Influence of Temperature Control of Coke Oven on Life Cycle of Refractories

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Abstract—Different stages of the oven drying are analyzed by the theory of molecular diffusion and crystal change in oven drying process. It’s pointed that in order to ensure uniform expansion and gray seam integrity, the speed of spreading to the outside about within water should be in accordance with the speed of evaporation about surface moisture in the drying period, heating up too quickly will easily lead to extending drying period and destroying masonry rigor. The expansion of silica brick is mainly from the volume effect form with the transition between the allotrope in the expansion period, the heating rate of crystal transformation point must be strictly controlled. At the same time, quartz content should be higher, lesser residual quartz content will be better. The hot state engineering period is consistent with the construction schedule, the construction sequence can’t be reversed, and it is not recommended at this stage to extend the construction period. Effective control of the heating rate of the three stages above lays a solid foundation to extend the oven life.

1. Introduction
The oven drying means baking coke oven in cold state. After being dried, dehydrated and heated up, the oven temperature reaches 900 °C above, and it prepares for transition of coke oven from cold state to production [1]. Oven drying is an important task before coke oven goes into production, and the oven drying quality has a critical influence on coke oven life. The masonry is made of silica bricks, clay bricks, high alumina bricks, refractory materials and so on. The heating rate plays a key role in course of coke oven gradually being heated from room temperature to coal loading state. It should be rationally controlled to make sure the masonry’s uniform expansion without cracks.

2. Temperature Control Basis of Different Stages
The whole oven drying process can be divided into three stages, drying period, expansion period and hot state engineering period, the last two periods are collectively called warming phase. The bases of
making warming plan are different in different stages. In the first period, the speed of internal water spreading outside should be in accordance with the evaporation speed of surface moisture; in the second stage, every part of the masonry should inflate slowly and evenly; in the last period, the construction progress should be consistent with the equipment installation.

2.1. Drying Period

For oven drying, when the flue temperature reaches 125 ~ 130°C, the grate brick temperature will be 105°C. At that time it can be considered as absolutely dry, that is to say, this is the end of the drying period. In the actual operation, 100 °C the flue temperature reaches usually assumed as the end of the drying period. Comparison of oven armor before and after installation is shown in Figure 1.

Firstly, exhaust gases from fuel burning during oven drying rises through the coking chamber into the oven hole, then declines from the burning chamber flues, finally goes through ramps, regenerator, small flue, exhaust plate, sub flue and total flue into the atmosphere by the chimney. Coke oven ignition is shown in Figure 2.

Generally speaking, the water in bricks and seam ashes is about 1.5% and 25% ~ 30% respectively. The main refractory and auxiliary materials quantity of a coke oven with 60 holes and 6m high can be seen from table 1, such oven contents 600t water which must be excluded in the dry period. Quantity of bricks and mortars for 6m Coke Oven is shown at Table 1.

| NO. | Kinds              | Weight/t | Sum/t |
|-----|--------------------|----------|-------|
| 1   | Silica bricks      | 10729    |       |
| 2   | Clay bricks        | 4581     |       |
| 3   | High alumina bricks| 127      |       |
| 4   | Andalusite bricks  | 29       |       |
| 5   | Quarry tile        | 202      |       |
| 6   | Floating beads bricks| 285    |       |
| 7   | Thermalinsulation bricks| 232 |       |
| 8   | Red bricks         | 357      |       |
| 9   | Mortar             | 1657     | 1657  |

The inherent and surface water are basically uniform before drying, but with the drying going, the balance of inherent and surface water is destroyed and surface water is taken out by hot air first of all, the water is spreading from inherent to surface, then is taken out by hot air again until the oven masonry is completely dry. The spreading outside speed of inherent water is relative to the temperature tightly, the higher the temperature, the faster the spreading speed. When the temperature is too high, the inherent water gasifies directly, engenders considerable pressure then dashes out from mortar joints. It makes mortar joint become loose, thereby destroys the tight property of masonry.

Furthermore, another disadvantageous situation will happen if the drying speed is too fast. The temperature is down gradually because hot air passes through coking chamber, burning chamber, ramps, regenerator, small flue and other parts respectively. If the drying speed increases, the temperature will increase in all these places, then the hot air reaches saturated state in burning chamber. When hot air flows to the bottom of masonry, the vapor may be cool down in small flue because temperature declines. This will not only extend drying period of masonry lower part, but also wash mortar joints, destroy the tight property of masonry. Thus, the drying speed of masonry should not be too fast.
2.2. Expansion Period

The expansion period is also called crystal transformation period, and it concentrates in close temperature period of crystal transformation point from 100°C to 600°C. The silica bricks used in the oven require SiO₂ content to reach more than 93% and SiO₂ exists in three crystalline forms, including quartz, cristobalite and tridymite, and every crystalline morphology also has several allotropes. From figure 1, during the oven heating process, the cristobalite volume change is most intensively at the temperature of 180°C~270°C, less at the temperature of 573°C, the tridymite volume change is the least in two crystal transformation point 117°C and 163°C. The transition between allotrope doesn’t have lattice rearrangement, only have lattice distortions or straightening, and the conversion speed is fast and reversible [2-4].

