TEMPERATURE OF BURNING COAL PARTICLES DURING COMBUSTION IN FLUIDIZED BED

by

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Results of experimental investigation of coal particle temperature are presented in this paper. Experiments were performed with two Yugoslav coals: lignite Kosovo and brown coal Bogovina. The coal particles were shaped into spherical form with diameter of d_c *= 5, 7 and 10 mm. Air was used as the fluidization gas. The fluidization velocity was in the range* v_f *= 0.18–0.22 m/s. The bed temperature was in the range* T_b *= = 590–700 °C. Inert material was silica sand with the mean bed particle diameter of* d_p *= 0.250 mm. The coal particle temperature was measured by inserting a thermocouple in its center. On the basis of numerous experiments the temperature histories of the coal particles were analyzed in all phases of combustion process in the fluidized bed. Particle and bed temperature difference corresponding to the 50% conversion of burning particle was chosen as the characteristic temperature difference for the whole burning period. This temperature difference for the investigated coals and for different particle diameters was in the range 58–205 °C. The analysis has shown that temperature difference increased with decreasing initial coal particle diameter.*

Introduction

During combustion in a fluidized bed, coal particle temperature was higher than that of the bed. Determination of coal burning temperature is necessary for creating reliable mathematical model of coal combustion, and for well predicting of NO_x and SO_2 emission and possibility of ash melting.

Coal particle temperature measurements can be conducted with different methods: photographic methods [1–3], thermocouple techniques [4–7], and optical probe [8, 9]. The results obtained differ one from another on account of different experimental conditions and different measurement methods applied.

The experimental investigations were performed with coal or char particles. The temperature difference between coal or char particles and fluidized bed was in the range 20–400 °C.

In addition, the coal particle size was not exactly known for the moment when the temperature difference between the bed and the burning coal particle was measured. As a referent value, authors usually took the maximum temperature difference. They usually adopted constant coal particle size, that is the initial value of coal particle diameter.

Photographic and optical probe methods are suitable for temperature measurements of small coal particles. These methods can not measure the temperature history of individual coal particles. A major difficulty of measurement with optical probe is to determine the fraction of the field of view of optical probe receiving radiation from the burning particle. By photographic method, particles can only be photographed while they are at the bed surface, where heat and mass characteristics are different from those within the bed. Fusible wire ring methods are not suitable for the coal particle temperature measurements, since the manufactured coal particle has different characteristics compared to the original coal and there is a doubt whether the particle temperature is above or below the fusion point of rings. The thermocouple technique is the most commonly used method. By these technique the coal particle temperature can be measured during almost the whole period of combustion. The thermocouple method imposes some restrictions on particle motion and in addition the temperature of small particles (d_c < 3 mm) can not be measured.

Experimental results presented in this paper were obtained in order to provide reliable data on Yugoslav coal burning particle temperature (lignite Kosovo and brown coal Bogovina) during combustion in a fluidized bed. The measurement method applied was with the thermocouple embedded in the center of the coal particles. It was the most convenient method for measurement of temperature of coarse particles, which were used in these experiments (d_c = 5, 7 and 10 mm).

Experimental

The schematic of the experimental apparatus is shown in Fig. 1. The *FB* was heated by a 2 kW electrical heater, controlled by a variable transformer. A ceramic *FB* furnace with *i.d.* 80 mm, the electrical heater and a spiral preheater were placed into the thermostatic oven, which was insulated by glass-fibers. The bed temperature was measured by the thermocouple (Cr–Ni). The ambient air was supplied into *FB* reactor using the axial fan through four nozzles symmetrically placed in the ceramic tube, with four openings at each nozzle. The airflow rate was controlled by the previously calibrated standard measuring orifice. Desired airflow rate was adjusted changing the input voltage of the fan. Before entering the *FB*, gas was preheated. Inert material was silica sand with mean particle diameter of d_p = 0.25 mm. The fluidization velocity was in the range v_f = = 0.18–0.22 m/s (v_{mf} = 0.063–0.078 m/s). The fluidization velocities were chosen so that

