



Effect of sawdust addition on coking pressure produced by two low vol bituminous coals



L. Florentino-Madiedo, D. Casal, E. Díaz-Faes, C. Barriocanal*

Instituto Nacional del Carbón, INCAR-CSIC, Apartado 73, 33080 Oviedo, Spain

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ABSTRACT

Two high-rank bituminous coals and three sawdusts of different origin were selected to study the effect of biomass on coking pressure. The effect of the biomass on the thermoplastic properties of the coals was assessed by means of the Gieseler test. In addition, the effect of the biomass on the thermal decomposition of the coals was studied by means of thermogravimetric analysis together with the modification of the permeability of the coal plastic phase. The individual coals and the blends were carbonized in a 17 kg movable wall oven; the coking pressure developed was measured and the quality of the resulting coke was assessed. It was found that the sawdust reduced coking pressure, especially in the case of the coal that developed the highest coking pressure. This effect was attributed to the modification of the permeability of the plastic phase to gas flow. It was concluded that although the addition of sawdust produces a decrease in coking pressure, additions should be limited to small amounts to avoid excessive deterioration of the quality of the product.

1. Introduction

The inclusion of biomass in coking blends has been increasingly investigated in recent years with a view to widening the range of alternative raw materials that can be included in coking blends [1–6]. One of the reasons for using biomass is the general concern about the generation of greenhouse gases resulting from the use of fossil fuels and the high consumption of coal in the steel industry [7–9]. When using additives, it is important to bear in mind the influence they have on coal thermoplasticity and on coke quality [10–12]. Another important cause for concern when including an additive in a coking blend, is the modification of the coking pressure that may be caused by the additive. The structure of a coke oven is not very strong and even the application of relatively low pressure may result in deformation and damage to the walls of the oven and shorten its life span with considerable economic loss for the coking industry. The phenomenon of coking pressure generation is complex and several different processes play a role at the same time. Coal devolatilization, fluidity, permeability of the plastic mass to the gas flow, resolidification of the coal mass, semicoke porosity and fissuring are all factors that are involved in the phenomenon of coking pressure generation [13–16].

During coking the oven walls are maintained at a high temperature (1300 °C), throughout the process so that, when the coal is charged into the oven, a temperature gradient appears in the coal charge. This means that layers of coke, semicoke and coal are present at the same time in

the oven extending from the wall to the centre i.e. from the hottest to the coolest part of the oven. Heat is then gradually transferred inwards and, as the coal layer reaches its softening temperature, the volatile products that start to evolve and escape can either pass into the already formed semicoke or condense on the coal. At this point the permeability of the plastic coal to gases is of great importance because this is the factor that determines whether the evolved gases escape or whether they remain entrapped in the plastic layer [17–20]. Furthermore, internal gas pressure is considered by some authors [19] to depend on the permeability of the plastic layer to the flow of gas and on the rate of gas evolution inside this layer. Also worth noting is that the escape of gases through the semicoke layer seems to depend not only on the type of pore structure but also on the fissure pattern, since these fissures provide pathways for the gases to escape through [21].

The coals that generate high coking pressure are usually high rank bituminous coals that tend to produce good mechanical strength coke and in high yields. However, the use of these coals in coking blendings may give rise to operational problems that must be controlled by blend optimization, by modifying the coking conditions or by using additives.

The use of additives modifies the coking pressure generated during coking [22–25]. Inert material such as coke fines or non-coking coals will modify the viscosity of the coal plastic phase and the permeability of the charge to gases. In addition the final contraction and resolidification process will undergo modification. Waste plastics such as polyolefins produce an increase in the coking pressure due to

* Corresponding author.

E-mail address: carmenbr@incarcsic.es (C. Barriocanal).

modification of the thermoplastic properties, permeability and the H donor/acceptor reactions of the coal during co-carbonization [12,26]. Although the possibility of using biomass as an additive in coking blends has been studied its effect on coking pressure has not yet been reported.

The aim of the present study is to determine the effect of sawdust on the coking pressure generated by two low-volatile matter coking coals and on the quality of the resulting coke in order to determine the optimal amount of sawdust that can be added in order to avoid the deterioration of the quality of the coke.

2. Experimental

2.1. Materials and methods

Waste chestnut (SC), pine (SP) and oak (SR) sawdusts and two low volatile matter content bituminous coals (C1 and C2) were selected as materials for the experiments. The sawdusts were obtained as wastes from flooring industries. The moisture of the sawdusts was around 5 wt%. Pine sawdust was torrefied (SPT) in a rotary oven at 300 °C in order to reduce its oxygen and volatile matter content. Proximate analyses were performed following the ISO562 and ISO1171 standard procedures for volatile matter and ash content, respectively. An elemental analysis was carried out using a LECO CHN-2000 for C, H and N, a LECO S-144 DR for sulphur and a LECO VTF-900 for the direct determination of oxygen.

2.2. Assessment of coal thermoplastic properties

The thermoplastic properties of the coals and of the blends containing 1, 2, 3 and 5 wt% of each sawdust were measured by means of the Gieseler test (ASTM D2639-74). A 5 g sample with a size < 0.425 mm was heated, while a constant torque was applied to a stirrer placed inside the crucible containing the coal charge. The parameters measured by this test were: (i) softening temperature, Ts; (ii) the temperature of maximum fluidity, Tf; (iii) resolidification temperature, Tr; (iv) plastic range, Tr-Ts, which is defined as the difference between the resolidification and softening temperatures; and (v) maximum fluidity, MF, expressed as dial divisions per minute (ddpm).

