A DEFINITION OF THE MATHEMATICAL MODEL OF COMBUSTION PROCESS IN THE STOVE

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This paper deals with characterization of the mathematical model combustion process of wood material in application on the model of fireplace in the stove. Software FLUENT was used for numerical flow simulations involving chemical reactions and heat transfers. Complex definition of mathematical model combustion of the log represents combustion process which is defined as a reaction of gaseous species (volatile combustible) with oxygen from incoming air.

Keywords: *CFD modelling; combustion; chemical reaction*

1 INFORMATION

Generally wood and biomass are considered as an ecological fuel but pollutants are generated during their combustion process. Pollutants are especially solid parts, carbon monoxide and polyaromatic hydrocarbons. Especially carbon monoxide and another organic matter can create in large volumes when combustion process and combustion equipment are not customized for combustion of biomass. Production of pollutants is not neglect able in these cases but becomes major problem for local environment.

Combustion of log in stove can characterize by many physicals phenomenon. It is flow of combustion air by inputs of air, then reaction of air (oxygen) with fuel, generation of heat and flow of gaseous species (exhaust gas) through fireplace, whereas the heat energy is releases. During this process happening to heat transfer between walls, exhaust gases and flame and by all known methods (conduction, convection and radiation). Direction of heat fluxes are not single-direction during combustion, but in time of intensive of burning exhaust gases transfers heat to walls and in time of afterburning walls and brick lining get hot of exhaust gases. Combustion of fuel (wood) is difficult process by itself.

Part of heat is released on the surface of log by combustion of fixed carbon. It is heterogeneous reactions which are very complicated whereas many another components intervene to reactions (e.g. H_2O) and reactions run of several levels. Most of energy releases in region up the fuel where volatile combustible burns which is released from fuel. This part forms majority part of releasing energy. Complication of combustion description this volatile combustible consists in that is not known composition of volatile combustible and their physical properties [1].

Model of stove is solved in simplified geometry for definition problems of wood combustion when the basic dimensions of stove (high, width and length) are conserved accordant with real stove. Reason of using simplified model is that main principle of solution is in detail modeling of combustion process with considering of heat transfer and radiation by walls of stove off detailed geometry of stove [2]. This simplification is sufficient for obtaining adequate solution in term of thermal and energetically.

Scheme of the geometry model of stove is evident from figure 1. The space of stove is separated into two regions. In top section releasing volatile combustible is burned with combustion air which is feed to bottom section through ashtray (second section). Both sections are divided by fire grate where log of square cross-section is located as is visible from figure 1. In top section exhaust gases are turned away from region of fireplace by top half-surface as is schematically in figure 1.

