Simulation of wood biomass combustion in hot water boiler

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Abstract. Calculation methods based on finite volume methods (CFD method) have proven to be very useful in optimizing (efficiency, emission) heat sources for wood burning. Such heat sources also include gasification hot-water boilers for the combustion of dry wood. One of the important parts of the entire process of converting the primary energy contained in the fuel to the transfer of heat to the heat carrier is the gasification of the fuel in the feed chamber and the subsequent burning of wood gas.

The paper presents CFD simulation of wood gasification process in the filling chamber and subsequent burning of wood gas on a model heat source.

As a model heat source, was selected a hot-water boiler with lower fuel firing with a flue gas-water heat exchanger tubular heat exchanger. It is a gasification hot water boiler for the combustion of dry wood. The interior of the boiler consists of a filling chamber where the fuel is dried and fused. The wood gas then passes through the nozzle to the combustion chamber, where it burns with the aid of secondary air. The flue gases pass their heat in the heat exchanger through the walls of the pipes into the water.

1. Introduction

Currently, the efficient use of all forms of energy is being intensively discussed. The basic indicator is not only the amount of energy gained, but also its efficiency and the burden on the environment. Small heat sources for burning wood and its various forms should also meet these indicators.

In the optimization of the flue gas heat exchanger, a hot water boiler of the EKOS 10 - 30 type was used as a model heat source for the optimization of its thermal parameters; It is a gasification hot water boiler for the combustion of dry wood. Figure 1 the interior of the boiler consists of a filling chamber where the fuel is dried and fused. The wood gas then passes through the nozzle to the combustion chamber, where it burns with the aid of secondary air. The flue gas transfers its heat to the heat exchanger and the boiler shell, which is filled with water. At present, the EKOS 10-30 boiler uses a pipe counter-flow flue gas exchanger - water 60 x 40 x 80 cm, with a tube diameter of 70 mm and a number of pipes 10.

Figure 2 shows the boiler model in Fluent, whose geometry was created in the Gambit program. When creating the geometry itself, a part of the boiler containing boiler water was omitted to simplify the calculation.
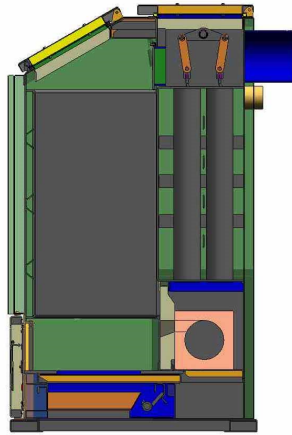

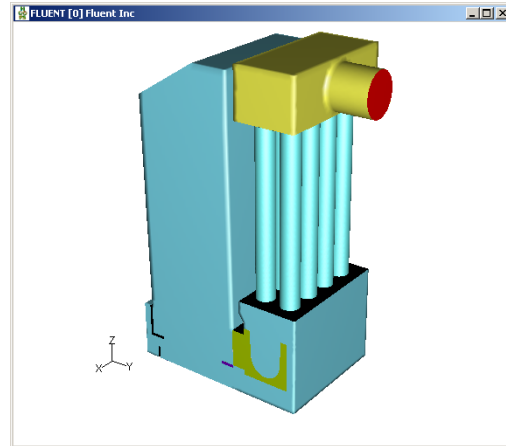**Figure 1.** Cut of hot water boiler EKOS 10-30.

Figure 2. The boiler model in Fluent.

2. Kinetic parameters of wood gasification

The complexity of wood gasification (pyrolysis) often leads to the choice of kinetic parameters that are applied to different cases. Since wood degradation is low during long-lasting elevated temperatures and volatile emissions are ignored, the following simple Arrhenius reaction equation of first order was found:

$$\frac{dm}{dt} = Am\,exp\left(-\frac{E}{RT}\right)$$

where t is time, A is the pre-exponential factor, E is the activation energy, R is the general gas constant, and T is the thermodynamic temperature.

The activation energy for wood ranges from 96 to 147 kJ/mol. To simulate the burning of wood in boilers, the Fluent calculation program was used in which the following boundary conditions were specified:

- Standard k-ϵ turbulence model,
- Standard wall function,
- solution setup - segregated, stationary, implicit,
- P1 radiation model
- kinetic model of combustion (two chemical reactions)
- DPM model (discrete phase model) with stationary burning particles, which represented pieces of wood with a diameter of 5 cm and were placed over a grid of 18 pieces, each particle having a specified wood gas flow rate of 0.0001 Kg/s,
- ambient pressure 101 325 Pa
- the air inlet was entered as a pressure input with a value of 0 Pa and a mass fraction of oxygen of 0.23,
- the flue gas outlet has been entered as a pressure output of -1 Pa

- heat transfer through walls was calculated by convection by entering a heat transfer coefficient of 600 W/m^2 also by radiation,
- heat transfer through the walls of the heat exchanger pipes was entered similarly as through the walls of the furnace,
- pre-exponential factor = 6.23.107 s^{-1},
- Activation energy = 124 kJ/mol,
- two-step carbon black formation, thermal NO_x formation.