2.3. Thermogravimetric analysis and permeability measurement

The TG/DTG analyses were carried out in a TA Instruments SDT 2960 thermoanalyzer. Samples of 10 mg sized to < 0.212 mm were heated at a heating rate of 3 °C/min up to 1000 °C. A nitrogen flow of 100 ml/min was maintained during the experiment to avoid oxidation and to remove the pyrolysis products. The derivative of the weight loss (DTG) was calculated from the TG data. The temperature of maximum volatile matter evolution (Tmax) was obtained from the DTG curves.

The experimental procedure followed to measure the permeability of the coal plastic phase has been explained previously [14]. Briefly, a representative coal sample of 2 g ground to < 3 mm was placed in a cylindrical quartz tube of 20 mm internal diameter. The height of the coal bed was 10 mm. The coal samples were heated up to 1000 °C at a heating rate of 3 °C/min and nitrogen was fed in from the bottom of the coal layer at a flow-rate of 0.01 m/s. Changes in pressure during heating were measured every 30 s and the permeability coefficient K of the coal's plastic layer was estimated in accordance with Darcy's rule. The experiments were performed at least twice.

2.4. Carbonization experiments and coke quality evaluation

The carbonization tests were carried out in a movable wall oven of approximately 17 kg capacity (MWO17) [24]. The dimensions of the oven are 250 mm L × 165 mm W × 790 mm H. A load cell was mounted on the movable wall to measure the force exerted on the wall

during carbonization. A programmable controller was used to control the oven temperature. The temperature at the centre of the coal charge was monitored by means of a thermocouple connected to a computer. The coal was top-charged with a hopper when the oven had reached 1100 °C. The temperature of the wall was kept constant throughout the test. The coke was pushed out 15 min after the centre of the charge had reached 950 °C. Coking lasted approximately 3.5 h. The cold mechanical strength of the cokes produced was assessed by the JIS test (JIS K2151 standard procedure). After the test the coke was sieved and the DI150/15 index was calculated from the amount of coke with a particle size greater than 15 mm. The coke reactivity and mechanical strength after reaction were assessed by means of the NSC test (ASTM D5341 standard procedure). Two indices were derived from this test i.e. the CRI index representing the loss of weight of a 200 g sample of coke with a size between 19 and 22.4 mm after reaction with CO₂ at 1100 °C for two hours and the CSR index representing the percentage of partially-reacted coke remaining on a 9.5 mm sieve after 600 revolutions in a standardized drum. The relationship between the CSR values obtained in a MWO of 17 kg capacity and those obtained in a MWO of 300 kg has been reported previously [27].

3. Results and discussion

The two coals selected were bituminous low volatile matter content coals with high carbon (> 80 wt% db) and low sulphur (< 0.7 wt% db) contents. Coal C2 with a higher C/H atomic ratio can be considered to have a higher degree of aromaticity (Table 1). In contrast the three sawdusts used have a high volatile matter content and low C and high O contents. The C/H atomic ratios of the sawdust are lower than those of the coals, the lowest being that of the SP. The C/O atomic ratios of the coals are more than 20 times higher than those of the sawdusts. The sulphur contents are very low (< 0.02 wt%) in all three sawdusts. As expected, torrefaction of the pine sawdust (SP) produced an increase in the C/O atomic ratio due to the elimination of oxygen from the structure of the sawdust. The particle sizes of the coals and the sawdusts are also included in Table 1. The two coals were ground to obtain similar particle size distributions, whereas the sawdusts were left unground. The biomass was used as received. The finest biomass samples were oak, 79 wt.% of whose particles were smaller than 0.5 mm whereas the coarsest particle size distribution was that of SC, 4 wt.% of whose particles were smaller than 0.5 mm.

3.1. Effect of biomass on coal thermoplastic properties

Some coals when heated in the absence of air soften at around 400 °C and their particulate state is then transformed into a fluid after

Table 1
Main characteristics of the coals and sawdusts.

Sample	C1	C2	SP	SPT	SR	SC
Ash (wt% db)	8.4	10.1	0.3	0.4	0.5	1.5
V.M. (wt% db) ^a	20.9	17.4	84.8	78.5	81.9	76.8
C (wt% db)	84.5	80.6	50.7	56.0	50.2	56.1
H (wt% db)	4.5	4.1	6.1	5.8	5.9	5.2
N (wt% db)	1.9	2.0	0.3	0.4	0.4	0.5
S (wt% db)	0.62	0.61	0.00	0.03	0.02	0.02
O (wt% db)	2.8	2.2	42.5	37.4	44.0	36.7
C/H ^b	1.56	1.64	0.69	0.80	0.71	0.90
C/O ^b	40.1	48.8	1.6	2.0	1.5	2.0
> 3 mm (wt%)	14.5	13.8	0.0	0.0	0.0	1.0
2–3 mm (wt%)	6.7	13.1	3.1	0.0	0.5	4.5
1–2 mm (wt%)	14.2	14.8	17.8	20.3	2.5	24.6
0.5–1 mm (wt%)	18.9	15.7	49.8	48.6	17.8	65.8
< 0.5 mm (wt%)	45.7	43.6	29.3	31.1	79.2	4.1

^a volatile matter.

^b atomic ratio.

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