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MODELING OF MASS LOSS OF CHAR PARTICLES DURING COMBUSTION AND INTERACTION WITH INERT MATERIAL

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ABSTRACT

The inspiration for this research was the numerical simulation of mass loss of char particles during its combustion in a CFB boiler. The mass loss was presented as the superposition of two separate processes i.e. combustion and surface erosion. The values obtained by the model and experimental data show a good level of conformity.

INTODUCTION

Until now many authors have attempted numerical simulations of the comminution of coal in the bed of the fluidized combustion (1,2,3). The main courses of numerical simulation were based on the system of combustion chamber or on the system of circulating fluidized bed in order to describe the intensity of the fuel comminution and the modification of the particle size distribution of a bed (4,5). However, none of the aforesaid attempts took the individual characteristics of coal into consideration, such as the chemical composition and petrographic structure, which both directly and indirectly affect the surface structure of the particle and its characteristics created during combustion. On the basis of tests carried out, as well as other research, it has been stated that the coal surface undergoes mechanical interaction with an inert material which changes the mechanism of combustion as well as accelerating the mass loss of the coal particle. However, the level of that loss is different and this is a characteristic feature of coal. The research conducted by Pelka (6) of the mass loss during combustion for Polish coal in a flow of inert material with the same rate of flow as G_s= 2.5 kg/(m^{2}s) shows that the difference of time of overall mass loss for hard coal (*d= 10 mm)* is much bigger than in the atmosphere and can even amount to a few hundred seconds i.e. 30-40%. Thus, determining a parameter decisive of intensity for that loss and the related coal properties could be an important instrument facilitating modelling of the combustion process in fluidized bed conditions. Therefore, in this research an attempt at analyzing numerical simulations of the mass loss of a coal particle has been made while taking both processes into consideration.

EXPERIMENTAL TESTS

In order to determine the real coal particle mass loss in the process of its combustion in a flow of inert material a laboratory model of a fluidized bed combustor chamber was constructed. The schematic diagram of the test stand is shown in Fig. 1. The main elements of the test stand were as follows: an electric combustor (1), an accelerate pipe (2) and a vessel of inert material (4).

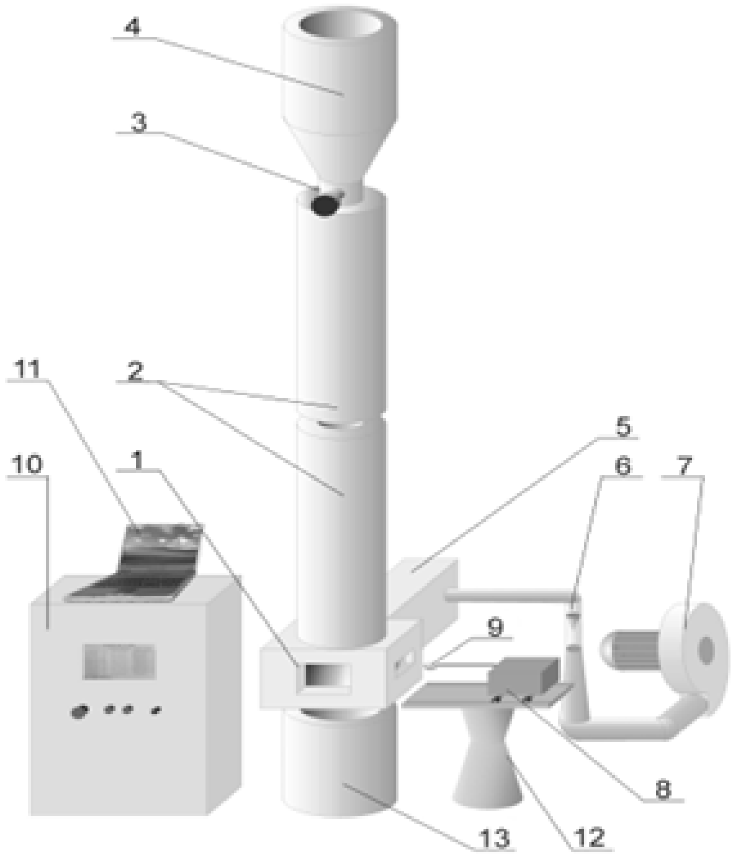

Fig.1. Schematic diagram of the test apparatus: 1-combustion chamber, 2-acceleration pipe, 3-regulation valve, 4-upper vessel of inert material, 5-air heater, 6-rotameter, 7-air blower, 8-extensometer branch scale, 9-thermocouple, 10-control panel, 11-PC- computer, 12-support, 13-lower vessel of inert material.