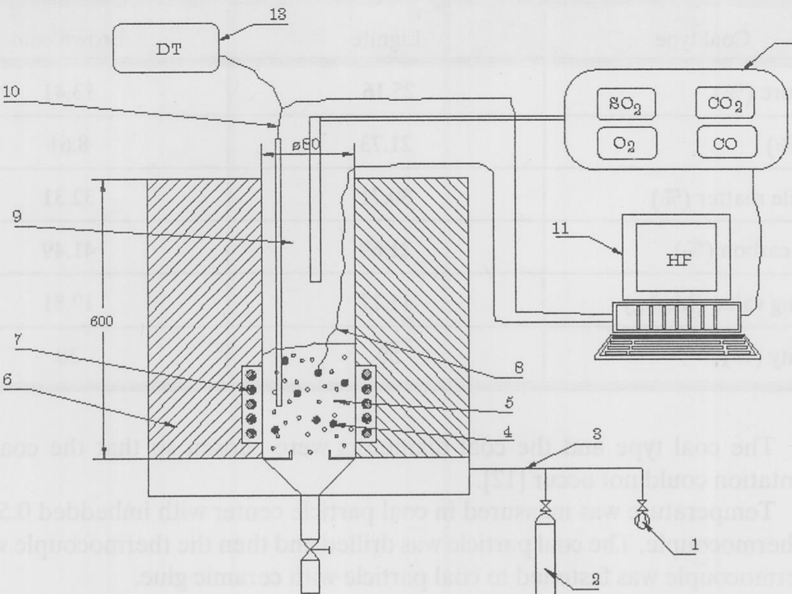

Figure 1. Experimental fluidized bed reactor
1 – Fan, 2 – N_2, 3 – Tubes, 4 – Coal particle, 5 – Fluidized bed, 6 – Thermal insulation, 7 – Electrical heater, 8 – Thermocouple in coal particle center, 9 – Fluidized bed reactor, 10 – Thermocouple in fluidized bed, 11 – Data acquisition system, 12 – Gas analyzer, 13 – Digital thermometer

the maximum particle heat transfer coefficient could be obtained at the given temperature [10, 11]. The static bed height was 90 mm in all experiments.

Experimental conditions were chosen in such a way that the coal particle diameter, the bed temperatures and coal type were in the range usually used for fluidized bed combustion.

In experiments two Yugoslav coals were tested: lignite Kosovo and brown coal Bogovina. These two types of coal were chosen since they are used for combustion in fluidized bed, and it enabled investigation of different parameters affecting the temperature of burning coal particle temperature.

The coal particles were shaped into spherical form, to eliminate the uncertainties associated with difference in shape. Investigations were performed with bed temperatures between T_b = 590 and 700 °C. Coal particles were shaped at the diameter of d_c = = 5, 7 and 10 mm. Proximate analysis of investigated coal is given in Table 1.

Table 1. Proximate analysis of investigated coals

Coal type	Lignite	Brown coal
Moisture (%)	25.16	13.41
Ash (%)	21.73	8.61
Volatile matter (%)	30.71	32.31
Fixed carbon (%)	21.69	41.49
Heating value (MJ/kg)	11.17	19.81
Porosity (%)	50	30

The coal type and the coal diameters were chosen so that the coal particle fragmentation could not occur [12].

Temperature was measured in coal particle center with imbedded 0.5 or 1 mm Cr-Ni thermocouple. The coal particle was drilled and then the thermocouple was set in. The thermocouple was fastened to coal particle with ceramic glue.

During processes of heating, drying and devolatilization the embedded thermocouple could overestimate the real temperature of coal particle, while during combustion, the thermocouple could underestimate the real char particle temperature. For these reasons the measurement error due conduction through the thermocouple was estimated [13]. The maximum of the temperature difference between the coal particle and the bed error was found to be less than 10%.

