Determination of the Working Parameters of the Biomass Boiler

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Abstract. The modern day trend is associated with the green energy. Thermochemical conversion is the commonly used way of extraction energy from the biomass. Nevertheless, the thermochemical processes of the combustion are not totally known. The simulation model of the woodchips boiler was made to understand the processes inside. Simulation model was made for Ansys Fluent 2019. Combustion model consist of two combustion stages: 1st – combustion of volatile compounds, 2nd – combustion of the solid parts. The simulation was validated by the series measurements at the boiler HERZ firemytic 80 BioControl.

1 Introduction

Biomass is produced by solar energy and from the energy point of view it serves as its accumulator. The advantage of biomass is that it can store energy relatively easily and in the long term. The disadvantage is the low efficiency of the conversion of solar radiation into energy. Biomass with an energy content of 40 to 90 MWh can be obtained per hectare per year, depending on the type of crop. This is less than 1 % of the solar radiation that will reach this area per year. Further losses are incurred when biomass is processed into fuel and burned to obtain heat or electricity [1, 2].

Biomass in terms of possible energy use includes any organic source containing bound chemical energy, wood and wood waste in various forms, agricultural crops and waste, animal and food waste and biodegradable fractions of industrial and municipal waste [1, 3]. Unlike fossil fuels - coal, oil and natural gas - the combustion of fresh (non-fossil) biomass is almost neutral in terms of carbon dioxide (the main greenhouse gas) emissions in a changing climate. Indeed, the amount of carbon in the form of carbon dioxide produced by the combustion of non-fossil biomass is equal to the amount of carbon that plants have "withdrawn" from the atmosphere through photosynthesis during their lifetime [1, 4].
Energy can be extracted from biomass in several ways, which can be divided into three basic categories:

- Thermochemical conversion (direct combustion, pyrolysis or gasification).
- Biochemical transformation (anaerobic fermentation or aerobic fermentation).

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- Mechanical-chemical conversion (oil pressing or esterification of crude bio-oils).

Thermochemical conversion is the commonly used way of extraction energy from the biomass. The solid fuel combustion process may be represented as a series of successive stages. Initially, the fuel is heated and the moisture is evaporated. Then, at temperatures above 100 °C, the pyrogenic decomposition of high molecular weight complex organic compounds and volatile release begins, while the onset of volatile release depends on the fuel type. When the ambient temperature exceeds the ignition temperature of the volatiles, they ignite, thereby ensuring further heating of the biomass particle before ignition. The higher the yield of volatiles, the lower their ignition temperature, while increasing heat generation [5-7].

Modern biomass combustion equipment has approximately 95 % efficiency what is competitive to a fossil fuel.

The main idea of the article is to develop simulation model of the woodchips boiler for the purpose of simulation of the solid biomass combustion process.

2 Materials and methods

2.1 Boiler and measurement scheme

The research equipment consists of woodchip boiler HERZ firemytic 80 BioControl and reference measurement system Testo 360. The technical parameters of the boiler and measurement system are at the Table 1.

Table 1. The technical parameters of the boiler and measurement system.

Boiler	
Type	HERZ firemytic 80 BioControl
Fuel	woodchips
Minimum output, kW	24.9
Maximum output, kW	83.0
Heat output in fuel rated thermal output, kW	90.1
Boiler class	3
Testo 360	
Temperature, °C	-40…1200
O_2	0... +21 Vol.% O_2
CO_2	0... +25 Vol. % CO_2
CO	0... +10000 ppm CO

As a fuel were chosen mix of deciduous and coniferous trees woodchips, which are commonly used for energy purposes in Eastern Slovakia region. The elementary analysis of the fuel is at the Table 2.

Table 2. The elementary analysis of the fuel.

Parameter	Value
C	53.55 %
H	6.4 %
S	0.13 %
N	0.28 %
W	7.14 %
A	0.88 %
Biomass content	98.1 %
Volatile content	81.41 %
Emission factor	86.04 tCO_2/TJ

2.2 Model description

Simulation model was made for Ansys Fluent 2019. The geometry of the model was made in Ansys Design Modeller accordantly to the real boiler dimensions. There are some approximation of the model comparing to the real boiler which have insignificant impact on the simulation results.

The calculation grid of the model was made via Ansys Mesh (Figure 1). The tetrahedrons were used as a grid cell type. The max skewness of the mesh was 0.74 and the min orthogonal quality was 0.2 and average 0.75, what is much better than appropriate to the solver (max skewness 0.95; min orthogonal quality 0.05). Total number of mesh elements was 772 539.

In the simulation next calculation models were chosen: energy, realizable k-ε, radiation, non-premixed combustion and discrete phase. Input parameters were chosen according to the boiler characteristic. There are two types of combustion calculation in the model. The first one simulate combustion of the volatile so it is homogeneous when the second type simulate combustion of the carbon as a solid part. The convergence of the simulation was chosen at 10^{-3}.

