# COMPUTATIONAL CASE STUDY OF BIOMASS CO-COMBUSTION IN A PILOT FLUIDISED BED REACTOR

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*OBJECTIVES: The aim of the paper focuses on a numerical study by means of the FLUENT code 6.2, accomplished on a pilot for co-combustion of Lignite and biomass. The novelty is developed also by the fact that the analysis is achieved not on classical pulverized combustion, but on a combination of fossil fuel with a renewable source working in a fluidized bed, and is developed on basis of results accomplished during pilot teststs. The facility built at the University Politehnica of Timisoara allowing the co-combustion in fluidized bed works in the range of 25 – 50 kg/h Lignite and 15 – 30 kg/h biomass.*

*By appropriate discreet dividing of the combustion space in cells one succeeded, by applying the latest FLUENT code 6.2, to determine different representative distributionss. The results have been accomplished in the frame of a national Excellency project, financed by the Ministry of Education and Research, which are addressed thanks for the financial support.*

*CONCLUSIONS: The optimization of the combustion is possible also by innovative studies using the modeling tools for different concentrations of pollutants and other combustion products, as well as energy fields. Also modeling is a fruitful tool to compare different solutions, priorto testing.*

**Keywords:** biomass, co-combustion, fluidized bed, CFD, FLUENT.

## 1. Introduction

The research described in this paper presents results from biomass co-firing simulation in a fluidized bed combustor. The paper focuses on a FLUENT classical approach, in order to get reasonable results to compare modelling results to the real experiment that was realized on an pilot rig, designed to study the real biomass combustion and the possibility of flue gas cleaning. It is very hard to simulate with FLUENT a fluidized bed combustion due to the lack of suitable mathematical models. The fuel used is a mixture of Lignite with biomass (sawdust) using different ratio mixtures.

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Elementary analysis of the lignite, biomass and mixture are presented in Table 1, under boundary conditions [1]. Objectives of numerical simulation are the simulation of the fields for the temperature in combustion chamber and the chemical species distribution in furnace ($CO_2$, $N_2$, $O_2$, $H_2O$, CO and $H_2$).

*Table 1*

**The RAW composition of fuels, on humid basis**

| | U.M. | Biomass | Lignite | 10B+90L | 20B+80L | 30B+70L | 40B+60L |
|---|---|---|---|---|---|---|---|
| C | % | 44.60 | 20.20 | 22.640 | 25.080 | 27.520 | 29.960 |
| H | % | 5.80 | 1.83 | 2.227 | 2.624 | 3.021 | 3.418 |
| O | % | 38.36 | 9.90 | 12.748 | 15.592 | 18.438 | 21.284 |
| N | % | 0.90 | 0.57 | 0.603 | 0.636 | 0.669 | 0.702 |
| S | % | 0.12 | 0.70 | 0.642 | 0.584 | 0.526 | 0.468 |
| A | % | 0.25 | 30.20 | 27.205 | 24.210 | 21.215 | 18.220 |
| W | % | 9.97 | 36.60 | 33.937 | 31.247 | 28.611 | 25.948 |
| Total | % | 100.00 | 100.00 | 100.000 | 100.000 | 100.000 | 100.000 |

## 2. The analysis domain

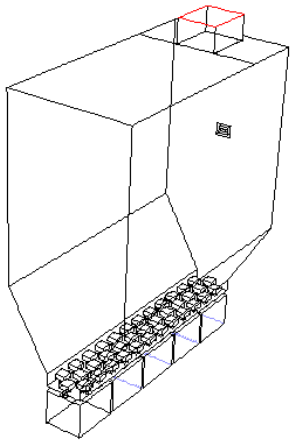

Fig. 1 Design of combustion chamber for co-combustion

Figure 1 shows the design of the fluidized bed furnace. Main dimensions are:

- length: 1 m;
- width: 0.5 m;
- height: 1 m.

The presented geometry is exigent of three-dimensional modeling because the air distribution through the 37 nozzles set up a 3D flow witch cannot be similar with bi-dimensional flow. The inlet and outlet of the nozzles were assimilated with rectangular surfaces for an optimal discretization with hexahedral elements. The combustion air inlet is situated at the bottom, and at the top is the outflow from the domain.

The domain drawing and meshing was done with GAMBIT 2.2. Dicretization was made with hexahedral elements and the grid got over 200 000 cells, exactly 207 872 cells.

