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EQUIPMENT AND POWER SYSTEMS

Temperature Regulation during Coke-Battery Drying by Coke-Oven Gas

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Abstract—The reconstruction of coke battery 1 at Isfahan steelworks is considered. The construction of a PVR-51 system at coke battery 1 (useful oven capacity 27.3 m^3, with lower heating-gas supply, is described. The automatic temperature-monitoring system for coke-battery heating by coke-oven gas is discussed. The gas motion in battery heating with internal furnaces is considered. A system for temperature regulation and maintenance in the upper heating channels is proposed.

Keywords: coke battery, refractory lining, upper heating channels, coke-oven gas, reflector

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Specialists from Giprokoks have taken on the reconstruction of coke battery 1 at Isfahan steelworks, with lower supply of coke-oven gas in the PVR-51 system (with paired heating channels and recirculation of the combustion products. The battery consists of 58 coke ovens (two sets of 29), with the following characteristics (when cold):

Length, mm:	
total	15040
useful	14200
Height, mm:	
total	5000
useful	4700
Width, mm:	
machine side	390
coke side	430
mean	410
Taper, mm	40
Useful capacity, m^3	27.3
Axial distance between furnaces, mm	1260
Number of heating channels in wall	30
Distance between heating-channel axes, mm	480
Heating level, mm	900
Number of charge holes	3
Number of gas-exhaust apertures	2

The battery was reconstructed by Tata Refractories Ltd (TRL, India), which supplied the refractories and assembled the lining. The mechanical equipment was installed and adjusted by the staff at Isfahan steelworks. Specialists from Tyazhpromeksport inspected the work and undertook drying and heating of the coke battery.

Coke-oven gas was used to dry and heat the coke battery, with automatic monitoring of all the temperature parameters at all levels and over the whole furnace array and real-time display of the data on a monitor. The temperature was recorded over the whole lining at 2-min intervals. Besides display of current temperature readings on the monitor, the system permits graphical tracking of the temperature rise, for timely reaction to any temperature changes in drying and heating.

For organizational and financial reasons, the work was repeatedly postponed. The heating of coke battery 1 began on December 1, 2013. The coke plant at Isfahan steelworks is in a sharply continental climate zone, in an urban location at a geodesic marker of +1757.500 m above sea level. In winter, the plant experiences low atmospheric pressure and sharp temperature fluctuations between night and day. In drying and heating of coke battery 1, the range was from –7°C at night to +12°C by day. Therefore, maintenance of constant temperature in the upper part of the heating wall was a problem in the early stages. The work relied on the recommendations for drying and heating of coke batteries by coke-oven gas in [1]. Accordingly, the temperature was maintained in the upper heating channels, and hydraulic drying and heating of the coke battery by gaseous fuel was employed [2].

In heating, the gas moves under the action of the smokestack draft. Therefore, that factor determines the volume of gas passing through the coke-oven channels in this period. On heating, the pressure in the flues on the battery side is low. It increases slightly at the end of heating, to 7–8 mm H_2O (70–80 Pa).

To determine the hydraulic drag when gas moves through the furnace channel on heating, the influence of the hydrostatic pressure in the ascending and descending fluxes must be eliminated. We know that gas motion is facilitated by the hydrostatic pressure in the ascending flux and hindered by that in the descending flux, with increase in the pressure required to overcome the drag.

According to the gas circulation on coke-oven heating, the ascending flux is formed from the furnace to the top of the heating channels, and the descending flux from the top of the heating channels to the gas's departure from the hearth channel. Practical data on furnace heating by coke-oven gas indicate that the system's drag is largely unchanged throughout heating and is ~4.2 mm H_2O (42 Pa), on average [1].

In heating, we observe stable volume of the coke-oven gas. That permits the following conclusions.

(1) Gas motion is basically laminar (when $Re < 2300$) [2, 3]. The drag varies mainly as a function of the actual speed (volume) and the internal-friction coefficients. Otherwise, in the given conditions, there would be enormous pressure difference at the beginning and end of heating.

(2) At the end of heating, the total draft increases. However, only a small part of the pressure overcomes the drag in the furnace system, in the given conditions, and this component is the same at the beginning and end of heating.

(3) With more or less constant pressure overcoming the drag and the need to increase fuel consumption, the air excess is reduced. That indicates automatic establishment of the volume of coke-oven gas and conditions in which the processes is basically controlled by increasing or reducing the fuel consumption.

Of course, the distribution of the total hydraulic drag between the individual components of the system remains to be determined.

Table 1 presents experimental data for the heating of the internal furnaces of coke ovens in the PVR-51 system by coke-oven gas.

As we see in Table 1, most of the drag is between the furnace and the upper heating channels; 30% is concentrated at the ignition holes.

