

Combustion of Coal Particles in a High Temperature Gradient

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The development of pulverized coal and fluidized bed combustion requires good numerical codes for modeling the systems. Several codes are already available. However, because of the lack of data on the chemical and physical properties of coal particles and on their combustion when submitted to high temperature gradients (ca. 10^4 K/s) these codes need improvement of sub-models, describing the key steps of the process. Our work is concerned with the physico-chemistry of combustion of individual particles of coal.

Experimental

The method is based on in situ observation and subsequent characterization of a coal particle falling in a drop tube furnace in a well defined chemical and thermal environment. The vertical furnace is made of two parts (longitudinal separation) which gives a good access to the reactor. Heating is achieved with six lanthanum chromite elements ; the total power is 12 Kw and allow to reach 2000 K. An isotherm zone of 400 mm is fairly well defined. Optical access is possible axially as well as by a 300 mm lateral window in the wall of the furnace.

The reactor is a 50 mm diameter tube, in quartz for low temperature experiments or in silico-alumina material for higher temperatures ; this last tube is equipped with 8 saphir windows. The particles are injected, from a vibrator in the isotherm part of the furnace through a water cooled probe. A water cooled movable probe allows the collection of reacting particles at different positions in the furnace. The residues are collected on filters for analysis.

Two online diagnostics are used :
- an axial two color pyrometer. The light emitted by the particle is collected by an optical monofiber, 1 mm diameter, whose extremity is located at the bottom of the furnace. The intensity of light is measured at 600 and 700 nm with photomultipliers. Signals are registered by a numerical

oscilloscope and transferred to a computer. Temperatures are computed in applying Planck law of emission, in assuming that particles behave as a grey body emitter.
- the second online diagnostics is a high speed movie camera. Films are taken through the lateral window.

Analysis of collected residual particles includes :

- Elemental analysis (metals are particularly important for understanding the chemistry of the phenomenon and as tracers for determining weight loss).
- Electron microscopy
- Textural characterization (mercury porosimetry, gas adsorption, thermoporosimetry using a differential scanning calorimeter etc.).

Description of phenomena and results

When a coal particle is heated in the presence of air, devolatilization occurs in the first step. Usually, the gases produced ignite and a diffusion flame surrounds the coal particle. When gas production vanishes, there is extinction of the flame and the carbonaceous material undergoes an heterogeneous oxidation with production of carbon monoxide.

Experiments were carried on a high volatile bituminous coal (37.2 % volatile matter) (1). The granulometry is between 80 and 100 μ m. The temperature determined by the pyrometer versus residence time may exhibit two different profiles (Figures 1 and 2). On Figure 1, the first temperature peak corresponds to the combustion of devolatilizing gases. Such a high temperature is attributed to soot particles produced during the combustion. The duration of this emission is of the order of magnitude of 10 ms. The second stage corresponds to the heterogeneous combustion of the coke particle resulting from the devolatilization of the initial coal particle. On figure 2, only one pulse is observed ; its duration is within 30 to 35 ms for particles of 80-100 μ m and furnace temperature of 1100 to 1300 K. For a given granulometry, one goes

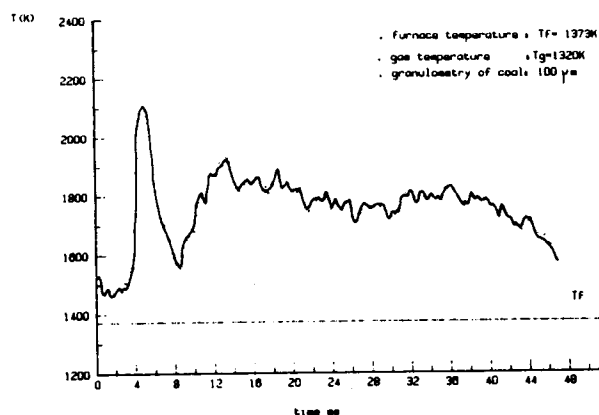


Figure 1. Temperature (two color pyrometer) versus time.

from type 2 to type 1 when temperature increases.