The tests were carried out on Polish hard coal from Sobieski mine whose properties are presented in Table 1. In this test spherical particles were used that had been picked out from randomly chosen real coal particles and then polished manually. The diameter of the tested particles was 10 mm. At the beginning particles of the chosen coal type were burned in an atmospheric air without any inert material. Following this, the test was conducted with the inert material. From the recorded signal the course of the real mass loss of the particle was isolated by subtracting the mechanical interaction of inert material.

Coal type	Mine	Proximate analyses				
		Volatile matter	Moisture	Ash content	Fixed coal	Calorific value
		%	%	%	%	kJ/kg
Hard	Sobieski	27,9	12,4	16,7	48,4	21558

Table 1. Results of proximate analyses of tested coal.

The first stage of the investigation was the combustion of coal particles without the influence of the inert material in an atmospheric air at temperature of 850^{o}C. For this reason the control valve of the solid flow was closed while only heated air was supplied to the combustion chamber. The tests were performed on seven samples in the same conditions. Following that, the tests of mass loss of coal particle were conducted in conditions of the flow of an inert material. The results obtained for different rates of flow of inert material G_s= {0,4,7,15} kg/(m^{2}s) are presented in Fig.2.

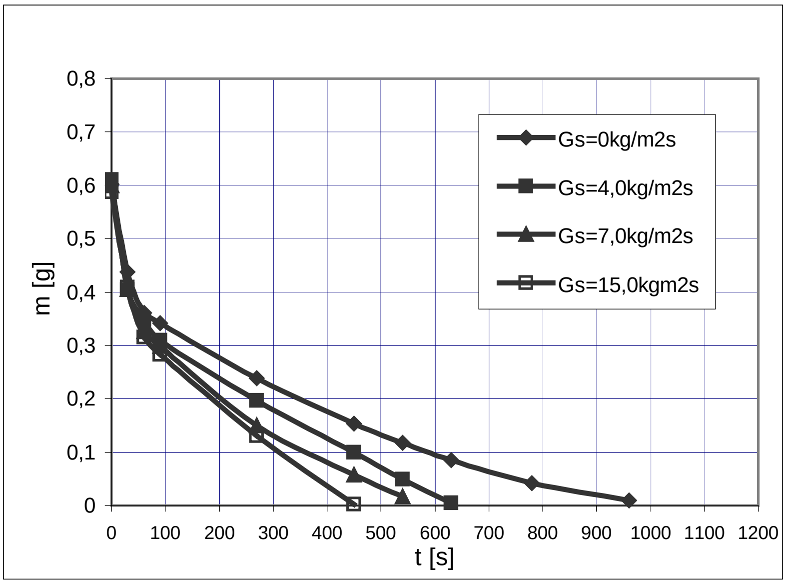

Fig.2. Mass loss of coal particles from Sobieski mine in the air and in the flow of inert material.

MATHEMATICAL MODELING

In the previous chapter it was shown that the presence of the flow of inert material during the combustion process of coal particles plays a significant role in the intensity of their mass loss. A detailed analysis of the role of inert material in all phases of coal combustion during the heating, ignition and combustion of volatile matter, as well as the combustion of char has been described in (6). The first three phases of testing the coal particles take place in a short period of time (about 60 seconds), when the biggest mass loss related to devolatilization and moisture evaporation takes place. Moreover, images from the microscope (7) show that the surface of the coal particle is still homogeneous and the percolation process has not occurred. Thus, the mass loss related to erosion of particle surfaces is very low and difficult to separate from the overall mass loss. In the aforesaid model only the erosion mass loss was taken into account during the process of char combustion. Furthermore, the following aspects in mathematical modeling have also been assumed:

- the char particle possesses a homogeneous structure and does not undergo fragmentation during the combustion process,
- the spherical shape of the particle stays invariable till the end of the process,
- the density of the particle does not depend on the temperature,
- the density of the char particle is constant in the whole volume,
- the diameter of the coal particle stays invariable during the devolatilization and combustion of the volatile matter,
- the rate of flow of inert material G_s is constant,
- the model did not take into consideration the heat exchange between a solid and the surface of char particle,
- the processes of char combustion and erosion of its surface are independent.

