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Attrition of lignite char under fluidized bed gasification conditions: The effect of carbon conversion

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Abstract

The effect of carbon conversion on the attrition of lignite char particles during fluidized bed gasification by CO_2 was studied in a lab-scale apparatus. The influence of bed temperature and inlet CO_2 concentration on carbon conversion and, consequently, on attrition was studied. The mechanical resistance of the char particles was also characterized at different stages of char conversion by specific attrition experiments. A predictive kinetic model for CO_2 gasification of the lignite char was developed from the experimental results, that was able to correctly predict the evolution of carbon conversion versus time. On this basis a semi-empirical model was developed in order to simulate the evolution of carbon elutriation rate with carbon conversion degree, i.e. the *gasification-assisted attrition* enhancement effect.

Keywords: Gasification; Lignite; Fluidized bed; Attrition; Elutriation

1. Introduction

Lignite is an abundant fuel and makes up approximately 40% of coal reserves in the world. Its commercial use is forecast to grow substantially [1].

The urgent need to apply techniques to capture and sequester CO_2 emitted from the use of coal has triggered the development of new processes like chemical looping combustion and sorption enhanced gasification [2,3]. Both these processes require that fuel gasification is carried out at a relatively low temperature. Fuels with highly reactive chars, such as low-rank coals and biomass, are best suited for such processes.

Fluidized bed (FB) gasification is acknowledged to have great flexibility in conversion of several solid fuels, including low-rank coals, into synthesis gas [4]. This technology also allows the use of catalysts and sorbents directly in the reaction chamber for improving the gas quality [5,6]. Unfortunately, gasification is more capital-intensive than combustion and the produced syngas has a high dust and tar content.

When injected in a hot FB, fuel devolatilization and primary fragmentation occur, and a fragile char particle is generated which further undergoes attrition and secondary fragmentation. All these phenomena are well known to affect the reliability and efficiency of FB combustion and gasification processes [7,8]. On the one side, attrition/fragmentation may significantly change the particle size distribution of the fuel in the bed, which influences

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the rate and the mechanism of fuel particle conversion, as well as particle heat and mass transfer coefficients. On the other side, they may cause the elutriation of fine material from the bed (i.e. the entrainment with the gas flow to the reactor exit) that results in the loss of unconverted carbon.

Several attrition studies have been carried out under fluidized bed combustion conditions, focused either on coal [8] or on alternative raw or pelletized fuels [7,9,10]. On the contrary, only very limited activity has been reported under FB gasification conditions [11–13]. One recent study on attrition of lignite char pointed out that fragmentation and attrition by abrasion of the char particles during gasification were significant, and suggested a *gasification-assisted attrition* enhancement effect [14]. In fact, it was observed that the weakening action of carbon conversion at the particle surface determines a significant enhancement of the attrition rate with respect to inert conditions. This mechanism, associated to the low reactivity of the generated fines, made the loss of carbon by fines elutriation during char gasification more significant than that typically found under combustion conditions.

In this work the attrition behavior of char from an Italian lignite (as a representative high-reactivity low-rank coal), was studied under CO_2 gasification conditions in a lab-scale FB apparatus. In particular, attrition was characterized as a function of the char conversion degree. The influence of bed temperature and CO_2 concentration on carbon conversion and, in turn, on attrition was investigated. On the basis of the experimental results, a kinetic model of lignite char under CO_2 gasification conditions was developed in order to predict the time resolved profiles of carbon conversion. The mechanical resistance of the char particles was also characterized at different stages of char conversion by specific attrition experiments. A semi-empirical model was finally developed to simulate the experimental profiles of carbon elutriation rate as a function of time.

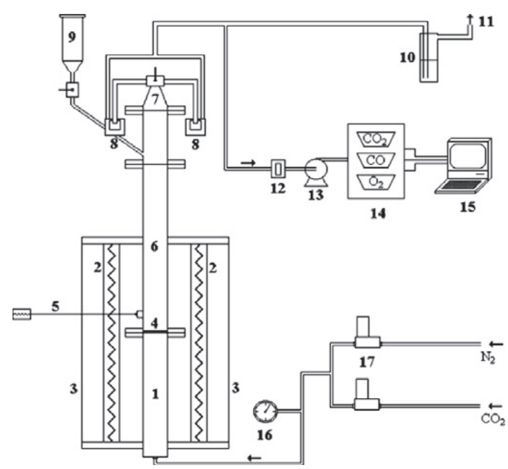
2. Experimental

The fuel used in the experiments was an Italian lignite (Sulcis) whose properties are reported in Table 1. The lignite particles were pre-devolatilized in N_2 in a FB operated at 850 °C. The obtained char particles were sieved in the nominal particle size range 6.3–8.0 mm. Two additional particle size ranges (2.36–5.0 mm and 5.00–6.3 mm) were also tested in selected experiments.

An electrically heated stainless steel atmospheric bubbling FB combustor 40 mm ID and 1 m high was used for the experiments (Fig. 1). Details of the apparatus are reported elsewhere [9]. A two-exit brass head was fitted to the top flange of the column. By operating a valve it was possible to convey flue gases alternately to two removable sintered brass filters. Batches (~1.0 g) of pre-devolatilized char were fed to the bed (0.3–0.4 mm sand, 180 g). The bed was fluidized with a N_2–CO_2 mixture with a CO_2 concentration in the range 20–100%. The bed temperature was varied in the range 800–900 °C. The fluidization velocity was fixed to 0.4 m/s. Elutriated fines were collected by means of the two-exit head by letting the flue gas flow alternately through sequences of filters for definite periods of time. The difference between the weights of the filters before and after operation, divided by the time interval during which the filter was in operation, gave the average fines elutriation rate relative to that interval. Fines collected in the

Table 1
Properties of Sulcis lignite.

Proximate analysis, % (as received)	
Moisture	6.3
Ash	16.9
Volatile matter	49.7
Fixed carbon	27.1
Ultimate analysis, % (dry and ash free basis)	
Carbon	71.7
Hydrogen	5.7
Nitrogen	1.8
Oxygen	13.1
Sulfur	7.7
LHV, kcal/kg	5137



1) gas preheating section; **2)** electrical furnaces; **3)** ceramic insulator; **4)** gas distributor; **5)** thermocouple; **6)** fluidization column; **7)** head with three-way valve; **8)** sintered brass filters; **9)** hopper; **10)** scrubber; **11)** stack; **12)** cellulose filter; **13)** membrane pump; **14)** gas analyzers; **15)** personal computer; **16)** manometer; **17)** digital mass flowmeters.

Fig. 1. Experimental apparatus.