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STARTING KETTLE BY THE PLAZMA BURNER

NAJÍŽDĚNÍ KOTLE POMOCÍ PLAZMOVÉHO HOŘÁKU

Abstract

In this paper the plasma technology of kettle PG350 starting is presented. Mathematical modeling was used for solving of this problem, when mixture coal was ignited of plasma burner. The computation was simulated on simplified kettle PG 350 geometry. Coal mixture was ignited by air about 7000 K instead of plasma. Task was defined as turbulent flow of air and coal particles with heat transfer and chemical reactions. In software Fluent 6.3 flow can be solved by turbulent models and heat transfer by radiation models. Mathematical model of continuous phase and discrete phase, which characterizes adrift of coal particle, was created. Combustion was solved by models of combustion in Fluent. Mathematical model was solved by finite volume method.

Abstrakt

V článku je prezentována plazmová technologie pro najíždění kotle PG350. Tato technologie byla řešena matematickým modelováním, kdy uhelná směs byla zapálená plazmovým hořákem. Výpočet byl modelován na zjednodušené geometrii kotle PG350. Uhelná směs se zapálí místo plazmy vzduchem o teplotě 7000 K. Úloha byla definována jako turbulentní proudění vzduchu a uhelných částic v práškovodu s přenosem tepla a chemickou reakcí. V softwaru Fluent 6.3 lze proudění řešit tzv. modely turbulence, přenos tepla pak tzv. radiačními modely. Byl vytvořen matematický model turbulentního proudění spojité fáze a diskrétní fáze, což charakterizuje unášení uhelných částic. Spalování je řešeno pomocí spalovacích modelů ve Fluentu. Model byl řešen metodou konečných objemů.

1 TECHNOLOGY OF PLASMA

Noble fuelling (black oil or gas), which are used for starting and stabilization coal- kettle [2], is possible to replace by plasma technology. This technology consists in thermochemical preparation of primary mixtures, which is made front lead burner by the help generator low-temperature plasma. This principle makes it possible to perform kettle starting from cold state without any noble fuelling or without other supporting sources. Technology of plasma has a lot of advantages:

NO_x emissions are decreased

- energy is spared
- mean velocity of oxidation and gasifying of powdery prime mixtures is increased 2 times till 3 times
- mechanical samel is decreased 2 times till 3 times
- cost investments in compared with existing technology for fire up and stabilization of coal kettles are lower
- operating costs in compared with existing technology for fire up and stabilization of coal kettles are lower

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2 DISCRETE PHASE MODEL (DPM)

In DPM model, flow of particles was modeled so, that small number of particles was followed in continuous phase. In Fluent there is possible to model combustion of coal particle with the aid of mathematical model of turbulence for compressible flow, that is governed by continuity equation (1), Reynolds momentum equations [5] (2), energy equation (3), and species transport equation (4)

Continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_j)}{\partial x_j}=0\,, \tag{1}$$

Momentum equation

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_i}{\partial x_j}\right)+\rho\delta_{i3}g++\rho f_j\ , \tag{2}$$

Heat transfer equation

$$\frac{\partial(\rho\bar{h}_i)}{\partial t}+\frac{\partial(\rho\overline{u_i h})}{\partial x_j}=\frac{\partial\bar{p}}{\partial t}+\frac{\partial}{\partial x_j}\left(\lambda_t\frac{\partial\bar{T}}{\partial x_j}\right)+L_j+\frac{\partial(\overline{\tau_j u_j})}{\partial x_i}, \tag{3}$$

Species transport equation

$$\frac{\partial(\rho\overline{Y_{m\,i}})}{\partial t}+\frac{\partial(\rho\overline{u_i Y_m})}{\partial x_j}=\frac{\partial}{\partial x_j}J_m+R_m+S_m, \tag{4}$$

where t is time, x_i is coordinate in i direction, ρ is density, $\overline{Y_m}$ is mass fraction of species i, $\overline{u_i}$ is velocity component, $\bar{p}$ is pressure, λ_t is thermal conductivity, R_m is net rate of production of species m, $\overline{J_m}$ is diffused flux of species m, S_m is the rate of creation by addition from the dispersed phase, μ_t is turbulent viscosity, L_j is heat transfer source.

