CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš
 ISBN 978-88-95608-04-4 ISSN 1974-9791
DOI: 10.3303/CET0918092

Primary fragmentation of coal particles at high heating rate

Osvalda Senneca, Sabato Russo, Riccardo Chirone
Istituto di Ricerche sulla Combustione - C.N.R.
P.le Tecchio 80- Napoli – ITALY
senneca@irc.cnr.it. Fax+390815936936

Attrition phenomena during combustion of solid fuels in fluidised beds has been the object of extensive research in the past (Beer 1987, Scala et al 2006, Dakic et al 1986). It was demonstrated, in fact, that attrition influences the fuel particle size distribution and ultimately the overall carbon conversion efficiency. Attrition phenomena include primary fragmentation of fuel particles during devolatilization, char particles attrition by abrasion and secondary percolative fragmentation. Primary fragmentation is that occurring immediately after the injection of the solid particles in the bed and is caused by thermal stresses as well as by internal overpressures associated with volatiles release. It is likely that primary fragmentation plays an important role not only in fluidised beds, but also in other applications characterised by high temperature and high heating rates such as in pulverized combustion, in coal-water combustion, in oxy-fuel combustion.
The present work reports a study of primary fragmentation of coals under a wide range of temperatures, starting from those typical of fluidised bed combustion (800-900°C) up to more severe temperatures typical of pulverised combustion (1400°C). Fast heating conditions have been achieved in an inert atmosphere using an heated strip reactor with heating rate of 10^5°C/min.
Experiments have been carried out on a bituminous coal and on an anthracite. Materials have been characterized in terms of fragmentation probability, particle multiplication factor and particle size distribution. Results show that under more severe conditions of temperature and heating rate primary fragmentation occurs as a consequence of both thermal shock and mechanical stresses associated with volatile release and is very pronounced for anthracite, having a rather organized and fragile structure. A high content of volatiles and humidity also promotes fragmentation.

1. Experimental

1.1 Materials

Two coals have been used for the experiments, namely a bituminous coal from South Africa and an anthracite NBAG whose properties are reported in table 1. Coals have been crushed and sieved in the size range 1-2mm. These samples will be referred to as raw materials. Three additional samples have been produced:

- a mild anthracite char, which was prepared in a tubular furnace by heating from ambient temperature to 500°C at 5°C/min in a flow of nitrogen;
- wet anthracite and wet SA coal, prepared by soaking the raw materials in water for 5h and then filtering, achieving for both materials a water uptake of 10% weight.

1.2 Heating of samples

Samples of the raw and wet materials, as well as samples of the mild anthracite char, have been subjected to severe heating in a heated strip reactor (HSR) described in detail in Salatino et al. (1999) and Senneca et al (2009).

Please cite this article as: Senneca O., Russo S. and Chirone R., (2009), Primary fragmentation of coal particles at high heating rate, Chemical Engineering Transactions, 18, 569-574 DOI: 10.3303/CET0918092

Table 1 Characteristics of the coals used

Proximate analysis, % w/w (as received)		
	Anthracite	S.A
Moisture	1.7	7.4
Volatile Matter	10.3	21.8
Fixed Carbon	84.7	57.9
Ash	3.3	12.9
LHV, MJ/kg	35.00	25.35

In each test 10 particles were laid on the strip of the HSR. The reactor was evacuated and filled with nitrogen. The strip was then taken to the desired temperature T_s in less then 0.2s and held at this temperature for 10s. At the end of the experiment particles were collected for further analysis. The test was reiterated several times in order to produce statistically meaningful samples.

