China Steel Technical Report, No. 36, pp.11 －16, (2023)

Optimizing the Coke Oven Temperature by Introducing the Coke Cake Center Temperature Measurement

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To optimize the coke oven temperature, reduce the risk of heavy pushing, and prolong the campaign life of the coke battery, the coke cake center temperature (CCCT) measurement was introduced into the coke-making process in a commercial top-charged coke oven by inserting the thermometers from the oven door. The net coking time (NCT) of the coal under a different production level can be revealed. The flue temperature was measured at every end of the CCCT measurement, by linear regression, the relationship between the flue temperature and the NCT can be known. The gradient of the flue temperature was found to be not a fixed number, but varied from 2.6 to 3.5ºC/flue accompanied by the NCT increased from 17 to 19 hours. Additionally, for better coke contraction, the end flue temperature was suggested to be not lower than 1000ºC due to the maximum difference between the average flue temperature and the CCCT at the end of the measuring of the end flues was 190ºC. This study enables the coke battery to be operated more scientifically and the risk of heavy pushing to be reduced. Consequently, the campaign life of the coke battery could be prolonged.

Keywords: Coke Cake Center Temperature Measurement, Net Coking Time, Campaign Life of Coke Battery

1. INTRODUCTION

Coke is one of the most important raw materials in the steel industry. However, the high pollution released from the coke-making process is not acceptable in nowadays society due to the growing environmental consciousness. To rebuild an end-of-life coke oven has become a difficult issue for the steel industry. Therefore, prolonging the campaign life of a coke battery is an important issue in every steel plant, especially for China Steel Corporation (CSC, Taiwan) which owns 4 phases of coke batteries with an average age of 40 years.

According to Madias's research(1), 20 to 30 years is said to be a reasonable campaign life of a coke oven. The key factors for prolonging the life of a coke oven include coal blend design, operation, refractories maintenance, and the coke oven temperature control. Poor design of the coal blend may lead to oven wall damage due to the overuse of low-volatile coal which leads to high wall pressure(2). The basic oxides (Fe_2O_3, CaO, and MgO) in the coal blend may lead to the penetration of the brick wall(3). The regularity of operation, or the production level, can avoid the thermal shock of the wall brick from the frequently change of oven temperature. Refractory maintenance is the repair of wall brick cracks, joints, deformation, etc. by ceramic welding, gunning, or dry sealing(1). Coke oven temperature control should focus on the operating temperature range as well as the cross-wall temperature range.

From the wall brick protection side, the operating temperature should be controlled in the range of 1100 to 1300ºC which is within the stability temperature range of tridymite (870 to 1470ºC)(1) to avoid oven wall deformation. Cross-wall temperature is carried out by infrared temperature measurement of all the flues before the finish of coking. The cross-wall temperature is set according to the different production levels and the temperature of each flue from the push side to the coke side should be increased gradually due to the increasing oven width. To further define an appropriate cross-wall temperature, the CCCT measurement is essential to understand the NCT of the coke cake at different production levels. The NCT of the coke cake in China Steel Corporation is defined as the time from which the coal charged until the lowest temperature in the coke cake rose to 900ºC. At this time, the coke has finished most of the lateral shrinkage[4] representing the gap between the coke cake and the oven wall being large enough. With an additional 1 to 3 hours of soaking time to reach the effective homogenization of the coke cake[5], the coke cake would be ready for a safety push without heavy push and stickers[6]. According to the abovementioned relationship between cross wall temperature and the NCT, with the view to prolonging the coke battery campaign life, it's important to figure out the relationship between flue temperature and the NCT.

There are many methods to measure the CCCT, including inserting a thermometer from the charging holes, and inserting a thermometer from the oven door at the bottom of the oven. Each of these methods has its pros and cons[7]. Inserting the thermometer from the charging holes enabled us to reveal the temperature history of the coal from the top to the bottom of the oven from charging to before pushing. However, the height of the commercially used coke oven is usually over 7 meters. The thermometer should be longer than the height of the coke oven. The long thermometer resulted in scratching of the oven wall, the thermometer bending easily, and a handling issue. Inserting the thermometer from the oven door at the bottom of the oven seems to be a more reasonable way to measure the CCCT. The length of the thermometer could be controlled to under 2 to 3 meters; therefore, the inserting and removing of the thermometer can be more convenient. Besides, the lowest temperature of the coke cake center on height direction occurs at the bottom[8], the temperature history of the bottom center of the coke cake is sufficient for estimating the NCT of the whole coke cake under different production levels and flue temperature.

