much more. Researchers then switched to a volumetric solar receiver structure without a semi transparent layer. Fend et al. [5]. (Fend et al., 2004) proposed an ideal temperature distribution in the solid phase where the maximum temperature is located inside the absorber. However, experimental data in the literature (Fend et al., 2004) illustrated that the maximum temperature is still located at the front surface of the absorber. [6].

This work has as a principal objective to contribute to master internal flows and heat transfer in porous media by determining the temperature, pressure and velocity distribution in volumetric solar receiver. The dynamic and heat transfer characteristics between the flowing fluid and surface of ceramic foams are investigated. For that purpose, the flow and the energy balance are solved in the domain with standard CFD tools. The ceramic foam geometry is represented by periodic packed tetrakaidecahedron regular structures.SST turbulent model is used to appropriate the predict simulation. In another workingin future, it will be necessary to study a comparison between different turbulent models to confirm Vieser and Menterwork[7,8] in which they concluded that the

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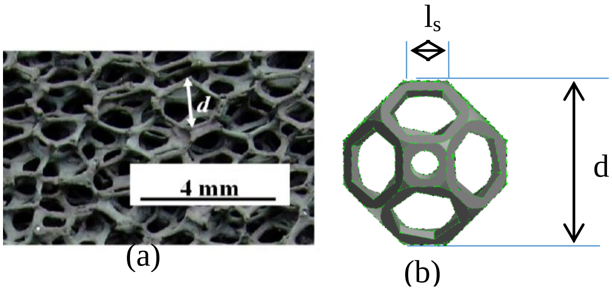
SST model in combination with an optimal wall treatment provides highly accurate results for a wide variety of heat transfer cases. Very important is to see the thermal conductivity influence especially the volumetric receiver performance; we present a comparison between different values of this parameter. Also is presented two row of ceramic foam results and compare them with one row's. All simulations done in this work are for instationary and three-dimensional flows. There were realized on an irregular structured grid (generated by the pre-processor *GAMBIT*) with the *FLUENT* software package, which solves the Navier-Stokes equations by using finite volume methods. The results validation is based on the comparison with data provided in Z. Wu et al *Z. Wu et al* Work [9].

II. PHYSICS MODELS

A. Geometry

The studied geometry is ceramic foams and can be described as a reticulated structure of open cells with typically 12–14 pentagonal or hexagonal faces (Figures 1-2). The following relationships [*Z. Wu et* al] [9] (simplified formulas were used to calculate the volume of the solid phase),

d=2.828 L$_s$



(a) (b)

Fig. 1- (a) Photo of ceramic foams, Z. Wu et al [9].
(b) Foams geometry

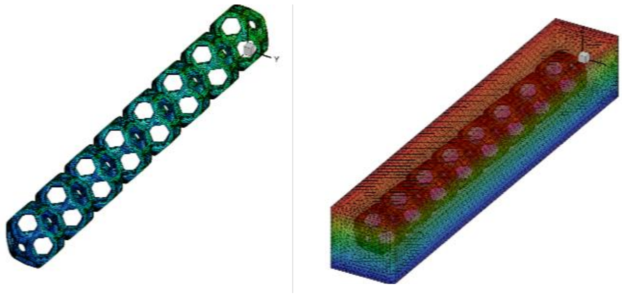


Fig. 2- Studied geometry

Our Structure foams is very different than used in Z. Wu et al [9].one (figures 2 and 3)

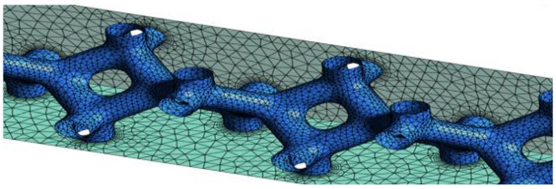


Fig. 3- Geometry of (Z. Wu et al.) [9].

B. Numerical Simulation

The irregular structured grid is generated by the pre-processor *GAMBIT*. According to this complex geometry, the grid is obtained using the tetra hybrid scheme.A very fine grid for accurately simulation of the intense turbulent flow and heat transfer is require; the final grid used in this paper was approximately 91000 elements (Figures 2.and4).This grid, which gave us high satisfaction (speed convergence and results qualities), is obtained after several attempting improvements concerning surface foams and volume receiver

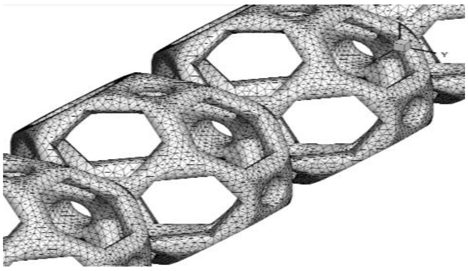


Fig.4- Computational Grid

The natural convection in the ceramic foams is numerically investigated using the commercial computational fluid dynamics software FLUENT (version 6.3), where the SIMPLE algorithm is used to couple the speed and the pressure. Using this approach, the governing equations are solved simultaneously i.e. coupled together. Governing equations for additional scalars will be solved sequentially.For that, we used a control-volume-based technique, which consists of dividing the domain into discrete control volumes using a computational grid, then, integrate the governing equations on the individual control volumes to construct algebraic equations for the discrete dependent variables (unknowns). After that, a linearization for discretized equations and solution is done.