Notably the temperature T_s of the strip was set to values in the range 900-1400°C. Due to the very high heating rate of the HSR, the strip can be considered isothermal for the entire duration of the test. The temperature profiles within the particles has instead been calculated by means of a model. The model assumes for the particles a cubic geometry. It includes the effects of conduction, convection and radiation. Results of the calculations are reported in Fig.1 for a strip temperature T_s=1400°C and a particle size of 1mm. It can be observed that the temperature gradient across the particle calculated by the model is approximately 200°C after 5 s, however the bottom half of the particle can be considered roughly isothermal. Model results have been validated by measuring the temperature of the particles with a near infrared (1.5-5μm) fast camera (38000frames/sec). As an example figure 2 reports a picture obtained with the thermocamera.

1.3 Characterization of samples

Samples were characterized before and after the heat treatment by image and laser granulometric analysis. Data have been worked out to evaluate:

- the particle multiplication factor, N/N_i;
- the probability that a particle undergoes fragmentation, S_f;
- the size distribution of particles (unfragmented particles plus fragments).

2. Results

Figure 3 reports a photographic sequence of a test carried out on raw Anthracite at T_s=1400°C. It can be observed that during high temperature isothermal treatment coal particles undergo very extensive primary fragmentation, producing some relatively large fragments as well as a multitude of fines. The phenomenon is very extensive at high temperature, but limited at lower temperatures, becoming negligible below 850°C, consistently with results reported in previous work with reference to fluidized bed operation.

Experiments carried out on South African coal show that this coal undergoes limited fragmentation compared to anthracite, probably because its structure is not as rigid and fragile. Wet SA exhibits somewhat enhanced fragmentation phenomena compared to the raw sample, whereas the adsorption of water does not emphasize the already marked phenomena of anthracite. On the contrary, a mild pre-pyrolysis of anthracite reduces primary fragmentation of this fragile fuel even at high temperature.

Such observations point at a combined role of thermal stresses and internal overpressure from volatile release. The experimental results obtained for all the samples tested are summarised in Figs. 4-6 in terms of particle multiplication factor, probability of fragmentation and particle size distribution. Altogether the analysis of these figures confirms that the degree of primary fragmentation is strongly affected by operative temperature, type of combustible material and pretreatment. In particular:

- Primary fragmentation of millimeter particle size is negligible at T_s=850°C but becomes relevant at T_s=1400°C where Sf=1 and N/Ni=10.
- Adsorption of water enhances primary fragmentation.
- Mild pre-pyrolysis reduces the extent of primary fragmentation.
- The probability of breakage and the number of fragments depends on the nature of coal, being very high for coals with a well organized and fragile structure.