In this study, we aimed to apply the CCCT measurement by inserting the thermometer from the oven door at the bottom of the oven of the 4th phase of the coke battery in CSC to achieve the NCT of the battery. After that, the relationship between the NCT and the flue temperature was analyzed by linear regression analysis to figure out the optimal setting of the coke oven temperature under different production levels.

2. EXPERIMENTAL METHOD

2.1 Temperature measurement and data collection

The CCCT measurement was executed in the 4th phase coke battery in CSC which is a 7.3 m high top charging coke oven with 34 flues in each heating wall. The flue temperature from 4th to 31st flue was set to be linearly increased with a gradient of 2.5ºC /flue which was provided by the oven manufacturer to ensure the NCT of the whole coke cake was the same; therefore, the temperature of the 4th and 31st flues was chosen to be measured to calculate the ideal temperature of the 5th to the 30th flues. The ideal temperature of the 1st to 3rd and 32nd to 34th flues which were called the end flues were always hard to define due to the influence of environmental temperature. For this reason, the middle of the end flues which were the 2nd and 33rd were chosen to be measured to provide more information about the flue temperature and the coking condition at the end flues domain.

As the abovementioned, the temperature of the coke cake center at the 2nd, 4th, 31^{st,} and 33rd flues were chosen to be measured. A CCCT thermometer with two measuring points was made to be inserted from the pusher side and coke side to measure the CCCT of the abovementioned flues. The locations of the two measuring points were designed according to the distance between flue to flue, and flue to the oven door. The draft of the CCCT thermometer is shown in Fig.1(a), and the thermometers were made according to the draft as shown in Fig.1(b). Considering the highest flue temperature of phase 4 coke battery was set at about 1200 ºC in the past six months before measuring, the K-type thermometer which can be used from -200ºC to 1260ºC was chosen. The K-type thermometer was protected by a 310 stainless steel tube to provide the mechanical strength for inserting into the charged coal.

To record the temperature history of the coking process from start to finish, the thermometers were inserted 5 minutes after the coal was charged into the coke oven and removed 1 hour before the pushing of coke. Wireless transmitters and receivers were used for data collecting so as not to interfere with the moving of pushing and discharging cars. The cross walls flue temperatures were recorded 2 hour before coke pushing by infrared temperature measurement for the linear regression of the relationship between the NCT and flue temperature.

2.2 Data analysis

Each of the collected data was first plotted into a line chart with coking time as the x-axis and temperature as the y-axis to ensure the data were recorded correctly during the whole coking process. The time that the temperature reached 900ºC was recorded for calculating the NCT.

The relationship between the NCT and flue temperature was then analyzed by linear regression to achieve its' linear equation as Y(NCT)=aX(flue temperature)+b. The NCT represented the NCT of the coke cake center at different flue locations (#2, #4, #31, and #33) which was the time duration from coal being charged until the CCCT reached 900℃. Due to there being two heating walls for one coke oven, the flue temperature was the average of the two flue temperatures on both sides of the coke oven.