When a desired *FB* temperature was reached, the thermocouple embedded in a coal particle together with several free spherical coal particles were introduced into the hot *FB*. During the experiments, the coal particle temperature, the *FB* temperature, gas concentrations of CO, CO_2, SO_2 and O_2 were continuously measured by data acquisition system.

Experimental results and discussion

Some typical temperature changes of brown coal and lignite coal particles of different diameters during combustion in the fluidized bed are shown in Fig. 2 and Fig. 3. Temperature change of the coal particle center and gas concentration of CO and CO_2 for different type and diameter of coal particle are shown in Fig. 4 and Fig. 5.

Temperature history curves during coal combustion have three characteristic zones:

(I) The initial heating zone, where the particle was intensively heated up to the FB temperature. In this period heating up and drying of coal particles finished, while the processes of devolatilization and char combustion initiated.

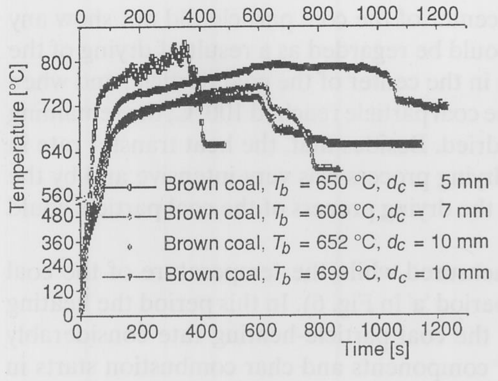

Figure 2. Typical temperature change of brown coal particle center during combustion in oxidizing atmosphere

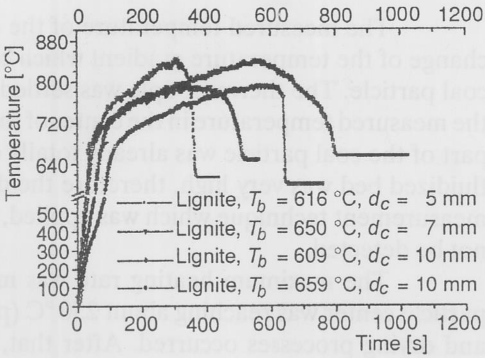

Figure 3. Typical temperature change of lignite coal particle center during combustion in oxidizing atmosphere

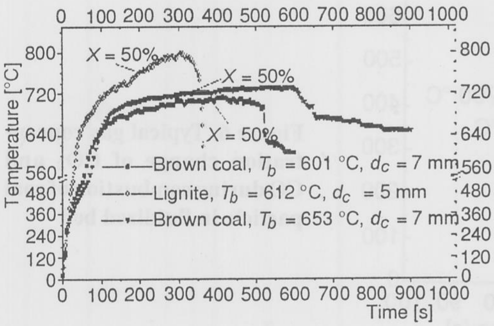

Figure 4. Typical temperature change of coal particle center during combustion in fluidized bed

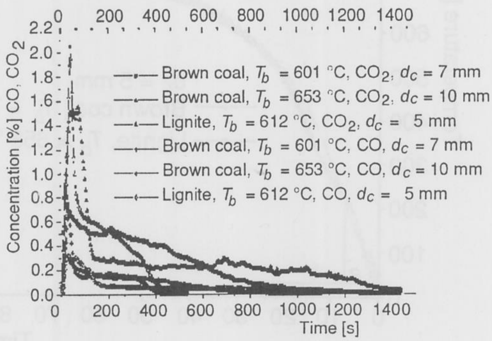

Figure 5. Typical temperature change of coal particle center for coal particles of different diameter

(II) In the second zone, a gradual increase of the particle temperature above the bed temperature was observed for most of the burnout period. Initially, in a short period, besides combustion of char particle, devolatilization and combustion of volatiles occurred, too. On account of that some increase of coal particle temperature was measured. After that, in the longest period of coal combustion, particle temperature increased but not so intensively. That period continued till the moment when the maximum of coal particle temperature was reached.

