Journal of University of Science and Technology Beijing
Vol.7(2000), No.1, p.30

Designing for Long Campaign Life Blast Furnace (2)—The Simulation of Temperature Field of Lining and Cooling Apparatus

Qingguo Xue[1), *Weiguo Yang*[2), *Susen Cheng*[1), *Maolin Wu*[1), *Tianjun Yang*[1)

1) Metallurgy School, University of Science and Technology Beijing, Beijing 100083, China
2) The Center of Engineering and Research for Iron and Steel, 100053, China
(Received 1999-1-10)

Abstract: Through the numerical modeling of temperature field for Blast Furnace (BF) lining and stave coolers, it can tell designers how to design a cooler which the hot surface temperature is less than its critical temperature under very high heat flux. Applying low heat resistance lining and staves cooler to BF is good for a layer of slag skull frozen on the hot surface of cooling stave. As long as the slag skull can stand, the furnace wall is stable and the heat loss of furnace does not increase. This is the basic principle for designing long campaignship BF.

Key words: blast furnace; numerical modeling; stave cooler; slag skull; temperature field

---

1 Introduction

Now most Blast Furnace (BF) operators believe that BF campaign life (particularly the below part) is not mainly determined by refractory lining, but by cooling apparatus. The refractory lining can be worn out within few years. But if the cooling apparatus can stand for longer time, the frozen iron and slag skull can renew itself and stand forever. It is sure that the BF operation is under an unstable state, today the skull melts down, but tomorrow they can be frozen again, *i.e.* a new layer of lining is forming. If the hot surface of the cooling apparatus does not exceed the temperature which the material can stand, (*e.g.* cast iron <760 ℃), it can also stand forever. That is the philosophy of the long campaign life BF.

In Japan, USA, Germany *et al.*, much work [1–12] that simulated the temperature field of BF coolers by mathematical model has been done, the BF coolers that were designed to make use of the results of the work greatly improved BF campaign life. In China, only a little work about the calculation for coolers temperature field has been reported till now. Generally speaking, the campaign life of most BF in China is less than 8 years (see **table 1**), but in Japan it can reach to 15 years, even longer.

Table 1 A few BF's campaign life in 1980s in China

Item	Inner volume / m^3	Beginning date	Stopping date	Life
No. 2 BF in Wuhan Iron & Steel Company	1 536	Aug. 1981	Mar. 1985	3 years and 7 months
No. 3 BF in Capital Iron & Steel Company	1 200	Jan. 1984	Dec.1989	5 years and 11 months
No. 10 BF in Anshan Iron & Steel Company	1 627	Dec. 1982	Feb. 1985	3 years and 2 months
		Aug. 1987	July 1989	2 years and 11 months
No. 5 BF in Benxi Iron & Steel Company	2 000	Sept. 1981	Apr. 1987	5 years and 7 months
		June. 1987	May 1990	2 years and 11 months

Finally, all considerations are centered on how to calculate the temperature field of cooling staves, and what are the main influences on the temperature field and what are new improvements on the cooling apparatus design.

In reference [13], the mathematical model was established, the physical model of stave cooler was designed and made discretization, it includes furnace shell, packing, cooling stave body and lining or slag skull. Here, the mathematical model is discretized by the finite element method, the program is designed by C-language, and some results for the cooler temperature field have been done and analyzed.

2 Programming for Temperature Field Calculation of Coolers

The finite element method for calculating three-dimension temperature field and C-language for programming are used. The frame diagram is shown in **figure 1**.