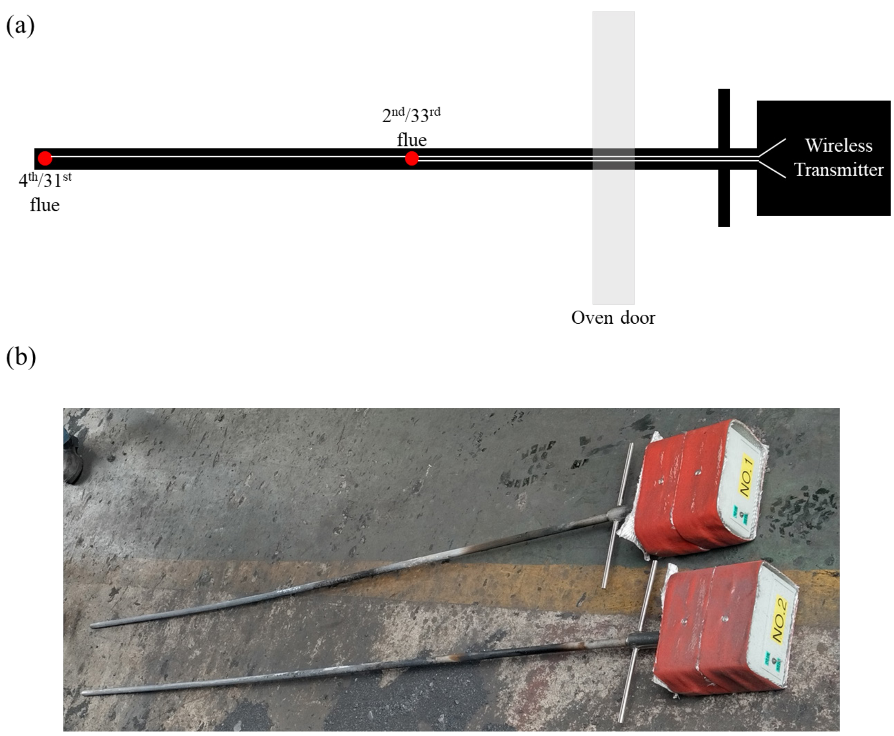

Fig.1. (a) The design draft and (b) the entity of the CCCT thermometer.

3. RESULTS AND DISCUSSION

3.1 Coke Cake Center Temperature Measurement

There are a total of 100 ovens in the 4th phase coke battery in CSC and are named #101 to #200. 20 ovens of the CCCT were measured and there was at least one set of data for every 10 ovens to increase the reliability of the NCT to flue temperature linear equation to represent the 4th phase coke battery. Fig.2(a) and (b) are two representative figures of the CCCT history during the coking process. According to these figures, the temperature history can be roughly divided into 4 stages. In the first stage, the thermometer was just inserted, and the CCCT increased rapidly from room temperature to 100ºC. After that, it took about 8 to 11 hours for the temperature to rise slowly from 100 to 110ºC. In the second stage, the water in the coal cake absorbed the heat became water vapor, and left the oven. Therefore, in this stage, the temperature rose slowly from 100 to 110ºC. Once all the water vapor had left the oven, the temperature rose rapidly from 110 ºC to 900ºC. In this stage, the solid coal first transformed into a plastic phase at 400 to 500ºC [9], and then started forming semi-coke accompanied by shrinkage to form coke[10]. The combination of the first three stages in the temperature history of the coking process is called the NCT. The last stage of the coking process is known as the soaking time or retention time. This stage is to homogenize the transformation of all the coal to coke and to guarantee the uniformity of the coke quality[5].

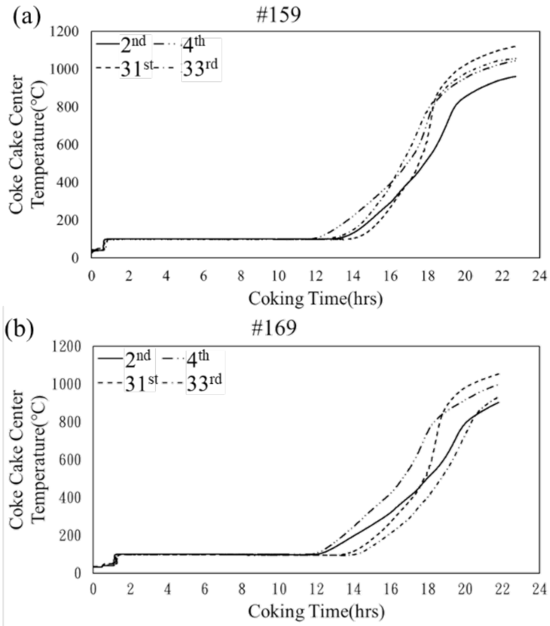

Fig.2. Representative figures of the CCCT history during the coking process (a) #159 oven, (b) #169 oven.

