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HEAT EXCHANGE IN THE GRID-IRON BRICK REFRIGERATOR

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Abstract.

In article defining brick granules thermal activity is considered by the method based on the heat conductivity non-stationary inverse problem solution. Influence of heat conductivity on brick granules cooling-off period at free convection and forced air cooling is shown. The dependence equation of brick granules thermal activity on temperature and porosity in the temperature ranges from 0 to 1200 °C is received. Calculated values of thermal conductivity for various porosity granules are given. At increase in granule porosity from 0 to 50% there is an almost twicefold decrease in thermal conductivity and heat exchange intensity. Prime influence of heat conductivity on heat exchange effectiveness in the grid-iron refrigerator and, therefore, on technological and operational indicators of its work is confirmed by the production tests. Increase in clinker response time in the refrigerator promotes decrease in heat losses and increase in the refrigerator thermal efficiency.

Keywords: Heat conductivity, granules porosity, cooling, brick refrigerator.

Introduction

Overall performance of the brick grid-iron refrigerator depends on heat exchange intensity between a brick granules layer and air-cooling and can be quantitatively expressed by the thermal efficiency (E). In turn, operation of the refrigerator affects the operation of the rotating furnace: clinker roasting mode, provision of agglomeration zone, fuel combustion process, torch form and structure, and clinker quality [1-7]. Transfer of heat in the grid-iron refrigerator when cooling clinker granules is carried out by means of two types of heat exchange: convective – from a granule surface to the cooling air, and heat conductivity – from the granule interior to the surface. From operation practice of the refrigerator it is known that large clinker granules, with a diameter over 50 … 60 mm, can be cooled insufficiently in the refrigerator. It leads to the fact that in the central part of a granule the temperature on escaping the refrigerator, after subdivision, can make about 500 … 600ºC. Elevated temperature leads to padding heat wastes with clinker and excess air, to decrease in efficiency of the refrigerator and, therefore, increase in fuel consumption. Elevated temperature of the granule interior of the large size demonstrates that transfer of heat is insufficiently intensively carried out by heat conductivity. In this regard it is necessary to consider this type of heat exchange in more detail.

Technique of granules thermal conductivity definition

For defining dependence of brick granules thermal activity on temperature and porosity, the method based on the solution of non-stationary inverse problem of heat conductivity was used. The principle of a method consists in the experimental defining temperature change in two granule points while cooling and model operation of a granule temperature profile with use of these data [8-10].

On the basis of the obtained temperature change data the calculation of a heat flux which equals to change of the granule heat content for a particular time term is performed [11]. Then the granules thermal conductivity of various size and porosity pays off.

The experimental technique was as follows. The brick granule was located in a muffle furnace and heated up to a temperature of 1000 °C in the center, then it was cooled with free convection (F.C.) or forcibly cooling air with a speed of about 2 m/s, the close to traveling speed of air in the grid-iron refrigerator. Temperature when cooling a granule was fixed by means of thermocouples every 30 seconds in two points: in the center (t_1) and apart half of the radius (t_2), and surface temperature of a granule (t_3) – by means of a radiation pyrometer (Fig. 1).

Calculation of thermal conductivity [lambda] when cooling a granule was defined by a formula [12]:

$$[\text{lambda}] = \frac{\Delta Q \cdot r}{2 \cdot S \cdot [\text{delta}]t \cdot [\text{delta}][\text{tau}]},$$

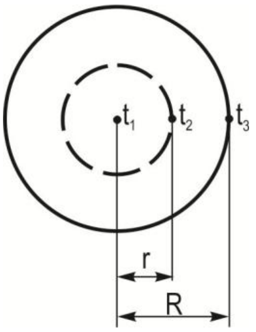

Fig. 1. Defining temperature in various granule points

where [delta]Q – change of granule interior heat content, J, in time [delta] [tau], sec, at temperature change on [delta]t, ºC; S – granule interior surface area, sq.m which radius of r equals to distance from the granule center to half of granule radius, m.

For each temperature measurement calculation [lambda] was carried out on a heat flux of Q which passes through the sphere r radius limiting the granule interior, surface area of the sphere and to temperature change at a size [delta] t for a particular time term.

Granule interior heat content is defined by a formula [13]:

$$Q = \frac{4}{3}[\text{pi}]r^3 \cdot [\text{rho}] \cdot c \cdot [\text{delta}]t,$$

where [rho] – apparent density, kg/m^3; C – thermal capacity, J / (kg · ºC) is defined depending on temperature, [14].

