Variability in Metallurgical Coke Reactivity Index (CRI) and Coke Strength after Reaction (CSR): An Experimental Study

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ABSTRACT: The coke reactivity index and coke strength after reaction are critical parameters for the efficient operation of a blast furnace. Therefore, maintaining desired qualities of the produced coke as per coal blend chemistry and coke oven battery parameters is essential. However, the coke reactivity index (CRI) and coke strength after reaction (CSR) vary from laboratory to laboratory even though they have the same determination methodology. In the present investigation, a unique laboratory sample holder for reactivity test has been developed. The test method by Nippon Steel Corporation (NSC) has been compared with the newly developed sample holder method. The correlation between coke CRI and CSR has been studied with samples with a wide range of reactivity in the repeatability test. Results confirmed that the reactivity of coke highly depends on the reaction of individual coke pieces participating in the test. Despite undergoing strict process monitoring of the testing procedure of hot strength of coke, the present study confirmed that a variation of ±2 points in coke CSR and CRI does not affect coke quality in a single reading. The study also includes the influence of the number of coke pieces in the test sample to optimize the coke bed height. This paper described in detail the methodologies adopted, addressing the factors resulting in differences in CRI/CSR values within the same coke.

1. INTRODUCTION

Metallurgical coke is a prime burden support raw material, which contributes ~60% of the hot metal production cost through the blast furnace route. It forms a packed bed in the blast furnace burden and withstands the flow passes of hot metal and slag toward the hearth. It also helps in withstanding high temperature and acts as a source of reducing gas towards the upper part of the reducing and smelting zone. The working volume of the blast furnace has increased to more than 5000 m³. These modern blast furnaces demand a high coke quality, an exceptionally high coke strength after reaction (CSR), and a moderate coke reactivity index (CRI). Hence, overall, the coke quality strongly affects the blast furnace performance and needs to be controlled by adjusting the fuel rate and other operating parameters. Therefore, effort is being made worldwide to improve the operational efficiency of blast furnaces with a lower coke rate. At a lower coke rate, high-quality coke is essential for maintaining the bed permeability as there will be less amount of coke in the burden.

The produced desired coke quality depends on two main variables: coal blend composition and process condition of the coke oven. Either of these variables will affect the quality of the product. The ultimate choice of the coal blend composition and process conditions depends upon the economic situation prevailing and plant availability. Therefore, coal selection and coal blend composition are significant factors for controlling the coke quality and cost. In general, coke makers increase the ratio of prime hard coking coal (PHCC) in the coal blend to achieve a high coke quality. This increase in prime hard coking coal is not an appropriate action for stamp charge coke oven batteries because it increases oven wall pressure and coal blend cost. Hence, many researchers have tried to efficiently use non-coking coal to reduce the coal blend cost without compromising the coke quality. Several factors like the intrinsic properties of coal and weathering phenomena also affect coke quality. The literature reported that the poor quality of coke affects the ironmaking process mainly in two ways, viz., (i) the blast furnace operations team increases coke rate to meet the process requirements if the coke quality deteriorates significantly and (ii) the coke plant process team increases the PHCC coal composition in the coal blend, resulting in high blend cost to improve the coke quality.

The hot strength of coke, i.e., coke strength after reaction, and the cold strength of coke, viz., coke M40, are the main aspects for evaluating the coke quality, primarily dictated by
coal blend properties. Several laboratory tests and procedures have already been developed to assess various coke qualities parameters. In the absence of any universally accepted test method, the method developed by Nippon Steel Corporation, Japan, is also considered by many standards.\textsuperscript{10−13} However, all of these specified test properties of metallurgical coke are only the test results under limited conditions, and the breakage phenomenon of coke particles may vary in the blast furnace. It has often been observed that in the plant, coke CSR and CRI significantly vary for the same coal blend when tested in different laboratories. These test results may be caused by many test parameters like gas flow control, differences in equipment, temperature profile of furnace, reaction vessel, etc., which affect the repeatability of the coke reactivity test.\textsuperscript{14,15} The standard allows variation of 2−3 points in CRI/CSR as per the repeatability and reproducibility (R&R), which is not acceptable for the modern blast furnaces for their smooth operation. Therefore, it is necessary to revisit the variability factors in the existing testing methodology.

