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Determination of coefficients of heat output of hot-blast stove checkers with horizontal passages

L.P. Gres

Doctor of Engineering Science, Professor
Department of Ecology, Heat-Transfer and Labour Protection
National Metallurgical Academy of Ukraine

Yu.K. Litovchenko

Ph.D. in Engineering Science
Department of Ecology, Heat-Transfer and Labour Protection
National Metallurgical Academy of Ukraine

A.E. Bystrov

Research scientist
Department of Ecology, Heat-Transfer and Labour Protection
National Metallurgical Academy of Ukraine

Yu.M. Fleyshman

Ph.D. in Engineering Science, Senior research scientist
Department of Ecology, Heat-Transfer and Labour Protection
National Metallurgical Academy of Ukraine

M.Yu. Ivanov

Research scientist
National Metallurgical Academy of Ukraine

Abstract
The benefits and results of physical modeling of new design of block checkers with horizontal passages are shown in the paper. They are developed by fellows of department of Ecology, Heat-Transfer and Labour Protection of National Metallurgical Academy of Ukraine in cooperation with Zaporozhogneupor PJSC. The main objective of experimental study was to determine the convection heat transfer coefficient and gasdynamic resistance of checker, as its main thermal characteristics. Dependences for determination of coefficients of convection heat transfer were defined from the obtained ratios of similarity criteria Nu = f (Re) for the rough continuous channel, vertical channels with two and three horizontal passages, and also the checker block with horizontal passages.
KEY WORDS: HOT-BLAST STOVE, CHECKER, HEAT EXCHANGE, HEAT TRANSFER COEFFICIENT

Block checkers with horizontal passages of the hot-blast stove possess the following advantages over those, which are produced in accordance with GOST 20901-75 and without horizontal passages [1, 2]:

- the increased service life due to existence of horizontal channels on the upper and lower surfaces of blocks and possibility of gas-flow from the neighboring channels in case of clogging the vertical channel at some height;
- higher coefficient of heat transfer due to existence of zones of the increased turbulization (vortex formation) in the area of vertical channels crossing with horizontal ones.

The coefficient of heat transfer of the checker block with vertical channels and horizontal passages was defined by machine (Fig. 1). The models of checker channels consisting of three steel pipes (diameter ø is 21 mm and length is 1300 mm): single rough continuous 1, with two 2 or 3 horizontal passages are experimentally investigated. The models imitating horizontal passages 4 in pipes 2, 3 were placed in vertical channels with an identical step on height equal to 60 mm. Pipes 1, 2, 3 were arranged in the tank 5 heated by P-shaped electric heaters 6 with power of 5 kW. Air was regulated by valves 7 and directed to the investigated channels 1, 2, 3 through pipes 8. The air consumption through the pipes was measured by means of flowmeters 9. Temperature of air heating in the explored channels was measured by spirit thermometers 10.

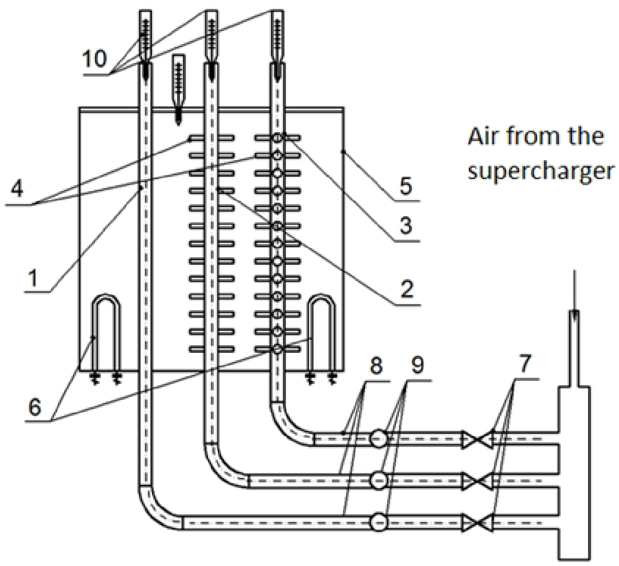

Figure 1. The scheme of machine for determination of gasdynamic and thermal characteristics of checker with horizontal passages

