A Carbonization Model with Consideration of Coking Mechanism

By Kunihiko NISHIOKA,** Shuhei YOSHIDA** and Michiharu HARIKI**

Synopsis

Estimation of coke strength which indicates the quality of coke and/or heat transfer simulation in a coke oven have been studied and analyzed independently. Whilst either constitutes an integral part of another and cannot be an independent subject each other; this is mainly attributable to the lack of an acceptable theoretical construction by which both subjects can be linked up.

The authors have worked out a carbonization model which enables us to estimate the carbonizing condition in a coke oven simultaneously through either aspect of coke quality and heat transfer, based upon the concept of coking mechanism previously reported.1)

The model is particularly characterized by the calculation of density variation in the coal zone and coke zone across the oven width during carbonization and a utilization of the resulted value as basic physical value to determine coke strength and heating pattern.

Also it is characterized by an introduction of the filling ratio of void's volume (Fv) which has already been explained in the previous papers into coke strength calculation by accounting the effect of structural defect which may be caused by an incomplete bonding of coal particles during softening and melting.

The model has been tested and identified by both laboratory-scale and actual large-scale coke ovens, and its validity is confirmed.

I. Introduction

Establishment of simultaneous estimate method of coke quality and heat transfer during carbonization in the coke oven will bring the most economical production of required quantity and quality of coke for blast furnace. As already mentioned, attention must be called to that the strength estimation of coke as its quality representation and heat transfer simulation of the coke oven have been hitherto each independent subject of research because of the lack for an acceptable theoretical construction to link them up, whilst either has close relation with another and cannot be considered each separately.2-12)

Based upon the concept of coking mechanism already reported,1) the authors have been getting on to developing a carbonization model which enables to simultaneously estimate coke quality and heat transfer condition during carbonization in a coke oven, and at the same time have worked out to gather preliminary data required for analysis of actual coke oven.13-14) After several discussions and reviews, the authors have developed a simulating carbonization model fully utilizable to analyze industrial coke oven operation, and therefore the construction of this carbonization model is proposed hereunder with several test results for verification.

II. Simulation Model for Carbonization in Coke Oven

Density change during carbonization at different points across the oven width can be quantitatively determined, according to the concept of coking mechanism previously reported.3)

The density change determined by this method will be the most necessary physical value for heat transfer calculation and furthermore will serve as an input value for coke strength estimation shown in the previous paper through its conversion into porosity; this will permit a coincident estimation of coke strength and heating pattern during carbonization. The authors have paid attention to this point and have elaborated the simulation model of coke oven which will be explained below.

I. Description of the Simulation Model

The proposed simulation model of the coke oven is made by calculating the coke strength and heating pattern during carbonization as a one-dimensional model only across the oven width as shown in Fig. 1, and its concrete construction is indicated in Fig. 2.

As mentioned above, the feature of this simulation is to consecutively calculate the density variation (ρ) in the coal and coke zones across the oven width based on the fundamental equation (1) from the beginning to the end of carbonization:

\[ \rho = \frac{W_{ci} - W_{oi} + W_{is}}{(1-\varepsilon)V_i} \]  \hspace{1cm} (1)

where, \( W_{ci} \): coke yielded from the charged coal in an arbitrary division No. \( i \) (kg)
\( W_{oi} \): coke yielded from melting materials flowing out from division No. \( i \) (kg)
\( W_{is} \): coke yielded from melting materials and gas flowing into division No. \( i \) (kg)
\( V_i \): volume of division No. \( i \) (l)
\( \varepsilon \): contraction ratio of coke (—).

And the density calculated by Eq. (1) is used as (ρ) in the following heat conduction equation (2):

\[ C_p \rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial X} \left( \lambda \frac{\partial T}{\partial X} \right) - q \]  \hspace{1cm} (2)

where, \( C_p \): specific heat (J/(kg·K))
\( \rho \): density (kg/m³)
\( \lambda \): thermal conductivity (J/(m·hr·K))
\( q \): heat of reaction (J/(hr·m³))
The density calculated by Eq. (1) is also converted into the porosity ($P = 1 - \rho / \rho_c$), where $\rho_c$ is the true specific gravity of coke. This will be substituted in the following equation for calculating coke strength as already shown in our previous paper):

$$DI_{f5} = 100 \exp \left[ -0.81 \left( 11.4MI - 114 \right) \right] \times \exp \left( -4.2P \right) \left[ -0.601 \right] \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cd -

Fig. 1. Simulation model of the coke oven.