In this model, chemical reaction can be set on particles, which are defined by users. This model plays an important role in particle combustion. Size, materials, velocity, mass flow, and kinds of particles (inert, combustion, droplet) can be set by user [4]. Injection can be defined by enter over selected area, single, group, hollow cone, falt- fan atomizér, air – blast atomizer.

Shapes of elements can be set as a spherical particle, elements with nonspherical smooth surface, nanoparticles. These shapes osculate with resistance in face of continuous phase, defined with the aid of resistive argument.

Equation of particles motion, coming out balance of forces is given relation using Lagrange access [3] (5):

$$\frac{du_p}{dt}=F_D(u-u_p)+\frac{g_x}{\rho_p}(\rho_p-\rho)+F_x \tag{5}$$

where $F_D(u-u_p)$ is power of hydrodynamic resistance applied to unit mass, F_x is complex acceleration, u is fluid velocity, u_p is particle velocity, $F_D = \frac{18\mu}{\rho_p D_p^2}\frac{C_D\,Re}{24}$ where μ is molecular viscosity of fluid, ρ is fluid density, ρ_p is particle density, D_p is particle diameter, *Re* is Reynolds number defined by relation $Re = \frac{\rho D_p \left|u_p - u\right|}{\mu}$, C_D is coefficient of hydrodynamic resistance.

Limitations of discrete phase model [4]:

- volume fraction of suspensoid phase must be less than 10-12 %
- suspensoid phase input over inlet and jet, exactly defined in a way
- time-sharing flux is impossible to model of DPM
- cloud model can not be used

3 BASIC COMBUSTION EQUATION

In practice, heat is usually gained by burning of solid, liquid or gaseous fuel. Required combustion oxygen is supplied most often from the air. According to air supply, burning can be divided in prefect burning and imperfect burning. Economical combustion occurs, when burning products contain only CO_2, SO_2, H_2O and when C, S, H_2 are not included in ash. Combustion is imperfect, if CO is not included in combustion products, C, S and sometimes H_2 are in ash. Combustion action is given by basic burning equations [8].

$$C + O_2 = CO_2 + 407MJ \tag{6}$$

$$C + 1/2O_2 = CO \;\; + 124MJ \tag{7}$$

$$CO + 1/2O_2 = CO_2 + 283MJ \tag{8}$$

$$H_2 + 1/2O_2 = H_2O(l) + 286{,}8MJ \tag{9}$$

$$H_2 + 1/2O_2 = H_2O(g) + 241{,}8MJ \tag{10}$$

$$S + O_2 = SO_2 + 297{,}7MJ \tag{11}$$

Where (*l*) is liquid, (*g*) is gas.

In Fluent equations for water are neglected in calculation, because engaged coal has contained slight water quantity. Equations are defined as stechiometric equations containing only reactants and products. Heat, which arises in reaction, is not set in these equations. It is takes into account in heat transfer source.

4 PROBLEM - SOLVING

4.1 Problem description

Simulation ignition coal mixture by the plasma burner was modeled by Fluent 6.3 [7]. Calculation was performed on simplified kettle PG350 geometry. Geometry with blinkers displacement was used for computation, see **Fig. 3**. Coal mixture was ignited by air about 7000 K. Problem has been solved by preset models (Nonpremixed and Premixed model), which were described in [8] and species model with discrete phase of coal, in which chemical reaction are defined.

