Examination and enhancement of checker works by means of choosing rational cell dimensions

S.A. Karpenko

Chief Executive Officer of Concern SouzEnergo

L.P. Gres

Doctor of Engineering
Professor of Department of Ecology
Combustion Engineering and Safety
National Metallurgical Academy of Ukraine

A.Ye. Bystrov

Research Scientist of Department of Ecology
Combustion Engineering and Safety
National Metallurgical Academy of Ukraine

L.A. Vorobyova

PhD in Technical Science
Associate Professor Department of Ecology
Combustion Engineering and Safety
National Metallurgical Academy of Ukraine

M. Yu. Ivanov

Research Scientist
National Metallurgical Academy of Ukraine

Abstract
The choice of rational cell dimensions of checker block is made to reduce material consumption and dimensions of Cowper blast heaters. An impact of cell dimensions variation (diameter of checker flue) and center between them upon the change of specific heating surface of checker works and also open area, specific brick volume and equivalent half thickness of wall between cells, minimal thickness of the latter is studied. Dependences between specific brick volume, equivalent and minimal wall thickness and the checker flue diameter in case of the changes of the latter from 0.1 up to 41 mm are established. It is shown that the installment of horizontal passages in checker blocks facilitate the change of flue diameters $d \le 15$ mm
Key words: COWPER BLAST HEATERS, CHECKER, HEAT EXCHANGE, CELL DIMENSIONS

Operating Cowper blast heaters (CBH) are required to enhance technical characteristics of resistance, material consumption, environmental compatibility and thermal performance efficiency.[1-3]. To reduce material consumption (dimensions) of CBH checker works and thus of linings and housings, heat loss through brickwork, thermal pollutions, the cell dimensions are being reduced over the last years that increases specific heating surface [4-6].

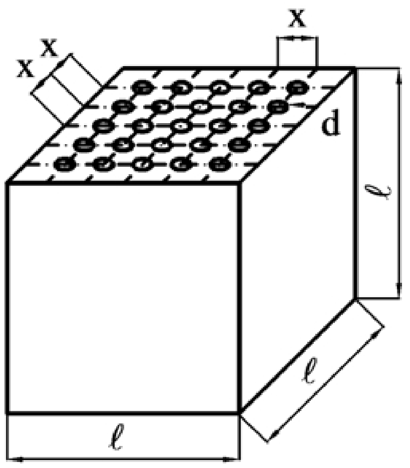

Figure1. Regular hexahedron as an element of checker work

Formulas to calculate specific heating surfaces of checkers are shown below:

For regular hexahedron

In a study [7], authors demonstrate that if ℓ is the base of regular hexahedron, center *x* between gaps of checker cells is changed by k times and diameter of cells d is changed by p times, where $p \neq k$

$$\ell_2 = k \cdot \ell; \; x_2 = k \cdot x; \; d_2 = p \cdot d = \varepsilon \cdot k \cdot d, \quad (1)$$

where

$$\varepsilon = \frac{p}{k}, \text{ and } p = \varepsilon \cdot k, \quad (2)$$

then specific open area will be changed ε^2 times

If $p > k$ and $\varepsilon > 1$, specific open area S_2 increases by ε^2 times in comparison with the initial specific open area S

$$S_2 = S \cdot \varepsilon^2. \quad (3)$$

In a study [7], it is illustrated that the modified specific heating surface F_2 and the initial specific area F are bound by equation

$$F_2 = F \cdot \frac{\varepsilon}{k}. \quad (4)$$

If $d_1 \cdot \varepsilon > x_1$, then checker flues are overlapped and the heating surface is reduced.

Under quite big value of ε area filled with checker work is disappeared, it is destructed into separate fibers

$$S \to 1, \; F \to 0. \quad (5)$$

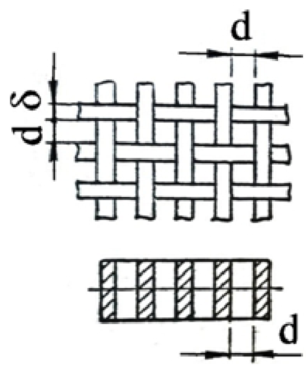

Figure 2. Cowper Stove checker with square cells

For Cowper stove checker with square cells

Specific heating surface F of Cowper stove checker with square cells (Fig. 2) and dimension d [8] and actual brick thickness δ is calculated as follows:

$$F = \frac{4 \cdot d}{(d+\delta)^2} \qquad (6)$$

Calculation data shown below in a table 1 is accomplished according to equation (6).