Though we have no quantitative explanation for the above observation, it is reasonable to assume that type 1 curve occurs when the rate of devolatilization is sufficiently high to stabilize a flame around the grain. A temperature increase enhances this rate.

Modelization of devolatilization and heterogeneous oxidation steps.

- Devolatilization.

The devolatilization stage is often described as a series of parallel reactions corresponding to a given distribution of activation energy (2,3). Using data given in literature for activation energy and pre-exponential factor and introducing the experimental temperature profiles we have computed using the LSODE code (Gear method) the duration of devolatilization and the rate of volatile matters. Using the data given by Anthony and Howard for a bituminous coal:

Preexponential factor : $1.65 \cdot 10^{13}$
 Activation energy
 . average value : 54.8 Kcal/mole
 . standart deviation : 17.2 " "

We have found that the duration of devolatilization is slightly higher than 10 ms while experimentally the duration of the first peak (Figure 1) is slightly shorter than 10 ms. Using several metals (Si, Fe, Al) as tracers to determine carbon loss of particles burnt in the furnace described above, it was found that more than 50 % of the coal mass is devolatilized. In that experiment coal particle during devolatilization is surrounded by a diffusion flame so that oxygen diffusion to coal surface is not expected to be significant. A high temperature of the particle, due to heat transfer from soot particles in the diffusion flame, might yield such a high ratio of volatile matter.

- Heterogeneous combustion of carbonaceous residue (step 2 on figure 1).

During step 2, the thermal balance of heat exchange at the surface of the particle can be written (4)

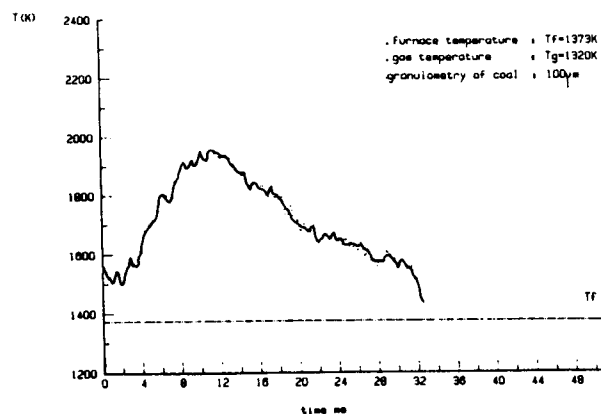


Figure 2. Temperature (two color pyrometer) versus time.

$$\frac{\pi}{6} D_p^2 \cdot \rho_p \cdot C_p \cdot \frac{\delta T}{\delta t} = |H_r + H_c + H_q| \pi D_p^2$$

D_p : particle diameter
 ρ_p : particle density
 C_p : heat capacity of coal
 T : temperature
 t : time
 H_r : radiative heat flux
 H_c : convective heat flux
 H_q : chemical heat flux

All parameters excepted H_q can be independently determined (4). In our computation we have considered, according to our high speed movie camera observation, that D_p is fairly constant during oxidation which means that the variable parameter is ρ_p . The chemical heat flux corresponds to the enthalpy of carbon oxidation. Provided carbon is oxidized into carbon monoxide and the enthalpy of carbon monoxide formation from carbon and oxygen is known (a value of 2340 cal/g has been used), it is possible to compute the weight loss of the particle versus time. Computation agree with final experimental value (5). It is worthy of note that the measure of the surface temperature of a coal particle during heterogeneous combustion makes possible to compute without any adjustable parameter the rate of weight loss of the particle.

Acknowledgement

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References

1. AFNOR M 03004 (July 1974).
2. G.J. Pitt, Fuel 41, 267, 1962.
3. D.B. Anthony and J.B. Howard, A.I. Ch. E.J. 22, 625, 1976.
4. D. Froelich, S. Corbel, G. Prado and J.L. Merry, Revue Générale de Thermique, XXIII (274), 569, 1984.
5. D. Froelich, PhD dissertation thesis, University of Mulhouse, France, 1985.