$T$: temperature (K)
$t$: time (hr)
$X$: distance (m).

In addition, the heating rate which is obtained from the heat transfer calculation is employed as an input value for the calculation of coal dilatation and of the carbonization temperature in the same way as that for micro-strength calculation.

This simulation can make a simultaneous estimation of both the coke strength and heat transfer during carbonization across the oven width.

2. Concrete Construction of the Simulation Model

1. Heat Transfer Calculation Model

It has already been explained that the heat transfer is calculated in one-dimensional model exclusively across the oven width by Eq. (2), as shown in Fig. 1. Equation (2), however, is in its nature applicable to the heat conduction in a homogeneous solid plate which entails internal endo- and exo-thermic reactions, and therefore it is necessary to take many external disturbance factors into consideration, so that the above equation can be applied to the heat transfer in transformation process from coal to coke. The treatment of thermo-physical properties, of moisture evaporation and of produced gas specially considered in this model is as follows.

(1) Treatment of Thermo-physical Properties

(A) Bulk Density

Calculation of density variation during carbonization by Eq. (1) and its conversion into input value by means of Eq. (2) are the most important characteristics for heat transfer calculation in this simulation model. The density calculation will be described in Section II.2.2(A).

(B) Specific Heat and Thermal Conductivity

(i) There are several papers regarding the specific heat including the reaction heat from the coal and the thermal conductivity deeming coke and coal layer to be a homogeneous solid, during carbonization. In this simulation, the values most recently obtained by Miura et al. have been used as an approximation as shown in Fig. 3.

(ii) Thermo-physical properties of the brick used are those measured by the authors using bricks actually employed in the coke oven as indicated in Fig. 4.

2. Treatment of Moisture Evaporation and Decomposition Gas

(A) Moisture Evaporation

Behavior of moisture evaporation has been treated in the same way as in the case reported by D. Merrick, as shown in Fig. 5; that is, when moisture at wall side evaporates at 100 °C in the beginning of carbonization (Fig. 5(a)), the steam condenses in the center until the temperature there reaches 100 °C (Fig. 5(b)). When the temperature reaches 100 °C, such steam flows out consecutively toward the oven wall (Fig. 5(c)).

(B) When the steam produced in (A) and thermally decomposed gas of the coal pass through coke layer near the oven wall, they are considered to make heat transfer calculation in this simulation model. The density calculation will be described in Section II.2.2(A).
exchanges in each coke layer.

2. Coke Strength Calculation Model

Based upon one-dimensional model, coke strength is calculated only across the oven width covering the wall side to the center of carbonization chamber as shown in Fig. 1, in the same way as for heat transfer calculation. Coke strength calculation consists of porosity and micro-strength calculations and consecutive conversion into coke tumbler strength, in conformity with the concept of coke mechanism previously reported. Each construction of them is explained below.

(1) Coke Porosity Calculation
(A) Calculation of the Deposition of Thermally Decomposed Gases

Thermally decomposed gas causes a partial coking in high temperature coke layer and reduces porosity. The amount of the deposition is calculated under the following three conditions:

(i) Thermally decomposed gas is produced in the temperature range of 350–550 °C.

(ii) All thermally decomposed gas passes through wall-side coke layer.

(iii) Thermally decomposed gas is coked in the temperature range above 700 °C, based upon the results described in our previous paper.

