International Scientific Colloquium
Modelling for Saving Resources
Riga, May 17-18, 2001

Optimization of Wet Sawdust Burner

L. Buligins, S. Lācis, A. Krauze

Abstract

The results of numerical simulation of wet sawdust burner operation with commercial code *Fluent* are presented. Experimental investigations have been carried out for the determination of restitution coefficients of sawdust particles governing the particle dynamics. The burner setup and shape has been optimized for the efficient drying, devolatilization and burning processes of different sawdust shape and size distributions. It is shown that burner operation conditions should be adjusted according to the particle terminal free fall velocity which is the key parameter determining the localization of drying, devolatilization and burning processes.

Introduction

The burners with power of several MW are quite commonly used for heating of small communities and villages in Latvia [1]. They often use as a fuel by-products of wood industry, typically wood chips, sawdust a.o., low price of which make them an attractive choice. Also in the European context there are tendencies of the increased use of biomass fuel being ecologically favorable over some other alternatives [1,2]. As fuel sawdust is characterized by several specific features, like wide size distribution, high moisture content, what requires specific approaches for the burner operation. The proposed burner type focuses on these specific requirements rising from the use of wet sawdust as a fuel. The general concept of the burner was proposed by Termika, Ltd, Latvia.

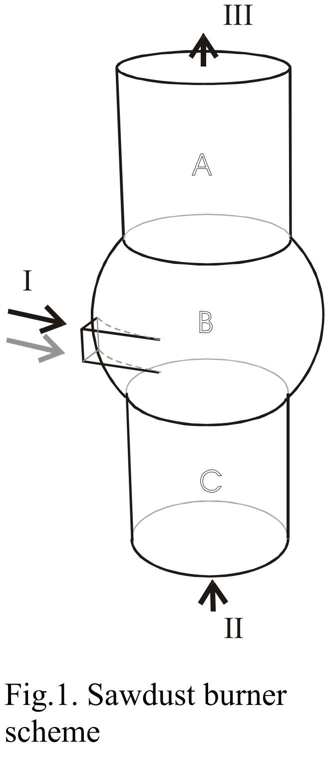

Fig.1. Sawdust burner scheme

1. The Burner Construction

A scheme of sawdust burner scheme is depicted in Fig.1. Geometry of simulation model consists of spherical eddy-burner chamber B, cylindrical upper part A and cylindrical lower part C. Part C has opening II (velocity inlet) at the bottom. This inlet is designed to enter air and/or flue gases, to burn char particles, which accumulate there. The chamber B has tangential inlet I for air-sawdust supply. Spherical burner chamber could be regarded as the key structure unit of present sawdust burner. Upper cylinder A joins spherical chamber with heat exchanger, thus it has outlet III.

Present burner construction is characterized by vertical orientation of axis. The central spherical part B of burner is designed so that the eddy of air captures sawdust coming from inlet I and due to centrifugal forces holds sawdust in this zone.

At this setup part of sawdust falls down to zone C where drying, devolatilization and char burning takes place. For the burner to function efficiently no hard fraction should leave burner via outlet III.

The computer simulation of the burner operation is done using its 3D model and *FLUENT* software. The following key processes are included in the simulation model:

1) Air supply to burner via inlets I and II (Fig.1),
2) Sawdust (eventually with moisture content) supply through inlet II (Fig.1)
3) Sawdust drying, inert heating, devolatilization of volatiles and final burning (via surface reaction) of char particles.

2. Sawdust Properties and Chemical Reactions

Most difficult part of sawdust burning simulation by FLUENT code is to choose the proper reaction model and simulation parameters [1]. Discrete phase model allows detailed description of wet sawdust burning simulation. Wood particles are described by a set of chemical reactions [3,4] producing certain species and additionally water steam due to the evaporation of moisture content. Dry wood particles consist of 80% of volatiles (gaseous products leaving particles during devolatilization) and 20% of char (pure carbon, burning via surface reaction). Wet sawdust contains additional liquid water fraction. Volatiles form complex gaseous substance, well described by generalized formula [4] of atomic content: $CH_{2.382}O_{1.075}$. Volatiles burn according to stoichiometric coefficients:

$$CH_{2.382}O_{1.075} + 1.058 \cdot O_2 \rightarrow 1 \cdot CO_2 + 1.191 \cdot H_2O$$

Char particles burn via reaction

$$C + O_2 \rightarrow CO_2$$

Thus 1.39 mass fraction of oxygen is needed to completely burn 1 mass fraction of dry wood particles. This ratio should be accounted calculating air supply to burner.