The second order upstream scheme is used because higher-order accuracy is desired.

C. Boundary conditions

The boundary conditions are very important to obtain an exact solution with a rapid convergence, and must be defined to solve the different equations. A velocity-inlet boundary condition with 0.5m/s, and static temperature equal to 300 K are used at inlet. A pressure-outlet boundary condition with zero gauge pressure (relative pressure, with reference pressure of 101,325 Pa) is used at the outlet boundary. All the strut surfaces were defined as non-slip, non-penetrating walls with a constant temperature of 330 K

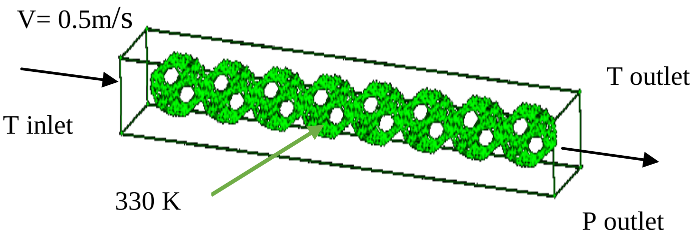


Fig. 5- The Geometry with boundary conditions

D. Turbulence model

To choose the turbulence model, it first should be clarified whether or not the flow regime is turbulent. The widely used criterion for distinguishing different flow regimes is the Reynolds number; unfortunately, there are many ways to calculate the Reynolds number for flow in a foam material [10].

The Reynolds number, which is based on the mean cell size and the superficial velocity $R_e = \rho u d / \eta$, ranges from 129 to 323[9].is used with the SST k–ω model in this study for all the computing cases. The Reynolds number is based on the pore diameter and average pore velocity, instead of the mean cell size and superficial velocity. Hens setting boundary conditions for a CFD simulation it is often necessary to estimate the turbulence intensity on the inlets. The turbulence intensity, I is defined as the ratio of the root-mean-square of the velocity fluctuations, u' to the mean flow velocity, u_{avg} for internal flows, the turbulence intensity at the inlets is totally dependent on the upstream history of the flow. If the flow upstream is under-developed and undisturbed, we can use a low turbulence intensity. If the flow is fully developed, the turbulence intensity may be as high as a few percent. The turbulence intensity at the core of a fully-developed duct flow can be estimated from the following formula derived from an empirical correlation for pipe flows [11].

$$I = \frac{u'}{u_{avg}} = 0.16\left(\mathrm{Re}_{D_H}\right)^{-1/8} \qquad (1)$$

111. RESULTS AND DISCUSSION

The effect of the grid on the results, is studied for two elements of grids; (91000), and (138107) (Fig 6).The superposition of temperature profiles with the two elements shows clearly that there is a small difference between the values. In order to reduce the calculation time the first grid is selected to conduct the various simulations.

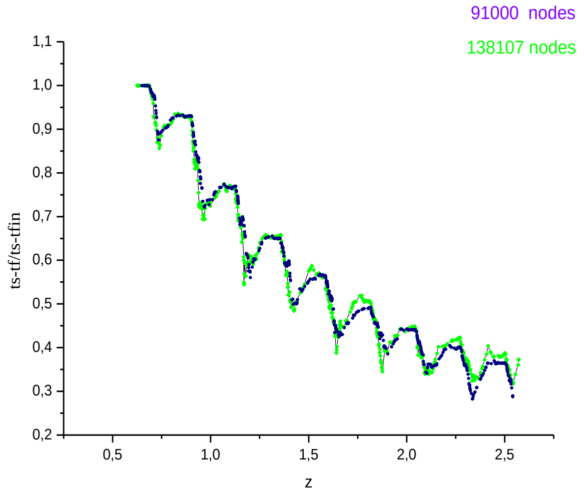


Fig.6-.Independance Grid

Figs .7 and 8 shows the static temperature profile and distribution in the porous medium; it is clear that the temperature increases along the flow direction