The equation of mass loss is presented as

$$\frac{dm_c}{dt} = \begin{cases} -A_z k C_t \Omega - r_c \dfrac{H_v}{K_c^2} \cdot m_c \cdot \left[\sum_{i=1}^{n} Cv_i . u_i^3\right] & for \quad m_c > m_a \\ -r_c \dfrac{H_v}{K_c^2} \cdot m_c \cdot \left[\sum_{i=1}^{n} Cv_i . u_i^3\right] & for \quad m_c \le m_a \end{cases} \tag{1}$$

The first term $A_z k C_t \Omega$ in above formula is well known from literature (8) and describes the mass loss of a burning spherical char particle where chemical reaction and diffusion are decisive in terms of the intensity of combustion. The second term given by

$$r_c \frac{H_V}{K_c^2} \cdot m_c \cdot \left[\sum_{i=1}^{n} c_i . u_i^3\right] \tag{2}$$

presents the mass loss as a result of the mechanical influence of inert particles on the surface of a burning char particle. The determination of mass loss as a result of particle impacts with different hardness H had been proposed and experimentally verified by Zang and by Ghadiri (9,10). Here the introduction of that somehow modified the relationship (1) of the char particle mass loss as a superposition of two independent processes has been proposed for the first time. In Eqn. (1) ρ_c represents the char density, K_c is the fracture toughness, m_c is the char mass, but however c_i and u_i represent i-class of concentration and velocity of inert particles. In order to determine the erosion of the char particle mass loss according to (2) the following algorithm of calculation has been used:

- the cumulative particle size distribution was assumed (Fig.3),
- the parameters of Rosin-Rammler distribution for tested class of particles were determined,
- the Rosin-Rammler distribution on *n*-class was divided,
- having overall G_s for the inert material $G_{s\,i}$ for all *n*-class was determined, according to

$$G_{s\,i} = G_s \cdot f(d_i) \cdot \Delta d_i \quad \text{for} \quad i=1...n \tag{3}$$

- the velocity of free fall u_i of a particle with diameter d_i for *n*-class was calculated
- the concentration of the inert material c_i is

$$c_i = \frac{G_{s\,i}}{r_{inert} u_i} \tag{4}$$

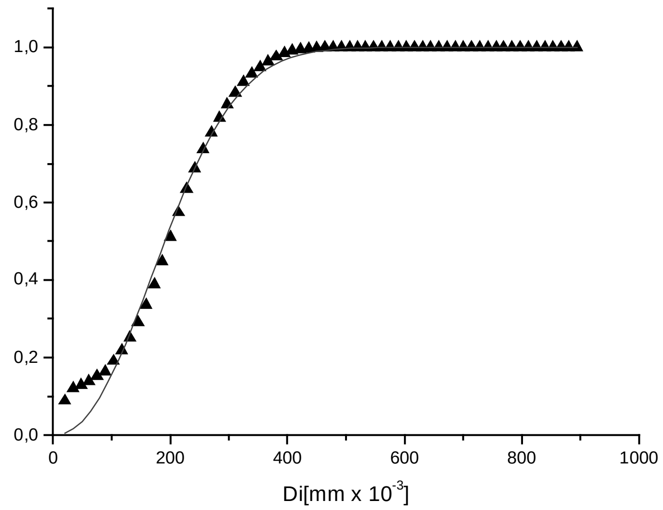

Fig.3. The cumulative particle size distribution obtained from the experiment and its approximation.