Table 1. Dependence of the maximal specific heating surface of Cowper stove checker work with square cells on its diameter

	Dimensions of the checker cell diameter, d, mm									
	40	30	25	20	15	10	5	1	0,5	0,1
F, m^2/m^3	100	133.3	160	200	266.7	400	800	4000	8000	40000

For hexagon checker with round holes

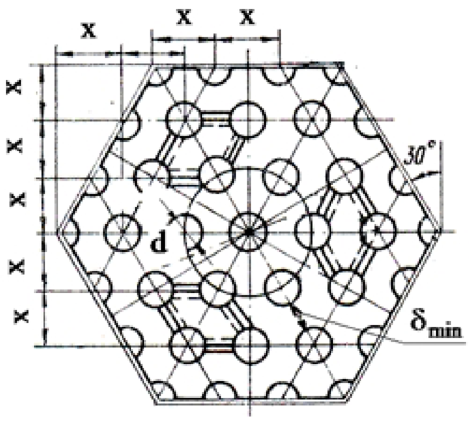

Figure 3. Hexagon checker with round holes

Based on the dependences for parameters of hexagon checker (Fig. 3) with round holes [9], there were data close to specific ones according to dependences (1)-(14) out of [7]:

- specific heating surface, $\frac{m^2}{m^3}$

$$F = \frac{4 \cdot S}{d}; \qquad (7)$$

- specific open area of the checker work, $\frac{m^2}{m^2}$

$$S = 1 - V_K = \frac{\pi \cdot d^2}{4 \cdot x^2}, \qquad (8)$$

where Vк - specific brick volume, $\frac{m^3}{m^3}$;

- space between holes

$$x = d + \delta_{min}; \qquad (9)$$

- equivalent wall half thickness in a block [8], m:

$$r_{eq} = (1 - S) \cdot \frac{d}{4 \cdot S}. \qquad (10)$$

Minimal wall thickness between cells, m

$$\delta_{min} = d \cdot \left(\frac{\sqrt{A}}{S} - 1 \right) \qquad (11)$$

where $A = 0.905$ for hexagon checker works with round holes

Dependence of checker block parameters and checker flue diameter are shown in a Table 2

Table 2. Parameters of checker blocks with round holes

	Cell dimensions d, mm								
	41	30	25	20	15	12.5	10	1	0.1
Vк, m^3/m^3	0.6969	0.6867	0.6932	0.6932	0.6932	0.6932	0.6932	0.6932	0.6932
$r_э$, mm	23.57	16.44	14.12	11.3	8.47	7.06	5.649	0.5649	0.05649
δ_{min}, mm	25	17.5	15	12	9	7.5	6	0.6	0.06

Thereby with duration of periods

$$\tau >> \frac{r_{eq}^2}{2 \cdot a}$$

(a-heat diffusivity, m^2/s), i.e. time of brick thermal inertia, increase of brick thickness leads to reduction of accumulating capacity, damping of brick tempe- rature fluctuation for the period and gain of heat exchange capacity.

Increase of heating area with brick volume $V_b = const$ results in damping of temperature fluctuation in a checker and rise of heat recovery factor r_o and thus heating temperature of blast:

$$r_o = \frac{t_{av.bl}}{t_{av.g}},$$

$t_{av.bl}$ - average temperature of heating of blast for the period °C; $t_{av.g}$ - average gas temperature for the heating period °C. And vice versa, increase of brick volume with the heating area F= const results in r_o =const and impacts the temperature fluctuation only [10].

Dependence of maximal specific heating surface of Cowper stove checker work on flue dimension d where $\delta_{cm} \to 0$ is made accordingly (6)

Actual heating surfaces tend to the stated maximal specific heating surfaces.