We must assume that the drag of individual components, like the total drag, is stable at individual heating stages. Therefore, on heating by coke-oven gas, the pressure in the upper heating channels is converted to stable positive pressure only when the gas temperature in the furnace reaches 300°C. In that case, the pressure in the upper heating channels is

$$\xi = 0. + 5.97 - 2.6 = +3.37 \text{ mm } H_2O \text{ (33.7, Pa)}.$$

Here 5.97 is the hydrostatic pressure from the furnace chamber to the upper heating channels.

Table 1. Hydraulic drag in heating (normal operation)

Component of furnace system	Drag, mm H_2O (Pa)
1. Furnace	1.0 (10)
2. Temporary chamber packing	1.3 (13)
3. Ignition apertures	1.3 (13)
4. Recording apertures	0
5. Heating channels	0
6. Transverse ducts	0
7. Regenerator packing	0.5 (5)
8. Gas–air valve	0.1 (1)
9. Total drag	4.2 (42)

It also follows from Table 1 that the low drag in the gas–air channels prevents their use to regulate the distribution of coke-oven gas over the length of the battery. Only the ignition holes may be used for that purpose.

Uniform heating over the furnace height is very important, but is not sufficient for safe and rapid heating of the coke ovens. Another condition ensuring that the coke ovens' lining remains in good condition is uniform heating of the battery over the length of the heating walls.

The demand for heat is different in the extreme and central parts of the battery. Besides the heat consumed in heating the lining at a single central heating channel, additional heat is required for heating of the lining at the top of the ovens' end walls and also as compensation for the radiant and convective heat losses to the surroundings.

The heat losses by the battery form a considerable proportion of the total heat consumption. However, whereas the heat losses at the top of the coke ovens are distributed over the lining of all the heating channels in the wall, the heat losses of the lateral surfaces (~35% of the total losses) are consumed by the upper furnace lining. As a result, the heat consumption at each of the two extreme heating channels of a single heating wall is a little more than ten times that at one central heating channel.

Another factor responsible for the difference between the central and upper heating channels is the inleakage of cold external air, which may be considerable at untreated seams. Besides direct cooking of the lining, the air dilutes and cools the coke-oven gas.

The inleakage of air is expressed as considerable drop in temperature of the gases in the upper heating channels at different heights and also in sharp temperature drop of the exhaust gas over a short section of path between the bottom of the regenerators at the charge-hole lattice and the gas's departure from the hearth channel.

Only slight discrepancy is possible at the lining junction between the upper and adjacent heating channels. Considerable temperature difference between the cen-

Table 2. Heating graph for coke battery 1 (17–300°C)

Day	Temperature, °C, at the top of the heating channels		
	reference channels 7 and 24;	vertical channel 1	vertical channel 30
0	17.0	15.0	15.0
1	30.0	29.5	30.0
2	46.0	30.4	32.3
3	55.5	42.9	46.0
4	58.0	46.5	48.0
5	57.5	46.0	49.5
6	63.6	49.6	53.0
7	70.75	61.3	58.0
8	83.0	65.35	63.0
9	92.3	75.1	73.0
10	97.3	84.1	83.0
11	103.7	87.1	87.9
12	107.3	98.3	100.6
13	111.6	108.2	110.7
14	115.8	112.8	112.5
15	119.6	115.35	115.7
16	124.5	119.5	120.4
17	128.0	126.6	129.7
18	132.3	132.5	136.6
19	136.7	136.0	141.2
20	142.2	138.9	142.5
21	147.9	145.95	145.0
22	155.75	151.2	153.8
23	160.8	155.3	159.8
24	165.7	160.0	162.75
25	170.0	164.5	168.3
26	181.2	172.2	180.5
27	187.8	179.6	186.1
28	190.5	181.4	185.0
29	193.9	186.9	192.0
30	197.9	189.0	196.0
31	205.7	196.7	205.1
32	209.1	202.8	207.6
33	212.2	205.6	212.4
34	214.2	206.0	215.5
35	217.7	209.4	218.5
36	222.3	211.1	222.1
37	226.5	220.0	225.3
38	228.8	225.0	228.0
39	232.1	225.8	232.1
40	235.3	231.0	233.2
41	239.8	237.3	240.7
42	243.1	240.7	243.5
43	246.0	239.5	249.5
44	249.0	246.0	251.0
45	252.9	253.8	254.2
46	262.5	263.4	274.9
47	273.5	276.0	285.5
48	284.5	285.2	298.0
49	293.6	290.0	299.8
50	306.7	304.2	309.5

tral and upper heating channels will inevitably lead to discrepancies at the vertical seams and may also lead to crack formation. At the same time, the top of the coke ovens is of critical importance in battery operation. Its temperature is relatively low on account of heat loss to the surroundings and the inleakage of air; there may be considerable buildup; the temperature variation at coke discharge is more pronounced than in other parts of the oven; and it experiences mechanical loads from the retaining walls and stripping rods on the machine side. Therefore, it is of enormous importance to maintain the top of the coke ovens intact from the very beginning of operation.