4.2 Geometry of solved area

Problem was solved in area, which consists of 3 inlet – inlet 1 and plasma generator 1 and 2, and one outlet, see **Fig. 1.**

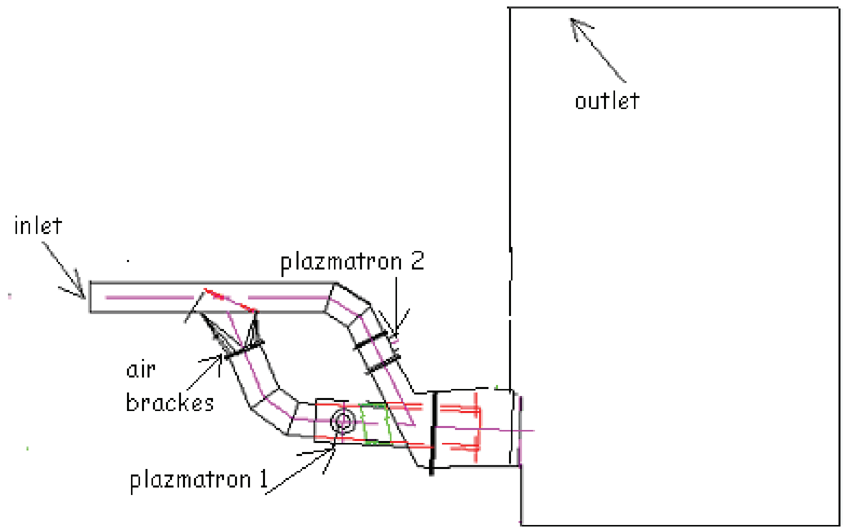


Fig. 1 Geometry of area

4.3 Computational grid

In Gambit created grid had 421761 cells and region was bounded by three inlets, one outlet and wall, see **Fig. 2**.

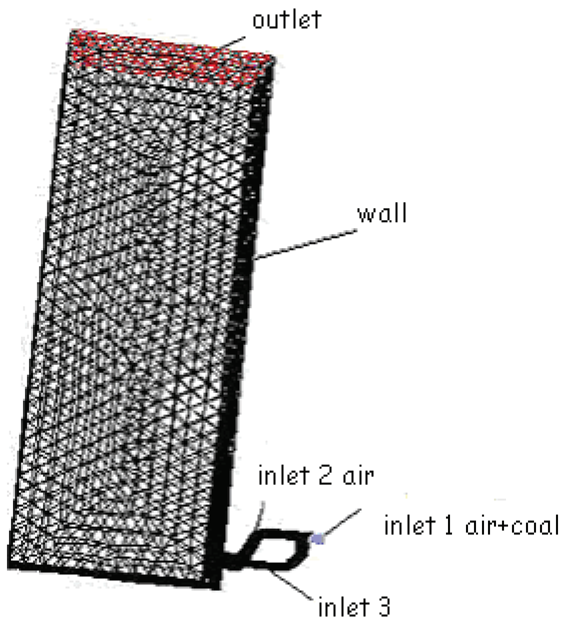


Fig. 2 Computation grid

The problem was tested on kettle PG 350 geometry. Registers were situated in powder tube, which was intake into kettle. Blinkers divided mixture into two branch of powder tube. Each part was plasma generator tipped. The problem was modeled for two examples of turning blinkers, see **Fig. 3** and **Fig. 4.**

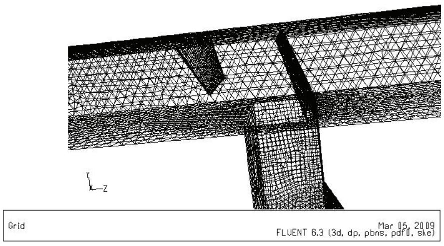


Fig. 3 Original displacement blinkers

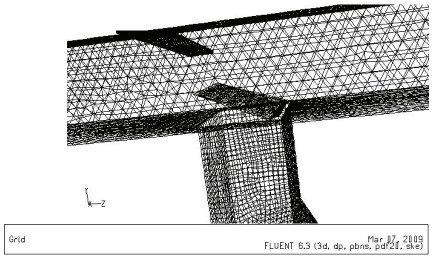


Fig. 4 Tilted gates

4.4 Physical properties

Air and coal particles were used for solution of these properties [7].