3. The results

The air is sucked through the grille down the front of the boiler, further divided into air, which goes directly between the grate and the air inherited in the grate rods itself, and then sucked into the burner where it reacts further with the wood gas and CO if this can be seen in the figure 3:
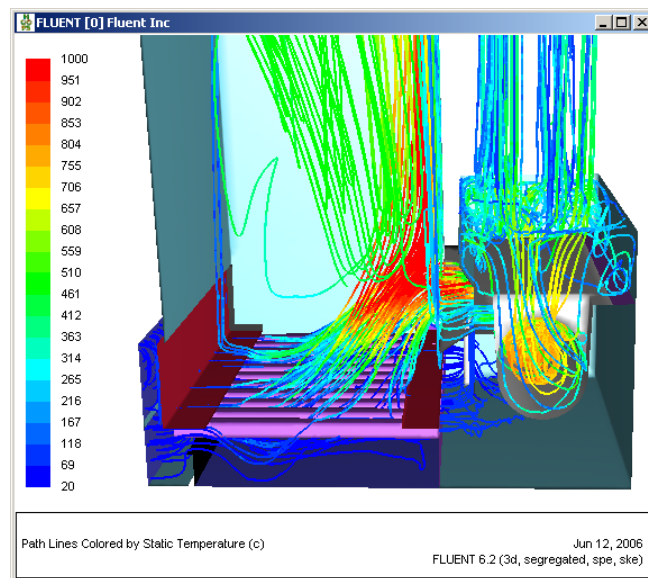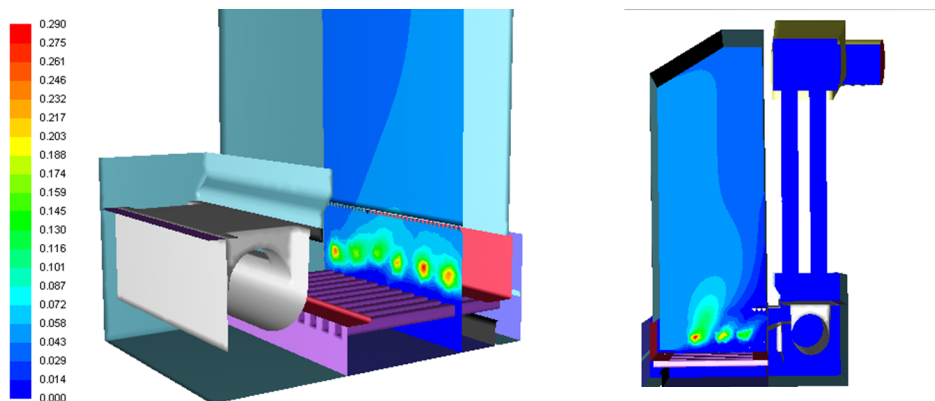

Figure 3. Gas flow trajectories with temperature.
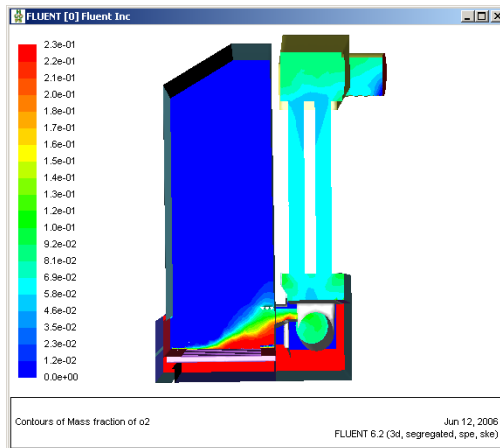

Figure 4. The mass fraction of wood gas contours.

Figure 5. O$_2$ mass fraction contours.
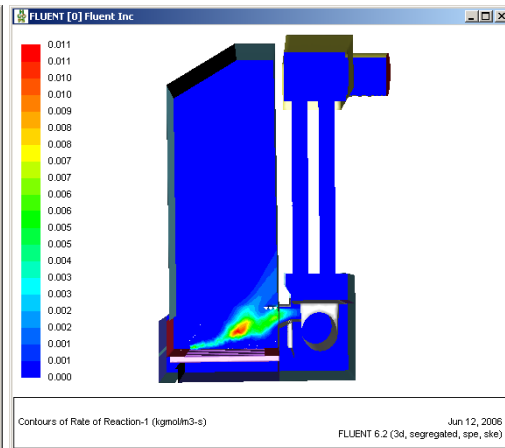

Figure 6. Reaction rate.