Considerable heat may be supplied to the extreme heating channels by direct combustion of additional fuel or by the supply of a greater proportion of the incoming coke-oven gas to those channels. The first approach is not selected because it complicates the heating system. The second requires corresponding increase in hydraulic drag in the central heating channels.

In current coke-oven designs, a separate ignition channel with interconnected ignition apertures is provided for the extreme heating channels. That permits the supply of the required coke-oven gas to those heating channels.

The uniformity of lining heating over the length of the heating wall is continuously monitored in heating, by measuring the temperature in all the heating channels over the two walls.

In the initial stage of heating, the temperature difference between the upper heating channels and the reference battery heating channels (measured by Chromel–Copel thermocouples of length 2.5 m) is considerably greater than the calculated value (Fig. 1, Table 2).

Therefore, the installation of a reflector consisting of plates of normal Sh-6 refractory at the inner chambers, ahead of the gas burner, was proposed (on the eleventh day of heating) so as to create drag in the gas flow to the center of the chamber and return some of the heat to the top of the wall. The temperature readings were shown on the monitor at 2-min intervals. Over time, the temperature in the upper heating channels at first increased with respect to the reference values but then the temperature in the reference channels fell by an amount equal to the temperature rise in the upper channels, while the total temperature rise over the whole furnace array fell (Table 2, Fig. 1).

In pursuit of a more uniform heating-gas distribution over the whole chamber length, the normal refractory reflectors were replaced by vertical reflectors made of 27076 regenerator packing (grade III-35), with holes permitting the passage of some of the coke-oven gas into the chamber, while the remainder is returned to the façade (Fig. 2).

This substitution permitted temperature maintenance in the upper heating channels at the reference

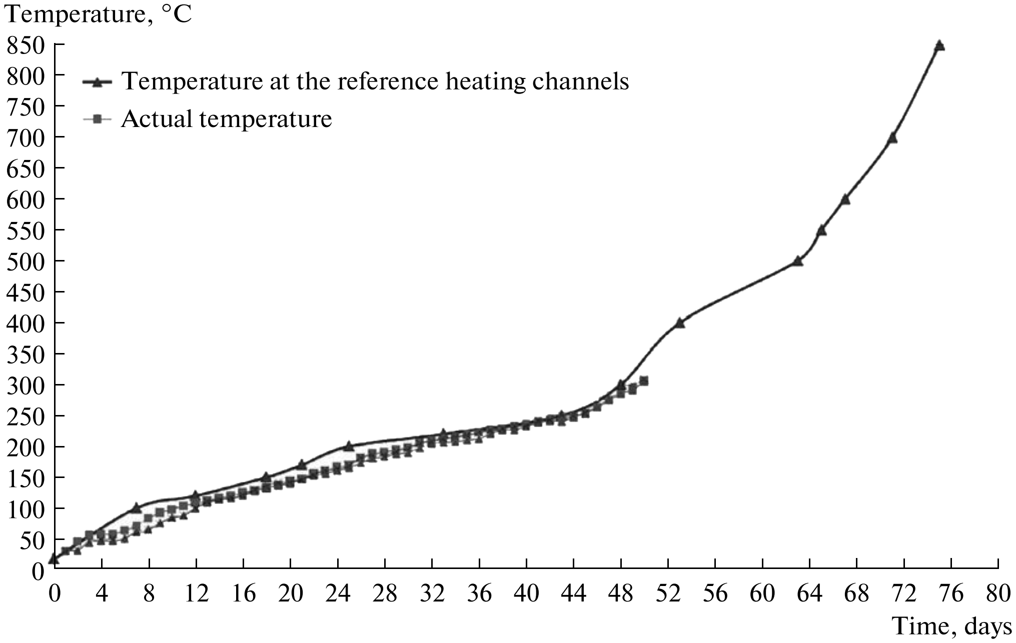

Fig. 1. Heating of coke battery 1: temperature at reference heating channels 7 and 24 and actual temperature in channels 1 and 30.