Standard flue temperature of the coke oven production is about 1300°C. From Figure 3, during the oven heating process, α-quartz is changes theoretically to α-tridymite or α-cristobalite in the horizontal. The transformation of different crystal morphology is sluggish, and it belongs to one crystal structure to another new one. This transformation is very slow from the crystal edge to the center, needs longer time, completes in a certain temperature range and in one direction only, with a significant volume effect at the same time. But the reaction of α-quartz to α-tridymite requires slower, longer heating time and the existence of a strong fluxing mineralizer. The oven comes into normal heating when its temperature rises to about 800°C. The everyday warming speed is very fast, about 50°C, so it is impossible for the reaction of α-quartz to α-tridymite and the volume effect cannot produce too. On the condition without mineralize, α-quartz is first changes to intermediate metastable cristobalite, then slowly to α-cristobalite on the temperature from 1300°C to 1450°C. Because the reaction temperature is higher than standard flue temperature of normal production, it is difficult to occur [5-7].

![Fig.3 SiO₂ crystal transformation](image)

(a) Longitudinal crack  (b) Cracking of capping brick

In addition to the requirement on the SiO₂ content of silica bricks, coke oven also stresses high tridymite content. For residual quartz, the less the better. Residual quartz content is not only the key indicator to evaluate silica bricks, but also determining factor of coke oven life. The key factor affecting the oven elongation is the depth of the quartz crystal transformation. The less the residual quartz
content, the higher tridymited degree, the smaller the residual expansion. The oven elongation can basically remain stable at the end state of the oven drying. Therefore, the expansion of high-quality silica brick during the oven drying is mainly from volume effect brought by transition between the allotrope.

2.3. Hot State Engineering Period
The hot state engineering is known as the period from 600°C to starting-up processes, and the expansion has basically ended. This workload is not large, but it includes many work types, with the feature of a wide operating range. The most time-consuming is spraying slurry to brick gas channels. A coke oven with 60 holes has 2112 channels, completing this work will take 5~6 days if two spraying machines are used. Other work still includes grouting protection board, building small stoves, burying cross brace and so on. Furthermore, the construction sequence cannot be reversed. Except in exceptional circumstances, the preparation of the oven drying plan generally don’t recommend to extend the hot state construction period.

2.4. Project scrapped Period
After nearly 20 years of coke oven production, due to the adjustment of industrial policy, the coke oven is cooled to normal temperature and the carbonization chambers is filled with coke. After natural cooling , the field investigation found that the longitudinal cracks of carbonization chamber were obvious, running through the bottom to the top, and the cracking of cover brick was serious. Change of coke oven wall after cooling is shown in Figure 4.

One silica brick of some carbonization chamber is selected as the representative sample to test the refractoriness and load softening temperature of the refractory brick at the relevant parts of the oven body. The test results are shown at Table 2.

| Inspection items                  | Value | Reference standard       |
|----------------------------------|-------|--------------------------|
| Refractoriness / °C              | 1730  | GB/T7322-2017            |
| Refractoriness under load / °C   | >1600 | YB/T370-2016             |

The results show that the physical and chemical indexes of refractoriness under load are slightly lower than the design value of 1620 °C, and the silica brick can basically meet the production demand of coke oven.

3. Conclusions
Oven drying is the important and complex technology process before coke oven goes into production. The oven drying quality has a critical influence on coke oven life. Therefore, we must attach great importance to the oven drying work and strictly follow the oven drying plan in the course of coke oven temperature management to guarantee coke oven masonry uniform expansion and tight property from cold state to the thermal process. The ultimate goal is to achieve smooth production of coke oven.

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References
[1] S. Y. Fang, “The selection of standard combustion chamber or standard temperature-taking vertical flue during oven heating-up period”, Coal Chemical Industry, vol142, 2009, pp. 51-52.
[2] J. Zhang, “Application of automatic temperature measuring system in heating up of 7m coke oven battery”, Fuel and Chemical Process, vol. 46, 2015, pp. 26-27.

[3] S. C. Li, W. H. Ma, J. He, “Development and application of new oven drying technology for coke oven”, Coal Chemical Industry, vol.44, 2016, pp. 14-17.

[4] L. L. Peng, “Behaviors of secondary heating-up after complete cooling of coke oven battery”, Fuel and Chemical Process, vol. 50, 2019, pp. 27.

[5] G. Y. Zhang, Modern New Technology and Coking Coke Oven Operation and Intelligent Optimization Control Practical Handbook. Beijing, Metallurgical Industry Press, 2005.

[6] B. X. Xu, Coke Production of New Technology, New Technology and the Quality of Coke Analysis Test Practical Handbook. Changchun, Jilin Audio and Video Press, 2003.

[7] X. D. Wang, Coking equipment, installation and maintenance of new technology and standards Practical Handbook. Haerbin, Heilongjiang Culture Audio and Video Press, 2004.