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Bindered anthracite briquettes as fuel alternative to metallurgical coke: Full scale performance in cupola furnaces

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HIGHLIGHTS

- Coke is an expensive fuel that consumes 20% of the coal's fuel value when produced.
- Bindered anthracite bricks is a fuel alternative that require only a mild drying step.
- 8 tons of anthracite bricks were tested in 2 full scale demonstrations.
- Our material perform similar to coke at full scale.
- Less fuel is required when using anthracite bricks due to the efficient combustion.

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ABSTRACT

The authors have developed bindered anthracite briquettes that can replace conventional coke as a fuel in foundry cupolas. The anthracite briquettes included fine anthracite grains that were bindered together with collagen, lignin and silicon. These binders gave the briquettes high mechanical strength through the full spectrum of temperatures encountered in a foundry cupola furnace – from ambient temperature up to 1550 °C. The bindered anthracite briquettes offered the same structural strength and fuel content as has conventional foundry grade coke. The conventional coking process involves pyrolyzing coal at 1000 °C for a day; and this consumes about 15% of the raw coal's energy, while releasing volatile organic air pollutants. In contrast, the briquetting process consumes scant energy, without releasing pollutants. During two full-scale demonstrations that each employed 4 tons of these briquettes, the anthracite briquettes performed similarly to the foundry grade coke, while the briquettes replaced up to 25% of the coke. During briquette replacements, the cupola temperatures, off-gas CO/CO_2 proportions, tuyere back-pressures, and metal-to-fuel ratios were maintained or improved. The iron castings produced during this briquette replacement were of the same high quality and composition as when mere coke was used; and these iron castings were sold. Observations through the tuyere windows – where oxygen-enriched air was lanced into the bottom of the cupola – showed that these anthracite briquettes reached the cupola's melting zone while maintaining their physical integrity. Once these briquettes reached the level of the tuyere windows, they exhibited faster burning in the oxygen-enriched air than did conventional coke.

1. Introduction

The cupola furnace is a vertical cylindrical shaft furnace that melts iron, while using coke as its main fuel. Coke has been conventionally used as the most common fuel in iron cupola furnaces, because it can withstand the intense crushing when loaded into the cupola, while also providing high energy value. Foundry-grade coke is produced by the carbonization of selected bituminous coals at around 1000 °C for up to 35 h; and the coking process consumes 15% of the energy value of the raw coal [1,2]. The main features that makes coke suitable for iron production in cupola furnaces are: (1) proper chemistry: less than 1% S, less than 8.5% ash, less than 1% volatiles, and over 90% carbon; (2) sufficient resistance to abrasion and size degradation so as to support the charge weight

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and the friction inside the cupola; (3) somewhat uniform size, so as to promote the permeability of the coke bed and generate an efficient gas distribution consumption of the fuel and (4) a proper reaction rate which is related with the coke pore structure [2–4]. Also, the coke serves as alloying element, since its Carbon is picked up via contact of the molten iron with the coke through the cupola furnace. In this sense, the fuel must remain in-tact to guarantee the contact between the molten iron and the carbon bed.

The United States hosts large reserves of coal, including anthracite coal. Also, the US hosts important reserves of the specific class of bituminous coal that offers the favorable fusing propensity that is needed to generate foundry-grade coke. However, this fusing bituminous coal supply has been interrupted several times during the past decade, leaving foundry personnel in a quandary. Moreover, the environmental regulations related to coke production have hampered the establishment of new coking facilities, leaving just 4 facilities that make foundry cupola-grade coke in the US [5]. Facing this situation, foundries and related industries have expressed considerable interest in finding suitable alternative fuels to conventional coke.

The replacement of a fraction of the coke in cupola operations by inexpensive fuels could offer such an attractive alternative. Anthracite coal offers a number of features that render it favorable as a fuel alternative, such as high carbon rank, low volatiles content, and availability. However, large chunks of anthracite coal will disintegrate into smaller pieces when subjected to the thermal shock that occurs inside a cupola furnace. Also, the chunks will burn only from the outside-in, and thus more gradually. These two factors diminish the furnace temperature [6,7], and thus limit the usefulness of anthracite chunks in cupolas. However, the authors herein found that when fine grains of anthracite have been properly bindered into briquettes by lignin, collagen, and silicon, the briquettes have not exhibited these unfavorable responses to thermal shock. Instead, the lignin and collagen fuse together in a manner that increased the briquette's strength. In this context, anthracite coal fines are of particular interest due to their lower cost than coke or anthracite coal chunks. In conventional coal processing, coal fines have formed slurries that are blended with silt; and this slurry has been wasted into silt settling ponds. These ponds have impounded millions of tons of this coal-silt slurry material through the course of 150 years of US coal mining [8]. Success of the anthracite fines binder technology could not only create a low price coke substitute for cupola furnaces, but also it could offer a financial incentive to cleanup these by-gone settling pond sites; and also fill active settling ponds less rapidly.

