Predicting Coke Quality on the Basis of CSR and CRI: A Review

M. L. Ulanovskii

Ukraine

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Abstract—Analysis of the regression equations proposed for the prediction of coke quality on the basis of CSR and CRI shows that some equations with relatively high correlation coefficients produce results inconsistent with experimental data and therefore require refinement. Equations that include characteristics calculated from the chemical composition of the ash and the physical constants of the oxides present (the molecular mass, the actual density, the melting point) lead to large errors and hence cannot be recommended.

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Analysis of extensive experimental data permits the formulation of mathematical models—in the form of regression equations—for the prediction of coke quality (CSR and CRI) on the basis of the batch characteristics and/or the chemical composition of the ash present; these equations may or may not take account of the conditions of coke production and slaking. This reduces the need for expensive measurements and permits optimization of the batch composition and the conditions of coke production. In the present work, we consider some of these predictive models.

1. MULTIPARAMETRIC MODEL

Usually, the models include 1–3 predictive parameters, but a ten-parameter model was recently developed [1]. It includes eight characteristics of the batch—the coking index \( K_o \), the content of equivalent clinker components \( CC_r \), the petrographic inhomogeneity of the coal components in the mixture (\( S_{c,c} \)), the yield of volatiles (\( V^d \)), the moisture content (\( W_r^o \)), the ash content (\( A^d \)), the sulfur content (\( S_{c,d}^d \)), and the degree of oxidation \( K_o \)—and also the coking period (\( T_{co} \)) and the proportion of dry-slaked coke (\( C_o \)). In addition, the equations include the conditional technological coefficient \( K_T \), which takes account of the batch preparation and coking conditions and the state of the coke furnaces at the specific plant—in the present case, OAO Nizhnetagil’skii Metallurgicheski Kombinat (NTMK).

Evidently, there is no attempt here to develop universal predictive models, since no examples of their testing at other enterprises are offered. The actual and calculated CSR and CRI values are compared only for coke from the production batch; no values are given for batch of optimized composition.

In our view, Eqs. (3) and (4) in [1], which each include 16 terms, may be simplified without loss of accuracy.

Thus, \( \Pi_o \) varies in the range 1.00–1.09; in other words, it varies by \( \pm 0.045 \) from the mean \( \Pi_o = 1.045 \). Taking account of the coefficients for \( \Pi_o \) in Eqs. (3) and (4)—27.978 and +12.072, respectively—we see that the contribution of \( \Pi_o \) to CSR may vary in the range \((-29.2 \pm 1.26)\); its contribution to CRI varies in the range \((+12.6 \pm 0.54)\). Hence, correction of the free term in the formulas for CSR and CRI by \(-29.2 \) and \(+12.6 \) permits the elimination of \( \Pi_o \), without introducing any significant error. Note, in this context, that the ISO 18894:2006(E) standard permits 3% discrepancies between two measurements in the ranges CSR 50–60% and CRI 30–40%.

Likewise, \( K_T \) varies in the narrow range \( 2 \pm 0.2 \). Taking account of the coefficients for \( K_T \) in Eqs. (3) and (4), we see that its contribution is \(+6.342(2 \pm 0.2) \) and \(-3.723(2 \pm 0.2) \), respectively—approximately \(+12.7 \pm 1.3 \) and \(-7.4 \pm 0.7 \). These contributions are opposite in sign and comparable in magnitude with the total contribution of the parameters \( W_r^o, A^d, \) and \( S_{c,d}^d \), each of which varies by no more than 0.2%, according to the data in [1]. In other words, the total contribution of the parameters \( W_r^o, A^d, \) and \( S_{c,d}^d \) may be compensated by \( K_T \), with the appropriate adjustment of the free term in Eqs. (3) and (4).

The models are satisfactory and are characterized by high determination coefficients (0.94–0.95) and acceptable accuracy in predicting CSR and CRI, according to [1]. However, it is difficult to explain the influence of \( K_r \), say, on CSR and CRI.