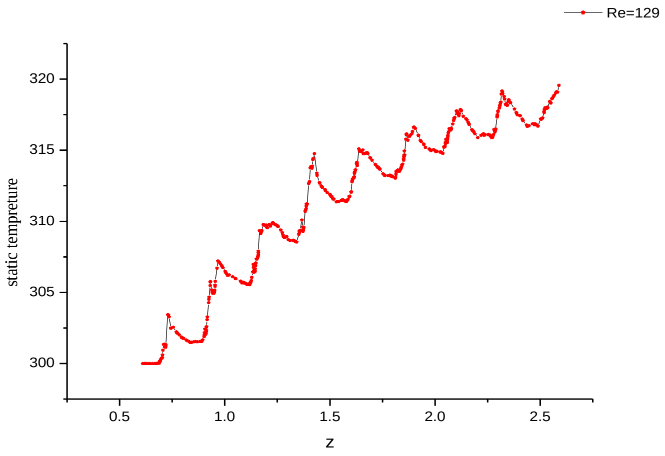


Fig. 7- Static temperature profile

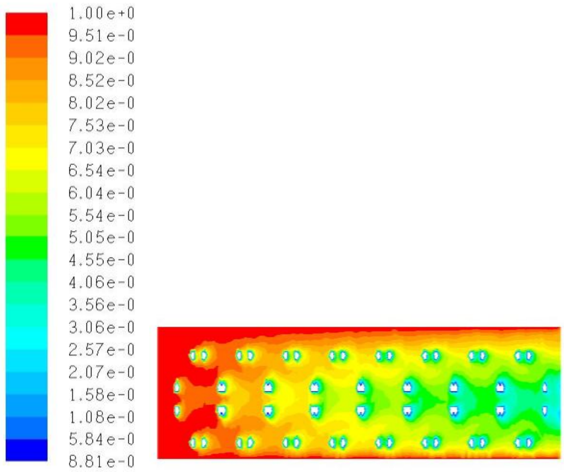


Fig.8- The temperature distribution along the flow direction.

Fig. 9 gives the dimensionless temperature distribution along the flow direction, which is defined as $(T_s-T_f)/(T_s-T_{f,in})$. T_s, T_f and T_{fin} are respectively solid temperature, Fluid temperature (air), and inlet fluid temperature, with different Reynolds numbers. According toZ. Wu et al [9].the fluid temperature exponentially increases along the flow direction,and the exponent decreases with the Reynolds number. The turbulent diffusion favores the heat transfert.

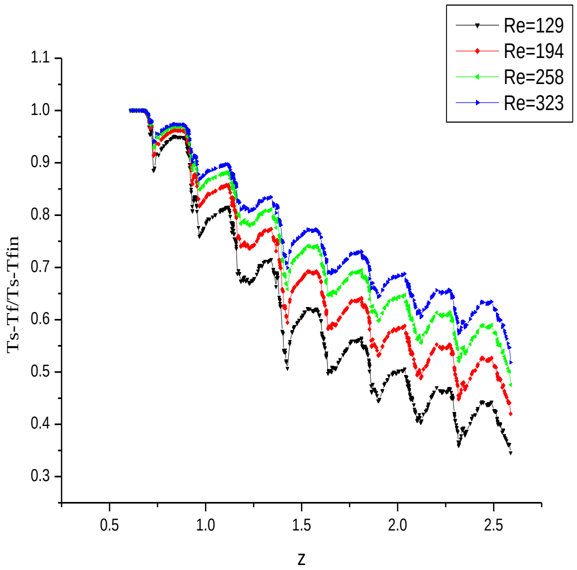


Fig. 9- Dimensionless Temperature Profiles
With different Reynolds number

It illustrates that the static pressure is linearly decreasingalong the flow direction, which is presented in Fig 10 for different temperature values T_s and T_f and affirmed by (Zhiyong wu, Cyril Caliot et al 2010).[1].

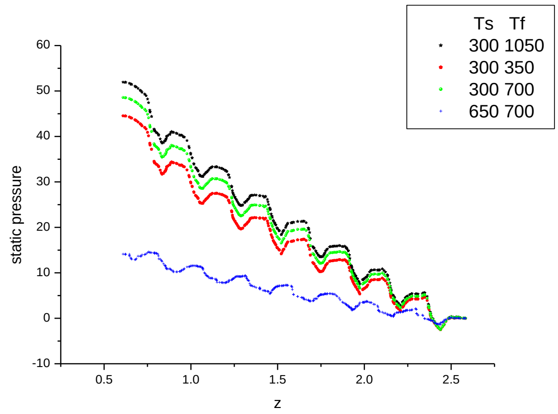


Fig. 10- Static pressure profiles.

Fig. 11shows the mean velocity distribution along the flow direction. The fluid accelerates in the region of thermal non-equilibrium because the density of air decreases with temperature[9].We can Remark that the geometry foams proposed causes a large variation in velocity in comparing our results with other works. This variation generate a high gradients inside the bulk porous media, which causes an important heat transfer, see also fig. 9.