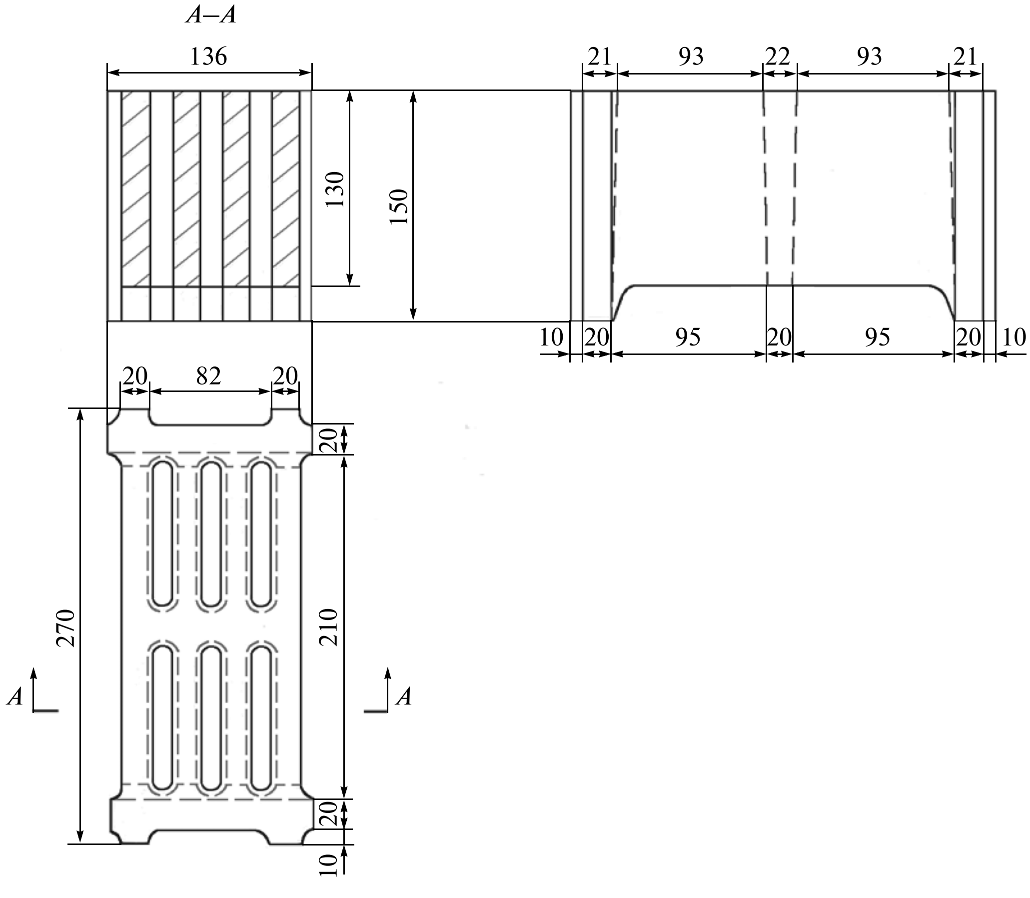

Fig. 2. Giprokoks 27076 regenerator packing.

Table 3. Hydraulic drag in heating (with reflectors)

Component of furnace system	Drag, mm H_2O (Pa)
1. Furnace	1.0 (10)
2. ÍTemporary chamber packing	1.5 (15)
3. Ignition apertures	1.3 (13)
4. Recording apertures	0
5. Heating channelsû	0
6. Transverse ducts	0
7. Regenerator packing	0.5 (5)
8. Gas–air valve	0.1 (1)
9. Total drag	4.5 (45)

The figures for items 4–6 and 8 are taken from Table 1.

levels. In addition, by changing the reflector position, more precise temperature regulation in the reference channels 7 and 24 was also possible. With increase in temperature in the upper heating channels relative to the reference values, the reflectors were tilted to a horizontal position. That also permitted regulation of the air flow rate to the furnace.

By adjusting the distance between the reflector and the burner—that is, by moving the reflector over the length of the furnace—the flame length and its distribution over the chamber's internal volume could be corrected, as well as the temperature in the extreme heating channels. When the temperature at the top of the heating channels reached 300°C, the reflectors were removed, since the daily temperature rise subsequently (up to 500°C) was 20°C.

The resistance of the heating system when using 27076 refractory (regenerator packing) was investigated on the basis of the findings in [2]. Measurements were made in five furnaces on the machine and coke sides using a TNZh pressure-difference meter. Table 3 presents the results.

Thus, the pressure in the upper heating channels in this case is

$$\xi = 0 + 6.18 - 2.8 = +3.38 \text{ mm } H_2O \text{ (33.8 Pa)}.$$

Here 6.18 is the hydrostatic pressure from the furnace chamber to the upper heating channels.

CONCLUSIONS

(1) Analysis of the data in Tables 1 and 3 indicates that the use of 27076 refractory (regenerator packing) as a reflector in the early stages of coke-oven drying and heating (temperature rise 20–300°C) only slightly changes the drag of the heating system, with practically no influence on the hydraulic and temperature conditions of drying and heating.

(2) The use of regenerator packing improves the flame distribution within the furnace at low heating-gas flow rates in the initial stages of coke-battery drying and heating. With increase in heating-gas flow rate, the flame length may be reduced, with more uniform distribution over the whole furnace.

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