1,2,3 – model of checker channels consisting of three pipes: single rough continuous with two and three horizontal passages respectively; 4 – the models imitating horizontal passages in pipes with a step on height of 60 mm; 5 – tank; 6 – electric heaters; 7 – adjusting valves; 8 – the measuring airfeeding pipes; 9 – air flowmeters; 10 – thermometers for measurement of air temperature at the exit from the explored canals

Water in the tank 5 was heated to boiling state by means of autotransformer and held equal to temperature of boiling 100 ºC, at the same time the air consumption in the studied channels 1, 2, 3 was identical. In laminar region at equal of air consumption, the indicators of thermometers 10 were equal. In turbulent area in a single rough continuous pipe 1, the minimum temperature took place, and in a pipe with three horizontal branches 3 – maximum one. The experiment was conducted before a steady thermal state, which was defined by stabilization of indicators of thermometers 10.

Results of processing of experimental data in the form of dimensionless dependences for a single rough continuous pipe, pipes with two and three horizontal passages and the checker block are presented in Table 1 and in Figures 2, 3, 4.

Table 1. Dependences for determination of coefficients of heat transfer convection

Channels name	Convection heat transfer coefficients, W/(m²·K)
Checker made of six-sided blocks with round holes [3]	$\alpha_к = 0.0218 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,8}$ *at* $\mathrm{Re} > 4260$; $\alpha_к = 2.95 \cdot 10^{-4} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,31}$ *at* $1700 \le \mathrm{Re} < 4260$; $\alpha_к = 1.83 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,14}$ *at* $\mathrm{Re} < 1700$. λ – checker heat transfer coefficient, W/(m · K); d – hydraulic diameter of the channel, m
Rough continuous steel channel (single pipe), $a_{к1}$	$\alpha_{к1} = 0.008255 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,875}$; $Nu = 0,0147 \cdot \mathrm{Re}^{0,82}$ *at* $\mathrm{Re} > 3500$; $\alpha_{к1} = 4.467 \cdot 10^{-12} \cdot (\lambda/d) \cdot \mathrm{Re}^{3,5}$; $Nu = 2.26 \cdot 10^{-13} \cdot \mathrm{Re}^{3,87}$ *at* $2500 \le \mathrm{Re} < 3500$; $\alpha_{к1} = 0.708 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 1.185 \cdot \mathrm{Re}^{0,1615}$ *at* $\mathrm{Re} < 2500$.
The vertical channel with 2 horizontal passages, $a_{к2}$	$\alpha_{к2} = 0.0012217 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,866}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} > 3200$; $\alpha_{к2} = 1.936 \cdot 10^{-6} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,933}$; $Nu = 2.03 \cdot 10^{-8} \cdot \mathrm{Re}^{2,521}$ *at* $2000 \le \mathrm{Re} < 3200$; $\alpha_{к2} = 0.776 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} < 2000$.
The vertical channel with 3 horizontal passages, $a_{к3}$	$\alpha_{к3} = 0.00933 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,9}$; $Nu = 0.00809 \cdot \mathrm{Re}^{0,923}$ *at* $\mathrm{Re} > 3200$; $\alpha_{к3} = 1.936 \cdot 10^{-6} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,933}$; $Nu = 2.03 \cdot 10^{-8} \cdot \mathrm{Re}^{2,521}$ *at* $2000 \le \mathrm{Re} < 3200$; $\alpha_{к3} = 0.776 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} < 2000$.
Checker with horizontal passages, $a_{к\ hp}$	$\alpha_{к\ hp} = 1.412 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,184}$ *at* $\mathrm{Re} < 1820$; $\alpha_{к\ hp} = 1.089 \cdot 10^{-7} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,31}$ *at* $1820 \le \mathrm{Re} < 3020$; $\alpha_{к\ hp} = 0.068 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,675}$ *at* $\mathrm{Re} \ge 3020$.