Others have attempted to briquette anthracite for foundry applications while using coal tar pitches, heavy petroleum residues, bituminous coal, sulfite liquors, organic resins and molasses [9–13]. However these attempts offered limited success, as those briquettes often exhibited premature disintegration within the furnace.

The Penn State-Furness Newburge team has been developing bindered anthracite briquettes as an alternative fuel source to displace conventional coke for use in foundry cupolas [14–16]. These briquettes maintain mechanical strength both at ambient temperature and at high pyrolysis temperatures, due to the action of three binders: collagen, lignin and silicon carbide nanowires [14–16]. Denatured collagen provides the ambient temperature binding, so that the briquettes maintain their physical integrity during the rough handling of the briquettes in the loading and dropping zone. Once the briquettes have been loaded into the cupola, lignin has acted as a fusing binder under the pyrolytic conditions; and the lignin has formed a polyaromatic structure within minutes [17], giving strength to the briquette at temperatures from 400 to 1200 °C. These temperatures are characteristic of the cupola heat zone. At higher temperatures of 1100–1500 °C, silicon carbide nanowires have formed from silicon reacting with carbon in situ; and this has provided hot crushing strength in the cupola melt zone. By exploring the product formula and the briquetting conditions, the authors have been able to produce lab scale anthracite briquettes with physical and chemical characteristics that are similar to foundry-grade coke. Based on these results, the team aimed herein to scale-up the production of bindered anthracite briquettes, and evaluate their performance when used as a partial coke substitute in full scale cupola operations.

The bindered anthracite briquettes are distinct from mere chunks of anthracite. When mere anthracite chunks have been used as a coke substitute, the chunks have caused the cupola temperature to drop [18–20]. This has been attributed to (a) the lack of porosity within anthracite chunks, which means they do not burn as quickly as coke and (b) we have observed that the anthracite shatters when greatly heated; and the fine shards can then blow out the top of the cupola before they burn, while also creating considerable tuyere back-pressure. In contrast to this, our previous work showed that the bindered anthracite briquettes burned as fast as coke; and we attribute this to micron-sized voids that occurred between the anthracite grains. These facilitated molecular diffusion of the oxygen between the anthracite grains, and consequently rapid burning.

2. Methodology

2.1. Materials

Anthracite fines #4 (1.19 mm × 2.38 mm) were obtained from Jeddo Coal Company (Hazelton, Pennsylvania). A fraction of this anthracite was crushed to produce smaller particles and obtain more dense packing during briquetting. Collagen was provided in granular form by Entelechy Company, which represented Hormel Foods Company (Austin, Minnesota). Before use, collagen was denatured into gelatin via water hydrolisis at 70 °C. Low sulfur softwood lignin from eucalyptus wood was cleaned and supplied by Innventia (Stockholm Sweden). Before use, the lignin was powdered by using an industrial crusher to obtain particles that could pass US mesh #40 (0.420 mm). The moisture content of the lignin was 25%. Silicon metal was purchased from Sigma–Aldrich (St.Louis, Missouri) as 98.5% silicon lumps. Before use, silicon was crushed and sieved to pass #100 mesh (0.146 mm).

2.2. Briquette production

Full scale anthracite briquettes (14.6 × 5.7 height cm) were produced in the Furness-Newburge Inc. facility (Versailles, KY). The formulation of the briquettes were based on results previously reported [15], including silicon metal (0–7%), lignin (2–8%) and anthracite fines (80–95%), along with Collagen (0–2%), which was dissolved in distilled water at about 70 °C. The mixture was pressed into a cylindrical die and compacted to the designated pressure. The briquettes were then removed from the die and dried in a heating conveyor.

To characterize the strength and reactivity of the anthracite briquettes, two size of lab scale samples where produced: bindered anthracite pellets, 1.9 cm diameter by 1.9 cm height; and bindered anthracite cylinders, 2.54 cm diameter by 5.08 cm height. These were prepared by the protocol of Lumadue et al. [15]. Briefly, the ingredients were selected, crushed, mixed and prepared as above. They were then compacted in a Carver #3912 unit hydraulic press at 69 MPa (unless otherwise specified), then removed from the die and allowed to sit at ambient temperatures to gain strength for a day before use.