Heat transfer inside burner includes all three processes: heat conduction, heat transfer due to convection and radiation heat transfer. Heat exchange between continuous and discrete phase is taken into account too. Simulation of gas flow accounts for momentum exchange between discrete and continuous phases as well as effects of thermo gravity. Essential for flow simulation is use of turbulence model in FLUENT code and influence of turbulence on discrete phase motion and mixing of chemical species.

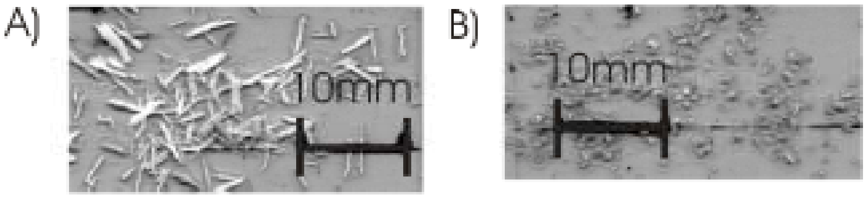

Fig.2. Examples of size distribution of sawdust particles

As it is clearly to see in Fig.2, sawdust is polydispers: depending on the different supply parties it has different size distributions. Thus sawdust burner should be able to function for different types of sawdust shapes inside the allowed range of particle size distributions. For simulation purposes three typical sizes 0.2mm, 1mm and 5mm were chosen (assuming spherical shape of particles). Simulation of non-spherical particles is possible by use of shape factor corrections [5,6].

Another intrinsic process of wood particle dynamics is the restitution of particles at walls. It is controlled by two restitution coefficients: normal and tangential [4]. These parameters have to be determined experimentally at flow conditions close to the flow in the burner; therefore the model experiment has been set up for investigation of restitution coefficients.

3. Experimental and Simulation Results

In Fig.3 A,B the experimental setup and simulation data are shown for sawdust dynamics without burning. The experimental setup consists of cylindrical vessel closed at bottom and open at the top of it with air/sawdust mixture supplied tangentially to the cylinder with different flowrates. Part of sawdust particles settles down at the bottom of the vessel, part leaves the vessel with outflowing air.

This experiment allows to determine the values of the restitution coefficient as well as the general properties of air-sawdust mixture flow and sawdust deposition character at the bottom of device. Parameter studies of restitution coefficients values and the comparison with experiment has displayed that values n=0.5 and t=0.8 (normal and tangential coefficients) gives reasonable agreement between experiment and simulation.

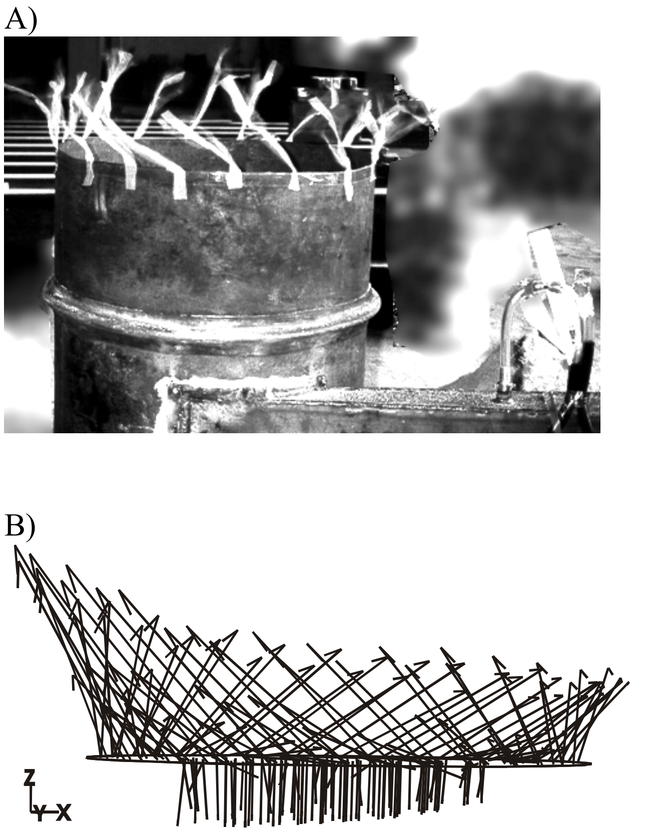

Fig. 3. Experiment on sawdust dynamical behavior.

