Analysis for Graphite Electrode Unit Consumption in Manufacture System and Use System of Steelmaking EAF

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Abstract

Based on the analysis on the consumption of electrode manufacture system and users’ system, the universality and characteristic of electrode industry development were revealed. The electrode consumption should be analyzed correctly and fully and relative content affecting discontinuous consumption should be added. The method of analyzing electrode consumption as well as consumption reduction has been presented.

Key Words: Graphite Electrode, Manufacturing, Consumption.

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Application & Consumption of Graphite Electrode for EAF Steelmaking

Graphite will be oxidized at a temperature of approximately 400°C and sublimated at 3650°C. It is a kind of brittle non-metal material. During operating in electric furnace, the top of graphite column which located in air is cooled by spraying water; In the bottom of graphite column, the temperature at the arc discharging point reaches 4000~20000°C. Affecting heat and phase transition, the electrode will be consumed continuously during oxidation, melt and sublimation processes; on the other hand, under the independent or combined effect of different external factors such as process, equipment and operation (for example, gravity, pressure, pulling force, fracturing force, vibration, power, looseness electromagnetic force, thermal stress, thermal shock etc), the electrode will be consumed discontinuously due to looseness, breakage or cracks. The former consumption could only be reduced but not to be avoided; while for the latter consumption, we should try our best option to avoid it. Since the graphite electrode is used in steel industry, both the manufacturers and users have hard trying to improve its quality and reduce its consumption. After forty years scientific endeavor in this field, the following work has been done and relative result has been obtained:

1.1 An Effort for Reducing Electrode Consumption made by EAF Steelmaking Enterprises

1.1.1 Research on Main Factors affecting Unit Consumption

From 1995 to 1997, Nanjo Toshio (Japan) published several articles about Industrial Heating, in which main factors affecting the unit consumption of electrode is listed (see Table 1).

1.1.2 The Development of EAF Steelmaking Technology

Figure 1 shows the development of EAF steelmaking technology in different stages. As seen in Figure 1, thanks to the development and application of some new technology, EAF steelmaking cycle has been reduced from 180 min in 1965 to less than 60 min, and even 35 min minimal; power consumption has been reduced from 630 kW·h/t to min 200 kW·h/t; and electrode consumption has been reduced from 6.5kg/t to min 1.0kg/t.

Figure 1 focuses on the development of steelmaking technology, which could be concluded as below:

1) To reduce the steelmaking cycle:
   a) to increase the input power of transformer of electric furnace: from RP (100~400 kVA/t) → HP (400~700 kVA/t) → UHP (700~1000 kVA/t);
   b) to make more use of physical and chemical heat; to add liquid iron; to pre-heat waste steel; to adopt oxygen blowing; to adopt C-O gun;
   c) to melt in EAF and refine in LF;
   d) to stir from the bottom of furnace;
2) To reduce the time of power-off:
a) water-cooling furnace door and wall;
b) to adopt computer control;
c) to add waste steel and liquid iron continuously;
d) eccentric bottom tapping;
3) To increase the capacity of furnace, so as to improve energy efficiency and reduce unit consumption. The furnace capacity has been increased from
\[ \text{Table 1 - Main Factors} \]
5~10t → 80~100t → max. 400t.
4) To reduce the oxidation area of electrode:
a) to cool electrode by spraying water;
b) to change three-phase AC to DC;
c) to replace low-quality electrode with high-quality electrode, from RP → HP → UHP;
5) To decrease electrode temperature, so as to decrease oxidation and sublimation:
a) to change low-voltage high-current short-arc operation to high-voltage low-current long-arc operation;
b) to change the power supply by optimizing the connection: from connection with AC power to cathode connection only with DC power.

1.2 Effort on Reducing Electrode Consumption made by Electrode Manufacturing Enterprises
In the past 40 years, electrode manufacturers all over the world have been trying hard to develop and improve electrode technology so as to meet the development of EAF steelmaking. Figure 2 shows the main work done by electrode manufacturers in Japan, which could be concluded as below:

1) To adopt high-quality raw material, including localizing petroleum and coal needle coke and stabling their quality, so as to produce electrode and nipple with low CTE.
2) To improve mixing and forming technology; to put lengthwise graphite (LWG) into application; to adopt tapered connection instead of column connection.
3) To use long nipple, so as to decrease the proportion of fall-off of remnant electrode.
4) To adopt anti-oxidizing treatment for finished electrode, so as to further reduce consumption due to oxidation.
   In conclusion, electrode consumption is reduced by adopting raw material with higher quality, more advanced process of production and post-treatment and equipment with better performance.

2. Analysis on Consumption of Electrode

2.1 Analysis on Unit Consumption shown in Fig. 1 & Fig. 2
As seen in Table 2:

1) The trend of two curves is same; so, unit consumption of the electrode is decreasing along with the time.
2) The Statistic of unit consumption of electrode: unit consumption in using system is always lower than that in manufacturing system.
3) Difference between two figures is rule-less, but it generally enlarged.
2.2 Relation between Fig. 1 & Fig. 2

Figure 1 indicates development impact of EAF steelmaking technology in steelmaking cycle, power consumption and electrode unit consumption from 1965 to 2001;

Figure 2 shows the transition of unit consumption from 1960 to 2003 after EAF steelmaking technology which has been innovated and the quality of electrode has been improved. In another word, Figure 2 includes the result shown in Figure 1.