RESULTS

The first stage of the model verification was a comparison of the results received on its basis with the results of the combustion of char particles in an atmospheric air. The module generating the mass loss as a result of erosion was turned off. The results obtained for the tested char of hard coal are presented in Fig.4. In the afore-mentioned model the initial temperature on the surface of a tested particle T = 1050°C was accepted on the basis of its measurement during the experiment in the atmospheric air. The numerical and the experimental results were very similar and hence it is possible to verify the second module of equation of mass loss as responsible for the erosion particle mass loss in the flow of inert material.

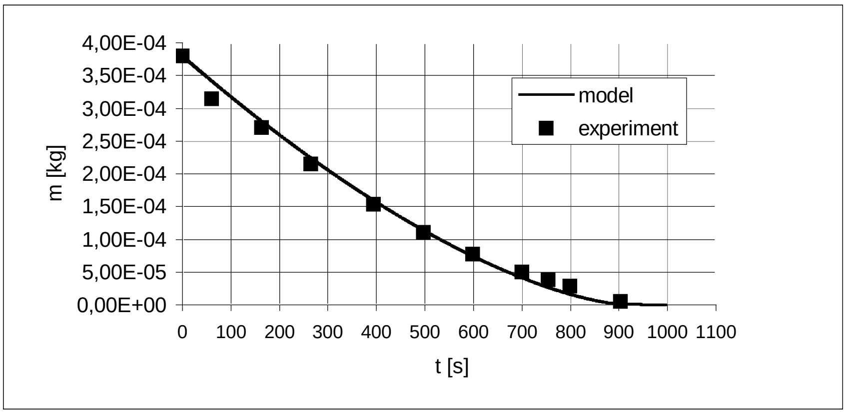

Fig.4. Mass loss of char particle as result of combustion in the atmospheric air .

In the first step taken in accordance with the experiment the cumulative particle size distribution of solid from the expression of Rosin-Rammler determined its parameters as d_{50} = 191.63123 and n = 3.84305.

$$f(d) = 1 - \exp\left[-0.7\left(\frac{d}{d_{50}}\right)^n\right] \quad (5)$$

Following that, the particle size distribution was divided into the appropriate amount of n- class within the range of d_{min} and d_{max} . In order to get convergences of the numerical solution with the experiment two parameters characterizing susceptibility to the erosion of mass loss: hardness H and fracture toughness K_c were regulated. In the calculation the hardness of char is deemed to be the hardness of Vickers coal in ambient temperature of $H = 0.25 \cdot 10^9$ N/m^2 and initial mass of char $m_c = 0.3 \cdot 10^{-3}$kg. The Fig.5 and 6 show courses of mass loss of char particles for G_s = {4, 7, 15} kg/(m^{2}s) during the experiment and those received form the mathematical model. It should be stated that times of the overall mass loss obtained from the mathematical model for different values of G_s are very similar to the values from the experiment. Their course, however, is slightly different. The results from the experiment show almost a rectilinear course but the course determined by the model is clearly not rectilinear. The difference gets bigger with a growth in the rate of flow G_s. Apart from the far from an ideal model the way of filtration and linearization of the signal of mass loss measurement recorded during the experiment can be the reason for the difference observed. The assumption of proportion of mechanical influence of the solid particles from the burning char particle surface exposed to erosion, fluctuation of the rate of flow G_s during the experiment and the lack of influence of the tensometric branch scale handle can influence the final course of the real process. Therefore, experimental methodology, as well as the imperfection of the mathematical model can be responsible for the discrepancy in observance. Finally, it should be stated that the module responsible for erosion mass loss that is proposed in this analysis correctly reflects the real process of mass loss of a char particle during combustion in the flow of inert material especially in the case of the low rate of inert material flow.