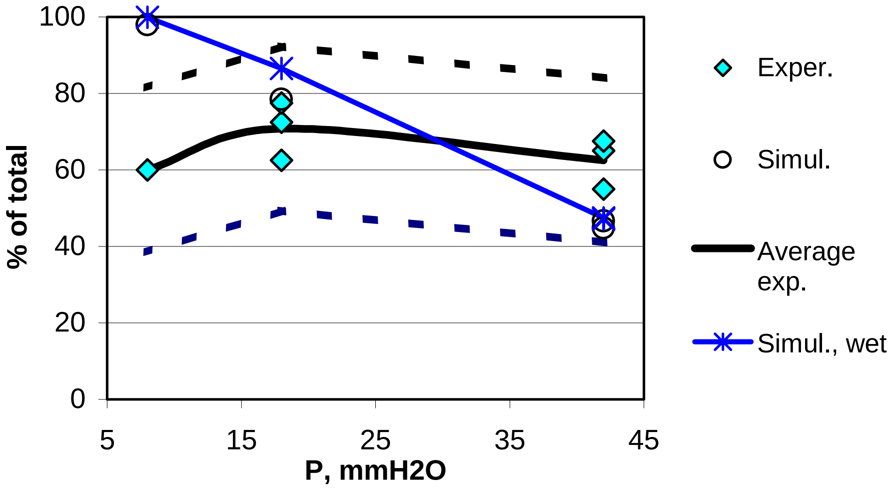

Fig. 4 Sawdust deposition in cylindrical burner model as function of pressure at inlet

Experimental results of sawdust (powder type, Fig.2B) deposition are shown in Fig.4. Experimental data are in good agreement with results of computer simulation. The main disagreement is at low pressures, i.e., at low total air flow rates. That is the case the weak drag force results in formation of large sawdust agglomerates in air flow. These agglomerates quickly fall down and form a deposit. As it clearly seen in Fig. 4, correction for moisture has no cardinal influence on simulation results of sawdust transport in air flow.

To achieve acceptable correspondence between real device and computer simulation results in the case of sawdust burning, one should take into account sawdust particle distribution. During our simulation behavior three different particle sizes (0.2 mm; 1 mm; 5 mm) were studied separately. Characteristic terminal free fall velocities for spherical wood particles are approximately 0.4 m/s for 0.2 mm particle diameter, 2 m/s for 1 mm and 50 m/s for 5 mm. Comparison of these velocities with air velocities 1 m/s at inlet II (see Fig.1) and 10 m/s at inlet I displays allows for the conclusions that 1) 0.2 mm diameter sawdust particles will never fall to the bottom of burner; 2) 5 mm diameter particles will fall down, but after devolatization and partial char burning remains could go up with the gas flow. These conclusions are confirmed by particle trajectories presented in Fig.5.