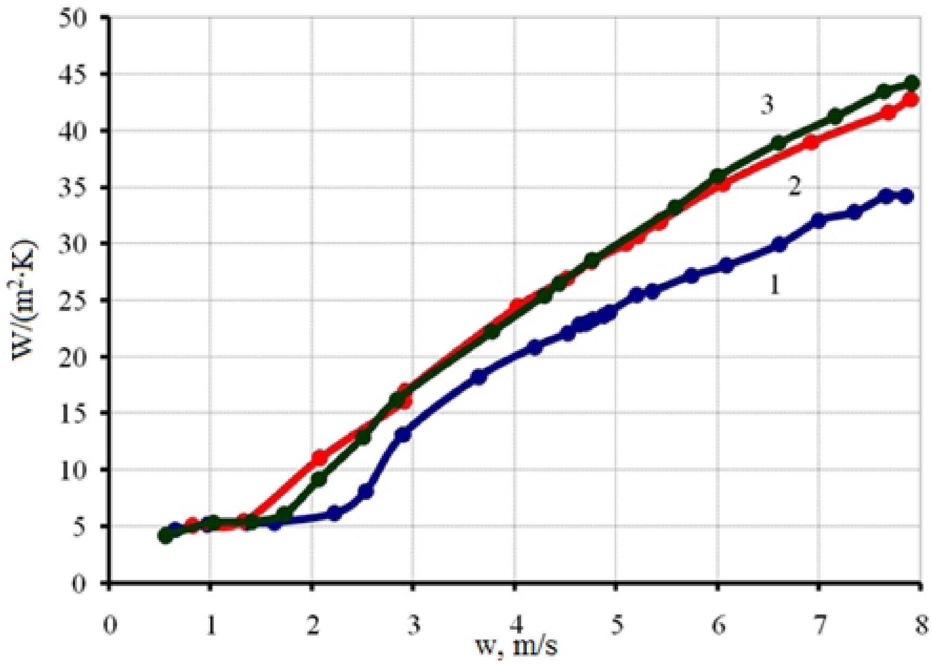

Figure 2. Dependence of convection heat transfer coefficient on air speed for rough continuous channel 1, for channels with two 2 and 3 horizontal passages 3

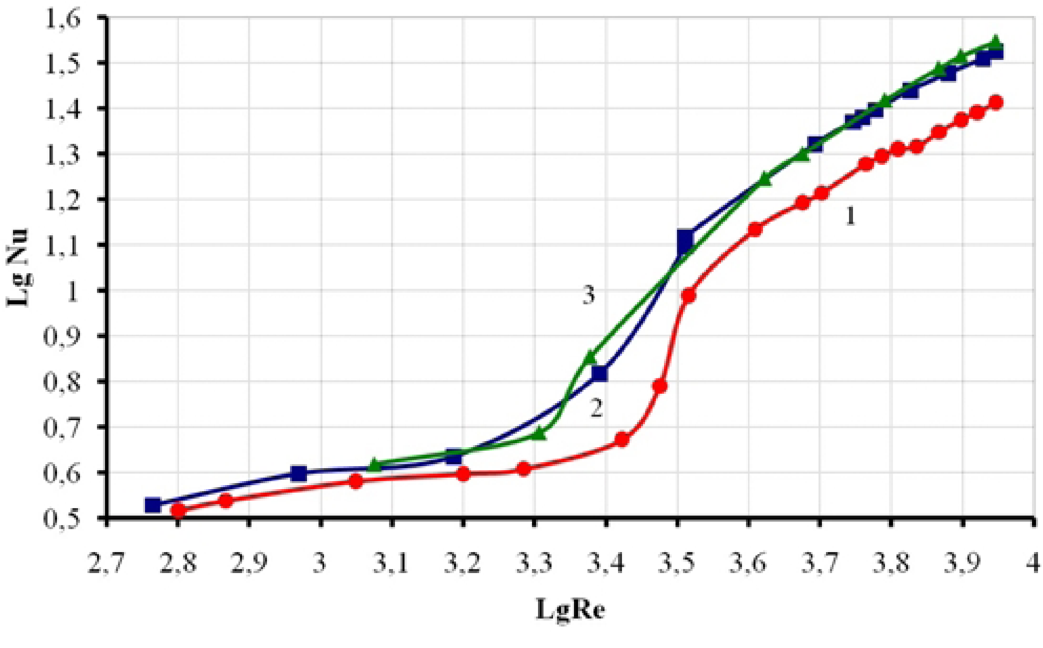

Figure 3. Dependence of Nusselt criterion on Reynolds criterion in logarithmic coordinates for rough continuous channel 1, for channels with two 2 and 3 horizontal passages 3