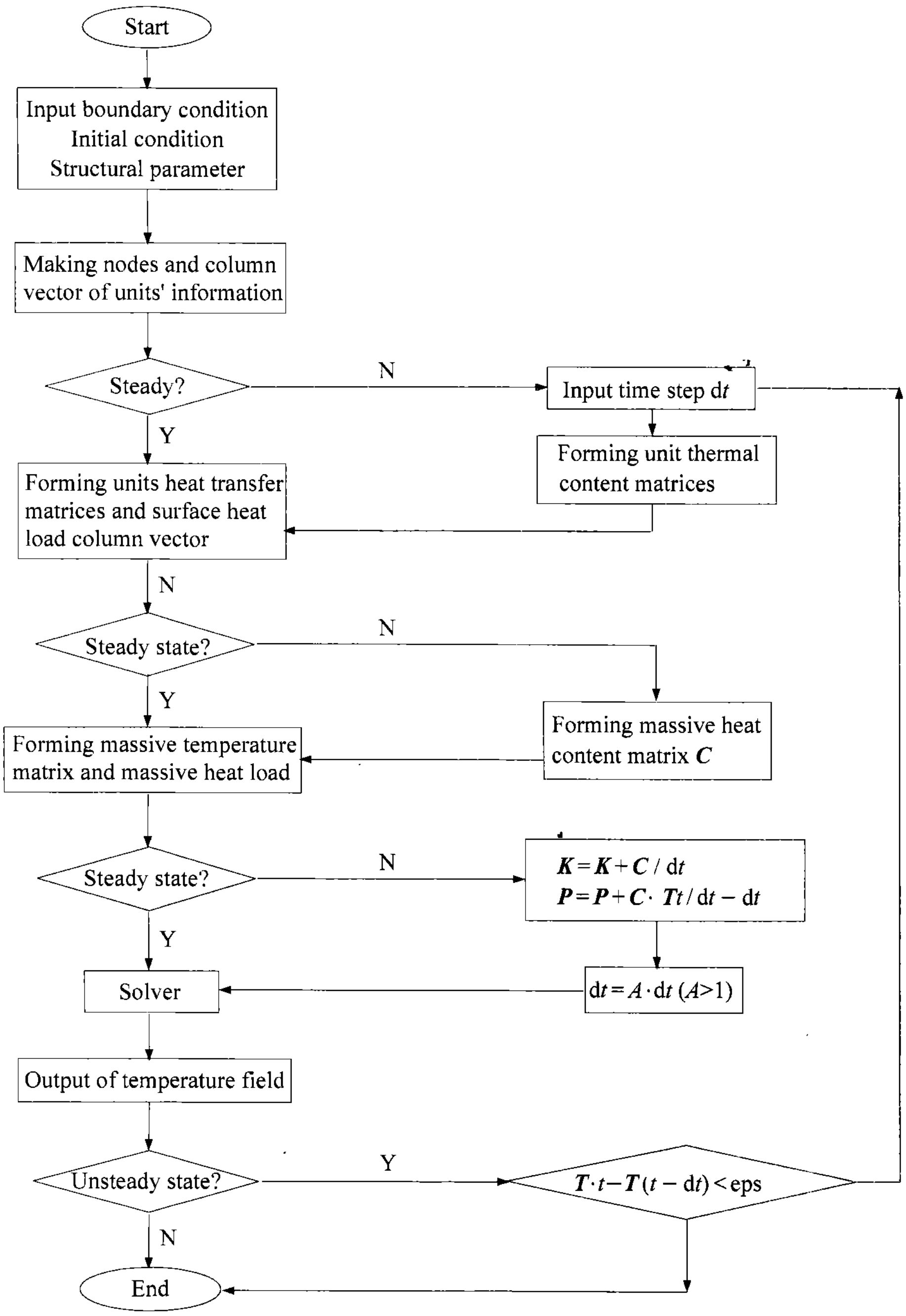

Figure 1 The frame diagram for programming

3 Analysis of Calculating Results

(1) The influence of structural parameters on the temperature field of cooling staves.

Figures 2 and **3** show the temperature profile of the old and new design stave with single layer of cooling pipe, respectively. From the two figures, it can be seen that the hot surface temperature can be lowered down by changing the cooler structural parameters. As the diameter of straight cooling pipes (d) is enlarged from 70 to 80 mm,the distance between the pipes centerline (L) reduced from 254 to 200 mm, and the distance between the centerline of straight cooling pipe and the hot surface of stave (l) decreased from 160 to 140 mm, then the hot surface temperature for the cast iron rib can be lowered less than 760 ℃ and the inlaid brick temperature less than 870 ℃ on extremely high heat flux. These temperatures are below their critical temperature.

In **figure 4**, the calculation parameters is: the diameter of front straight cooling pipes, $d_f = 70$ mm; the diameter of back S-shaped cooling pipe, $d_b = 50$ mm; $L = 254$ mm; $l = 160$ mm, respectively. Figure 4 shows that the temperature profile of the cooling stave with double layer of cooling pipes is less than that in figure 2. Com-

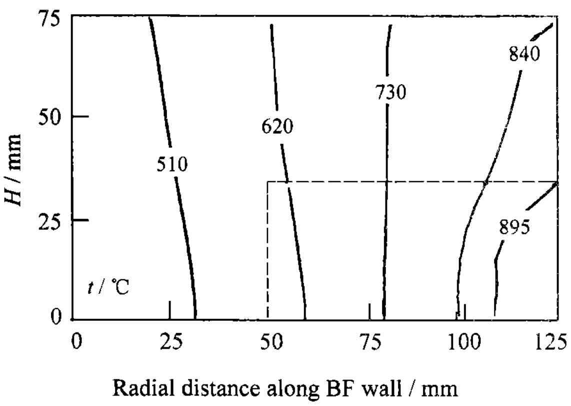

Figure 2 Temperature profile of the old design stave with single layer of cooling pipe, d=70 mm, L=254 mm, l=160 mm.