Thus, the technique of defining heat conductivity is based on heat content change of the brick granule interior in various instants calculated by results of the experimental experience of defining temperature in various granule sections.

Defining Brick Granules Thermal Activity

For carrying out researches on defining brick granules thermal activity the clinker of various sizes and porosity which is selected on escaping of the recuperation refrigerator was used. The size of clinker granules changed from 17 to 70 mm. For calculation of granules porosity its density was defined by the weight relation to volume. The volume of granules was calculated on the basis of effective diameter, as well as was defined by amount of the water which is forced out from a vessel at immersion of a granule.

For a granule of each size 4 experiments of temperature change in the center and apart half of radius were made on 3, when cooling. The characteristic of the most representative clinker granules used for defining thermal conductivity is presented in Table 1.

Table 1: Characteristics of brick granules.

#	Diameter of granules, mm	Weight of granules, g	Density of granules, g/cm^3	Porosity of granules, %
1	17	5,75	1,97	40
2	35	51,5	2,25	31
3	41	80,3	2,21	32
4	43	93	2,13	33

5	60	271	2,40	26
6	70	502	2,68	17

From the Table it is visible that at increase in the size of a granule from 17 to 70 mm density increases from 2,1 to 2,68 g/cm^3 and, respectively, its porosity decreasesfrom 40 to 17%.

Let us consider intensity of various size separate granules cooling from temperature of 1000 to 100ºC in the center under conditions of free convection (F.C.) and the forced airing with a speed of about 2 m/s (Fig. 2).

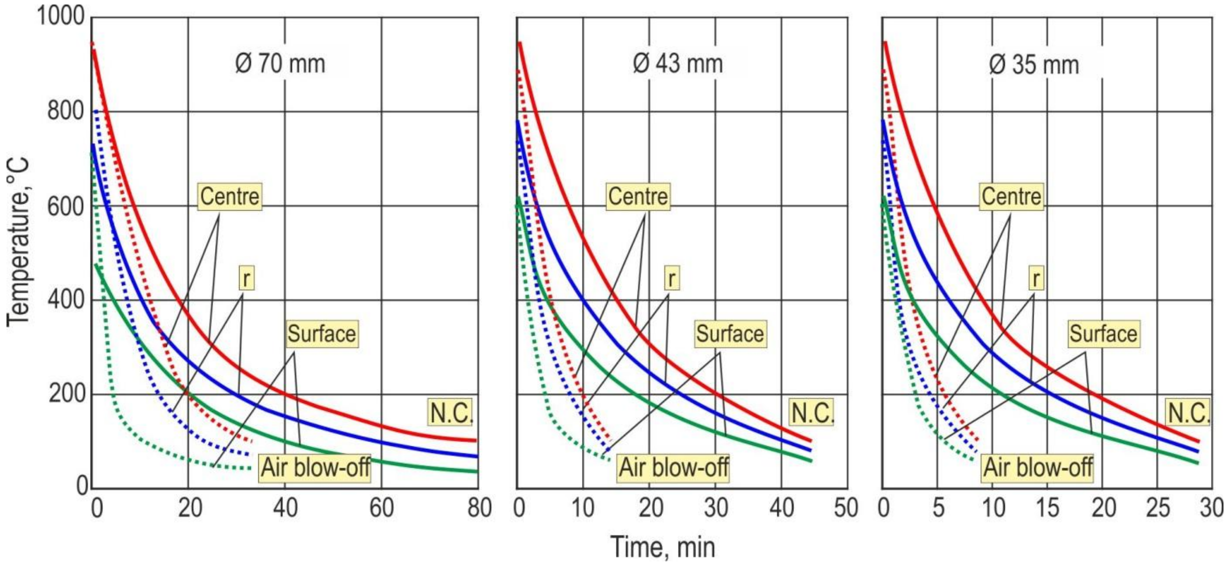

Fig. 2. Dependence of various size granules temperature on their size and refrigerating conditions

The large brick granule with a diameter of 70 mm cools down to 100ºC in the center in 80 minutes at free convection. At the same time temperature in a point apart makes half of granule radius 70ºC, and surface temperature – 40ºC. On cooling of a granule surface up to the temperature 100ºC time twice smaller is needed, i.e. 40 minutes. At the same time temperature equals 195ºC in the granule center.