The convection heat transfer coefficients for the checker block with horizontal passages (Fig. 4) are determined by expression:

$$\alpha_{\kappa\ hp} = \frac{\alpha_{\kappa 1} \cdot n_1 + \alpha_{\kappa 2} \cdot n_2 + \alpha_{\kappa 3} \cdot n_3}{n_1 + n_2 + n_3}$$

where $a_{\kappa i}$ were taken for identical numbers Re_i, and $a_{\kappa 1}$, n_1 are convection heat transfer coefficient and number of rough continuous channels; $a_{\kappa 2}$, n_2- convection heat transfer coefficient and number channels with 2 horizotal passages; $a_{\kappa 3}$, n_3 - convection heat transfer coefficient and number channels with 3 horizotal passages.

At that n1=n3=1, n2=10.

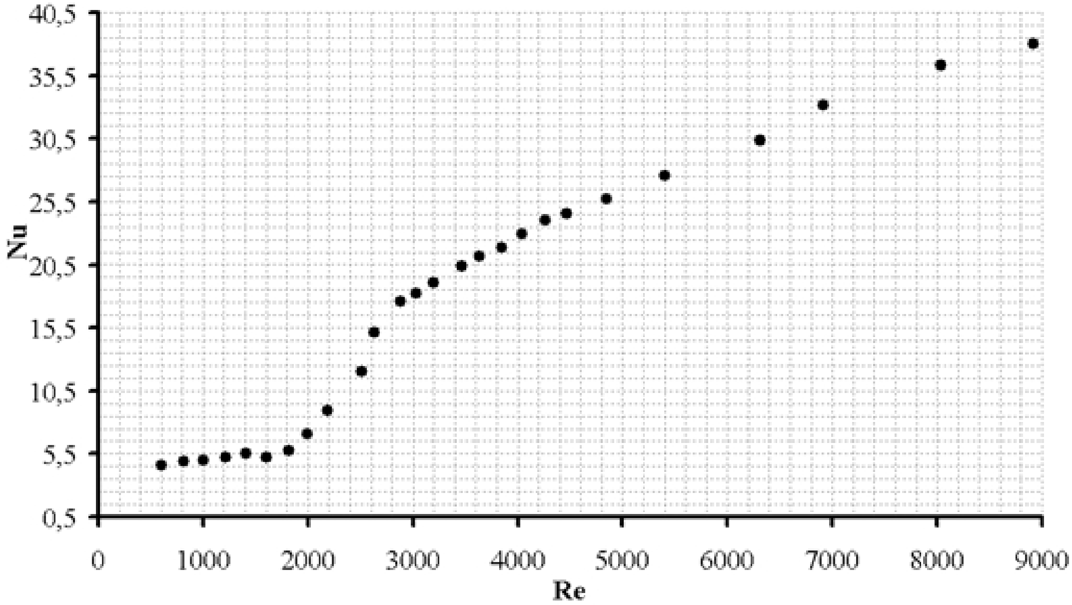

Figure 4. Dependence of Nusselt criterion on Reynolds criterion for the checker block with horizontal passages

Conclusions

Gasdynamic and thermal characteristics of checker with horizontal passages on experimental installation are investigated. Dependences of Nusselt criterion on Reynolds criterion for the continuous rough channel and channels with two and three horizontal passages in laminar, transitional and turbulent areas of a current are obtained. On the basis of the obtained experimental dependences, we performed calculation of coefficients of heat transfer and criteria of Nu for a regenerative block checker of the air heater with horizontal passages which can be used in design calculations.

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