BULK TESTING Int

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TECHNICAL NOTICE N° 5

Coke reactivity

Background

Traditionally, chemistry, size, and strength (tumbler stability and hardness) have been considered the most important properties for evaluating coke for use in the blast furnace. However, coke reaction with carbon dioxide and coke strength after reaction has also been reported by many companies to be important indices in evaluating coke. The Japanese in particular have been studying reactivity and its influence on blast-furnace performance and productivity. For example, they have reported decreases in hot metal fuel rates corresponding to increases in CSR (Coke Strength after Reaction) values. The magnitude of fuel rate reductions varies for different blast furnaces and operating parameters.

Some of the earlier studies investigating coke reactivity can be traced back to the 1950's and 1960's. Then, researchers hoping to learn more about coke behaviour in the blast furnace and ways to improve coke quality and performance began to study the thermal-chemical nature of coke. In order to better simulate actual conditions in a blast furnace, numerous tests were developed whereby a sample of coke would be reacted in a controlled temperature and gas flow environment with an oxidising agent. Percent weight loss measurements were calculated on the reacted coke samples, enabling researchers to predict how readily a particular coke would chemically react in the blast furnace.

A renewed interest in coke reactivity occurred in the late 1970's and 1980's when better instrumentation and sampling techniques led to a broader understanding of the operation of the blast furnace. The use of both physical and mathematical models of the blast furnace zones, the monitoring of heavily-instrumented blast furnaces, and the quenching and subsequent sampling of commercial furnaces have aided in determining the effect of changes in coke reactivity on furnace operating parameters such as fuel rate, furnace permeability, and hot metal production. As a result of major changes in blast furnace design and operating parameters, coke rates to the blast furnace have dropped below 1000 lbs./ton of hot metal. Thus, the need for strong and consistent coke properties has become more important than ever.

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Definition of Coke Reactivity

Coke reactivity refers to the rate at which coke carbon reacts with oxidising gases such as carbon dioxide, oxygen, air, or steam. The rate of reaction depends upon the character of the coke surfaces, the surface area exposed, and the chosen test conditions (gas composition, velocity, concentration, and temperature). The various reactivity tests are empirical in nature and are determined for prescribed conditions as to the amount and size of coke, geometry and dimensions of the reaction chamber, duration of reaction, and the gas composition, pressure, and temperature.

Japanese Method Reactivity Test

This test reacts a large quantity of lump-sized coke with carbon dioxide at a high temperature.

Also, the reacted coke is tumbled to determine its strength after reaction. Specifically, 200 grams (0.44 pounds) of 19 by 21 mm (3/4 by 7/8 inch) dry coke are reacted with carbon dioxide, adjusted to a flow rate of 5 litres per minute (0.18 cubic feet per minute), for two hours at a temperature of 1100 degrees Centigrade (2012 degrees Fahrenheit). The Coke Reactivity Index (CRI) is reported as the percent weight loss of the coke sample after reaction. The reacted coke is then tumbled in an I-drum for 600 revolutions at 20 rpm. The cumulative percent of plus 10 mm (3/8 inch) coke after tumbling is denoted as the Coke Strength after Reaction (CSR). Generally, cokes with high CRI values have low CSR's, and cokes with low CRI values have high CSR's.

Factors Affecting Reactivity

The effect of coke reactivity on blast furnace performance is not completely clear. However, most blast furnace operators agree that the coke should not readily react at lower temperatures in the upper zone of the furnace to avoid wasted carbon. Also, highly reactive coke may become substantially weakened so that it cannot properly support the burden during its descent in the blast furnace. By the time the coke works its way to the high-temperature combustion zone, or raceway, the coke may become so weak that it causes major upsets to occur in raceway performance. Poor raceway behaviour restricts gas and liquid permeability in the blast furnace, reducing overall furnace efficiency.

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Coke properties that affect reactivity include:
1. Texture (carbon forms)
2. Structure (porosity and pore wall thickness)
3. Ash composition (alkalis, sulphur, iron, etc.).