For regular hexahedron

It was previously demonstrated for the equation

$$F_1 = \frac{n \cdot \pi \cdot d}{k \cdot \ell^2} = F \cdot \frac{1}{k}$$

that F_1 is a monotonic function k without extremum. The case is:

$$\frac{\partial F_1}{\partial k} = \frac{-F}{k^2}; \; -F\frac{1}{k^2} = 0; \; \frac{1}{k^2} = 0 \text{ where } k \to \infty.$$

$$k = \frac{d_1}{d} \to \infty \text{ where } d \to 0 \text{ will be } F_{1min}$$

$$\frac{\partial^2 F_1}{\partial k^2} = 2 \cdot F \cdot \frac{1}{k^3} > 0, \text{ i.e. where } \frac{\partial F_1}{\partial k} = \frac{-F}{k^2}$$

$F_1 \to 0$ where $k \to \infty$.

Our concern is an assumption

$$F_{max}. \text{ B } F_1 = \frac{F}{k},$$

F_1 will have the largest value when

$$k = \frac{d_1}{d} \to 0, \text{i.e. where } d_1 \to 0$$

$$S = \frac{n \cdot \pi \cdot d^2}{4 \cdot \ell^2} = S_2 \cdot \frac{1}{\varepsilon^2}; \qquad \varepsilon = \frac{p}{k}$$

$$F = \frac{n \cdot \pi \cdot d}{\ell^2} = F_2 \cdot \frac{k}{\varepsilon}.$$

Where $n = \frac{1}{x^2}$ - quantity of holes for 1 m² of checker cross section (squared with the side 1 m); x is the distance between holes in a checker.

$$S = \frac{n \cdot \pi \cdot d^2}{4} = \frac{1}{x^2} \cdot \frac{\pi \cdot d^2}{4}; \qquad \frac{dS}{dx} = \frac{-\pi \cdot d^2}{2 \cdot x^3};$$

$$-\frac{\pi \cdot d^2}{2 \cdot x^3} = 0 \text{ where } x \to \infty;$$

$$\frac{d^2 S}{dx^2} = \frac{3 \cdot \pi \cdot d^2}{2 \cdot x^4} > 0,$$

i.e. we have min S where $x \to \infty$

The hexahedron heating area in 1 m³ checker work, $\frac{m^2}{m^3}$

$$F = \frac{\pi \cdot d}{x^2}, \; \frac{x}{d} = \varepsilon \text{ or } F = \frac{1}{\left(\frac{x}{d}\right)^2} \cdot \frac{\pi \cdot d}{d^2} = \frac{1}{\left(\frac{x}{d}\right)^2} \cdot \frac{\pi}{d}.$$

Where $d = const$ and x=var.

$$\frac{dF}{dx} = \frac{-2 \cdot \pi \cdot d}{x^3}; \; \frac{-2 \cdot \pi \cdot d}{x^3} = 0 \text{ where } x \to \infty$$

$$\frac{d^2 F}{[d(x)]^2} = \frac{6 \cdot \pi \cdot d}{x^4} > 0. \text{ As } \frac{d^2 F}{[d(x)]^2} > 0,$$

then $x \to \infty$, we have $F \to 0$, i.e. F_{min}.

When d=var and x=const where $d \to 0$ and $F \to 0$.

For Cowper Stove checker work

$$F = \frac{4 \cdot d}{(d+\delta)^2} = \frac{4}{d + 2 \cdot \delta + \frac{\delta^2}{d}}.$$

F increases when the wall thickness δ and flue diameter are reduced. If $\delta \to 0$, then

$$F \to \frac{4}{d}$$

For hexagon checker with round holes

Let us differentiate the equation

$$F = \frac{\ell^2 \cdot \pi \cdot d}{x^2 \cdot \ell^2} = \frac{\pi \cdot d}{x^2}$$

with respect to d:

$$\frac{dF}{d(\mathrm{d})} = \frac{1}{\mathrm{x}^2} \cdot \pi \cdot 1 > 0$$

For $F = \frac{1}{x^2} \cdot \pi \cdot d$.

When $d \to 0$ and $F \to 0$, the whole open area is filled with checker work.