In Eq. (3) for CSR, we see coefficients of \(-68.263 \) for \( K_r \), \(+88.383 \) for \( K_r^2 \), and \(-0.157 \) for \( K_r C_{A^d} \). When
Table 1

<table>
<thead>
<tr>
<th>Unit</th>
<th>Batch</th>
<th>CSR, %</th>
<th></th>
<th>CRI, %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>actual</td>
<td>prediction 1</td>
<td>prediction 2</td>
<td>actual</td>
</tr>
<tr>
<td>2</td>
<td>Production</td>
<td>48.8</td>
<td>49.5</td>
<td>50.2</td>
<td>35.6</td>
</tr>
<tr>
<td></td>
<td>Optimized</td>
<td>–</td>
<td>52.7</td>
<td>53.7</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>Production</td>
<td>56.7</td>
<td>56.6</td>
<td>56.1</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Optimized</td>
<td>–</td>
<td>59.4</td>
<td>58.9</td>
<td>–</td>
</tr>
</tbody>
</table>

\[ K_y = 1 \] (which is within the range 0.88–1.14 considered) and \( C_{sl} = 0 \) (wet slaking), the contribution of \( K_y \) to CSR is about +20. In Eq. (4) for CRI, the corresponding coefficients are +326.276, –192.998, and +0.534. Accordingly, when \( K_y = 1 \) and \( C_{sl} = 0 \), the contribution of \( K_y \) to CSR is about +20. In Eq. (4) for CRI, the corresponding coefficients are +326.276, –192.998, and +0.534. Accordingly, when \( K_y = 1 \) and \( C_{sl} = 0 \), the contribution of \( K_y \) to CRI is about +20.

For dry slaking (\( C_{sl} = 100\% \)), analogous calculations show that the contribution of \( K_y \) to CSR and CRI is +4.4 and +138.6, respectively, which is practically the same as in wet slaking. The consistent and selective (mainly on CRI) influence of \( K_y \) must have some explanation, or else further verification is required.

After eliminating the parameters \( W_f^r \), \( A^d \), \( S^d \), \( \Pi_o \), and \( K_y \) and correcting the free terms, we obtain simplified equations

\[
CSR = 74.1 - 68.263K_y - 1.465CCe - 0.434S_{cc} \\
- 0.145\Pi_{co} + 0.224C_{sl} + 88.383K_y^2 + 1.094CCe \\
\times 10^{-2} - 1.444\Pi_y^2 \times 10^{-2} + 4.217V^d\Pi_{co} \times 10^{-2} \\
- 0.157K_yC_{cc};
\]

\[
CRI = -93.6 + 326.276K_y - 0.118CCe + 0.417S_{cc} \\
- 0.039\Pi_{co} - 0.096C_{sl} - 192.998K_y^2 + 0.165CCe \\
\times 10^{-2} - 1.283\Pi_{co}^2 \times 10^{-2} - 2.967V^d\Pi_{co} \times 10^{-2} \\
+ 0.534K_yC_{sl} \times 10^{-1}.
\]

Table 1 compares the actual and calculated (prediction 1) CSR and CRI values from [1] with the values given by simplified Eqs. (1) and (2) (prediction 2).

The CSR and CRI values given by Eqs. (1) and (2), which each include six parameters rather than eleven, are very similar to those in [1]. The discrepancy is no more than 1.5%, which is less than the discrepancies permitted by the relevant GOST standard in measuring CSR and CRI. We recommend that the applicability of Eqs. (1) and (2) also be verified whenever plants test Eqs. (3) and (4) from [1].

2. ASSESSING THE INFLUENCE OF SLAKING ON CSR AND CRI

Many characteristics of dry- and wet-slaked coke, including CSR and CRI, were compared in [2]. It was found that, in the ranges 36 ≤ CSR ≤ 54 and 32 ≤ CRI ≤ 46%, their mean values for dry-slaked coke are, respectively, 5.0% higher and 2.4% lower than for wet-slaked coke.

When \( C_{sl} = 100\% \) (dry slaking) and \( K_y = 1.0 \), the contribution of dry slaking to CSR and CRI is +6.7 and –4.3%, respectively, according to similar estimates based on simplified Eqs. (1) and (2) derived from [1]. Very similar results were obtained in [3]: the actual mean CSR values for 2005 are 56.8% and 50.1% for dry- and wet-slaked coke, respectively; the difference is +6.7%. The corresponding figures for CRI are 31.1 and 35.0%; the difference is –3.9%.

The positive influence of dry slaking may be attributed to partial burnup of the most reactive carbon structures that react with the oxidative components (CO₂, H₂O) of the gases circulating in the dry-slaking unit [3].

Besides these measurement data, calculations by linear regression equations for dry- and wet-slaked coke give paradoxical results, in our view [4]: at fixed