The literature reported that the difference in mass loss of individual coke particles reflects inherent variability in coke reactivity.\textsuperscript{16} However, the study reported coke produced from single coal only and had not covered commercial coke samples. Preceding research was also conducted by Wang et al.\textsuperscript{17} to study the variability in the reactivity and coke gasification effects during the coke reactivity test. The authors also examined the coke CRI and CSR variability through the newly developed testing method for coke quality evaluation, namely, coke gasification with carbon dioxide at different temperatures. The study reported that an increase in temperature rapidly increases CSR for those coke samples that have high CRI and low CSR compared with coke with a lower coke CRI and a higher coke CSR.\textsuperscript{17} The Stefan flow theory was also used in the coke solution loss reaction study and established a kinetic model for coke solution loss reaction for better understanding the coke reactivity.\textsuperscript{18} Also, thermogravimetric analysis, mass transfer coefficient, and effective internal diffusion coefficient were recommended to understand coke reactivity properly. At 1100 °C, the solution loss region was the largest and increased in local porosity, which was relatively homogeneous, whereas in the coke outer-surface region, the solution loss region and degradation region occurred at 1300 °C. Still, variability at 1150 °C for CO\textsubscript{2} concentration and local porosity within the coke led to the highest coke degradation and the lowest coke strength after reaction.\textsuperscript{19−21} The literature also reported that the sensitivity of the coke CRI and CSR determined from the quality control laboratories should be adequate because it depends on several operating parameters like heating rate, bulk density, moisture content, temperature, etc.\textsuperscript{16,22−27} Also, many researchers have developed a prediction model based on various factors that can give insight into coke quality based on data mining techniques.\textsuperscript{28−31} Therefore, in this study, the authors have conducted detailed research on factors affecting variability in coke reactivity test under the standard test condition for laboratory and commercial coke samples produced from stamp charge batteries using a specially designed sample holder probe. The study of inter-laboratory comparison test (ILCT) on CSR and CRI at different laboratories is also part of the present research. The study also includes the influence of the number of coke pieces taken in the test to optimize the coke bed height during testing and the repeatability of the test. The test results obtained with the Nippon Steel Corporation (NSC) procedure are compared with the results obtained using a customized laboratory-developed sample holder.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Experimental setup: (a) schematic diagram of the modified reaction vessel; (b) pictorial view of the modified sample holder; and (c) sample activities in different zones.}
\end{figure}
Table 1. Coke Quality Parameters of Different Coke Samples

| coke ID    | coke type       | ash   | VM  | FC   | BIS  | BIS  |
|------------|-----------------|-------|-----|------|------|------|
| CK-1       | Industrial Oven-1 | 16.62 | 0.53 | 82.85 | 65.3 | 67.9 |
| CK-2       | Industrial Oven-2 | 15.40 | 1.10 | 83.50 | 64.5 | 66.6 |
| CK-3       | Industrial Oven-3 | 16.40 | 1.00 | 82.60 | 61.1 | 62.1 |
| CK-4       | Industrial Oven-4 | 16.38 | 0.50 | 83.12 | 67.4 | 68.2 |
| CK-5       | Industrial Oven-5 | 17.30 | 0.80 | 81.90 | 66.4 | 66.3 |
| CK-6       | Industrial Oven-6 | 15.90 | 1.20 | 82.90 | 65.5 | 67.4 |
| CK-7       | Industrial Oven-7 | 16.31 | 0.84 | 82.85 | 65.2 | 68.0 |
| CK-8       | Industrial Oven-8 | 15.56 | 0.80 | 83.64 | 70.6 | 71.4 |
| CK-9       | Laboratory Oven-1 | 14.96 | 0.76 | 84.28 | 50.2 | 53.1 |
| CK-10      | Laboratory Oven-2 | 14.48 | 0.89 | 84.63 | 42.8 | 47.7 |
| CK-11      | Laboratory Oven-3 | 14.78 | 0.82 | 84.40 | 60.4 | 60.2 |

2. EXPERIMENTATION

In the present study, experimental work was conducted in the raw material testing laboratory of Tata Steel Limited. A total of 24 metallurgical coke samples were collected from different coke oven plants as well as from laboratory ovens. The experimental work was conducted in three different phases of the present study. In the experiment’s first phase, various sources of six coke samples (two coke samples from by-product recovery stamp charge coke plant with dry quenching, one coke sample from by-product recovery stamp charge coke with wet quenching, one coke sample from heat recovery stamp charge coke plant, and two coke samples from laboratory coke oven) had been selected for determining the coke reactivity using the NSC method. In the second phase of the experimental work, 12 coke samples were collected from different sources to examine the repeatability and reproducibility of the coke CRI and CSR using the NSC method. For better clarity on variability in testing, one representative sample was sent to various coke testing laboratories for an inter-laboratory comparison test (ILCT). The output of these two studies has been used to develop a hypothesis for variability study in the coke CRI/CSR test. In the third stage of the study, 11 coke samples (eight coke samples from the coke oven plant and three coke samples from the laboratory oven) were studied in the modified reaction vessel.