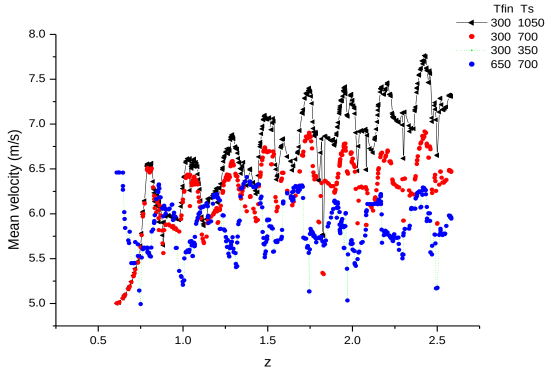


Fig. 11- Velocity Profile.

In order to see the influence of the density of foams we propose to compare two ranges of twos Fig 12 and 13with thickness of 4 and 8 mm respectively.

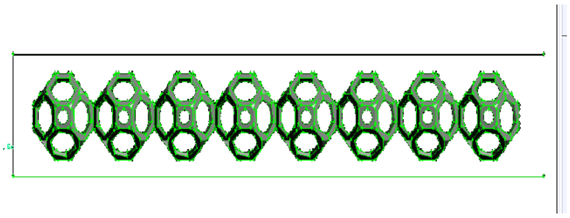


Fig. 12-geometry for y = 4mm

The temperature distributions of tow average particle diameters are shown in Fig. 14the temperature increases along the air flow direction, and as expected the receiver heat absorbing surface has the highest temperatures. The results also show that the surface temperatures are higher for the larger particles; this is confirmed by Chang Xu et al, [12].
The two ranges of foams causes more fluctuations and gradients and gives highly temperature.

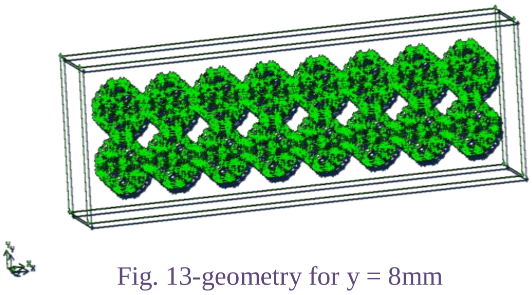


Fig. 13-geometry for y = 8mm

Fig.15shows the static temperature for different conductivities, (0.65,0.70,1.07)The samples named , SP2, SP4, were prepared using , 1:49, 1:24, mass ratio ofDC249TM silicone resin and SiC(Xiuwen Wu et al))[13]it is observed that the conductivity increases more over the temperature increases,the material plays an important role for the temperature distribution.,

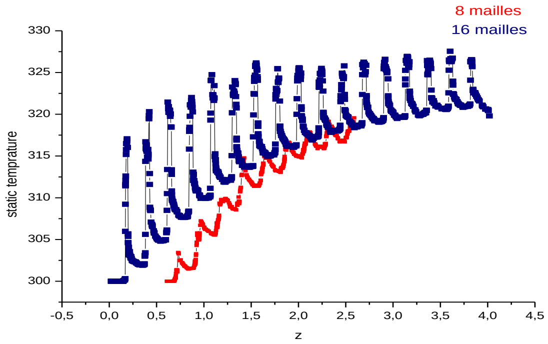


Fig. 14- Profile of temperature of tow thickness

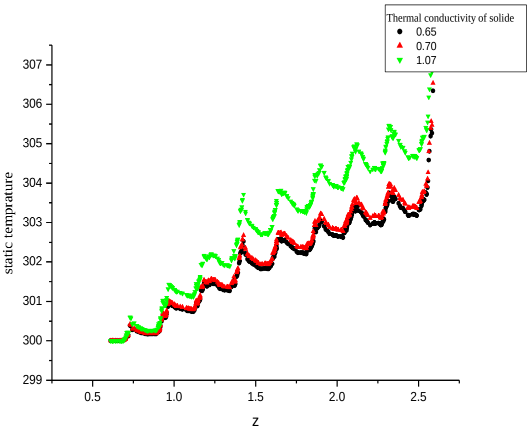


Fig 15-fluid temperature distributions for various solid thermal conductivities

Conclusion

In this study, an instationary turbulent air flow in ceramic foams was performed by using the fluent software.

- The effects of the geometric parameter and the walls temperature on the air flow in the porous medium are investigated.

A sensitivity study was conducted to see the effect of the inlet velocity, porosity, and thermal conductivity.

- The static pressure linearly decreases along the flow direction. The mean velocity increases in the entrance zone. And presents large fluctuations through out the entire porous medium.
- The mean fluid temperature increases along the flow direction,
- The thermal conductivity of the solid phase of the absorber material is important to perform the volumetric solar air receiver,the material plays an important role for the temperature distribution
- The surface temperatures are higher for the larger particles

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