Fuel Processing Technology 177 (2018) 101–108

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Research article

# A particle-size regulated approach to producing high strength gasification-coke by blending a larger proportion of long flame coal

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ARTICLE INFO

*Keywords:*
Low-rank coal
Size distribution
Viscous embedded state
Coking mechanism
Gasification-coke

ABSTRACT

To produce a qualified gasification-coke by blending a larger proportion of low-rank coal, the effects of blending ratio, particle size distribution, and maceral components on the coke strength were studied, and a new coking mechanism was put forward in terms of the physical texture. The results show that the influence of coal particle size varies with the different cohesiveness of coals. Fat coal (FC) with a smaller size gets a better performance on the coke strength, while a larger size is needed for gas coal (GC), and the optimum size of long flame coal (Shenfu coal, SFC) varied with its blending ratio. SFC and GC should be crushed coarsely (2–3 mm surpasses 40%) to act as the framework with the less external surface in the viscous embedded state. FC should be crushed finely (< 0.2 mm) to form flowing metaplast that being filled uniformly in the gap between these coarse particles, thus reinforcing the embedded state and leading to a high coke strength with a less blend of FC (25 wt%). Moreover, liptinite enriched in the coarse particles of GC and SFC improves the cohesiveness of blended coal moderately. A qualified gasification-coke ($M_{25}$ > 90%, *CRI* > 50%, *CSR* > 35%) can be obtained by blending > 40 wt% SFC with this new coking mechanism.

## 1. Introduction

China has abundant reserves of low-rank coals with high volatile content and low price. It may be a cost-effective approach to producing high-value tar and gas directly during the pyrolysis process of low-rank coal [1]. Thus the staged conversion of low-rank coal is vigorously advocated as a clean coal technology [2,3]. In addition, the fixed bed gasification technology, as one of the mature techniques that realize the clean and efficient utilization of coal, is gradually facing the challenge in the shortage of lump feedstock and the contaminations brought out by the volatile matter of coal. The most successful attempt is usually focused on the technology of briquette from pulverized low-rank coal by adding coal-tar pitch or other binders, resulting in relatively high cost [4]. Moreover, briquette usually contributes little to the reduction of contaminations, and it often faces a pulverization problem of briquette in the fixed bed gasification [5].

On the other hand, significant overcapacity still exists in China's coke industry, and the singleness of product, especially the metallurgical coke, always brings about some problems when a temporary price reduction happens. In this opinion, broadening the utilization of the coke oven is very important for regulating the production of metallurgical coke. Accordingly, a coupled concept, which uses much low-rank coal to produce lump gasification-coke in the coke oven, is proposed. Therefore, the existed coke oven can be run continuously to achieve the stabilization benefit in coke industry, and the existed tar separation device can reclaim the high volatile matters in the low-rank coal, thus the staged conversion of low-rank coal is realized [6–9]. Moreover, the production of lump coke with little volatile matters has many advantages, including increasing the utilization value of low-rank coal, broadening the purpose of coke oven, resolving the shortage of lump feedstock for fixed bed gasifier and eliminating phenolic wastewater in the gasification process.

Up to now, some evaluation standards for the gasification-coke have been proposed based on the experience of the industrial practice. In general, the feedstock needs to meet the requirements of $M_{25}$ > 80% and $M_{10}$ < 15% (coke mechanical strength), *CRI* > 50–55% and *CSR* > 30–35% (coke reactivity and coke strength after reaction) for Lurgi fixed bed gasification [6,7], but for BGL gasification, it requires a higher index of $M_{25}$ to avoid the unstable operation of the gasifier [4]. At the same time, a high *CSR* promises the excellent permeability that is favorable to avoid excessive bed pressure drop and lead to a better dispersion of the gasifying agents [4]. However, the realization of these

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https://doi.org/10.1016/j.fuproc.2018.04.024
Received 9 January 2018; Received in revised form 17 April 2018; Accepted 17 April 2018

**Table 1**
Analyses (wt%) of coal samples.

| Sample | Proximate analysis | | | Ultimate analysis (daf) | | | | | $G_{R.I.}$ [a] | $X$ [b] (mm) | $Y$ [b] (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_{ad}$ | $A_{ad}$ | $V_{daf}$ | C | H | $O_{diff}$ | N | S | | | |
| SFC | 10.52 | 4.40 | 34.02 | 82.98 | 4.70 | 11.10 | 1.02 | 0.20 | 0 | 36 | 0 |
| GC | 2.24 | 7.88 | 34.90 | 86.37 | 5.35 | 6.22 | 1.18 | 0.88 | 47 | 45 | 15 |
| FC | 0.80 | 20.74 | 32.03 | 87.06 | 5.39 | 2.55 | 1.33 | 3.67 | 93 | 13 | 33 |

ad: air-dried base; daf: dry and ash-free base; diff: by difference.
[a] $G_{R.I.}$ refers to a modified Roga index (GB/T5447/2014).
[b] $X$ and $Y$ refer to the final contraction and maximum thickness of the plastic layer, respectively(GB/T479-2000)

