Fluid Flow Simulations Using New CFD Module – Wood drying simulation

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Abstract:

The new CFD module has been tested for a drying application: Wood drying by a forced air flow has been simulated in 3D by a coupled solving of porous flow simulation, thermal transfer, humidity transfer and transient wood humidity calculation. The air injection system is simulated in order to show if homogeneity of drying depends on the injection equipment or not.
For planning reasons this work doesn't correspond to the initial abstract.

Keywords:
CFD module, fluid flow, porous flow, heat transfer, humidity transfer, multiphysic coupling, drying process

1. Introduction

The wood as energy resource is more and more widely use since few years, especially in regions with large wood resources and for heating of large buildings. Most of the large boiler plants use small plaque of wood. One of the most important parameter to get a good boiler return is the plaque humidity. Lower the humidity higher the return is, but the most important think for boiler managing is to get a constant humidity in time. Even you don't want a very low humidity you need a drying system in the storage plant to supply plaque with constant humidity.

This report shows the 3D simulation of a drying test at industrial scale and compare the results with measurements.

2. Models

2.1 Geometry and mesh

The drying test has been performed in a parallelepiped tank (Illustration 1) with bottom air injection through inverted U shape channels. The air injection flows from a DN200 tube inside the separated inlet box in the tank and then in the three U channels. These ones are inverted U with a thin space under it, 3mm thick, to let air flow inside the tank. The tank is fulfill by the wood plaques.

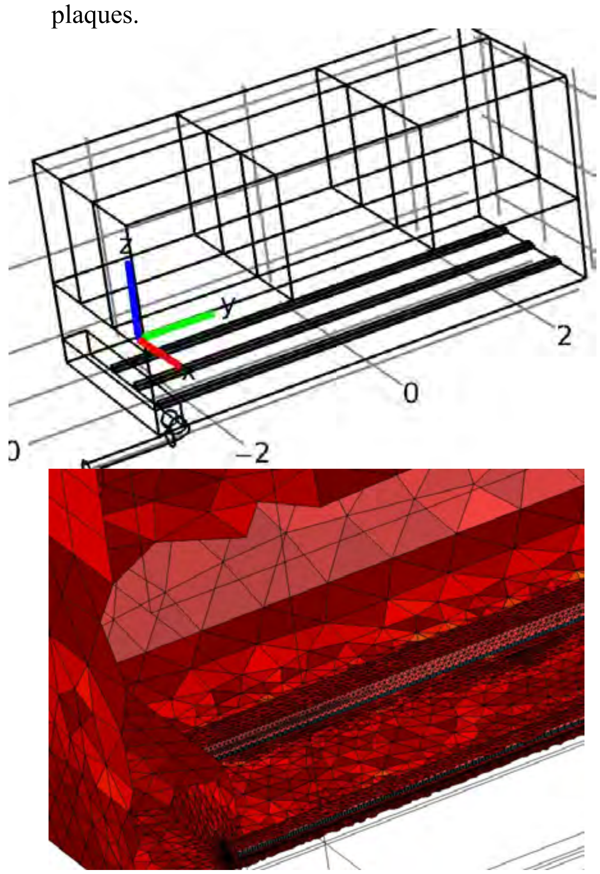

Figure 1. Geometry (top) and detail of the mesh of U shape canal of air injection (bottom).

The mesh is builder with the following stages: the three U channels are meshed using boundary layer mesh tool after meshing the thin surfaces under the U walls by mapped mesh tool and cut of the rectangle elements. This allow to get at least three elements in air flow. Then the inlet tube and inlet zone are meshed also using boundary layer mesh tool. Thirdly the bottom part of the tank is meshed in the same way, and the top parts are meshed using elevation. The total mesh contains almost 500000 elements and the worst element quality is more than 0.2.

2.2 Models

The model for inlet free flow is “nitf” mode : turbulent air flow coupled with heat convection. This mode is not solved in the tank domain.

In the tank domain we assume that the wood plaques storage may be considered, at tank scale, as a porous media. We define models of three other modes : the flow in porous with the thldl” mode (Darcy flow), the “ht” and “chpm” modes to solve heat transfer in porous media and by convection and humidity transfer by convection, and then another “ht” mode model to count absolute wood humidity we call “xbois”.s”.s”.. The drying speed depends on the the difference between wood humidity and wood humidity in equilibrium with air:

$$m_{0.}dX/dt \quad = \ k_X .S .(X - X^*)$$

with
$k_X = (6{,}814.10^{-6}.(T\ ^{2}\ 273) + 6{,}027.10^{-5}).(1 - HR).100 / 60$ in kg.m-2.s-1

and
S the specific surface of wood plaques assumed to be 770 m^{-1}.