air	coal
$\rho = 1.225\ \mathrm{kg \cdot s^{-1}}$	ρ = volume – weighted – mixing law
$c_p = 1006.43\ \mathrm{J \cdot kg^{-1}K^{-1}}$	c_p = mixing law
$\lambda = 0.0242\ \mathrm{W \cdot m^{-1}K^{-1}}$	λ =volume – weighted – mixing law
$\upsilon = 1.50124 \cdot 10^{-5}\mathrm{m^2 \cdot s^{-1}}$	

4.5 Boundary conditions

Flowing medium was air. The mass flow of air on inlet 1 was 4.32 $\mathrm{kg \cdot s^{-1}}$ and temperature was 343 K. Via this inlet, coal particles entered too, they were defined through injections by mass flow 0.72 $\mathrm{kg \cdot s^{-1}}$. Via inlet 2, the air entered. This air supplied plasma about temperature 7000 K and mass flow 0.0334 $\mathrm{kg \cdot s^{-1}}$. Inlet 3 was defined as inlet 2. Outlet boundary condition was defined as pressure outlet, p = -75 Pa.

4.6 Mathematical model

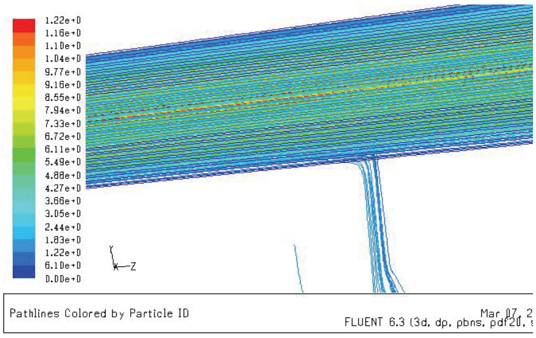
On the basic of Re number, mathematical model was chosen.

$$\mathrm{Re} = \frac{\upsilon \cdot d}{\nu} = \frac{10.710 \cdot 0.55438}{1.50124 \cdot 10^{-5}} = 395500 \tag{12}$$

Re number is $395500 > 2320 \Rightarrow$ turbulent flow. Standard k-ε model of turbulent was chosen for modellig.

4.7 Results

Difference displacement blinkers on flow particles is seen on **Fig. 5** and **Fig. 6**. Lapse few particles flunking, when blinkers are downswept, see **Fig. 6**. The greater parts of the particles pass into the bottom of the power tube, when blinkers are open full, see **Fig. 5**.



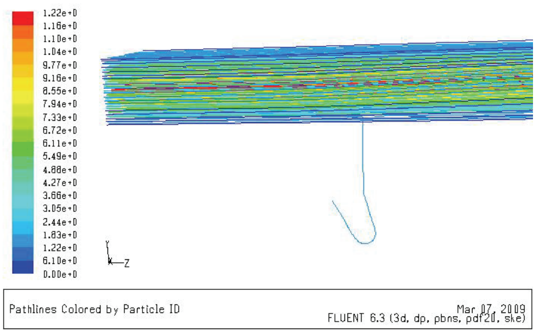


Fig. 5 Flow particles

Fig. 6 Flow particles – tilted gates

Discrete model is most exact in comparison with CFX modelling. There is an illustration of velocity magnitude, see **Fig. 8.** Static temperature of during reaction is imaged in **Fig. 7** and mass fraction of CO_2 in **Fig. 9.**