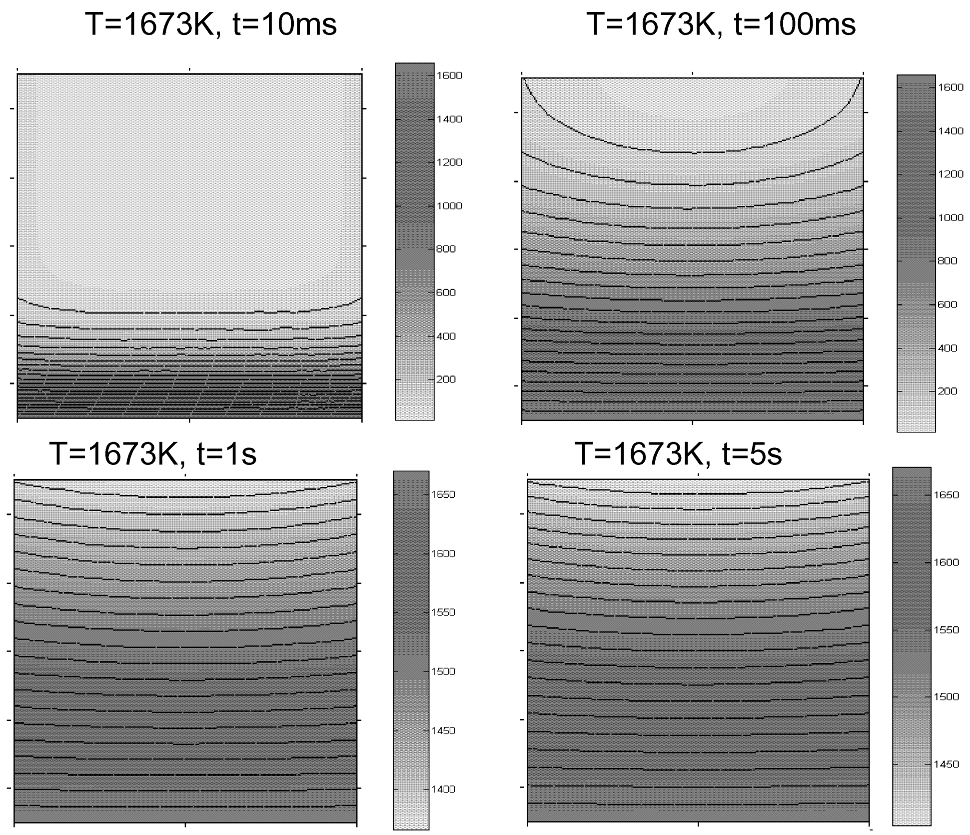

Figure 1 Calculated temperature inside a cubic particle on the HSR at T_s=1673K.

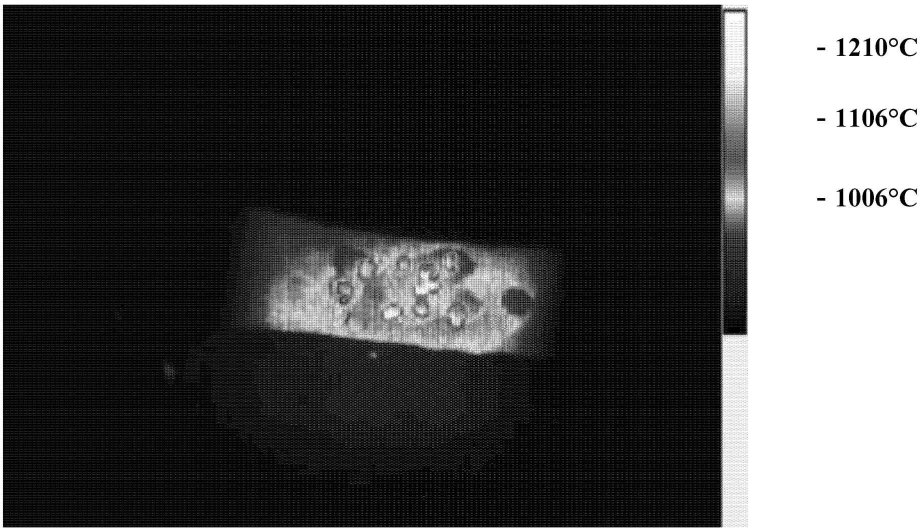

Figure 2   Frame of the thermocamera movie relative to the instant immediately after switching off the heated strip.