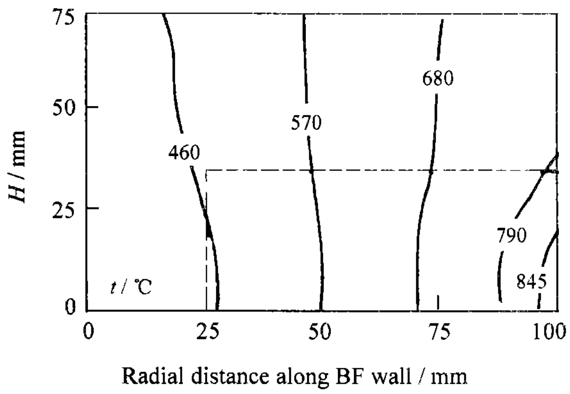

Figure 3 Temperature profile of the new design stave with single layer of cooling pipe, d=80 mm, L=200 mm, l=140 mm.

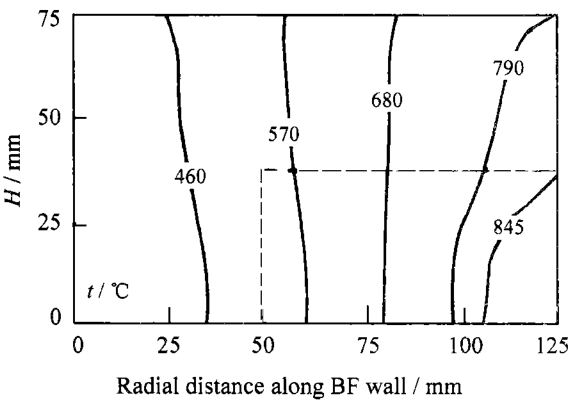

Figure 4 Temperature profile of stave with double layer of cooling pipes, d_f = 70 mm, d_b = 50 mm, L = 254 mm, l = 160 mm

paring the temperature profile for stave in figure 3 with that in figure 4, it can be seen that the stave in figure 3 can take the place of the stave in figure 4. From the point view of heat transfer, manufacturing, weight and thickness of the staves, the stave with single layer of cooling pipe has better property than one with double layer of cooling pipes. For the stave with the single layer of cooling pipes, the technological requirements is lower, the weight is lighter, the thickness is thinner and the production cost is cheaper.

The computing results also show that the cooling capacity of the new stave cooler in figure 3 is better than the old one in figure 2, the maximum temperature on hot surface (the hot surface of stave with only 10mm slag skull) is reduced from 573 ℃ to about 503 ℃, but the heat flux that the new stave can stand increases from 49 to 58 kW/m^2. It is proven that the change of the structural parameters for cooling stave can improve its temperature profile, our task is to select the suitable designing parameters to maintain the hot surface temperature less than its critical temperature.

4 The influence of Unstable Operation on the Cooling Stave

Figure 5 shows the influence of the thickness of slag skull on the maximum temperature of the stave rib (t_{max}, ℃), and on the heat flux (q, W/m^2) through the stave cooler along the radial direction of BF. When the thickness of slag skull changes from 100 to 10 mm, t_{max} changes from 572 to 765 ℃, and q from 67 to 126 kW/m^2. Only when a thin layer of slag skull exists, can the cooling stave not be burnout.

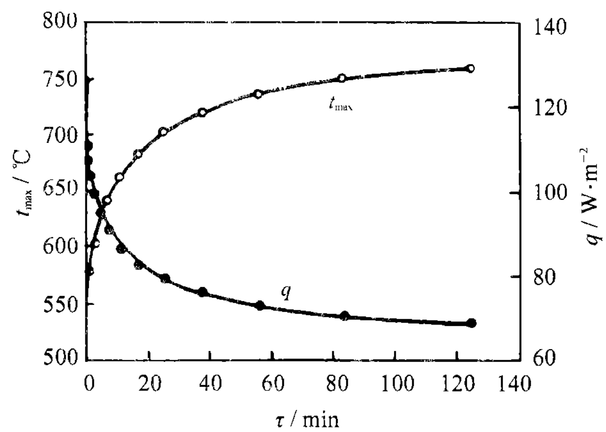

Figure 5 Influence of thickness of slag skull from 10 to 0 mm on t_{max} and q

Figure 6 shows the influence of the temperature of hot gas stream from 1200 to 1400 ℃ on t_{max} and q. When the temperature of gas stream changes from 1200 to 1400 ℃, t_{max} changes from 864 to 930 ℃, it will result in the stave burning down.

Figure 7 shows the influence of the periphery hot gas stream on t_{max} and q. When the coefficient of heat convection between gas stream and the hot surface of stave changes from 232 to 375 W/m^2.℃, t_{max} changes from 864 to 913 ℃, the temperature has gone beyond the critical temperature 760 ℃.