With these conditions, behavior of thermally decomposed gas has been considered as shown in Fig. 6. In this model calculation, the amount of deposition from thermally decomposed gas is largest in the wall-side coke zone where the temperature reaches the coking temperature range by the beginning of carbonization. The deposition concerned is expressed by the following equation.

\[ Y_{\text{dil}} = aVM(100 - VM)(f(T_i) - f(T_{i+1})) W_j \]

where, \( Y_{\text{dil}} \): weight of deposition in arbitrary division No. \( i \) from thermally decomposed gas produced in center-side division No. \( j \) (kg)

\( VM \): volatile matter of coal (kg)

\( W_j \): amount of thermally decomposed gas produced in division No. \( j \) (kg)

\( f(T) \): cumulative deposition ratio of thermally decomposed gases before reaching temperature \( T \) (%)

\( T_i, T_{i+1} \): temperature in division No. \( i \) and No. \( i+1 \) (°C)

\( a \): constant

(B) Calculation of Coking Yield from Melting Materials

The melting materials compresses the coal layers in the center, and simultaneously penetrates into wall-side coke layers and are coked to reduce porosity. This is treated as follows in this model.

Consider an arbitrary division No. \( i \) across the oven width in Fig. 7. Division No. \( i-1 \) in the wall-side is a semi-coke layer and the center-side division No. \( i+1 \) is a loose coal layer with voids before dilatation as shown in the top (Fig. 7(a)). When coal in division No. \( i \) is dilated and its dilated volume becomes larger than void’s volume in stage (Fig. 7(a)), surplus dilatation materials are produced (Fig. 7(b-i)). The
surplus dilatation volume \((V_{ri})\) is given by the following equation.

\[
V_{ri} = \left(\frac{1 + D_i}{100}(\rho_B/\rho_T) - 1\right) V_i \quad \text{...(5)}
\]

where, \(V_{ri}\): surplus dilatation volume \((l)\)
\(D_i\): true dilatation of coal \((\%)\)
\(\rho_B\): bulk density of the charged coal \((kg/l)\)
\(\rho_T\): true specific gravity of coal \((kg/l)\)
\(V_i\): volume of arbitrary division No. \(i\) \((l)\)

The value \(D_i\) in Eq. (5) is greatly affected by the heating rate as previously reported, \(^{18}\) and the dependence can be expressed by Eq. (6).

\[
D_i = 1.114D_0(\log a_i + 0.42) \quad \text{...(6)}
\]

where, \(D_0\): true dilatation at heating rate 3°C/min \((\%)\)
\(a_i\): heating rate in division No. \(i\) \((°C/min)\)

The surplus dilatation materials are divided into two parts, one for compression of coal layer in center-side division No. \(i+1\) and another for penetration into coke zone in wall-side division No. \(i-1\) (Fig. 7 (b-ii)).

The sharing ratio is currently treated as a parameter.

Coking yield from melting materials which penetrate into wall-side division No. \(i-1\) is thus calculated by Eq. (7).

\[
Y_{MI-1} = kV_{ri}V_i\rho_B(1+bVM)(100-VM)/(1+V_{ri}) \quad \text{...(7)}
\]

where, \(Y_{MI-1}\): coke yielded from melting materials penetrating into wall-side division No. \(i-1\) coming from division No. \(i\) \((kg)\)
\(k\): penetration ratio of surplus dilatation volume into wall-side coke zone \((-\)}
\(b\): constant

Equation (7) can also be expressed by the following equation (8) when the term \(V_{ri}\) is replaced by Eq. (5):

\[
Y_{MI-1} = kV_i(1 + D_i/100)(\rho_B - \rho_T) \times (1+bVM)(100-VM)/(1+D_i/100) \quad \text{...(8)}
\]

(C) Treatment of Variation in the Volume of Softening Layer and Coke Contraction

Coke contraction after resolidification affects not only the density of coke zone which is calculated by Eq. (1) but also the softening layer volume. This can be explained as follows: when wall-side division No. \(i-1\) is softened and surplus dilatation is produced, the wall-side division No. \(i\) in charged coal (Fig. 8 (i)) is compressed as already explained (Fig. 8 (ii)). Then, when this division No. \(i\) is softened and surplus dilatation is produced, coal layer of the center-side division No. \(i+1\) is compressed and volume of No. \(i\) is increased. At the same time, such volume is further increased by the contraction of the wall-side coke layer (Fig. 8 (iii)).