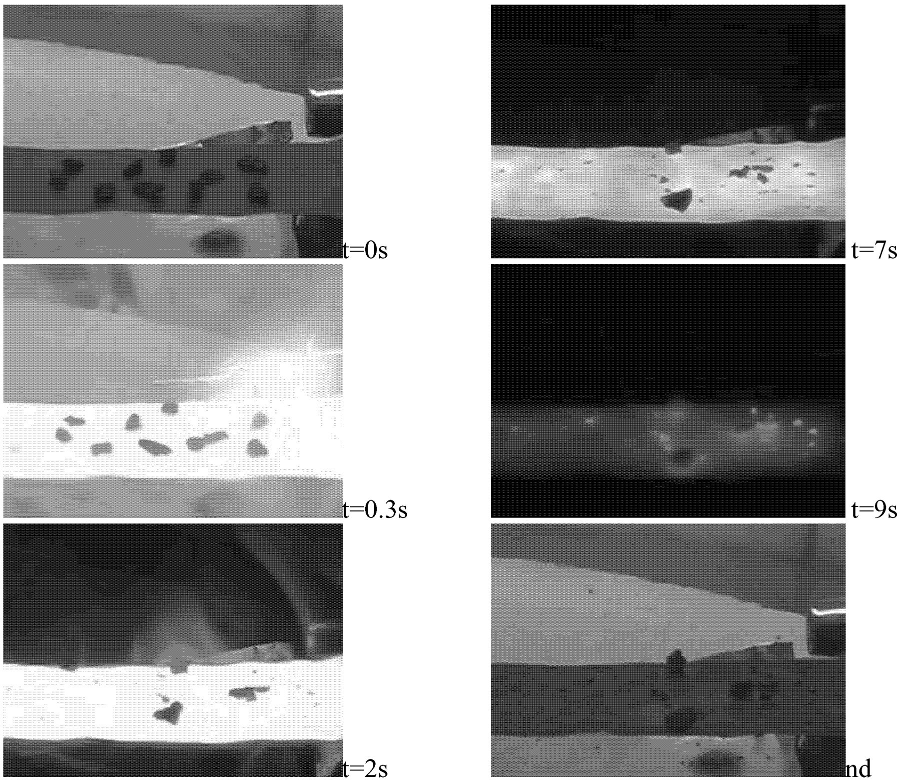

Figure. 3   Fast pyrolysis of Anthracite in the HSR at T_s=1400°C

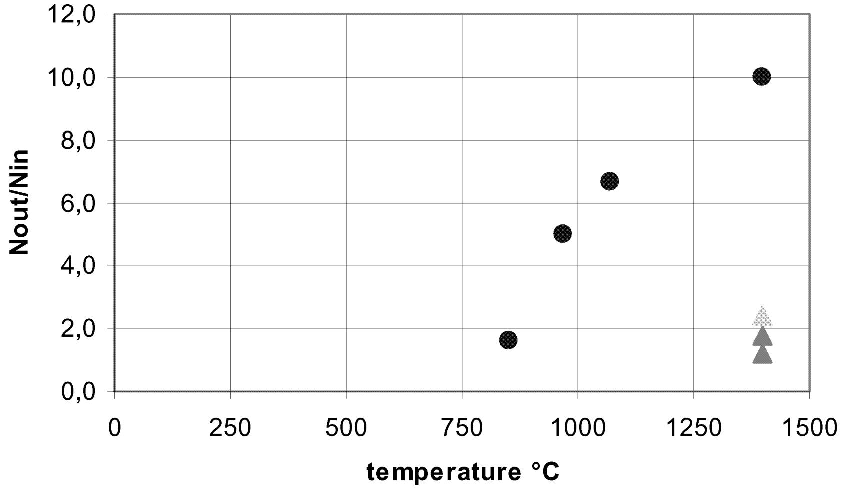

Figure 4   Particle multiplication factor, N/N_i as a function of the strip temperature T_s. Blu circles: Anthracite; green triangles: wet SA; pink triangles: raw SA; grey triangles: mild anthracite char.