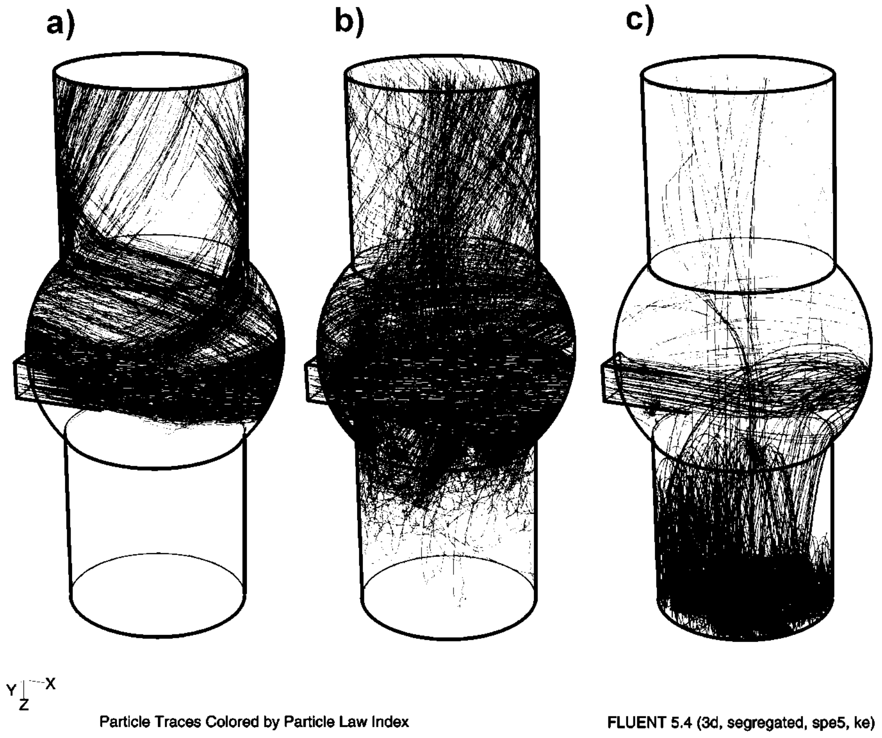

Fig.5 Trajectories of particles, a) 0.2mm, b) 1mm, c) 5mm

The peculiarities of sawdust transport determine the location of physical and chemical processes inside burner. 0.2 mm sawdust immediately after entering spherical burner chamber starts to move up. Particle drying (water evaporation) and devolatilization takes place mainly in spherical chamber but char burnout in upper cylindrical part. 1 mm particles are heavier, so the char burnout starts already in spherical chamber. Part of this sawdust fraction reaches lower cylindrical part. Behavior of 5 mm particles is more complex. As predicted, they all fall down. Drying and devolatilization takes place in lower cylindrical part of burner and after that the char rest of particles burn out and size and density of particles decreases. When drag force acting on particle exceeds weight, particle lifts with up-going gas stream.

Localization of drying, devolatilization and chemical reaction processes determines the concentration fields of chemical species and the temperature field for gas mixture.