3.2 Linear Regression of the Net Coking Time and Flue Temperature

During the period of measuring, the production level and the flue temperature of the 4th phase coke battery were altered according to the market and researching demand to achieve different NCT. Finally, we received the data for the NCT in the range of 15 to 21 hours and most were concentrated in 17 to 19 hours. The linear regression of the NCT and flue temperature of coke cake at #2, #4, #31, and #33 flue, and the regression equations are shown in Fig.3. It can be seen that the flue temperature increased from #4 to #31 flue under the same NCT. The results coincide with the design of the coke oven in that the flue temperature should be gradually increased from the pusher side to the coke side due to the increasing oven width. The R^2 of the four regression equations are all above 0.75 which means the equation can account for over 75% of the relationship between the flue temperature and the NCT especially for the NCT in the range of 17 to 19 hours. The ideal flue temperature of the coke cake at flue #4 and #31 at different NCT were then calculated according to the linear equations in Fig.3.. Fig.4. shows the ideal temperature of flue #4 to #31 at 17 to 19 hours of the NCT and can be the guide for the temperature setting of the 4th phase coke battery under different production levels due to the strong reliability of the linear equations. The suggested average oven temperature and the temperature gradient of each flue at different NCT are listed in Table 1. The suggested average oven temperature decreases with the increasing NCT, and this trend is a fortunate coincidence with the real operation of the coke oven. The result indicated that the linear equations can fit the real temperature demand of the coke battery at different NCT.

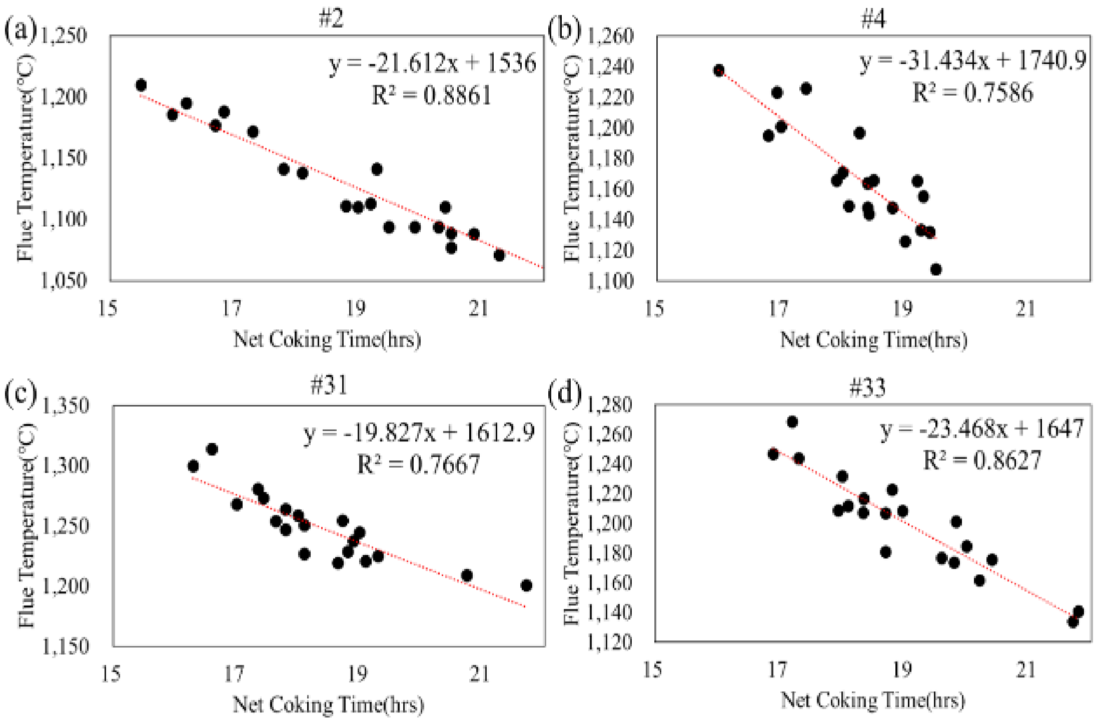

Fig.3. Relationship between the NCT and flue temperature of coke cat at different flue (a) #2, (b) #4, (c) #31 and (d) #33.