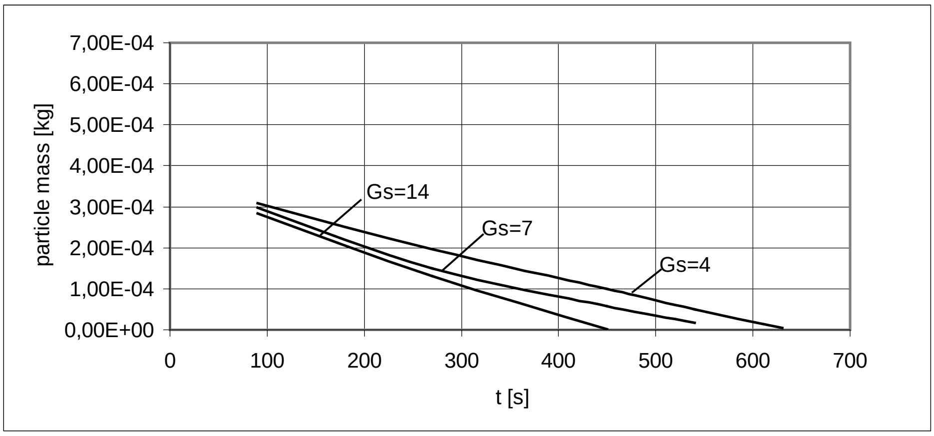

Fig.5. Mass loss of a char particle as a result of combustion in the flow of inert material –experiment.

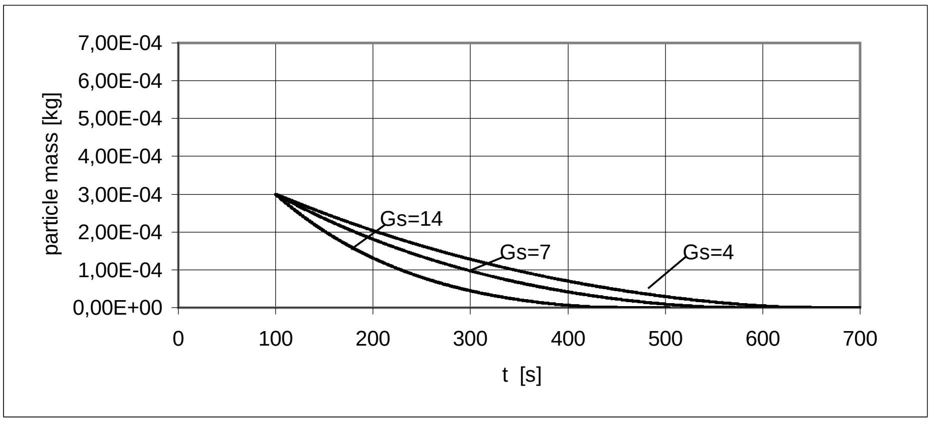

Fig.6. Mass loss of a char particle as a result of combustion in the flow of inert material –model.

CONCLUSIONS

The modeling of the combustion process of coal particles in fluidized bed presents a lot of difficulties both in the area of the combustion mechanism, as well as the real image of the effect of a fluidized bed on a burning coal particle. Hence, in this research it has been decided to model this complex process as a superposition of two processes generating the mass loss of a coal particle i.e. the combustion as well as the surface erosion of a particle as a result of interaction with the inert material. The results obtained show that it could be an effective method for representation of the aforesaid research experiment, especially with a low flow rate. On the basis of this it can be possible to determine both the individual share of combustion and erosion process, as well as their total value. Two factors were introduced into this equation of mass loss i.e.: hardness *H* and particularly fracture toughness K_c point at the possibility of systemizing coal on account of susceptibility both in terms of percolation and consequently the erosion process. The model values assumed for K_c are only the close approximation of their real values because they had been estimated for the constant values of hardness. Therefore, the real value of coal hardness seems to be the key parameter, as well as its changes during all phases of the combustion process. With the known velocity of collision of fluidized bed particles with burning coal surface particle and real values of *H* and K_c this method seems to be correct in modeling of combustion process of coal particles in real fluidized bed conditions.

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NOTATION

A_z - surface area of a char, m^2
C_t - oxygen concentration away from a char, kg/m^3
c - concentration of inert material, m^3/m^3
d - diameter of char particle, m
G_s - flow rate of inert material, kg/m^2s
H_v - Vickers hardness, N/m^2
k - reaction rate constant, m/s
K_c - farcture toughness, $Nm^{-3/2}$
m_a - mass of ash, kg
m_c - mass of char particle, kg
t - time, s
T - temperature, K, ^oC
u - velocity of inert material, m/s
r_c - density of char, kg/m^3
r_{inert} - density of inert material, kg/m^3
Ω - stoichiometrical coefficient