The collection and preparation of the test sample were completed based on the standard operating procedures followed by Tata Steel Limited. The prepared coke samples were subjected to the hot strength test based on the Bureau of Indian Standard (BIS).10 The prepared 200 g coke sample (+19 to −19 mm size) was then charged in the standard reaction vessel. Also, each of the prepared coke pieces was weighed separately before starting the experiment and after completing the experiment in the present investigation for better clarity of the result. All other test parameters like temperature, reaction time, and gas flow were kept identical to meet the test standard as described in the standard.10 The reaction vessel lid was customized in five equidistant zones across the thermocouple tube to study the variability in mass loss of individual coke pieces during gasification, as shown in Figure 1. An additional chamber filled with 10 mm diameter alumina balls was fixed with the sample holder to maintain a 50 mm deep layer of refractory balls to distribute gases properly. Individual coke pieces were carefully charged in all five zones of sample holder in different vertical and horizontal positions.

2.1. Coke Reactivity Measurement. In the experimental study, the coke reactivity index (CRI) and coke strength after reaction (CSR) were measured as per the BIS standard.14 In the determination of CSR and CRI, 200 g of coke sample prepared as per the standard size is reacted in a reaction vessel at 1100 °C in a CO₂ atmosphere at a flow rate of 5 liters per minute (LPM) for 120 min. The percentage weight loss after reaction is known as the coke reactivity index (CRI). The reacted coke sample is then tumbled in an I drum for 600 revolutions at 20 RPM for 30 min and screened on a 10 mm round screen. The % weight retained on the 10 mm screen is known as coke strength after the reaction. The calculations are made using eqs 1 and 2 as follows:

\[
\text{CRI} = \frac{(M_1 - M_2) \times 100}{M_1} \tag{1}
\]

\[
\text{CSR} = \frac{(M_3 \times 100)}{M_4} \tag{2}
\]

where \(M_1\) is the original test sample or weight before reaction; \(M_2\) is the sample mass or weight after reaction in CO₂; and \(M_3\) is the sample mass or weight of +10 mm coke after tumbling.

Each prepared coke piece (+21 to +19 mm size) was then carefully weighed before the reaction after completing the test. In the first set of data analysis, the individual coke piece weight was recorded in ascending order of weight to determine the random variability in mass within the selected coke samples. Similarly, all of the reacted coke pieces were weighed individually and again arranged in an experimental study order. In the present investigation, randomly, six test samples were first selected and weight loss was determined without following any order. In the second set of data analysis, 12 different coke samples were tested using the conventional NSC method for repeatability and reproducibility (R&R) test and variability in reactivity.

The coke reactivity index is measured in the laboratory by reacting CO₂ with coke in a standard test method. It represents the % loss in weight for the total sample mass charged in the furnace. However, results showed that the entire coke pieces did not go through a similar reaction, and at the end of reaction time, all have different weight losses. In the third set of experiments, 11 coke samples were tested using the modified sample holder to correlate mass loss and...
variability in coke reactivity. The properties of coke samples tested by the Bureau of Indian Standard (BIS) method and the modified sample holder are presented in Table 1. The proximate analysis of coke samples was conducted in a chemical laboratory for samples received on a dry basis, and therefore only ash, volatile matter (VM), and fixed carbon (FC) are reported by the laboratory.

In the conventional test method, the prepared coke piece charging procedure inside the reaction vessel is not appropriately defined in the standard. Hence, the charging phenomena of coke pieces different from operator to operator resulted in the variation in coke bed during the testing. Therefore, five zones were formulated in the modified reaction vessel lid to address the issue, and the charging of prepared coke pieces sequence into the vessel was defined. Each coke piece was weighted and carefully charged in the modified reaction vessel in various layers and five zones, as depicted in Figure 1.

2.2. R Software Tool. R is a language and environment used for statistical computing and graphics. The central aspect of R is an interpreted computer language that allows branching and looping and modular programming using functions. R has an effective data management system and an integrated collection of intermediate tools for data analysis. These advantages over other statistical software encourage the growing use of R in research. The R software was used for generating the heat map profiles for a better understanding of CRI or weight loss for various zones and layers of coke in the reaction vessel. The heat map function in R produces a high-quality matrix. It offers statistical tools to normalize raw input data and run cluster algorithm, and shows the magnitude of phenomena in color in two dimensions.