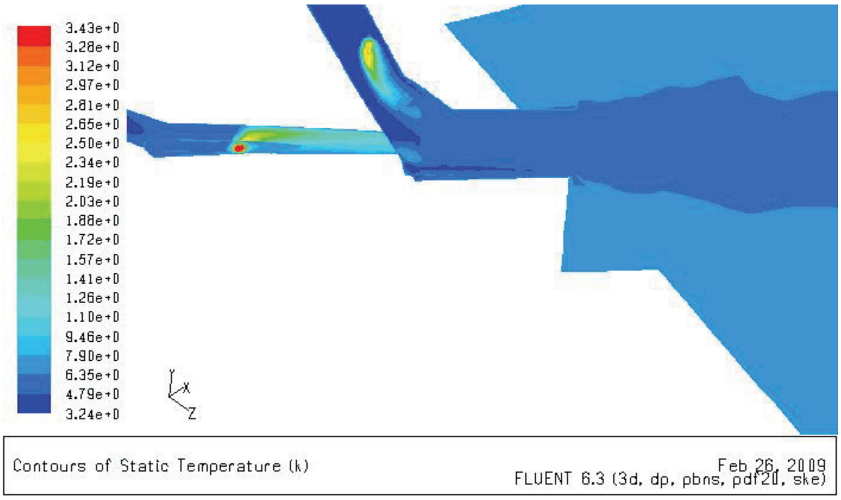


Fig. 7 Static temperature

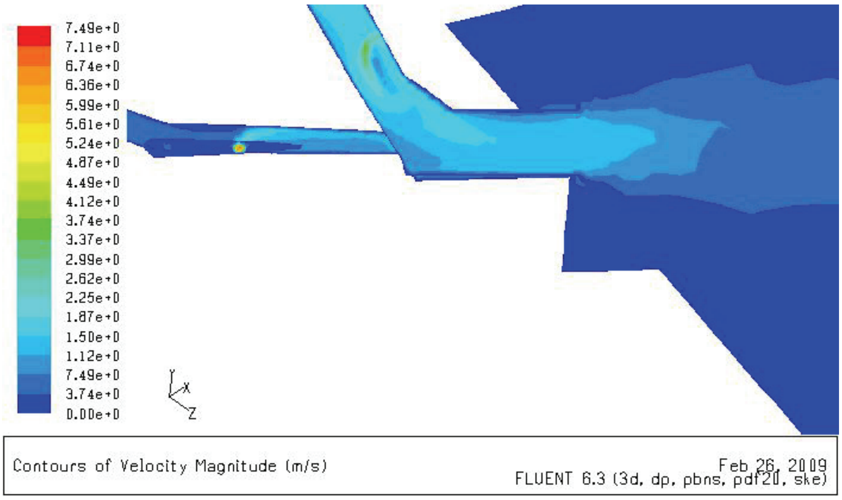


Fig. 8 Velocity magnitude

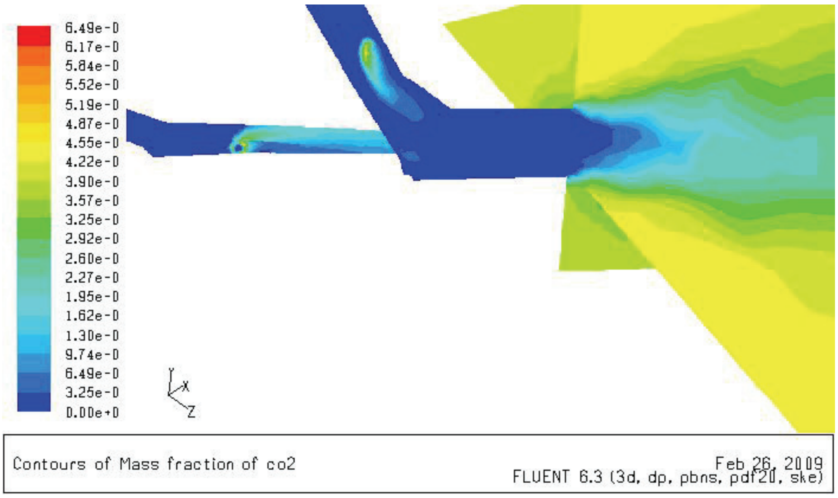


Fig. 9 Mass fraction of CO_2

5 CONCLUSION

The paper deals with modeling and evaluating of coal particle combustion with the aid of plasma burner. The problem was computed by Species transport model, because this model gave the most exact results [7]. Calculation was performed on simplified kettle PG350 geometry. Kettle was started by the help of plasma generator 1. Plasma generator 2 was only used back-up power supply for starting, see **Fig. 1**. Therefore, problem was modeled on geometry, see **Fig. 5**. Registers were turned, so that main part of coal mixture was flowed largely to lower branch in this geometry. Few part of primary mixture with air was flowed to upper branch.

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