The air flow rate is constant. So we defined two studies, one to solve in stationary assumption the air flow in injection system and in the tank, the second to solve in transient form the three other models. The initial thermal field is obtain by a stationary solving of heat transfer.

2.3 Boundary Conditions

The following conditions are used:

- Injection tube inlet: Air temperature and flow rate,
- Thin spaces under the U channels:
    - outlet of free flow, pressure is equal to pressure from “dl” mode solving (Darcy flow in thank).
    - Inlet of porous media flow, velocity is equal to perpendicular component of free flow velocity field.
    - Temperature is continuous.
    - Air humidity is fixed to external value (depending on time).

Surface of the tank: outlet of porous media flow: atmospheric pressure and heat leak due to air free convection.

2.4 Methodology

Some of the models parameters are not well known because they depends on the wood, especially the porous models parameter and the specific surface of the plaque:

- The porosity is calculated from the external volume, the measured initial weight and the dry wood volumetric mass: it is known when the storage contains only one species. We used the value of 450kg/m3.
- The permittivity is not known and has been fitted from the comparison of calculated and measured pressure drop.
- The specific surface of the plaque in the storage isn't well known even if it is related to the permittivity. It's value was fixed from the J. AST [1] thesis to 770m-1, but this value may also be fitted . This may be done after checking other uncertainties effect, in particular the air temperature variations during the day cycle.

3. Results

The pressure drop in the tank is 14mbar after permittivity fitting in order to obtain the measured total pressure drop: 22mbar. The permittivity is equal to 0,46 10-8 m2 for a porosity of almost 0,5.

The velocity field of free flow is shown on Figure 2. The air flows to the second and third channel, but do a kind of recirculation inside the first channel inlet. Despite this strange flow shape, the flow rate is higher in the first channel. The air velocity rise up to 50m/s inside the channels for an inlet velocity of 11m/s.

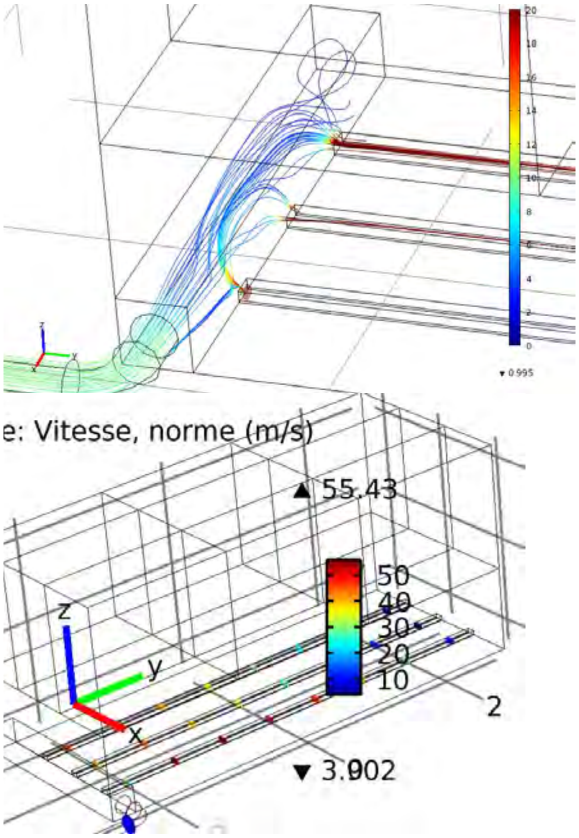

Figure 2: Current lines (top) and cut planes (bottom) colored by velocity (m/s) in the air injection.

The wood humidity simulation depending on the plaques position in the tank and depending on time is the main result of the study. The initial humidity is assumed to be equal to the measured average value of 0,35. During the first ten days, the wood plaques are dryed from the bottom of the tank. The humidity decreases faster bellow 0,15 but only in a small area. Then this area grows and a drying front slowly goes up.