3. RESULTS AND DISCUSSION

The operational efficiency of the blast furnace highly depends on the hot strength of the coke, viz., coke CRI and coke CSR. It is well known that the sensitivity of the coke CRI and CSR is very high according to the adopted existing NSC method. The present research results from the conceptualization of the hypothesis to the results are described in detail in the different sections.

3.1. Repeatability and Reproducibility Test Result. A study was conducted in the laboratory to determine the repeatability and reproducibility (R&R) test. These tests were performed on three different sets of machines by the other operators. The results of 12 tests in this study are presented in Table 2. The data presented in Table 2 confirmed the variation in individual coke CSR for actually reported samples and its retest values. For initially reported samples, the coke CSR varies in the range of 65.5–67.6, while for a retest, it has changed in the range of 63.8–70.3.

Similarly, for the coke CRI, the variation range has shifted from 23.6–26.6 to 22.5–27.1 for initial reported values and retest values, respectively. The result shows that for retesting, the standard deviation in the coke CSR and coke CRI has shown higher values of 1.55 and 1.26, respectively. Although the standard deviation in both the coke CRI and coke CSR is still in the acceptable range of testing, there is a significant difference in the maximum difference between coke CRI (2.75 points) and coke CSR (3.8 points).

3.2. Inter-Laboratory Comparison Testing (ILCT) of Coke CRI/CSR. The selected samples were prepared at the Raw Material Testing (RMT) Laboratory, Tata Steel Limited, Jamshedpur, India, for inter-laboratory comparison testing (ILCT) to study the coke reactivity test variability within the same sample in the different laboratories. One prepared coke sample was distributed to all participating laboratories to determine the coke CRI and CSR in this exercise. Having a single source of coke sample will nullify the possible error of sampling and the effects of heating rate, bulk density during carbonization, which affects the resulting coke quality. Each laboratory conducts the coke reactivity followed by the coke CSR test by adopting the standard operating procedure, and results were compiled in the form of a Z score.

The Z score is a statistical number calculated in terms of relationship to the mean and standard deviation of a group of data points. The mathematical equation of Z-scores (eq 3) for data is expressed as follows

\[ Z = \frac{x - \mu}{\sigma} \]

where \( x \) is the individual data, \( \mu \) is the mean, and \( \sigma \) is the standard deviation for a data set.

This ILCT result is being used as a statistical tool in which various individual laboratories participate. The test results conducted with six different participating laboratories are shown in Table 3. The result indicates that variations in coke CRI and coke CSR show standard deviations of 1.4 and 1.3, respectively. The study also depicts that the coke CRI varies from 22.8 to 26.7, while the coke CSR varies from 64.9 to 68.2. The Z score value is well within the acceptable range for all six

| Table 2. Repeatability and Reproducibility Test Result of Coke CSR and CRI by the BIS Method |
|-----------------------------------------------|
| sample ID | actual CSR | retest CSR | actual CRI | retest CRI |
| sample-1  | 66.1       | 67.1       | 24.2       | 24.2       |
| sample-2  | 67.1       | 66.8       | 24.3       | 24.3       |
| sample-3  | 66.2       | 66.7       | 24.0       | 24.0       |
| sample-4  | 67.4       | 67.7       | 24.2       | 24.0       |
| sample-5  | 67.0       | 65.8       | 25.3       | 25.1       |
| sample-6  | 66.5       | 70.3       | 25.3       | 22.5       |
| sample-7  | 67.3       | 67.0       | 25.2       | 25.2       |
| sample-8  | 67.6       | 68.0       | 23.6       | 22.9       |
| sample-9  | 67.6       | 67.3       | 25.3       | 25.9       |
| sample-10 | 66.1       | 63.8       | 26.6       | 27.1       |
| sample-11 | 66.0       | 66.7       | 26.0       | 24.9       |
| sample-12 | 65.5       | 65.5       | 25.3       | 25.4       |
| min.      | 65.5       | 63.8       | 23.6       | 22.5       |
| max.      | 67.6       | 70.3       | 26.6       | 27.1       |
| avg.      | 66.7       | 66.9       | 24.9       | 24.6       |
| st. dev.  | 0.71       | 1.55       | 0.89       | 1.26       |
| lab code  | coke CSR   | coke CRI   | Z score CSR | Z score CRI |
| lab-1     | 64.9       | 26.7       | 1.74        | −1.48       |
| lab-2     | 67.7       | 22.8       | −0.47       | 1.25        |
| lab-3     | 67.5       | 25.5       | −0.32       | −0.64       |
| lab-4     | 66.3       | 24.9       | 0.64        | −0.18       |
| lab-5     | 68.2       | 24.4       | −0.85       | 0.17        |
| lab-6     | 68.0       | 23.3       | −0.74       | 0.89        |
| min.      | 64.9       | 22.8       |             |             |
| max.      | 68.2       | 26.7       |             |             |
| avg.      | 67.1       | 24.6       |             |             |
| st. dev.  | 1.28       | 1.42       |             |             |