These coke properties can be readily traced to the parent coals making up the blend composition. The rank, type, and grade of the constituent coals determine the characteristics of the resultant coke. It has been shown that coke with isotropic texture derived from weakly-coking high volatile coal is chemically weak and easily attacked by the gasification reaction with carbon dioxide. Better coking high and medium volatile coals produce coarse circular and lenticular carbon forms with lower reactivity which proceeds around pores and cracks in the coke walls, and low volatile coals produce ribbon-like carbon forms with intermediate reactivity which proceeds around pores and cracks and also between the carbon layers.

Reactivity increases as porosity increases. The carbonisation of different coal types produces varying coke structures that, in turn, affect reactivity. For example, coals that are high in inerts produce thick-walled cokes, while similar rank coals with low inerts produce thinner-walled cokes.

In addition to properties of coke carbon texture and structure, another factor that affects reactivity is the composition of the ash (or mineral matter) in the coke. For example, the presence of alkalis and iron can lead to an increased rate of reaction with carbon dioxide.

Use of a Pilot Oven to Measure or Predict CSR's of Cokes Produced from Individual Coals and Coal Blends

Traditionally, chemistry, size, and cold strength (tumbler stability and hardness) have been considered the most important properties for evaluating coke for use in the blast furnace. However, coke reaction with carbon dioxide (CRI) and coke strength after reaction (CSR) have also been reported by many companies to be important indices in evaluating coke. Accepting the premise that CSR is a critical property when assessing blast furnace performance, this article presents practical and theoretical techniques for measuring and predicting CSR's of cokes produced from individual coals and coal blends. Once this data is generated, coal blends maximising CSR, while at the same time maintaining or increasing stability and not negatively impacting oven pushing and coking pressures, can be designed. Constraints on coal availability, existing contracts, costs, and coke plant operating variables will all impact the maximum achievable coke quality.

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Why is CSR Important ?

Many coke plants and blast furnaces around the world use CSR as a specification just as important as cold strength, size, and chemistry. Researchers have studied reactivity and its influence on blast furnace performance and productivity. The use of both physical and mathematical models of the various blast furnace zones, the monitoring and sampling of heavily-instrumented blast furnaces, and the quenching and subsequent sampling of commercial furnaces have aided in determining the effect of changes in coke reactivity on furnace operating parameters such as fuel rate, furnace permeability, and hot metal production. It has been widely reported in the literature that increases in CSR have led to decreases in blast furnace fuel rates. The magnitude of fuel rate reductions varies for different blast furnaces and operating parameters.

The exact effect of coke reactivity on blast furnace performance is not completely clear; however, most furnace operators agree that the coke should not readily react at lower temperatures in the upper zone of the furnace to avoid wasted carbon. Also, highly reactive coke may become substantially weakened so that it cannot properly support the burden during its descent through the blast furnace. By the time the coke works its way to the high-temperature combustion zone, or raceway, the coke may become so weak that it causes major upsets to occur in raceway performance. Poor raceway behaviour restricts both gas and liquid permeability in the blast furnace, reducing overall furnace efficiency.
As a result of major changes in blast furnace operating parameters and practices through the 1990's, such as increased usage of auxiliary fuels and improved operating efficiency, coke rates to the blast furnace have dropped well below 1000 pounds per ton of hot metal. Thus, the need for strong and consistent coke properties has become greater than ever. Ideally, cokes should be high in CSR and low in corresponding reactivity. The optimum CSR will depend on the particular blast furnace, it's associated practices, and overall production goals.

Definition of Coke Reactivity and Description of ASTM Test Procedure

Coke reactivity refers to the rate at which coke carbon reacts with oxidising gases such as carbon dioxide, oxygen, air, or steam. The rate of reaction depends upon the character of the coke surfaces, the surface area exposed, and the chosen test conditions (gas composition, velocity, concentration, and temperature). The various reactivity tests are empirical in nature and are determined for prescribed conditions as to the amount and size of coke, geometry and dimensions of the reaction chamber, duration of reaction, and the gas composition, pressure, and temperature.
Although there is no universally accepted standard procedure for measuring coke reactivity, the Japanese method (Nippon Steel) reactivity test is widely recognised both domestically and abroad. ASTM officially adopted this test method as its standard procedure in 1993. The test determines both the Coke Reactivity Index, or CRI, and the Coke Strength after Reaction, or CSR, of a given sample of coke.