Therefore, it has been considered in this model that the division No. \(i\) so expanded as above has a contraction depending on carbonizing temperature as shown in Fig. 9 after resolidification (Fig. 8 (iv)), and affects the enlargement of softening layer transferred to the center side.

Fig. 7. Transfer model of the melting materials in coal.

Fig. 8. Changes in coke volume.

Fig. 9. Relation between heating temperature and shrinkage of coke during carbonization.
The results obtained in items (A) to (C) above are applied to density calculation by Eq. (1), and the obtained density thereby is converted into the porosity which can be substituted in the equation for coke strength calculation.

(2) Micro-strength Calculation

It has already been explained in the previous paper\textsuperscript{1} that micro-strength greatly depends on the coalification rank and carbonization temperature. Thus, the micro-strength is calculated by the following equation.

\[
MI_i = e(T_i - 1000) + f(R_o) \hspace{1cm} \text{(9)}
\]

where, \(MI_i\): micro-strength of arbitrary division No. \(i\) (-)
\(T_i\): carbonization temperature in arbitrary division No. \(i\) (°C)
\(R_o\): micro-strength at 1 000 °C which is indicated as the function of coalification rank (-)
\(e\): constant (-).

Carbonization temperature \(T_i\) in the above equation is obtained by heat transfer calculation.

(3) JIS Drum Index Calculation

Coke porosity \(P\) during carbonization is given by the equation \(P = 1 - \rho/\rho_t\), where \(\rho\) is the density given by Eq. (1) and \(\rho_t\) is the true specific gravity of coke. This micro-strength given by Eq. (9) enable the calculation of consecutive JIS drum index by using Eq. (3). It must be noted that since Eq. (3) is applicable only when the coke is a porous material without any structural defects, it cannot be applied to coke having some structural defects. Paying attention to this point, the authours have introduced the filling ratio of void’s volume \(F_V\) in the strength calculation for the coke with structural defects which arises from insufficient bonding of coal particles during softening and melting, and have succeeded in expanding the application of Eq. (3).

In case that coal particles are sufficiently bonded \((F_V\) is more than or equal to 1), the JIS drum index can be calculated by Eq. (3). When they are not sufficiently bonded \((F_V\) is less than 1), however it is considered that the structural defect caused by such insufficient bonding of coal particles gives influence on the JIS drum index via tensile strength as previously reported.\textsuperscript{15} Consequently, the following equation is applicable.

\[
DI_{15} = 100 \exp \left[ -0.81 \left( F_V (11.4MI - 114) \times \exp ( -4.2P ) \right)^{0.6} \right] \hspace{1cm} \text{(10)}
\]

III. Verification of the Simulation Model

The verification of the simulation model has been performed by the use of both a 250 kg test coke oven and an industrial large scale coke oven. The following results were obtained.

1. Verification with a 250 kg Test Coke Oven

A 250 kg test coke oven with oven width of 450 mm has been charged with blended coal as shown in Table 1 under conditions of water content of 8 % and bulk density of 720 kg/m\(^3\). The charged coal was carbonized at the heating element temperature of 1 140 °C for 24 hr. Change of carbonizing temperature at different points across the oven width has been measured by setting nine thermo-couples from wall side to oven center in the same way as previously reported.\textsuperscript{13}

Figures 10 to 12 show the comparison of measured results with the simulated values. These figures clearly show the coincidence between measured and calculated values not only of heating rate in the softening temperature range and porosity at different points across the oven width, but also heating patterns. It should be pointed out that it is possible to calculate the coke strength during the carbonization at any points across the oven width by the proposed simulation model, as represented in Fig. 13. The curve represented by --- in the figure indicates variation in the JIS drum index calculated by weighed average of strength at each point across the oven width. It suggests a very satisfactory coincidence of measured values with calculated ones.