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laboratories. Although all of the test samples were prepared from a single lot by the same sampler in a single laboratory, the variability is significantly high considering blast furnace operational requirements. Thus, any change in coke CRI/CSR value of ≤2.0 points should primarily not be used as a reason for the change in the coal blend at the coke oven plant and resulted not adversely affecting any change in coke rate at the blast furnace operation. The study suggested that these 2 points coke CRI/CSR variations may be due to the testing condition. Therefore, all of these deviations are a result of variability in the reactivity and corresponding coke CSR.

3.3. Effect of Average Mass Loss of Coke Pieces on Coke Reactivity Index. The variation in coke CRI and coke CSR affects the blast furnace's stable operation. Hence, the different reactivity of coke samples was carefully examined and compared with the Nippon Steel Corporation (NSC) method and the newly developed method. Figure 2 shows the relationship between weight loss of individual coke pieces and coke CRI. Results confirmed that the coke CRI depends linearly on weight loss with a strong correlation coefficient ($R^2 = 0.91$). Results also show that coke CRI is on the higher side of coke samples, which reacts higher during the gasification reaction.

The mass loss % of individual coke pieces in different zones from the modified sample holder is presented in Figure 3. The result shows that average mass loss across the five vertical zones, viz., Z1, Z2, Z3, Z4, and Z5, has a relatively lower variation than the average mass losses in horizontal layers. It can be seen from the results that for the bottom layer, the average mass loss is 47.29 wt %, while the top layer is 13.85 wt %. Also, in zone Z3, the reactivity is very high compared to other zones (Figure 3). Hence, in the existing NSC methodology, channeling effects in different zones cannot be avoided. The results depict that the mass loss variations for various layers also reflect that gasification is dependent on the reaction regime, which was also explained by previous research.14 On the other hand, the literature reported that the fissuring and crushing mechanism during sample preparation could also account for differences in coke reactivity (12–14).

R software tool was used for generating heat map profiles for a better understanding of CRI or weight loss for various zones and layers of coke in the reaction vessel. Heat map is a technique of data visualization, which shows the magnitude of phenomena in color in two dimensions. The reactivity of coke for individual coke pieces as studied in the customized sample holder has been demonstrated with the help of a heat map in Figures 4a–h and 5a–c for plant coke samples and laboratory coke samples, respectively. The mass loss in five different zones and layers from layer 1 (bottom) to top layer depicts the actual weight loss of individual coke particles to their initial mass before reaction at 1100 °C in the reaction vessel. The mass loss of coke pieces for plant coke (eight samples) has shown a wide range of variation from bottom layers to top layers, as shown in Figure 4a–h.

Coke pieces with higher CRI values are brighter red, and a gradient approaches white color with a decrease in CRI of the particle. The result shows that the variation in the mass loss in an individual zone from bottom to top in the direction of gas flow during the reaction was considerable. The CRI for coke pieces present in the bottom layers was highest in all cases, and it has mainly been found in the range of 35–50 wt %. The heat map analysis confirmed that the bottom two layers are undergoing maximum reduction. It is shown from the results that several zones have a relatively high CRI in a particular test. In samples CK-8, zones 1, 3, and 5 have the highest CRI values, indicating preferential gas flow through those zones. For all coke samples, the overall gradient (change in CRI) is smooth when moving from the bottom layer to the top layer of coke.

It is observed from Figure 5a–c that similar trends in the heat map are also seen for laboratory coke samples. Since the coke is produced in a laboratory oven, it has a lower CSR and a higher CRI, and individual particles lose more weight than the coke produced on a plant scale. Also, in contrast to plant coke samples, the overall gradient from the bottom to the top layer is nonuniform. Coke positions in layer three (L3-Z3) and layer four (L4-Z5) seem to have abnormal weight losses (Figure 5b), which may happen due to the heterogeneity in coke produced from a laboratory oven as some particles can reduce comparatively faster than other particles. The coke CSR of the experimental cokes has shown a little higher value than the test results for the BIS method. It is evident in all cases as the coke layers separated in different compartments compared to the NSC method, in which all coke particles form a bed together. As mentioned earlier, the coke reactivity variation may occur in the same coke sample if the operating parameters like operating temperature of the furnace during testing, reaction vessel dimension, etc.11–14 are not uniform. Therefore, the above-mentioned parameters affecting the test results were
monitored carefully to avoid any impacts on the test results using the same equipment and operators.