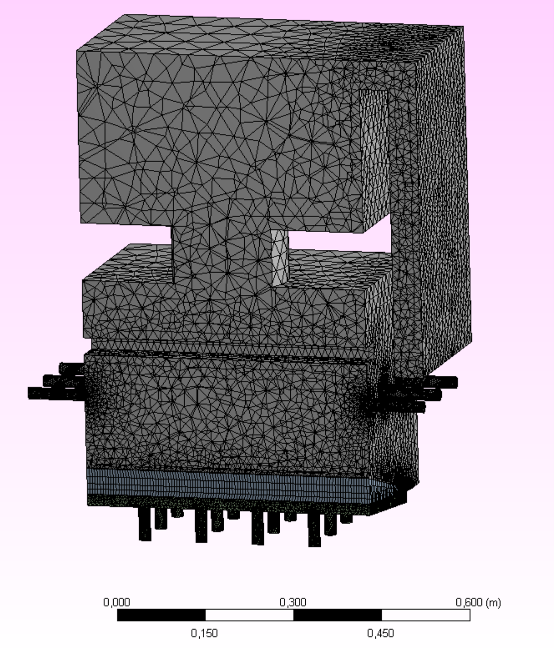

Fig. 1. Mesh of the model.

3 Results and discussion

Results of the measurement of woodchips combustion are at the Table 3. Total combustion process was divided at four major phases such as: cold start, warm start, intense running and burn-out.

Table 3. Results of the measurement of woodchips combustion.

	Temperature of the combustion chamber, °C	Temperature of the heart, °C	Temperature of the exhaust gases, °C	O_2, %
Phase of cold start				
min	27.0	-	37.0	20.1
max	65.0	-	41.0	21.0
average	46.0	-	39.0	20.9
Phase of warm start				
min	220.0	220.0	60	12.6
max	557.0	557.0	113	20.1
average	414.0	414.0	90.3	16.1
Phase of intense running				
min	400.0	400.0	96.0	9.7
max	641.0	641.0	109.0	15.0
average	563.4	563.4	103.6	12.5
Burn-out phase				
min	165.0	165.0	80.0	13.1
max	571.0	571.0	115.0	21.0
average	287.8	287.8	95.2	19.5

The main phase of working of the boiler is intense running so the results of that period of was compared to the simulation results.

3.1 Temperature of heart and exhaust gases

Comparison of the temperatures of combustion chamber and heart of the measurement and simulation results are at the Figure 2.

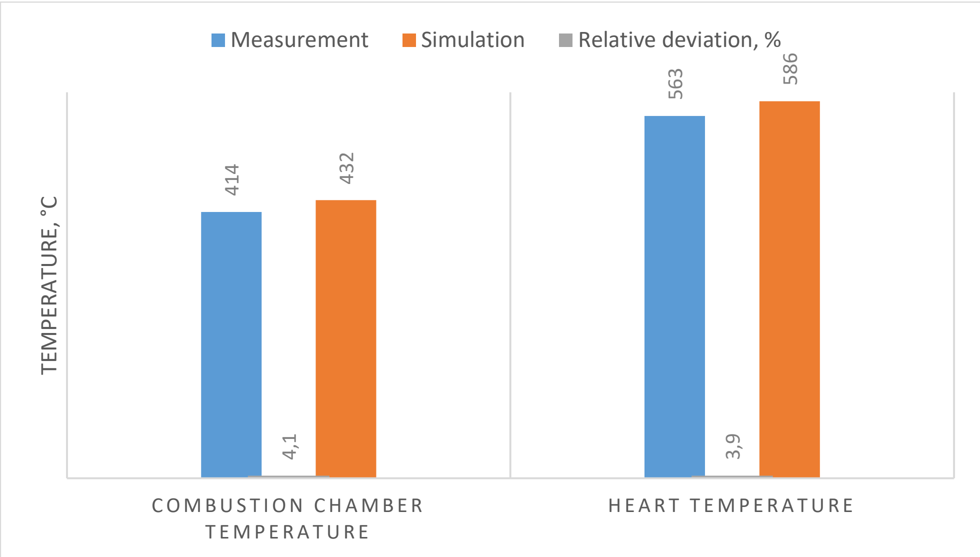

Fig. 2. Temperatures of combustion chamber and heart.

Temperature of the combustion chamber presents the temperature of the chamber laying and heart temperature is the temperature of the grate. According to the measurement data average temperature of the combustion chamber was 414 °C and temperature of the heart was 563 °C. Comparing the simulation results (temperature of the combustion chamber was 432 °C and temperature of the heart was 586 °C) it can be summarized that results are close, the relative deviation was 4.1 and 3.9 accordantly.

3.2 Concentration CO_2, CO, O_2

The comparison of the CO concentration of the measurement and simulation are at the Figure 3.