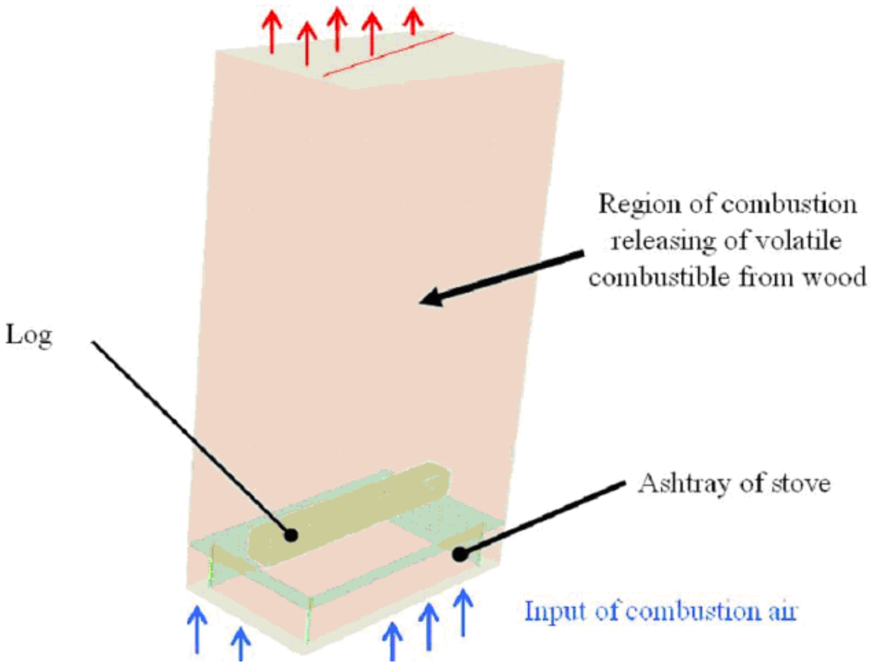

Figure 1: Simplified model geometry of stove

2 DEFINITION OF MATHEMATICAL MODEL OF FLOW GASEOUS SPECIES INCLUDING CONSIDERATION OF COMBUSTION MODEL

Problems of flow in stove can be characterized as turbulent, incompressible flow gaseous species [4], [5] in all section of stove where volatile combustible is combusted with oxygen (O_2) under creation of combustion products (CO_2, H_2O) by stoichiometric combustion equation. Except the heat transfer by convection and radiation are considered in region of stove and by walls to surroundings. Phenomena of radiation heat transfer are simulated using by walls definition of thickness and material to surroundings when stove is located to surroundings thereby heat transfer can be simulated from region of stove to surroundings. It is very complex model which realistically simulation process of wood burn in fireplace of stove**.** Definition of mathematical model presents system of partial differential equations which were solved by program Fluent 6.3.26 [5] which is based on method of finite volume. Mathematical model defines basic equation:

$$\frac{\partial u_j}{x_j} = 0, \tag{1}$$

where u_j is i th component of velocity.

Mass conversation equation

$$\frac{\partial (u_j u_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \rho}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j^2} + g, \tag{2}$$

where

ρ - density,
p - pressure,
ν - kinematics viscosity,
g - gravity.

Species transport equation

$$\frac{\partial(\rho \overline{u_j} Y_{i'})}{\partial x_j} = -\frac{\partial}{\partial x_i} J_{i'} + R_{i'} + S_{i'}, \qquad (3)$$

where

$Y_{i'}$ - mass fraction for i th species,
$J_{i'}$ - diffusion flux of species i ,
$R_{i'}$ - net rate of production of species i by chemical reaction.

Above basic equations were extended for energy equation. Detailed description of energy equation is in [5].

Beech wood was used as implied fuel according to that volatile combustible presents 73 % when the rest to 100 % is defined as fixed carbon. Then composition of volatile combustible was provided. Composition was recalculated on the original fuel moisture after. Stoichiometric coefficient, theoretical consumption of oxygen and air were defined by composition of volatile combustible and also exhaust gases production and composition. For assumed input power P_K=8kW was defined consumption of oxygen, production of exhaust gas and individual components, see (table 1).

Table 1: Theoretical production of exhaust gases and real consumption of air

Input power	Mass flow of volatile combustible and water		Real air	Concentration of exhaust gases			
P_K	w_H		$V_{VZ\text{-}SK(dry)}$	H_2O	CO_2	N_2	O_2
kW	kg/s from volume of wood	kg/(s.m^3)	kg/kg	mass fraction %			
			6.29	10.97	13.95	66.27	8.82
			kg/s	kg/s	kg/s	kg/s	kg/s
8	0.000502	1.2.447	0.003156	0.000401	0.00051	0.002424	0.000322

In the species transport equation (3) the rate of production ($R_{i'}$) species *i´* was defined owing to chemical reaction (combustion of volatile combustible) by model EDDY-DISSIPATION [3], [5]. Combustion is defined for gaseous species in all region of stove in this application. One square log is used see (figure 1). Log is divided into the two parts. Internal part of log is composed by wood raw material with definition physical properties. Outer part of log is composed by level from which volatile combustible is released by source term (SOURCE TERM). Stoichiometric equation for combustion volatile combustible with oxygen is defined by the equation (volatile combustible + 0.788O_2 → 0.714CO_2 + 1.371H_2O) when carbon dioxide and water vapour are released. Then above definition equation was extended any radiation model (DISCRETE ORDINATES [5]).

3 DEFINITION OF PHYSICAL PROPERTIES AND BOUNDARY CONDITIONS

Three walls from ovenware (LACfire) and one wall from glass (ROBAX Glass) are defined from reason of consideration real heat transfer through walls of stove including of radiation. Walls are defined by corresponding transparence with respect to radiation to surroundings thus the model corresponds to real stove. Physical properties (density, specific heat capacity and thermal conductivity) of individual materials are introduced in (table 2).

Table 2: Physical properties of using materials

Physical properties	LACfire (ovenware)	ROBAX Glass
Density ρ (kg/m^3)	2250	2600
Specific heat capacity c_p (kJkg-1K-1)	0.836+4.1*10^{-4}T	0.8
Thermal conductivity λ (Wm^{-1}K^{-1})	1.69-2.4*10^{-4}T	1.6

Mass flow inlet boundary condition (MASS-FLOW-INLET) is defined for inlet of combustion air into stove through fire grate by (table 1). Pressure outlet boundary conditions (PRESSURE-OUTLET, p=-10 Pa) is defined on the outlet of stove. Mixture is defined by following components (O_2, N_2, CO_2, H_2O, volatile combustible). Composition of air (23%=O_2, 77%=N_2) is defined on the inlet of stove.