Table 1 The suggested average oven temperature and temperature gradient of each flue at different NCT.

NCT (hrs)	Average Oven Temperature (℃)	Temperature gradient of each flue (℃/flue)
17	1240	2.6
18	1215	3.1
19	1190	3.5

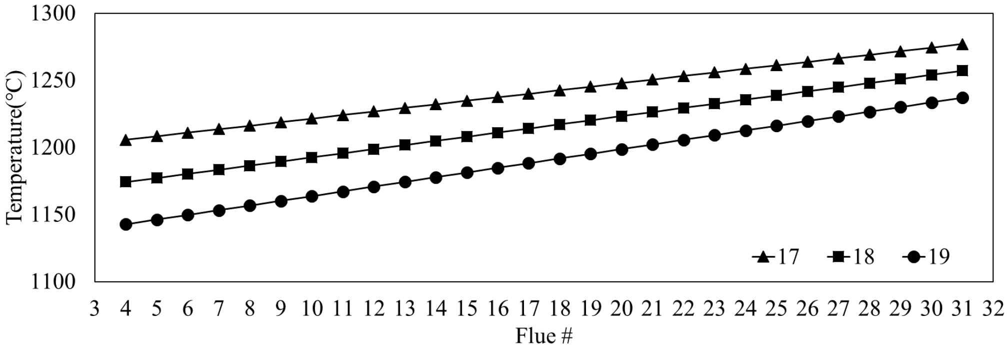

Fig.4. Ideal temperature of flue #4 to #31 at different NCT.

3.3 Temperature Gradient of Each Flue

The calculated temperature gradient of each flue in Table 1 is different from the set value of 2.5ºC/flue. Considering the equation was derived from the data measured at the 4th phase coke battery, the calculated temperature gradient of each flue was probably the real demand of the coke oven. Therefore, the temperature gradient of each flue under different production levels or NCT should be set according to the results in Table 1. In order to further understand the influence of the difference in temperature gradient of each flue, the temperature of flues at different NCT was calculated and the set gradient are shown in Fig.5. In Fig.5(a) and (b), the triangle marks represented the flue temperature set according to the calculated temperature gradient listed in Table 1 and the square marks represented the flue temperature set according to the temperature gradient of 2.5ºC/flue. The NCT in Fig.5(a) was 18 hours and the average oven temperature was set to be 1215ºC, the calculated temperature gradient was 3.1ºC/flue. In Fig.5(b), the NCT was 19 hours and the average oven temperature was set to be 1190ºC, the calculated temperature gradient was 3.5ºC/flue. In both cases, it showed that compared to the standard temperature of the coke oven, the actual temperature demand of the coke oven showed a lower temperature at the pusher side and a higher temperature at the coke side. These results indicated that if the flue temperature gradient was set according to 2.5ºC/flue, the temperature may be insufficient at the pusher side which may result in a poor coking condition, insufficient contraction of coke, and heavy pushing.

3.4 End Flue Temperature Control

The end flue temperature is hard to control and define because it is close to the oven door and is greatly influenced by the surrounding temperature, leakage gas, frequent opening and closing of the oven door, etc. The CCCT was found to be able to offer a guide to the end