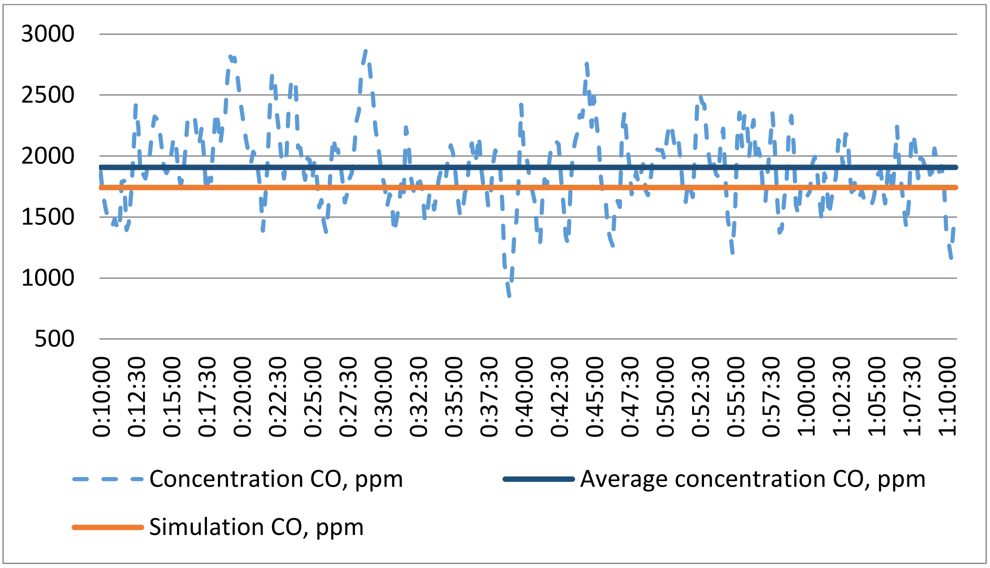

Fig. 3. CO concentration of the measurement and simulation.

To compare the steady-state simulation with the measured result the average concentration of the CO was calculated. According to it simulation shows smaller concentration of the CO approximately by 8.6 %.

The comparison of the CO_2/O_2 concentration of the measurement and simulation are at the Figure 4.

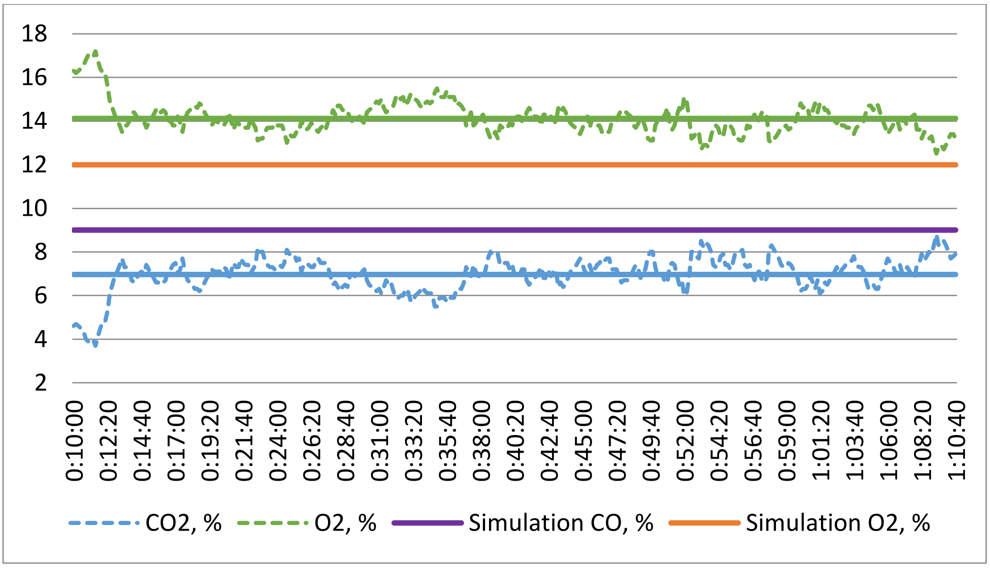

Fig. 4. CO_2/O_2 concentration of the measurement and simulation.

The CO_2/O_2 ratio during the measurement was from 3.9/17.1 % to 8.8/12.2 % with the average value 7/14 %. The CO_2/O_2 ration according to the simulation was approximately 9/12 %. The difference between the values may be explained by the chemical model which was used in simulations. Also, the lower concentration of the CO and O_2 leads to bigger concentration of the CO_2.

4 Conclusions

The main idea of the article is to develop simulation model of the woodchips boiler for the purpose of simulation of the solid biomass combustion process. Simulation model was made for Ansys Fluent 2019. Combustion model consist of two combustion stages: 1st – combustion of volatile compounds, 2nd – combustion of the solid parts.

The simulation was validated by the series measurements at the boiler HERZ firemytic 80 BioControl. According to the measurement data average temperature of the combustion chamber was 414 °C and temperature of the heart was 563 °C. Comparing the simulation results the relative deviation was 4.1 and 3.9 accordantly.

The chemical model of the simulation was equilibrium. According to the results of the simulation and measurement it can be summarized that such model is inaccurate. The CO concentration and CO_2/O_2 ration of the measurement a significantly vary from the simulation data.

Nevertheless, it can be consumed that such model compilation can be used for research of physical parameters of the solid fuel boilers when the chemical site is irrelevant.

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