The standard ASTM test method D 5341 for measuring CRI and CSR requires reacting 200 grams (0.44 pounds) of 19 by 21 mm (3/4 by 7/8 inch) dry coke with carbon dioxide, adjusted to a flow rate of 5 litres per minute (0.18 cubic feet per minute), for two hours at a temperature of 1100 degrees Centigrade (2012 degrees Fahrenheit). The CRI is reported as the percent weight loss of the coke sample after reaction. The cooled, reacted coke is then tumbled in an I-drum for 600 revolutions at 20 rpm. The cumulative percent of plus 10 mm (3/8 inch) coke after tumbling is denoted as the CSR. Generally, cokes with high CRI values have low CSR's, and cokes with low CRI values have high CSR's. It should be noted that "hot" strength, as measured by CSR, does not correlate with "cold" strength, as measured by the ASTM tumbler test.

Factors Affecting CSR

Coke properties that affect reactivity include:

1. texture (carbon forms)
2. structure (porosity, pore size, and pore wall thickness)
3. ash composition (alkalis, sulphur, iron, etc.)

These coke properties can be readily traced to the parent coals making up the blend composition. The rank, type, and grade of the constituent coals determine the characteristics of the resultant coke. It has been shown that coke with isotropic texture derived from weakly-coking high-volatile (HV) coal is chemically weak and easily attacked by the gasification reaction with carbon dioxide. Better coking HV and medium-volatile (MV) coals produce coarse circular and lenticular carbon forms with lower reactivity, whereas, low-volatile (LV) coals produce ribbon-like carbon forms with intermediate reactivity.

Reactivity increases as coke porosity increases. The carbonisation of different coal ranks and types produces varying coke structures which, in turn, affect reactivity. Cokes produced from low rank HV coals exhibit thin coke walls and large pores, whereas cokes produced from higher rank HV and MV coals exhibit thicker walls and less pore area. LV coals produce cokes similar in porosity to those produced from the lower rank HV coals. Coal type, or the relative proportion of inert and reactive macerals, also affects coke structure. For example, coals that are high in inerts produce thick-walled cokes, while similar rank coals with low inerts produce thinner-walled cokes. Porosity is also influenced by carbonisation conditions such as bulk density, heating, and pulverisation.

In addition to the properties of coke carbon texture and structure, another factor that affects reactivity is the composition of the ash (or minerals) in the coke. For example, the presence of alkalis (sodium and potassium), iron, calcium, and magnesium can lead to an increased rate of reaction with carbon dioxide.

Techniques for Measuring or Predicting CSR's

Generally, there are two techniques for assessing the impact of individual coals (and blends of coals) on the CSR of the resultant coke product:

a. mathematical models based on empirical data
b. pilot oven testing

One example of a widely used mathematical model is the Inland model, which is well documented in the literature. That model predicts coke CSR's for individual coals based on coal properties including Gieseler plastic temperature range, ash and sulphur contents, and the following ash constituents: Fe_2O_3, Na_2O, K_2O, CaO, MgO, SiO_2, and Al_2O_3. The resultant coke CSR produced by a coal blend can then be calculated by weight compositing each of the predicted CSR's of the component coals. The model is a useful tool when looking at a wide range of coals when developing commercial coal mixes. It should be noted, however, that the model does not work well for certain coals, and CSR may not be an additive property. In addition, the Inland model does not include rank parameters such as vitrinite reflectance which determine the resultant coke texture and structure - both important coke properties that affect resultant CSR.

If enough coal sample is available, a better, more reliable technique would be to carbonise the coal in a pilot oven and then test the resultant coke for CSR. The next section introduces this technique.

Test realization

Sample of sized product between 19 & 21 mm is needed ; approx. 2 kg after dividing
Delivery of results indicative period is about 7/9 days after collection or reception of sample.

More details :

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