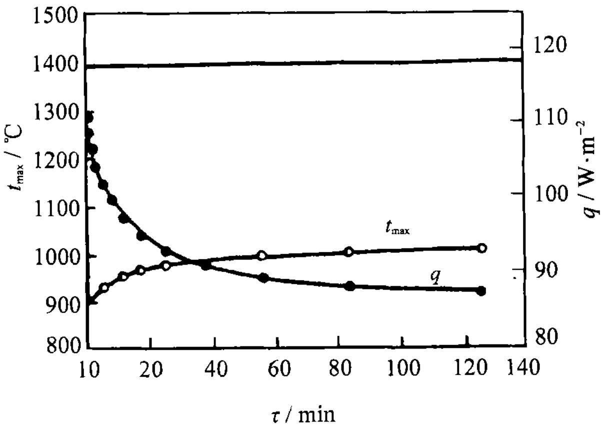

Figure 6 Influence of temperature of hot gas stream from 1200 to 1400 ℃ on t_{max} and q

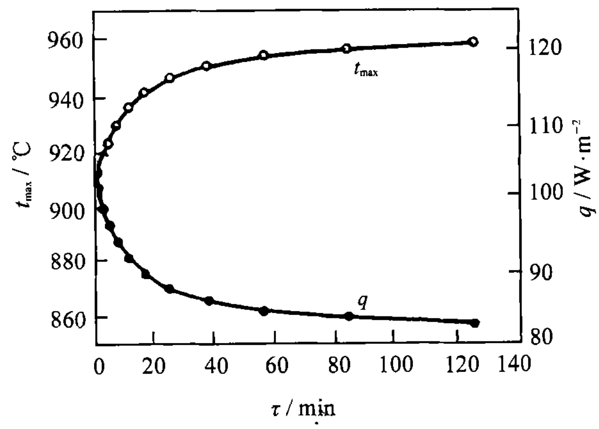

Figure 7 Influence of development of the periphery hot gas stream on t_{max} and q

In a word, an unstable operation can result in the increasing of hot surface temperature, temperature gradient and thermal stress inside the stave cooler; then the coolers will be burnout for overheating.

5 Conclusions

(1) The modeling of heat transfer of BF lining and cooling system shows that the temperature field of cooling stave can be changed with adjusting the structural parameters of the cooling stave.

(2) It is possible that the unstable blast furnace operation leads to the cooling stave burning down, it should be avoided.

Reference

[1] Peter Heinrich, Hartmut Hille, Hans-Jurgen Bachofen, *et al.*: *Iron and Steel Engineer*, 69 (1992). No. 2. p. 49.
[2] Robert G. Helenbrook, Wolfgang Kowalski, Klaus-Henning Grosspietsch, *et al.*: *Iron and Steel Engineer*, 73 (1996), No. 8. p. 30.
[3] G. M. Smithyman: *I&SM*, 25 (1998), No. 3. p. 87.
[4] Teruaki Morimoto, Masaaki Yoshimoto, Toshiyuki Matsumoto, *et al.*: [In:] *Ironmaking Conference Proceedings* (41), Iron and Steel Society-AIME, PITTSBURGH, 1982. p. 132.
[5] Yoshiyuki Murai, Takao Yamamoto, Kazuteru Aoyama, *et al.*: [In:] *Ironmaking Conference Proceedings* (44), Iron and Steel Society, DETROIT, 1985. p. 475.
[6] R. Hebel, R. Steiger, R. Jeschar, *et al.*: [In:] *Ironmaking Conference Proceedings* (54), Iron and Steel Society, NASHVILLE, 1995. p. 101.
[7] Robert W. Steiger, Robert E.Braun, David P. Grundyisch: [In:] *Ironmaking Conference Proceedings* (44), Iron and Steel Society, DETROIT, 1985. p. 485.
[8] J. Van Laar, G. J Tijhuis, M. Spreij, *et al.*: *I & SM*, 21 (1994), No. 12. p. 25.
[9] G. X. WANG, A. B. YU, P. ZULLI: *ISIJ International*, 37 (1997), No. 5. p. 441.
[10] R. Vogel, J. Van Laar, R. Henstra: [In:] *Ironmaking Conference Proceedings* (42), Iron and Steel Society-AIME, DALLAS, 1993. p. 483.
[11] Gerard J. Tijhuis: *Iron and Steel Engineer*, 73 (1996), No. 8. p. 43.
[12] Jeong Whan Han, Jeong Ho Lee, Young Keun Suh, *et al.*: [In:] *Ironmaking Conference Proceedings* (55), Iron and Steel Society, PITTSBURGH, 1996. p. 223.
[13] Susen Cheng, Qingguo Xue, Weiguo Yang, *et al.*: *J. of Univ. of Sci. and Tech. Beijing*, 6 (1999). p. 178.