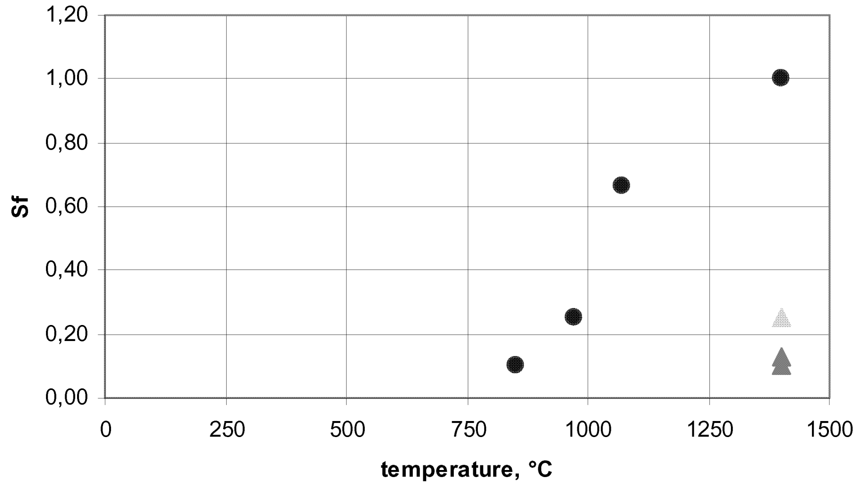

Figure 5   Ptobability of fragmentation as a function of strip temperature. Blu circles: Anthracite; green triangles: wet SA; pink triangles: raw SA; grey triangles: mild anthracite char..

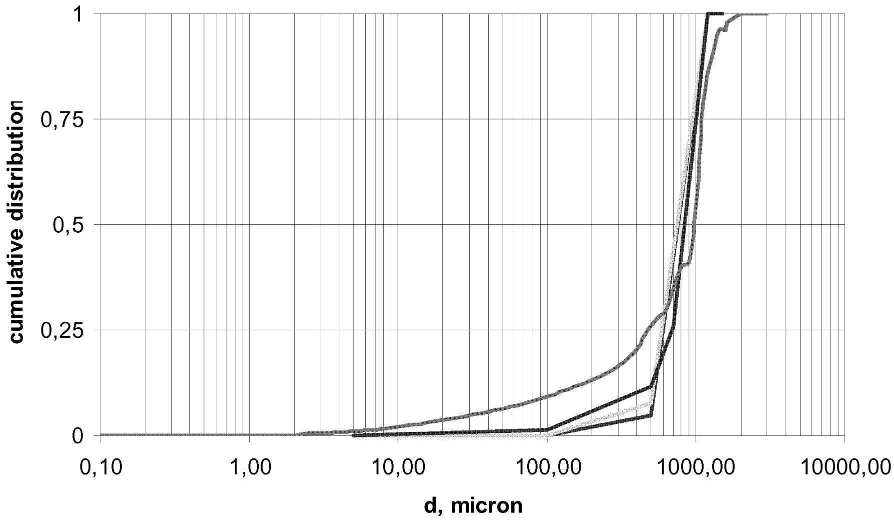

Figure 6 Cumulative particles size distribution of fragments obtained in primary fragmentation tests carried out at different temperature: 1400°C (red line), 1100°C (pink line), 950°C (green line), 850°C (bleu line).

3. Discussion and conclusions

Experiments of pyrolysis at high heating rate and high temperature have been carried out on different coal samples using an heated strip reactor. Results have shown that extensive fragmentation may occur resulting in a sensible reduction of average particle size.

Primary fragmentation may be due to the stresses produced by the thermal shock as well as to mechanical stresses associated with the release of volatile matter. In fact experiments confirm that the phenomenon is very pronounced for anthracite, which has a rather organized and fragile structure.

A high content of volatile matter and humidity within the structure also promotes primary fragmentation. Further work is needed to better clarify the phenomenon and the relative importance of thermal/versus mechanical stresses.

References

J.Beer, 1987, International Symposium on Coal Combustion, TsinguaUniversity,Beijing, China, September, Keynote Lecture

R.Chirone, L. Massimilia, P. Salatino, 1991, Prog. Energy and Combustion Science 17, 297

P. Dacombe, M. Pourkashanian, A. Williams, L. Yap, 1999, Fuel 78, 1847

P. Salatino, O. Senneca, S. Masi, 1999, Energy Fuels 13, 1154

O. Senneca, R. Chirone, C .Allouis, 6th Mediterranean Combustion meeting, Ajaccio, Corsica, 7-11 June 2009

F. Scala, R. Chirone, P. Salatino, 2006, Energy Fuels 20, 91

D. Dakic, G. Honing, M. Valk, 1089, Fuel 68, 911.