For a brick granule of the average size – with a diameter of 43 mm, the first cooling time of the granule center from temperature 100ºC at free convection makes 44 minutes. After 44 minutes of cooling the temperature apart half of radius and a surface are equal 80 and 60ºC respectively. Decrease in surface temperature of this granule of 1000 to 100ºC happens in 34 minutes. At the same time the central part of a granule has temperature of 165ºC.

The brick granule with a diameter of 35 mm is cooled to 100ºC in the center, at free convection, in 29 minutes. In 29 minutes temperature in a point apart makes half of granule radius - 75ºC, surfaces – 55ºC. After 22 minutes of cooling temperature on a granule surface reaches 100ºC, and in the center – 170ºC.

Table 2: Temperature change in various points of brick granules depending on their size, porosity and refrigerating conditions.

Diameter, mm	Porosity, %	Natural convection				Fan blowing			
		Time of cooling from 1000 ° C, mines	temperature, °C			Time of cooling from 1000 ° C, mines	Temperature, °C		
			surface	r	center		surface	r	center
17	40	9 10 20 30	63 55 30 28	–	100 95 73 70	–	–	–	–
35	31	5 10 20 29	304 195 90 55	430 280 145 75	570 360 185 100	5 8 10	110 60 33	165 85 53	220 110 75
41	32	5 10 15 20 30 40	356 213 153 117 72 52	–	690 331 236 179 123 100	5 10 13 15	125 51 38 33	–	383 139 100 84
43	33	10 20 30 40 44	295 180 120 78 60	400 245 160 103 80	530 308 202 128 100	10 14 20	88 60 43	150 80 55	200 100 71
60	26	10 20 30 50 70	287 201 142 79 56	424 270 190 115 84	490 300 213 134 100	10 20 23 30	82 41 37 33	218 92 79 64	306 120 100 83
70	17	20 40 60 80	223 120 74 52	280 159 106 82	348 190 127 100	20 30 40	56 37 31	133 80 62	185 100 79

Under conditions of the forced cooling the granule with a diameter of 70 mm cools down of 1000 to 100ºC in the center in 33 minutes, with a diameter of 43 mm – in 14 minutes, with a diameter of 35 mm – in 8,5 minutes. The cooling-off period of a surface of these granules to 100ºC makes 10, 8 and 5,5 minutes. At the same time temperature of the center of each granule makes 435, 235 and 155ºS. Graphs of surface temperature of granules from a cooling-off period, at the forced cooling, are characterized by jump of temperature values from 1000 to 160 … 170ºC in a short time frame, about 5 minutes. It demonstrates that heat convection between air-cooling and a granule of clinker proceeds rather intensively. Further cooling of a granule surface slows down in spite of the fact that intensity of an obduv air remains to a constant. Delay of decrease in temperature is bound, first of all, to the fact that on process of cooling of clinker heat conductivity affects. Thus, the limiting stage of cooling of clinker granules in the grid-iron refrigerator is heat conductivity. And more it will affect large granules with a diameter over 50 mm.

temperature change in various points of brick granules in particular instants depending on their amount, porosity and the mode of cooling are presented in Table 2.

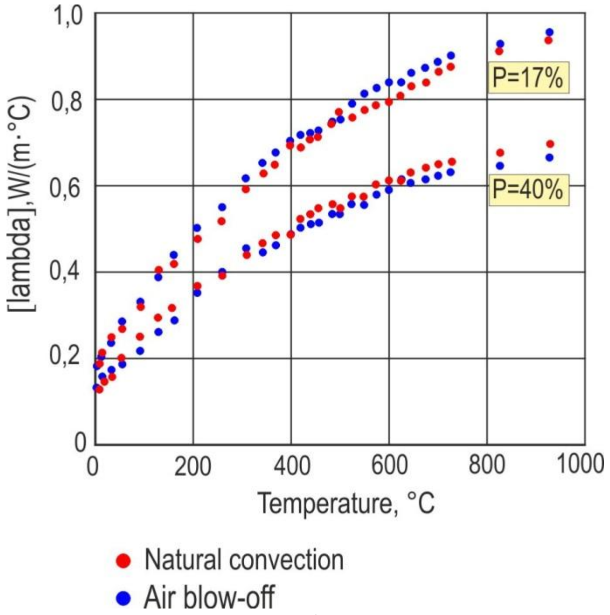

Fig. 3. Dependence of thermal conductivity [lambda] of various porosity granules on temperature and refrigerating conditions

On the basis of the experimental data obtained as a result of carrying out an experiment on temperature change in various points of brick granules at their cooling calculations for defining brick granules thermal activity depending on temperature are carried out. Change of granules thermal conductivity maximal (P=40%) and minimum (P=17%) is presented to porosity from temperature in the Figure 3.