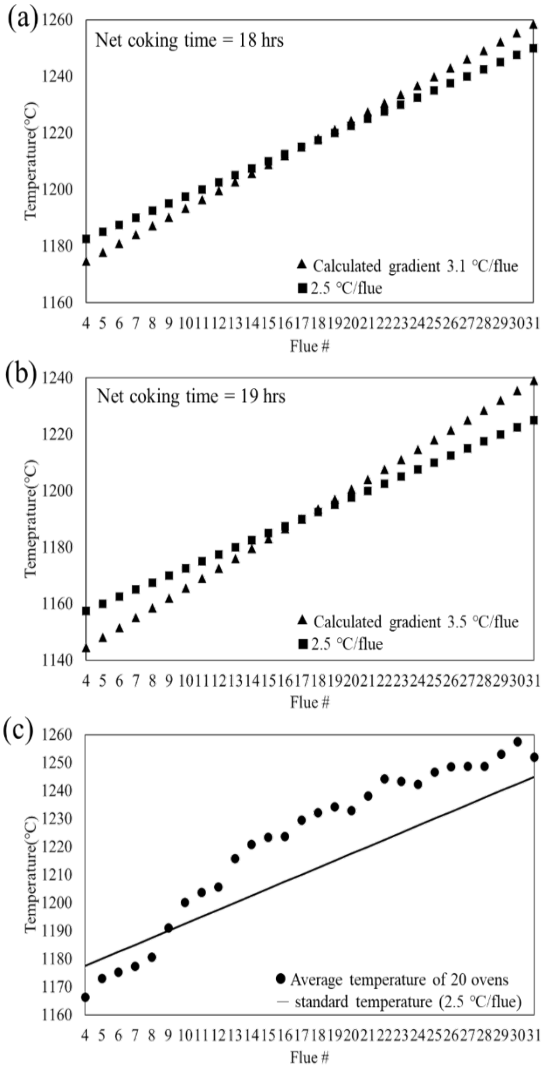

Fig.5. Flue temperature set according to calculated gradient and 2.5ºC/flue at (a) 18 hours NCT and (b) 19 hours NCT, and (c) average temperature of 20 ovens versus standard flue temperature (set as 2.5ºC/flue).

flue temperature setting. Fig.6 shows the temperature difference between the average flue temperature and CCCT at the end of the measuring at #2, #4, #31, and #33 flues. The temperature difference ranges from 128 to 190ºC. As shown in Fig.2, the temperature of the CCCT at the end of the measuring barely changed; therefore, the CCCT can be treated as the coke cake temperature before pushing. The CCCT at the end of the measuring indicated the coking condition of the coke cake. According to Nomura's research[6], most of the coke shrinkage occurs in the temperature range of 600 to 800 ºC. Hence, considering the max temperature difference was 190ºC, the end flue temperature is suggested to be above 1000ºC to ensure a good coking condition and coke quality, and also to avoid heavy pushing.

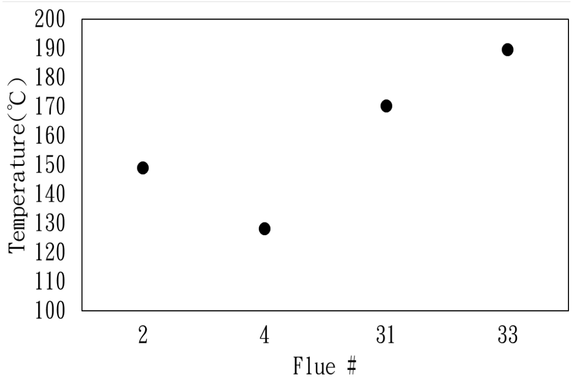

Fig.6. Difference between the average flue temperature and CCCT at the end of the measuring of #2, #4, #31, and #33 flues.

4. CONCLUSIONS

The CCCT measurement improved the understanding of the temperature history of coal in the coke oven which was not clear before the introduction of the CCCT thermometer. The temperature gradient of the inner flue (#4 to #31) was found not to be set as a fixed value of 2.5ºC/flue but should be increased from 2.6 to 3.5 ºC/flue as the NCT increases from 17 to 19 hours. On the end flue, the difference between the average flue temperature and the CCCT at the end of the measuring was 128 to 190ºC. To reach a good contraction of coke, 800ºC of the coke cake center temperature is needed, the end flue temperature was suggested to be set no lower than 1000ºC to lower the risk of heavy pushing. This study enables the coke oven to be operated more scientifically, the coke quality to be more stable, and the risk of heavy pushing to be reduced. Therefore, the campaign life of the coke oven could be prolonged.

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