4 RESULTS OF NUMERICAL SIMULATION

Cross section through stove was created for evaluation of numerical simulation. Temperature field is showed in (figure 2) from which is evident maximum of flame temperature 1480°C. Production of CO_2 is showed in cross section by distribution of mass fraction in (figure 3). Comparison of theoretical assigned values of concentration exhaust gases and values obtained from program FLUENT are evaluated in (table 3) at the inlet of stove and total heat power transfer is evaluated in (table 3).

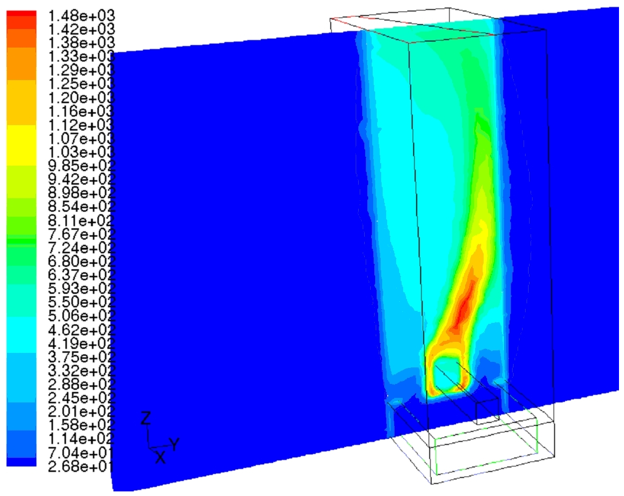

Figure 2: Temperature field in cross section

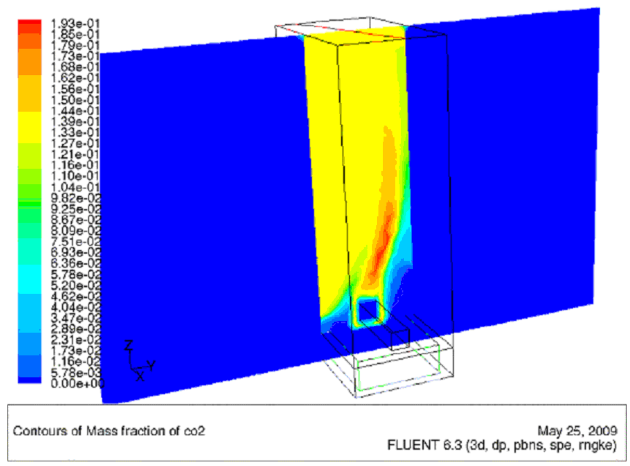

Figure 3: Distribution of mass fraction CO_2 in cross section

Table 3: Comparison of outlet parameters

Mass fraction	Theoretical production	Numerical calculation
O_2	8.82	9.9
CO_2	13.95	12.8
H_2O	10.97	10.1
N_2	66.27	67.2
Transfer power P(W)	8000	7862

5 CONCLUSION

Article describes problems of definition of mathematical model combustion of wood in simplified model of stove including specification of combustion model. Complex definition model is extended for heat transfer by convection and radiation through walls definition thickness to surroundings. Results of numerical simulation are compared with theoretical derived calculation of concentration exhaust gas and heat power transfer with good agreement. Successive view will be tended to definition mathematical model for real stove and verification of model with experimental measuring.

REFERENCES

[1] THUNMAN, H., NIKLASSON, F., JOHNSSON, F., LECKNER, B.: Composition of Volatile Gases and Thermochemical Properties of Wood for Modeling of Fixed or Fluidized Beds. *Energy* & *Fuels*, 15 (6), 2001, p. 1488-1497. ISSN 0887-0624.

[2] NOVOZHILOV, V., MOGHTADERI, B., FLETCHER, D., KENT, J. H.: Computational Fluid Dynamics Modelling of Wood Combustion. *Fire Safety Journal*, 27, 1996, p. 69-84. ISSN 0379-7112.

[3] MAGEL, H. C., SCHNELL, U., HEIN, K. R.: *Simulation of detailed chemistry in a turbulent combustion flow*. Proceedings of the 26th Symposium (international) on Combustion. Pittsburgh, USA, 3.7. 1996. ISSN 0082-0784.

[4] KOZUBKOVÁ, M.: *Modelování proudění tekutin FLUENT, CFX*. Ostrava: VŠB-TU, 2008, 154 s., ISBN 978-80-248-1913-6, (Elektronická publikace na CD ROM).

[5] FLUENT: Fluent 6.3.26 - *User's guide* Fluent Inc. 2003. VŠB-TU Ostrava <URL:http://sp1.vsb.cz/DOC/Fluent_6.3.26/html/ug/main_pre.htm>.

ACKNOWLEDGEMENTS

This research was supported by project „Krbová kamna pro nízkoenergetické domy“- FI-IM3/185