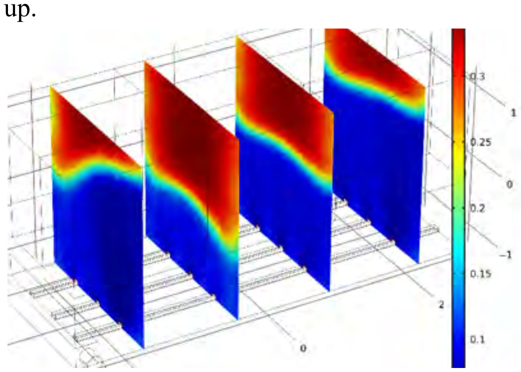

Figure 3: Wood plaques absolute humidity depending on time, after 6 days on top (scale maximum 0.35 which is the initial humidity)

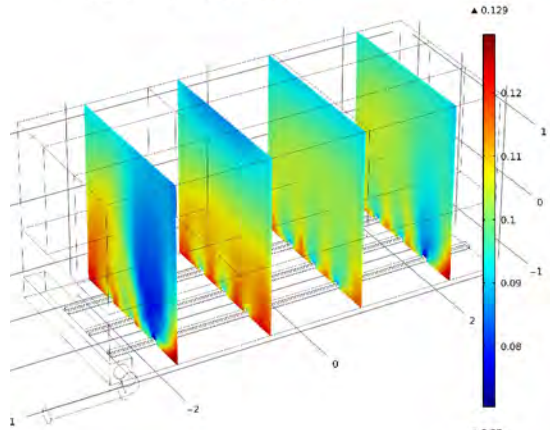

Figure 4: Wood plaques absolute humidity depending on time, after 14 days (maximum scale 0.12)

On the Figure 3 and 4 we see the dryed part in blue, and the red upper part were the humidity is still almost equal to 0,35. During this first part of the drying the heat consumption of water evaporation is limiting the drying speed. This can be seen on the temperature fields on Figure 5. The temperature decrease strongly on the drying front inducing a large increase of air humidity (Figure 6).

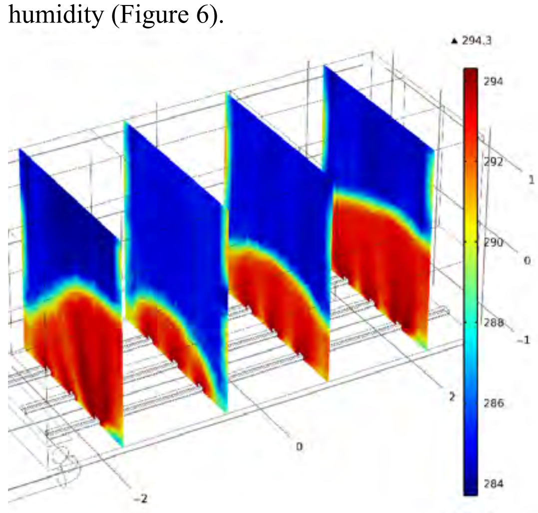

Figure 5: Temperature after 4 days of drying

On the Figure 6 we can also see the injection effect on drying homogeneity. Near the air injection, where the air speed is higher, the humidity decrease is faster.

In second part of the drying, the wood humidity decrease is more slow and isotropic. But this kind of drying under 15% is not necessary.

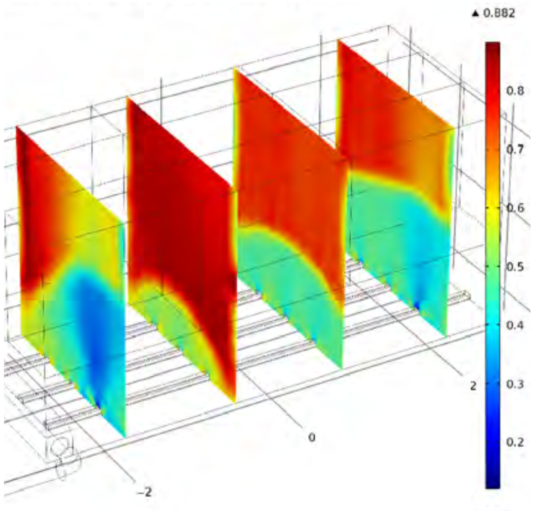

Figure 6: Relative humidity of air after 4 days of drying

5. Conclusions

A drying test of wood plaques has been simulated using the CFD module. This study, made in 3D, shows the effect of air flow repartition on drying speed. The beginning of the drying is limited by heat consumption of evaporation. A drying front goes up slowly and may be kept horizontal if air injection is well designed. To study other parameters effect, as flow rate, temperature, day cycle, a reduced model, for example in 1D may be used.

8. References

1. J. AST thesis, “ETUDE DE L'EVOLUTION DES CARACTERISTIQUES PHYSICO-CHIMIQUES DES PLAQUETTES FORESTIERES EN FONCTION DES MODALITES DE STOCKAGE ET DE SECHAGE”*, 9/12/2009 Bordeaux 1 university.*