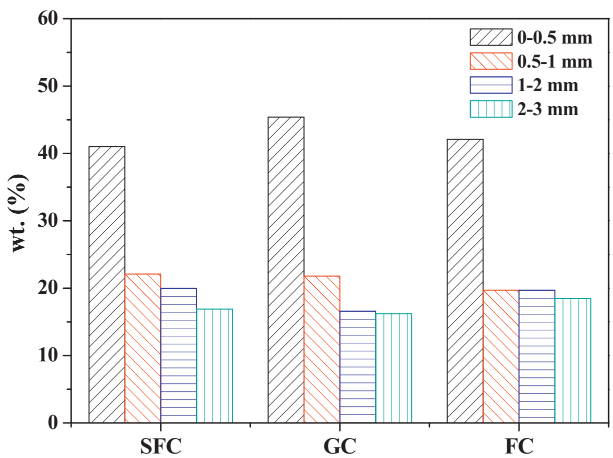


**Fig. 1.** Normal size distributions of coal samples.

indexes usually requires a high caking index ($G_{R.I.} > 60$) for blended coal, and the blending ratio of low-rank coal can only reach 30–35 wt%, according to the conventional blending coking method [6,7]. How to produce a qualified coke by blending > 40 wt% low-rank coal and a little amount of strong caking coal to meet the fixed bed gasifier and ensure the normal performance of coke oven is still a big challenge. Besides, many methods such as added binders, briquettes, and modification of coals were adopted to increase the usage of low-rank coals in the production of metallurgical coke [10–13], but a relatively high blending cost may be a problem in the production of gasification-coke by using these methods. Therefore, a basic investigation of coal blending methods for blending with a great deal of low-rank coal and a little amount of strong caking coal is necessary.

In this study, an attempt was made to produce the high strength coke for fixed bed gasification by blending > 40 wt% long flame coal (low-rank coal). Research on the effect of particle size distributions of different coals on coke quality was investigated. Moreover, a novel method to produce high strength coke using much low-rank coal was developed and a feasible coking mechanism was proposed, which can enrich the theory of coking blending with much low-rank coal.

## 2. Materials and methods

### 2.1. Materials preparation

#### 2.1.1. Raw coal

A low-rank coal, long flame coal (SFC, non-caking coal) from Shenfu coalfield in Shaanxi province, two medium-rank coal, gas coal (GC, weak caking coal) and inferior fat coal (FC, strong caking coal) from Inner Mongolia in China were used in this study. The detailed proximate and ultimate analyses of these coals are given in Table 1. Besides, corresponding caking indexes ($G_{R.I.}$, a modified Roga index according to GB/T5447–2014), as well as the final contraction and the maximum thickness of the plastic layer ($X$ and $Y$ value, according to GB/T479–2000, similar to the Sapozhnikov-Bazilevich plastometric indices (GOST 1186–87)), are also given in Table 1.

These coals were crushed and sieved to the particle size < 3 mm, and the normal (conventional) size distributions of these coals are shown in Fig. 1. In addition, the subsamples with particle sizes in 2–3 mm, 1–2 mm, < 1 mm, < 0.2 mm, and < 0.05 mm were collected respectively for further use.

#### 2.1.2. Maceral concentrates

The liptinite, vitrinite, inertinite, and minerals were separated by density gradient centrifugation [14,15]. The dense medium is $ZnCl_2$ solution that the density changes from 1.150 to 1.500 g cm$^{-3}$ with an interval of 0.025 g cm$^{-3}$. The proportion of each maceral component is calculated as follows:

$$\mathrm{Ratio}(i) = M_{\rho_i}/M_0 \times 100\% \qquad (1)$$

where $i$ refers to the liptinite, vitrinite, inertinite and minerals, $M_0$ is the total mass of the sample, $M_{\rho_i}$is the mass in the density ranges of each maceral component, which can be easily distinguished from the inflection point in the mass distribution curves of Fig. 2. In this study, the density ranges of < A, A − B, B − C, and > C were chosen for each maceral separation. The mass loss ratio is lower than 0.5% during the separation process. The enrichment ratio of each maceral concentrate reaches over 80% (according to the GB/T8899–2013). For the SFC, it is difficult to separate the minerals because of low ash content (or symbiotic minerals) in the macerals, especially in the inertinite.

### 2.2. Size distribution schemes

Three types of size distribution in the binary (SFC + GC and SFC + FC) and ternary blends (SFC + FC + GC) were performed to illustrate the effect of particle size distribution on the coke strength. The detailed size distributions are as follows:

*Binary blends*: (i) SFC < 3 mm, < 2 mm, < 1 mm, < 0.2 mm, respectively + FC/GC < 3 mm; (ii) SFC < 3 mm, < 2 mm, < 1 mm, < 0.2 mm, respectively + FC/GC < 1 mm; (iii) SFC < 3 mm, < 2 mm, < 1 mm, < 0.2 mm, respectively +FC/GC < 0.2 mm.

*Ternary blends*: (I) all coal size < 3 mm; (II) SFC and GC < 3 mm + FC < 0.2 mm; (III) SFC and GC 2–3 mm > 40% + FC < 0.2 mm.

### 2.3. Coking process

1 kg blended coal with 10 wt% moisture content was placed in a coke oven ($d \times h = \Phi 102$ mm × 200 mm), then the bulk density of blended coal reached to 1.05 g cm$^{-3}$ (dry basis) via pressing, simulating the stamp-charging coking process. The sample was placed in the vertical tube furnace in which the height of the constant temperature zone is > 200 mm, swept for 30 min under $N_2$ atmosphere, and then heated to 950 °C with a rate of 3 °C min$^{-1}$ and a holding time of 1 hour. Finally, the coke was cooled to room temperature under $N_2$ atmosphere.