## 3. The mathematical models

The present problem is a fuel with empirically known analysis combustion. In this case the non-premixed combustion (PDF) is the only

combustion model available [1]. As in the FLUENT offers two approaches to simulate a fluidized bed, one had to decide for applying between:

- The Eulerian formulation, as continuum, that is suitable for VOF (volatile organic) simulation, but not compatible with PDF model;
- The Lagrangean formulation, as discrete phase (liquid or solid particles) in a fluid phase, that is compatible with the PDF model, but with certain limits. The main limitation requires that the volume of disperse phase do not exceed 10 % from fluid phase volume ( for the mass there is no limitation). This limitation is acceptable for a circulating fluidized bed, but not very suitabel for a boiling fluidized bed, where the solid phase volume is 30 – 40 % from total.

Under these circumstances, one selected the Lagrangean model to be used. The combustible phase was charged like solid combusting particles in the fluid oxidant phase. By using PDF model, it is indispensable that the combustible flux must be the combusting particles, and it is introduced as disperse solid phase injections. The fuel with empirical defined analysis is done in FLUENT only at dry, ash free (DAF) level mass. The mineral matter may be considered as a fuel with a zero content of volatile matter and char (meaning it does not release combustible matter, and does not influence the combustion), but with ash density, specific heat and conductivity value.

The moisture in liquid phase is released very quickly, it takes about 0.01 s. The energetic aspect of the vaporization of the moisture is taken into consideration by reducing the fuel heat value. As a result the entire moisture may be considered like gaseous state (vapors) and included in the combustion air composition.

For simulation following phases were adopted:

- The combustible phase, consist from injections of solid particles of DAF mixture, as disperse phase. The distribution of particles is considered Rosin-Rammler type (RR);
- The oxidant phase consists from the air and the fuel moisture;
- Concerning the combustion model for ash a separate phase is not necessary.

Concerning the selection of the model, one used according to [2], [3]

- the Solver, characterized by being segregated, implicit, 3D, steady,
- velocity formulation: absolute;
- energy: enable;
- turbulence model: k-ε standard;
- radiation: DO (discrete ordinates);
- discrete phase: enable, allowing the interaction with continuous phase by radiation; multiphase: off.

## 4. The boundary conditions

### The inlet and fuel injections boundary conditions

As fuel was a mixture of biomass (B) with Lignite (L), by fractions:

- 10 % biomass + 90 % lignite (10B+90L),
- 20 % biomass + 80 % lignite (20B+80L),
- 30 % biomass + 70 % lignite (30B+70L) and
- 40 % biomass + 60 % lignite (40B+60L).

Table 2 shows a set of inlet values.

*Table 2*

**Calculated values for inflowing**

| Parameter | U.M. | Value |
|---|---|---|
| RAW mass combustible flux | kg/s | 0,011879 |
| DAF mass combustible flux | kg/s | 0,004496 |
| Low heating value of the RAW mixture | kJ/kg | 6435 |
| Low heating value of the DAF mixture | kJ/kg | 17000 |
| Reduced low heating value of the DAF mixture by moisture vaporization | kJ/kg | 13800 |
| Combustion air mass flux | kg/s | 0,0478 |
| Air moisture mass flux, including the fuel moisture | kg/s | 0,0057 |
| Post combusting air mass flux | kg/s | 0,0146 |

Particle-size distribution of the fuel is: minimum diameter of fuel particles 0.5 mm, maximum diameter of fuel particles 5 mm, diameter of particles from dominant class 1 mm and scattering parameter n=2.

### The outlet boundary conditions

The outflow is “free” type without any special condition. From radiation viewpoint is considered black body (absolute absorber).

### The wall boundary conditions

The walls are isolated, without cooling and are considered adiabatic. From radiation viewpoint the entire thermal flux is returned to the fluid (flue gases) through convection and radiation, the wall temperature being stabilized.

## 5. Results

Table 3 presents a series of global values related by Fluent software to domain boundary conditions.