Values of thermal conductivity coincide for various refrigerating conditions within an experimental error that testifies to reliability of the experimental data and compliance of a technique of calculations to the proceeding process.

For defining thermal conductivity at zero porosity of a brick granule we will use the dependence equation of heat conductivity on porosity [15]:

$$\text{lambda}\ _P \cdot 100$$

,

$$\text{lambda}\ _0 =$$

where [lambda]0 – a granule thermal conductivity porosity of 0%, W / (m · ºC); [lambda]P – a granule thermal conductivity porosity of P, W / (m · ºC); P – porosity, %.

On experimentally received values of thermal conductivity for granules porosity of 17 and 40% the thermal conductivity for clinker of zero porosity paid off. The values of heat conductivity for a granule of zero porosity received when calculating with use of values of thermal conductivity of a granule porosity of 17% coincide with the values received when using values [lambda] of a granule by porosity of 40%.

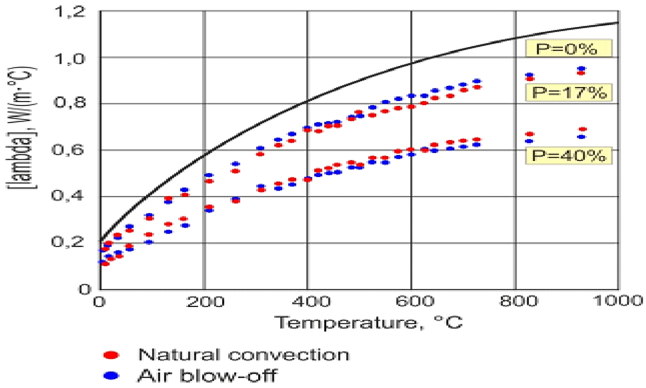

Fig. 4. Dependence of thermal conductivity [lambda] of various porosity granules on temperature and refrigerating conditions

Dependence of change of thermal conductivity [lambda] on temperature calculated according to the experimental data for granules by porosity of 17 and 40%, as well as average values of coefficient [lambda] for granules porosity of 0% is presented in the Figure 4.

The received dependence of [lambda] 0 on temperature it is possible to present the equations in the form:

$$\text{lambda}\ _0(t) = a \cdot t^4 + b \cdot t^3 + c \cdot t^2 + d \cdot t + e,$$

where coefficients: a=-1,04 · 10-13; b=7,14 · 10-10; c =-1,80·10-6; d=2,13·10-3; e=0,21.

Taking into account that clinker granules, as a rule, always have particular porosity, it needs to be considered when calculating thermal conductivity. Therefore the generalized dependence equation of thermal conductivity on temperature and porosity can be presented as follows:

$$[\text{lambda}](t,P) = (a \cdot t^4 + b \cdot t^3 + c \cdot t^2 + d \cdot t + e) \cdot \frac{100-P}{100}.$$

\The values of thermal conductivity depending on temperature for various porosity granules received on such experimental equation can be presented in the form of graphic dependence (Fig. 5). The numerical values of thermal conductivity [lambda] calculated on the equation for various porosity granules are reduced in Table 3.

Table 3: Calculated values of granules thermal conductivity for various porosity, W / (m · °C)

Temperature, ºC	Porosity, %					
	0	10	20	30	40	50
100	0,41	0,37	0,33	0,29	0,24	0,20
200	0,57	0,51	0,46	0,40	0,34	0,29
300	0,71	0,64	0,57	0,50	0,42	0,35
400	0,82	0,74	0,66	0,57	0,49	0,41
500	0,91	0,82	0,73	0,64	0,55	0,45
600	0,98	0,88	0,79	0,69	0,59	0,49
700	1,04	0,94	0,83	0,73	0,62	0,52
800	1,09	0,98	0,87	0,76	0,65	0,54
900	1,12	1,01	0,90	0,79	0,67	0,56
1000	1,15	1,04	0,92	0,81	0,69	0,58
1100	1,17	1,06	0,94	0,82	0,70	0,59
1200	1,19	1,07	0,95	0,84	0,72	0,60

From the Figure 5 and Table 3 it is visible that with decrease in temperature the thermal conductivity decreases, and, therefore, heat exchange intensity in the low-temperature part of the grid-iron refrigerator, i.e. on cold decreases.