\[
\begin{array}{cccccc}
\text{Ash} & \text{Volatile} & \text{Max.} & \text{Total} & \text{Mean} \\
(\%, \text{d.b.}) & (\%, \text{d.b.}) & \text{fluidity} & \text{reactive} & \text{reflectance} \\
\text{(log d.p.m.)} & (\%) & (\%) & (\%) \\
8.2 & 26.8 & 2.20 & 79.0 & 1.15 \\
\end{array}
\]

Table 1. Properties of the blended coal.

\[
\begin{figure}
\centering
\includegraphics[width=\textwidth]{graph10.png}
\caption{Heating rates across the oven width.}
\end{figure}
\]

\[
\begin{figure}
\centering
\includegraphics[width=\textwidth]{graph11.png}
\caption{Variation of porosity across the oven width.}
\end{figure}
\]
Transactions ISIJ, Vol. 23, 1983 (487)

DI15 value after carbonization for 24 hr is 91.8 while that calculated is 91.9.

2. Verification with an Industrial Large Scale Coke Oven

1. Data Collection from Industrial Large-scale Coke Oven

In order to verify the simulation model with an industrial large-scale coke oven, it is required to measure, in advance, wall temperature at combustion chamber and the bulk density distribution of charged coal in carbonization chamber, both of which are necessary for model calculation.

Furthermore, the proper sampling of coke at different points inside the carbonization chamber and the accurate measurement of temperature in the oven center are indispensable, so that the measured values can be compared with those calculated. Collection method of these data from industrial coke oven is briefly explained below since it has already been reported in a summarized form.13,14>

(1) Industrial Large-scale Coke Oven Used
Sumitomo Metal Industries, Ltd., Kashima Steel Works, II-C Battery (Koppers type)

i) Dimensions of oven:
   - height: 7.125 m
   - length: 16.5 m
   - width: 0.46 m

ii) Operation condition:
   - working ratio: 100 to 120 % (carbonization time 24 to 20 hr)

2. Results of Verification

It has been confirmed that the calculated values and measured ones almost coincide as to the temperature of different points in the carbonization chamber at the end of carbonization, though there is a little deviation as shown in Fig. 16.

The coke strength has been calculated by the simulation model and compared with actual values measured at different points in carbonization chamber.

Fig. 12. Temperature change at different points across the oven width.

Fig. 13. Variation of calculated JIS drum index during carbonization at different points across the oven width.

Fig. 14. Characteristic distribution of wall temperature from C/S to M/S (8 min after the end of combustion, No. 138 flue, battery 2-C).
The result shows the satisfactory coincidence of both values as shown in Fig. 17. Also it has been confirmed that the coke strength is lower at the oven top and at the middle of charging holes. The reasons for this can be assumed from the simulation model as follows. At the oven top, bulk density of charged coal is lower and also wall temperature in the combustion chamber is lower. On the other hand, at the middle of charging holes the bulk density of charged coal is lower than that right below the charging hole and this effect may be significant.

As clearly verified by the tests and examination using laboratory-scale and industrial-scale model ovens as described above, the proposed simulation model can very accurately estimate both the coke quality and heat transfer in the coke oven during carbonization.

IV. Conclusions

Detailed construction of simulation model for carbonization in the coke oven was worked out with consideration of the concept of coking mechanism previously reported.1) Validity of the model has been verified by the results of experiments using laboratory-scale and industrial-scale coke ovens.

The most important characteristic of the proposed simulation model can be summarized as:

i) the calculation of density variation during carbonization in the coke and coal zones across the oven width

ii) the utilization of values obtained therefrom as basic physical values to determine coke strength and heat transfer condition. In this way, the simulation model can provide a simultaneous estimation of coke quality and heat transfer condition during carbonization in the coke oven.

Also the filling ratio of void's volume ($F_v$) previously reported1) has been employed in the calculation of coke strength, considering the effect of structural defect that may be caused by an insufficient bonding of coal particles during softening and melting.

The simulation model elaborated in this way has been verified by using laboratory-scale and industrial-scale coke ovens, and its validity has been confirmed. Greater efforts will be made for further improvement of accuracy of the proposed simulation model so that it may be of use for operational analysis of the coke oven.

REFERENCES

7) W. Simonis: Glückauf-Forschungshefte, 29 (1968), 103.