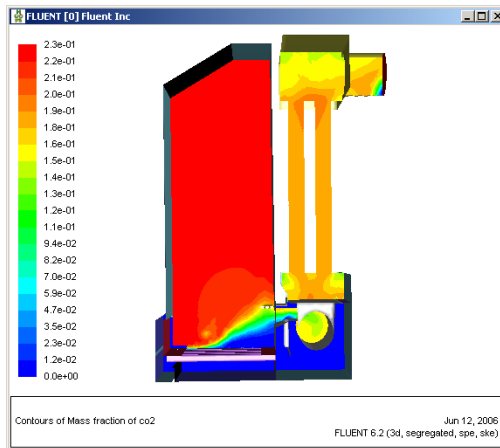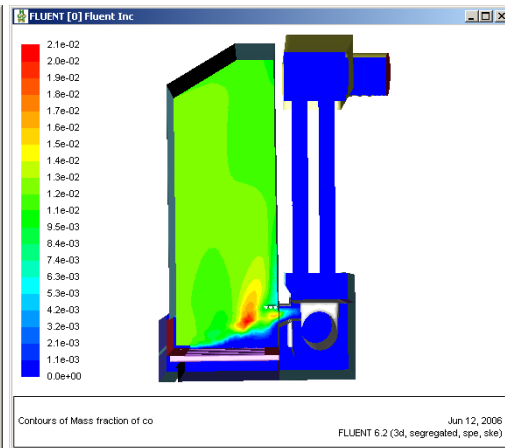**Figure 7.** CO$_2$ mass fraction contours.

Figure 8. CO mass fraction contours.

Figure 4 shows the contours of the mass fraction of wood gas which is released from 18 elements with a diameter of 5 *cm*. These 18 elements are arranged in three rows of six pieces. Figure 5 shows the O$_2$ mass fraction contours where it can be seen that the highest concentration is at the bottom of the boiler. In figure 6 are the reaction rate contours that are highest near the wood gas and oxygen contact points. From figure 7 it can be seen that the CO$_2$ concentration is of the highest value in the wood gasification chamber. Figure 8 shows the mass fraction contours of CO.

The NO fractions of the mass fraction are visible in figure 9. NO is formed mainly at lower temperatures and sufficient oxygen concentration, that is, in the region of the tubular heat exchanger, but they are negligibly small. The carbon black contour fractions are shown in figure 10. The heat flow through the boiler walls was about 7 *kW* and the heat flow through the heat exchanger tubes reached only 3.5 *kW*. These findings make it necessary to change the structure in the area of the tube exchanger by increasing the number of heat exchanged areas, i.e. by increasing the number of tubes. It would also be desirable to optimize the flow in those pipes because the calculations showed its unevenness.
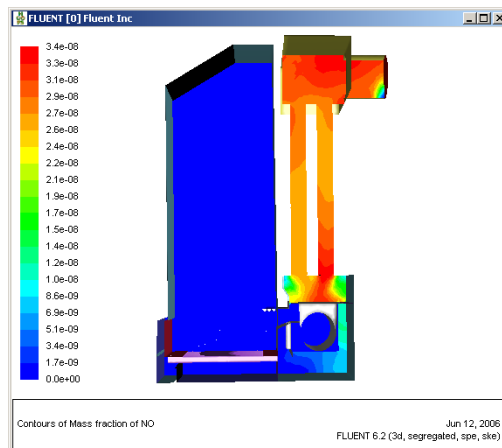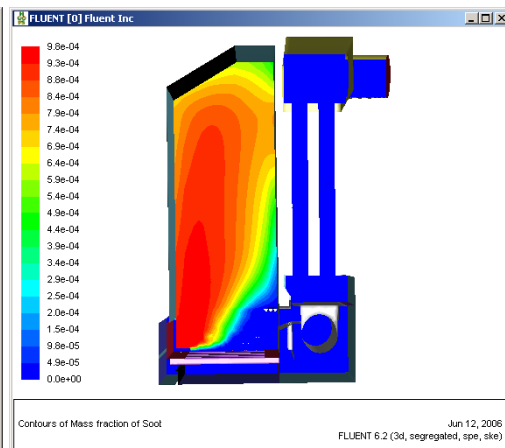
Figure 9. NO mass fraction contours.

Figure 10. The contours of mass fraction of soot.

4. Conclusion

The first results of simulating the process of wood gasification, wood gas burning and heat transfer by CFD methods on a model boiler point to the advantages that these methods allow. After gradual refinement of the model and its verification by measurements, the model is used to optimize the boiler and its thermal parameters.

5. Acknowledgement

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