Dependence of thermal conductivity on porosity at a constant temperature represents the linear relation (Fig. 6). At increase in porosity up to 50% the thermal conductivity of a granule decreases twice, that is heat exchange intensity will decrease at the same size.

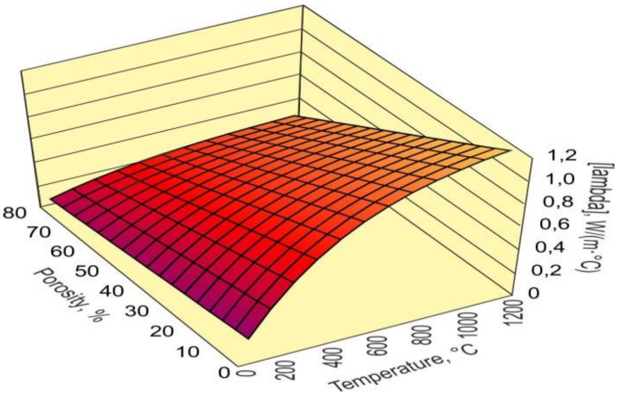

Fig. 5. Dependence of thermal conductivity [lambda]

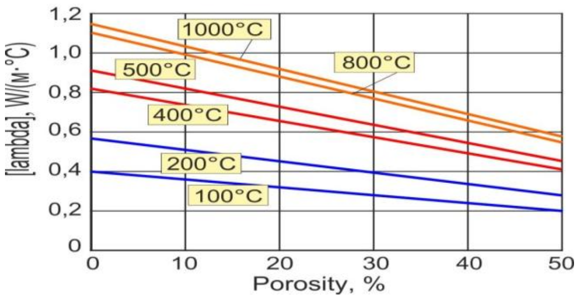

Fig. 6. Dependence of thermal conductivity [lambda]

of brick granules on temperature and porosity on granules porosity at various temperature

In process of decrease in temperature of clinker granules from 1200 °C there is a decrease in thermal conductivity and, respectively, decrease in heat exchange intensity. Therefore, for more complete cooling of granules it is necessary to increase the volume of the cooling air or a clinker response time in the refrigerator on a cold lattice.

Table 4: Functions of the grid-iron refrigerator.

Parameters	Volume	Mode	
		1	2
Clinker cooling-off period	min	17	40
Volume of an excess air	nm^3/kg clinker	1,21	0,33
Temperature of an excess air	^{o}C	165	110
Temperature of the cooled clinker	^{o}C	170	90
Heat wastes by the refrigerator	KJ/kg clinker	400	118
Heat efficiency of the refrigerator	%	68	91

Increase in heat exchange intensity in the grid-iron brick refrigerator at increase in time of its stay on a grid-iron lattice (Tab. 4) is confirmed by the production tests. Increase in mean time of stay of clinker in the refrigerator from 17 to 40 minutes promotes decrease in temperature of the cooled clinker on escaping of the refrigerator from 170 to 90 °C. Total losses of heat with clinker and an excess air decreased by 282 kJ/kg of clinker. At the same time heat efficiency of the refrigerator increased from 68 to 90%. Besides, decrease in volume of the cooling and aspiring air led to economy of the electric power.

Conclusion

Thus, the dependence of brick granules thermal activity on temperature and porosity received on the basis of the experimental data, as well as the carried-out production tests demonstrate that heat conductivity, especially if the size over 50 mm coming to the refrigerator of granules exerts decisive impact on heat exchange in the grid-iron refrigerator and effectiveness of its work.

Summary

1. Defining dependence of brick granules thermal activity on temperature and porosity is based on the solution of a non-stationary inverse problem of heat conductivity. The principle of a method consists in the experimental defining temperature change in two granule points: in the center and apart half of radius.

2. On the basis of the experimental data by defining temperature change of brick granules when cooling with free convection and airing the granule thermal conductivity changing depending on temperature and porosity is specified. The dependence equation of granules thermal conductivity on these parameters is received.

3. Decrease in temperature of brick granules leads to deterioration in heat exchange at the under temperatures due to decrease of thermal conductivity. Increase in porosity up to 50% reduces a granule thermal conductivity twice. It is established that heat conductivity, especially if the size of the granules coming to the refrigerator over 40 … 50 mm exerts decisive impact on heat exchange in the grid-iron refrigerator and effectiveness of its work.

4. Increase in clinker response time in the refrigerator from 17 to 40 minutes promotes the common decrease in heat losses by 282 kJ/kg of clinker and increase in heat efficiency of the refrigerator from 68 to 90%.

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