*Table 3*

**Global values related to domain boundary conditions**

| Parameter | U.M. | Value |
|---|---|---|
| Air + moisture mass flux at inlet | kg/s | 0,05356 |
| Post combusting air mass flux | kg/s | 0,01452 |
| Flue gas temperature at outlet | ºC | 1189 |
| Mole fraction of $CO_2$ | % | 9,75 |
| Mole fraction of $O_2$ | % | 4,88 |
| Mole fraction of CO | ppm | 1,23 |
| Mole fraction of NO | ppm | 416 |

The simulation results related to combustion chamber fields are presented in the next figures (figures 2-13):

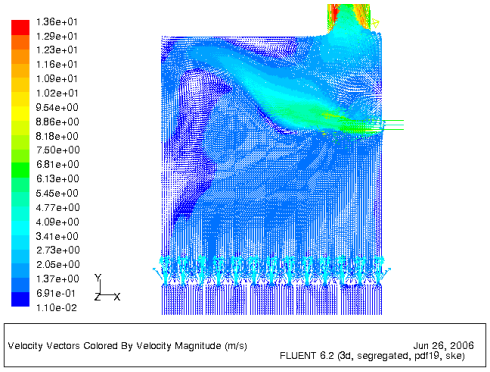


Fig. 2 Velocity vectors.

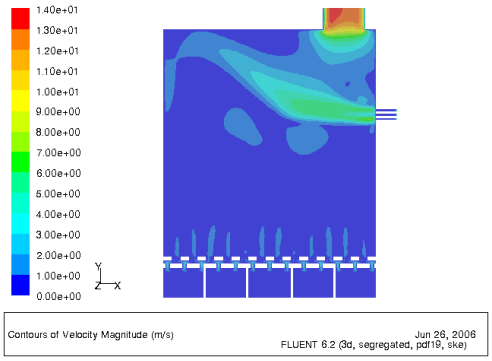


Fig. 3 Velocity magnitude [m/s].

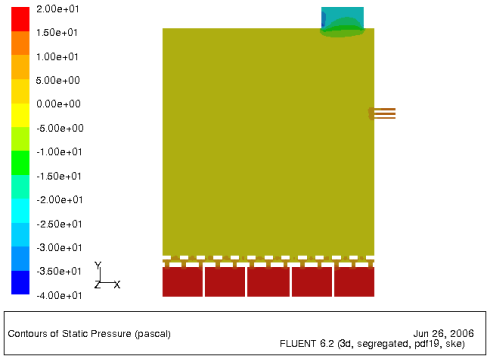


Fig. 4 Static Gauge Pressure [Pa].

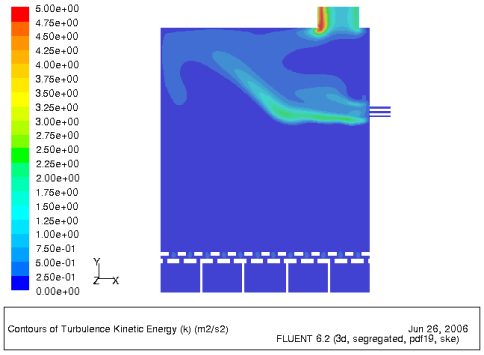


Fig. 5 Turbulent Kinetic Energy (k).

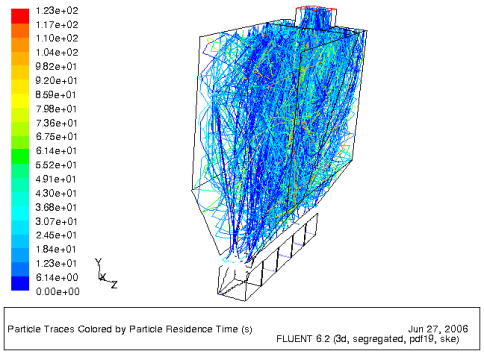


Fig. 6 Particle Traces.

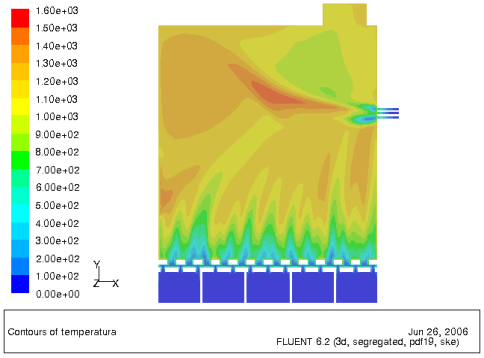


Fig. 7 Temperature field [$^{o}$C].

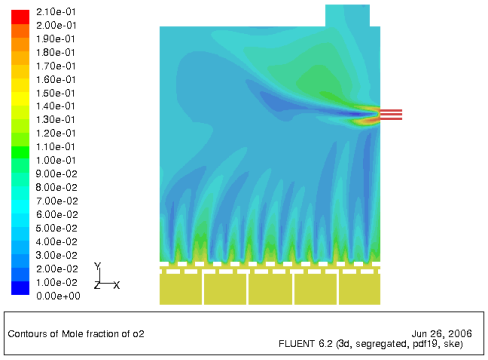


Fig. 8 Mole fraction of $O_2$.