(III) In the third period, when only char combustion occurred, slow or abrupt decrease of coal particle temperature was measured.

The measured temperature of the center of the coal particle did not show any change of the temperature gradient which could be regarded as a result of drying of the coal particle. The thermocouple was settled in the center of the coal particle, and when the measured temperature in the center of the coal particle reached 100 °C, the remaining part of the coal particle was already totally dried. Besides that, the heat transfer rate in fluidized bed was very high, therefore the drying process was very intensive and by the measurement technique which was applied, the drying process of the coal particle could not be detected.

The maximum heating rate was measured while the temperature of the coal particle center was reaching about 250 °C (period 'a' in Fig. 6). In this period the heating and drying processes occurred. After that, the coal particle-heating rate considerably decreased. Devolatilization of light volatile components and char combustion starts in this period (Fig. 4, Fig. 5, and part 'b' in Fig. 6).

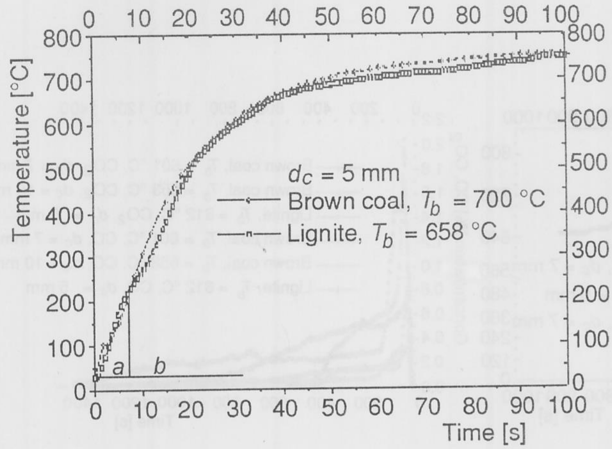

Figure 6. Typical gas concentration change of CO_2 and CO during combustion of coal particle in fluidized bed

The measured concentrations of CO and CO_2 (Fig. 5) showed that the combustion process lasted longer that it could be detected with temperature measurements (Fig. 4). Therefore measurement of coal particle temperature in the last period was not reliable.

Reasons of slow or abrupt decreases of char particle temperature in the last period could be:

- cracking of the char particle, which enables easy penetration of oxygen,
- fragmentation, when the head of the thermocouple can be on the new formed external surface of the char particle,
- the char particle can be taken off from thermocouple.

It was not easy to define a criterion for determining the temperature difference between the coal particle and fluidized bed, which could be related to the initial size of coal particle.

The value of the temperature difference in the first period of combustion was not reliable, since besides the char combustion, the volatiles could burn at the coal particle surface also.

On the other side, since the temperature differences (Fig. 4) increased with increasing conversion degree of coal particle, the maximum temperature differences were usually measured after the burning particle reached a high conversion degree, much over 50%. For that value of conversion degree the coal particle changed its size considerably. Besides that, in some experiments maximum temperature differences could not be noticed for the following reasons: cracking, fragmentation, *etc.*

Therefore the referent temperature difference was taken at the moment when burning coal and char particle reached the X= 50% conversion degree (Fig. 4). The size of burning particle for X= 50% conversion degree could not be significantly different from its initial size because of the following:

- the particle was porous, and it enabled combustion within the particle,
- the bed temperature was relatively low and combustion was at least partly under kinetic control, when combustion occurs within the porous particle,
- if attrition is ignored and the shrinking particle model is adopted, then maximum change of particle size could be 12.5%, for X=50% conversion degree,
- at the completely burnt locations of the coal particle it was probably that ash layer remained, and by that way retained coal particle size.