When $x \to \infty$ and $F \to 0$, it results from the equation

$$S = \frac{\ell^2 \cdot \pi \cdot d^2}{x^2 \cdot 4 \cdot \ell^2} = \frac{F \cdot d}{4}$$

when $d \to 0$, $S \to 0$; and when $x \to \infty$, $S \to 0$.

Conclusion

The impact of checker flue diameter and center between cells on the values of specific brick volume, equivalent wall thickness between checker flues and minimal wall thickness between cells was explored.

The dependences of specific brick volume, equivalent and minimal wall thickness on the diameter of checker flue in case of changes of the latter from 0.1 up to 41 mm were shown.

It is verified that within limits when the wall thickness between checker flues goes to zero we will get the minimal specific open area of flue and its heating surface

Horizontal passages in the checker blocks provide an opportunity to shift to diameter of checker flues d ≤15mm and that significantly reduces the dimensions of Cowper stove heaters, material consumption of firebricks and metal cover and heat losses.

References

1. Kalugin Ya.P. (2001) Perspektivnyy vysokotemperaturnyy vozdukhonagrevatel’ dlya domennykh pechey [Advanced high-temperature air heater for blast furnaces]. *Chernaya metallurgiya* [Ferrous metallurgy]. No 4, p.p. 28-30.
2. Krone T., Pateyski B. (1994) Sovremennaya konstruktsiya bloka vozdukhonagrevateley [Modern design of the unit of air heaters]. *Chernaya metallurgiya Rossii i stran SNG v XXI veke* [Proceedings of the International Conference “Ferrous Metallurgy in Russia and the CIS Countries in the 21st Century”]. Moscow: Metallurgiya. Vol. 2, p.p. 113-124.
3. Kalinin E.K., Dreytser G.A., Yarkho S.A. (1990) *Intensifikatsiya teploobmena v kanalakh* [Intensification of heat transfer in channels]. Moscow: Mashinostroenie,. 208 p.
4. Solomentsev S.L., Korshikov V.D., Basukinskiy S.M. (1988) Otsenka temperaturnykh usloviy raboty nasadki domennykh vozdukhonagrevateley [Estimation of the temperature conditions of operation of the nozzle of blast air heaters]. *Izvestiya vuzov. ChM.* [News of Higher Educational Institutions. Ferrous Metallurgy]. No7, p.p. 126-128.
5. Khauzen X. (1981) *Teploperedacha pri protivotoke, pryamotoke i perekrestnom toke* [Heat transfer in countercurrent, direct current and cross current]. Moscow: Energoizdat, 384 p.
6. Karp I.N. (1994) Analiz protsessa teploperedachi v regenerativnykh teploobmenni-kakh s sharovoy nasadkoy [Analysis of heat transfer in regenerative heat exchangers with ball nozzles]. *Doklady Akademii nauk Ukrainy* [Reports of the Academy of Sciences of Ukraine]. Kyiv: Teplofizika. No 6, p.p. 77-80.
7. Gres L.P., Litovchenko Yu.K., Bystrov A.E., Fleyshman Yu.M., Vorob’eva L.A., Ivanov M.Yu. (2015) Issledovanie vliyaniya izmeneniya razmerov yacheek nasadok regene-ratorov na sovershenstvovanie ikh parametrov [Investigation of the effect of changing the dimensions of cells of regenerator nozzles on the improvement of their parameters]. *Metallur-gicheskaya i gornorudnaya promyshlennost’* [Metallurgical and Mining Industry]. No 5, p.p. 102-104.
8. S.I. Averin, E.M. Gol’dfarb, A.F. Kravtsov (1969) *Raschet nagrevatel’nykh pechey* [Calculation of heating furnaces]. Kyiv, Tekhnika. 540 p.
9. F.R. Shklyar, S.P. Kashtanova, V.M.Malkin (1982) *Domennye vozdukhonagrevateli* [Blast-furnace air heaters]. Moscow, Metallurgiya. 176 p.
10. Gol’farb E.M. (1967) *Teplotekhnika metallurgicheskikh protsessov* [Heat engineering of metallurgical processes]. Moscow: Metallurgiya,. 440 p.