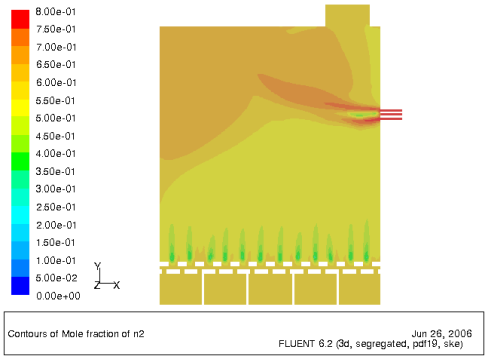


Fig. 9 Mole fraction of $N_2$.

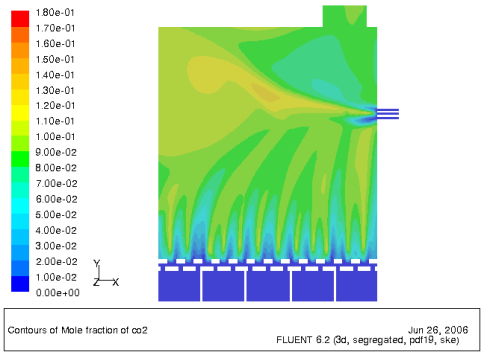


Fig. 10 Mole fraction of $CO_2$.

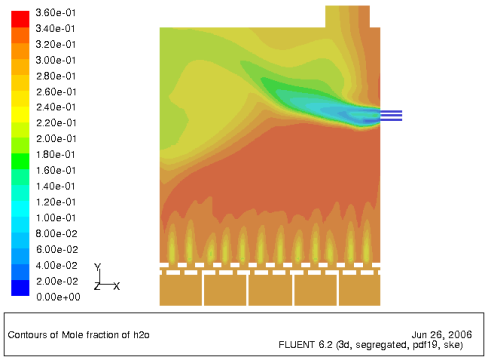


Fig. 11 Mole fraction of $H_2O$.

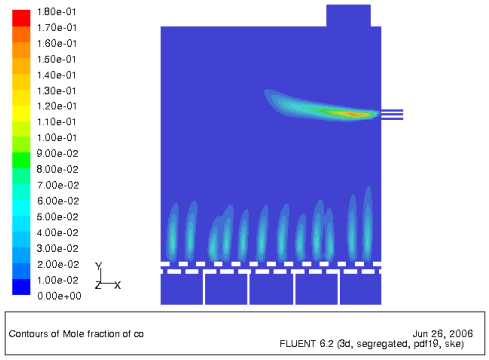


Fig. 12 Mole fraction of CO.

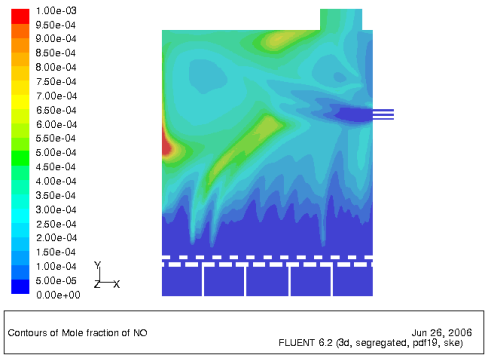


Fig. 13 Mole fraction of NO.

## 6. Conclusions

- The temperatures at the combustion zone outlet are above 800 ºC, thus, the not cooled walls must be made by a temperature resistant material;
- The flue gas high temperatures at the combustion zone outlet necessitates flue gas cooling, according to the installation's design;
- The amount of the combustible components (CO + $H_2$) at the outlet is very small; accordingly, no special measures need be taken;
- The simulation with FLUENT of a fluidized bed in the experimental installation is at a pinch of FLUENT possibilities. The temperatures and species concentration fields in fluidized bed zone are not uniform, misfit the experimental measurements. A granular fuel combustion model is needed.

## Acknowledgement

This work has been carried out with foundings awarded by the Romanian Government in the frame of excellency research projects (TECEBAC, OVAPED). For the general co-ordination and scientific advice the coordinator and partners are warmly acknowledged. Also founding through the CORINT research support has been granted.The anonymous referrers of the paper and the conference organizers are warmly acknowledged.

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