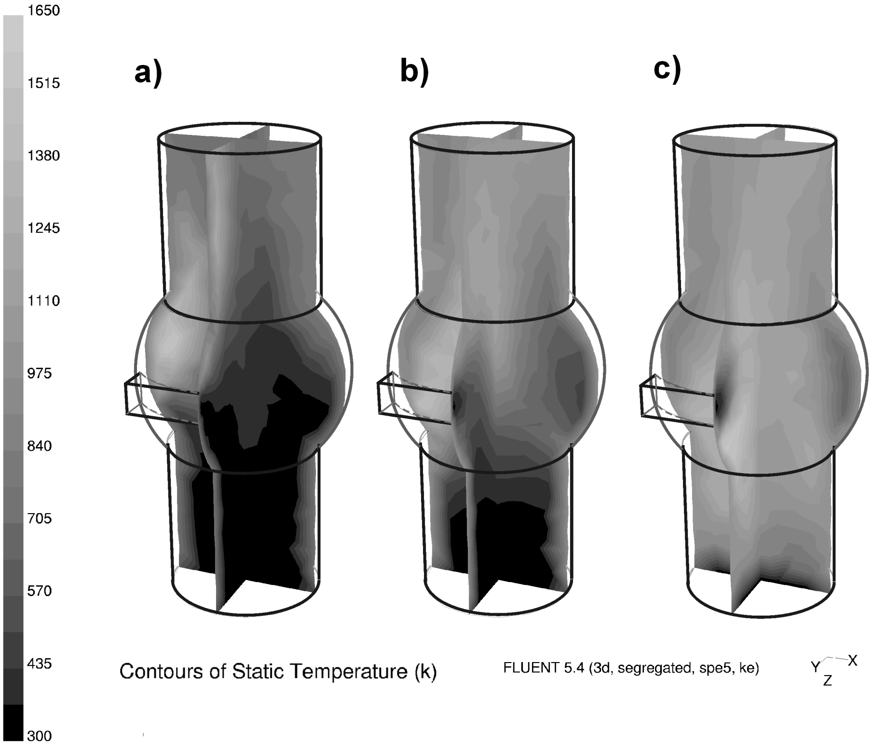

Fig.6 Temperature distribution inside burner, a) 0.2mm, b) 1mm, c) 5mm

Temperature field is depicted in Fig.6 for three sizes of wood particles (all three cases correspond to situation in Fig.5, where particle tracks are depicted). Analysis of these results shows that the increase of particle size leads to a more homogeneous temperature distribution throughout the burner volume. Small size particles burn in central and upper part of device, thus the cold air (300K) from inlet II reaches the central part of burner before it gets heated. For medium size sawdust particles this effect is less expressed. Larger temperature gradients in case of small particles could lead to undesirable thermal stresses in constructions of the burner.

Tab.1. Integral characteristics of burner at three different sawdust mass flow rates.

	Sawdust mass flow rate		
	0.05 kg/s	0.1 kg/s	0.2 kg/s
Average outlet temperature [K]	996.8	965.3	895.2
Burner power [MW]	0.4451	0.9031	1.823
Devolatilization [%]	100.0	100.0	100.0
Char burnout [%]	91.0	48.0	23.8
Water evaporation [%]	100.0	100.0	100.0

Integral characteristics were calculated for all cases of burner geometry and operation parameters. Most interesting of them are presented in Table 1 for three selected sawdust flow rates. In all three cases air supply was adjusted to sawdust mass flow. Sawdust drying and devolatilization was completed in all cases, confirming that combustion regime was properly chosen. The char burnout is a rather long process, thus at higher air flow rates char burnout drastically decreases being is the reason for lower outlet temperatures. Power produced by the burner depends on sawdust mass flow rate almost linearly.

Conclusions

During realization of present research project *Fluent* simulation capabilities were adapted for special task: simulation of complex physical and chemical processes in eddy chamber sawdust burner. During optimization of burner different geometries and air/sawdust supply rates and flow directions in respect to the vertical axis were considered. It was found that sawdust particle size distributions plays important role in combustion processes inside burner. Changing air supply rates and proportion at two inlets combustion could be effectively controlled. Main constraint for change of air supply proportion is necessity to avoid formation of sawdust agglomerates in gas flow inside burner. Partially this problem could be solved by introducing the recirculation of flue gases. Increase of wood particle size mainly leads to the homogenization of scalar fields (temperature, chemical species) over burner volume. Burner geometry and set of operation parameters, called as base variant was found to be the most appropriate for construction of real size working model.

Acknowledgements

Authors wish to thank Latvia Ministry of Education and Science for financial support. We would like to thank Termika Ltd for providing general concept of eddy-chamber burner.

References

[1] Medium power sawdust eddy-chamber burner. Final Report of Project No.1720, headed by S.Lācis. University of Latvia, Riga, 2001, 96 pp.

[2] http://www.biomasse-normandie.org .

[3] Turns, S.R.: An Introduction to Combustion, Concepts and Aplications. McGraw Hill, New York, 1996, 566 pp.

[4] Fluent 5, Users Guide, Fluent Inc., 1998.

[5] Haider, A., Levenspiel, O.: Drag coefficient and terminal velocity of spherical and nonspherical particles. Powder Technology, 1989, No.58, pp. 63-70.

[6] Morsi, S.A., Alexander, A.J.: An investigation of particle trajectories in two-phase flow systems. J.Fluid Mech., Vol.55, 1972, No.2, pp. 193-208.

Authors

Dr.-Phys. Buligins, Leonīds
Faculty of Physics and Mathematics
University of Latvia
Zellu str. 8
LV-1002 Rīga, Latvia
e-mail: lbulig@lanet.lv

Dr.-Phys. Lācis, Sandris
Faculty of Physics and Mathematics
University of Latvia
Zellu str. 8
LV-1002 Rīga, Latvia
e-mail: slacis@lanet.lv

B.Sc. Krauze, Armands
Faculty of Physics and Mathematics
University of Latvia
Zellu str. 8
LV-1002 Rīga, Latvia
e-mail: mf70018@lanet.lv