The variability in mass loss of coke from the bottom to the top layer in the reaction vessel during gasification reaction is expected as the bottom layer coke pieces react with pure CO₂ compared to the top layer. The carbon dioxide enters the reaction vessel from the bottom. It passes through preheated alumina balls before reacting with hot coke, which converts 

Figure 4. (a–h) Heat maps for stamp charge coke oven plant coke samples.
carbon dioxide to carbon monoxide while passing up through coke samples bed during the test. It is confirmed from the results that the presence of carbon monoxide affects reactivity during gasification.15

The variation in retesting for modified vessel (sample holder) is presented in Table 4. Results confirmed that the accuracy of coke CRI and CSR is better in the modified holder than in the traditional method. Results demonstrated that the accuracy in both coke CSR and CRI is ±1. Therefore, it can be concluded that the modified reaction vessel has less variability compared to the conventional method. However, the present study confirmed that up to ≤2.0 variation in coke CRI and coke CSR as a single value of coke quality, especially coke CRI and coke CSR, should be the same. Therefore, it is recommended that the coke oven and blast furnace operator should not act proactively, and considering only CSR and CRI values independently as test results can be misleading. In other words, any blend change in single reading needs to be avoided, which increased hard coking coal percentage in the coal blend to get the desired quality of coke CSR, which may cause an increase in a push force to affect battery health.

Table 4. Retest Result from Modified Reaction Vessel

| coke ID | coke type       | actual CSR | retest CSR | accuracy (±) | actual CRI | retest CRI | accuracy (±) |
|---------|-----------------|------------|------------|--------------|------------|------------|--------------|
| CK-1    | Industrial Oven | 67.9       | 67.1       | +0.8         | 24.4       | 25.0       | −0.6         |
| CK-3    | Industrial Oven | 66.6       | 66.1       | +0.5         | 24.2       | 25.1       | −0.9         |
| CK-8    | Industrial Oven | 62.1       | 62.3       | −0.2         | 24.7       | 24.2       | +0.5         |
| CK-11   | Laboratory Oven | 60.2       | 59.4       | +0.8         | 27.7       | 28.6       | −0.9         |

Figure 5. (a−c) Heat map for the laboratory oven coke sample.

4. CONCLUSIONS

A novel method has been presented in the present investigation to assess coke CRI/CSR variability. A total of 24 coke samples were considered. The study confirmed that the reactivity of the coke sample significantly varies across different layers for coke pieces during the gasification reaction in the NSC test methods. Since the bottom layer of coke is directly in contact with pure CO₂, it undergoes maximum weight loss. It is evident from the results that the reactivity of individual coke pieces in terms of mass loss further decreases in the gas flow direction.

The study also confirmed that the coke reactivity strongly correlated with the mass loss during gasification. The top-layer coke pieces have relatively slight weight loss than bottom layers, and therefore care is to be taken during sample preparation. The study showed that the reactivity decreases significantly after the fifth layer for plant coke and the sixth layer for laboratory coke. Hence, optimizing the number of pieces in the test sample can further reduce the variation, which can be optimized while selecting the sample weight so that the bed height of the coke can have minimum layers.
modified reaction vessel has improved accuracy, and all of the test results are within ±1 accuracy for coke CSR and CRI values.

Also, the interlaboratory comparison testing results confirmed that the coke CRI and coke CSR might vary by 2 points despite nullifying the effect of sample preparation, testing machine, and operators. The present study concluded that ≤ 2 point variations in coke CRI and coke CSR are possible in the same coke sample despite strict process monitoring. The variation in test results can be minimized to ±1% by standardization of the sample charging process, as seen in the modified reaction vessel. Therefore, considering the tolerance in testing, any blend change may increase the coke production cost and oven push force. There are several inherent factors associated with testing, which can affect the test results. The study also concluded that the single test reading of the coke CRI and CSR is inappropriate for defining the coke quality and deciding for a change in the coal blend, which may increase coke cost and push force and deteriorate the coke oven battery health.

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Notes

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