It was measured that temperature difference between the burning particle and the fluidized bed was decreasing with decreasing initial size of the particle (Fig.7). The referent temperature differences for the investigated coals are:

for brown coal Bogovina:	d_c = 5 mm,	ΔT = 100±20 °C,
	d_c = 7 mm,	ΔT = 88±15 °C,
	d_c = 10 mm,	ΔT = 70±12 °C,
for lignite Kosovo:	d_c = 5 mm,	ΔT = 180±25 °C,
	d_c = 7 mm,	ΔT = 166±26 °C,
	d_c = 10 mm,	ΔT = 145±20 °C.

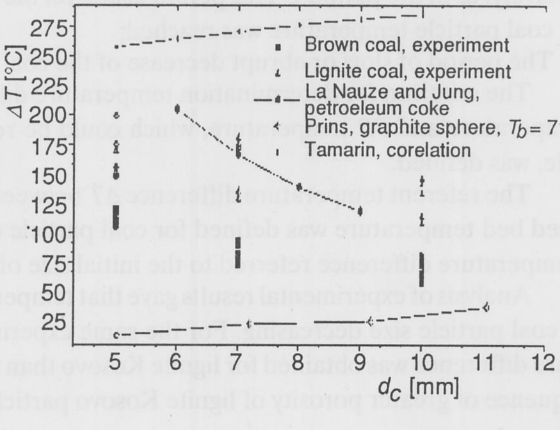

Figure 7. Difference between coal particle temperature and bed temperature for coal conversion degree X = 50%, and maximum temperature difference by other authors

Greater temperature differences ΔT were measured for lignite Kosovo particles than for brown coal Bogovina. As a consequence of greater porosity and lower rank, the burning rate of lignite Kosovo particle was higher than that of brown coal Bogovina. Combustion occurred mainly within the coal particle, which led to the higher coal particle temperature.

Using the embedded thermocouple method different authors [5, 14, 15] obtained different maximum temperature differences between the coal particle and the bed (Fig. 7). This relatively great discrepancy (10 ... 250 °C) is mainly the consequence of different experimental conditions (coal type, coal diameter, porosity and rank of coal, fluidized bed temperature, *etc.*).

The temperature difference value obtained for lignite Kosovo and brown coal Bogovina, defined for the 50% conversion degree of coal particle are quantitatively between the values obtained by other authors.

Conclusions

Extended experimental program of particle temperature measurements of two Yugoslav coals (lignite Kosovo and brown coal Bogovina) during combustion in the fluidized bed was conducted.

The temperature of coal particle center and gas concentrations of CO and CO_2 were continuously measured during the whole burn-off period by data acquisition system. On the basis of numerous experiments the temperature histories of the coal particles were analyzed for all phases of combustion processes in fluidized bed.

Three characteristic periods were recognized from the curves representing temperature change of coal particles:

(I) The period of intensive increase of coal particle temperature towards FB temperature;

(II) The longest period, where coal particle temperature increased, but no so intensively, as in the period I. This period lasted till the moment when the maximum of coal particle temperature was reached;

(III) The period of slow or abrupt decrease of the coal particle temperature.

The criterion for determination temperature difference between the coal particle temperature and *FB* temperature, which could be related to the initial size of coal particle, was defined.

The referent temperature difference ΔT between coal particle temperature and fluidized bed temperature was defined for coal particle conversion degree of 50%, and that temperature difference referred to the initial size of coal particle.

Analysis of experimental results gave that temperature difference increased with initial coal particle size decreasing. For the same experimental conditions greater temperature difference was obtained for lignite Kosovo than for brown coal Bogovina, as the consequence of greater porosity of lignite Kosovo particles.

Acknowledgments

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Nomenclature

d_c [m] – diameter
T [°C] – temperature
ΔT [°C] – difference between coal particle center temperature and fluidized bed temperature
v_f [m/s] – superficial velocity
v_{mf} [m/s] – minimum fluidization superficial velocity
X – coal particle conversion degree
FB – fluidized bed

Subscripts

b – fluidized bed
c – coal particle
p – bed particle

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