It can be concluded that both new technology in electrode manufacture and that in electrode application help to reduce electrode consumption. The curves are the result of jointed effort of electrode manufacturer and electrode user, who emphasize differently.

2.3 Reason for Lower Unit Consumption in Fig. 1 than that in Fig. 2

Average unit consumption of electrode (kg/t) = Amount of Electrode (kg) / Steel Output (t)

By comparing the above two Figures, we may find the reason as follows:

1) Electrode Amount in Figure 2 is Different and bigger than that in Figure 1.

The average unit consumption of electrode in Figure 2 reflects the actual situation for electrode manufacturer during such period, which is according to:

Average unit consumption of electrode (kg/t) = Sales Amount of Electrode (kg) / Steel Output (t)

Sales Amount of Electrode = transportation consumption + storage consumption + continuous consumption + discontinuous consumption + amount under manufacturing and in stock (period end– period start) + compensation amount to user etc.

While calculating the average value of electrode amount in Figure 1, only continuous consumption and the part of discontinuous consumption are considered; also when calculating the minimum value, probably only continuous consumption is considered, that is:

Average unit consumption of electrode (kg/t) = the Amount of Consumed Electrodes (kg) / Steel Output (t)

Therefore, it is obvious that the electrode amount in Figure 2 is bigger than that in Figure 1.

2) Steel Output in Figure 2 is smaller than the Actual Amount.

Refining the melt in LF started from the 1980s. After this time, not only electric steelmaking is done in EAF (for melting) and LF (for refining), but also Converter
steelmaking is equipped with LF for refining. An electrode is adopted for both methods. It is not easy for electrode manufacturer to classify the electrode consumption and steel output using the above three furnaces; so in many cases the electric steel-making output would be used as the total steel output for calculation. Through this way, the steel output for calculation is lower than the actual value. Therefore, generally speaking, the above two points make the electrode consumption in Figure 2 higher than that in Figure 1.

3. Conclusion

When graphite electrode is being used in EAF, under the independent or combined effect of different external factors such as temperature etc., the technical indexes of different parts of electrode column will change: the index will increase or decrease, the effect will improve or depredate. Once some external force is too much to bear (the bearing capacity is obtained during manufacture and will change along with the using environment), there will be continuous or discontinuous consumption. In order to reduce it, both electrode manufacturer and user should make effort.

Figure 1 and Figure 2 show the comprehensive effect based on the respective effort made by two sides. While due to graphite’s characteristics and using environment, oxidization and sublimation is unavoidable. Also other harmful external forces are hard to be controlled, so the discontinuous consumption still exists. For instance, the interconnection of electrodes should be improved in order to reduce the discontinuous consumption. Bad joining always increases looseness, breakage and cracks etc. Nowadays electrode connection has already developed from by manual clamp → moment clamp → mechanical moment clamp → manipulator.

Anyway, making thorough analysis and research on the principle and the reason of electrode consumption is the precondition of better production.

Reference:


Table 1. Main Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Variation of Factor</th>
<th>Variation of Unit Consumption</th>
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<tbody>
<tr>
<td>Tapping Amount</td>
<td>each ± 1t</td>
<td>± 24g/t</td>
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<tr>
<td>Steel Charging / Tapping Amount</td>
<td>each ± 1kg/t</td>
<td>± 5.2g/t</td>
</tr>
<tr>
<td>Slagging Material / Tapping Amount</td>
<td>each ± 1kg/t</td>
<td>± 9.3g/t</td>
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<tr>
<td>Tapping Temperature</td>
<td>each ± 1°C</td>
<td>± 4g/t</td>
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<tr>
<td>Power-off Time</td>
<td>each ± 1min</td>
<td>± 17g/t</td>
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<tr>
<td>Output Power</td>
<td>each ± 1kW/t</td>
<td>± 5.6g/t</td>
</tr>
<tr>
<td>Arc Current</td>
<td>each ± 1kA</td>
<td>± 60g/t</td>
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Note:

1) All the above several factors have quantitative influence on the unit consumption of electrode.
2) Limited by particular condition and affected by the variability of material, process and operation during actual production, the calculation is complicated and it is hard to obtain an average value. Therefore, only qualitative indication is given hereinabove.

Table 2. is the quantitative comparison of unit consumption in Fig. 1 & Fig. 2

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<tbody>
<tr>
<td>EAF Technology Manual / (kg/t)</td>
<td>6.5</td>
<td>5.13</td>
<td>4.90</td>
<td>3.20</td>
<td>2.50</td>
<td>2.00</td>
<td>1.55</td>
<td>1.23</td>
<td>1.0</td>
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<td>TOKAI Catalogue / (kg/t)</td>
<td>9.68</td>
<td>7.28</td>
<td>6.52</td>
<td>5.99</td>
<td>4.22</td>
<td>3.51</td>
<td>2.92</td>
<td>2.77</td>
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<td>2.45</td>
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<tr>
<td>Difference / (kg/t)</td>
<td>0.78</td>
<td>1.39</td>
<td>1.09</td>
<td>1.02</td>
<td>1.01</td>
<td>0.92</td>
<td>1.22</td>
<td>1.12</td>
<td>1.45</td>
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Fig. 1. Development of EAF Steelmaking Technology in Different Stages.

Fig. 2. Transition of Electrode Consumption Rate in Japan.