INCREASING OF HEAT TRANSFER THROUGH FIRING OF CHANGING CAPACITY

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This paper presents the experimental and theoretical investigation focused on the improving at industrial furnaces operating by changing burner capacity.

The testing were carried out at slot type furnace on 840 C^o and bath type pilot equipment on 1 100 C^o. The time of firing by full (120 kW) and low (40 kW) capacities could be adjusted variably.

There was experienced, that under the condition of investigation the total energy consumption 10-15% could be reduced without increasing of time of processes. The theoretical calculation justified this establishment.

The checking at real industrial circumstances is going on.

Keywords

Heat transfer, impulse-type firing, furnace, heat flux, energy consumption, combustion technology.

Nomenclature

Nu - Nusselt number; Re –Reynolds number; τ - time sec.; q – heat flux, W/m^2;

ε - emissions factor, T – temperature, K; C_o – Stephan-Boltzmann constant, $\frac{W}{m^2 K^4}$

Introduction

The efficiency of heating up processes at industrial furnaces is determined by the heat transfer phenomenon between the flue gas-wall system and the surface of the charge.

The first phase of the heating up process is very effective from point of view of the heat transfer. As the temperature of charge is increasing, it will be reduced and close to the end of process the heat flux is minimal. The waste of flue gases is increasing significantly.

The impact of this unfavourable phenomenon can be lowered with application of firing of changing capacity (impulse-type firing).

This technology is based on periodically changing firing of full and low capacity. Although during the period of low achievement the heat flux on the surface is smaller, the heating through process is going on - according to the law of the heat conduction. The temperature field of the heated blocks will be more homogenous. The heating up period is increasing, but the time of heat equalisation can be reduced. At the same time the firing by low capacity results a significant reducing of energy consumption.

The other impact is the periodical disturbing of the boundary layers through the changing of mass flow. It was established, that the forced convection shows a transient behaviour in the first phase of heating up cycle. Its period of time is in range of 30-60 sec.

The heat transfer is enhancing during this time significantly [1] according to the approximate equation

$$Nu = 0,133\ Re^{0,854}\ [1+2,52\ e^{-0,07\tau}] \qquad (1)$$

If the cycle time of changing of firing capacity has the same range, it will result better heat transfer condition too.

On the basis of these impacts by using of firing of full-low capacity can be expected the following effects:

- the consumption of energy (natural gas) decreases
- the convective heat transfer is more intensive
- the average temperature of furnace and its capability for NO_x emission regarding to the whole heating up process will be lower
- the necessary time of heat equalisation of charge decreases.

Earlier it was carried out at Hungary an experimental investigation on deep furnace supplied with high velocity burners. The results showed that the time of heating through of steel blocks could be achieved by reduced energy consumption in case of application the impulse-type firing. The realisation of the experiment and the results were summarised in [2].

The experiences of TÜKI at firing with regenerative burners proved too, that the heat transfer can be improved through changing the burner’s capacity periodically [3].

Present paper targets to summarise the TÜKI’s R+D activity on this area.

Experimental investigation

The first target of the experimental investigation was to declare the relationship between the energy saving achieved through firing by changing capacity and the heat flux induced within the furnace.

As basic equipment for the investigation a slot type furnace had been chosen with internal sizes of 600×600×1 200 mm. It is provided with TÜKI developed high velocity recuperative burner mounted on the side wall **Fig. 1.**

The furnace was provided with lining consists of heat resistant concrete. The slot of variable height had been located on the longer wall side of the furnace on the level of the bottom. Its length was 800 mm, harmonising with its original applying for heating up of roads for manufacturing of screw and manual forging. The length of slots was large enough for placement of the water cooled pipe and the heat flux measuring equipment provided with cables.

The capacity of natural gas burner had been changed between 40 kW (low capacity) and 130 kW (full capacity). The time of period at both full and low capacity -τ_1 and τ_2- was variable.

As the first phase an experimental investigation had been carried out at the temperature of 840C°. At this temperature the burner was able for preheating of combustion air to 300Cº.

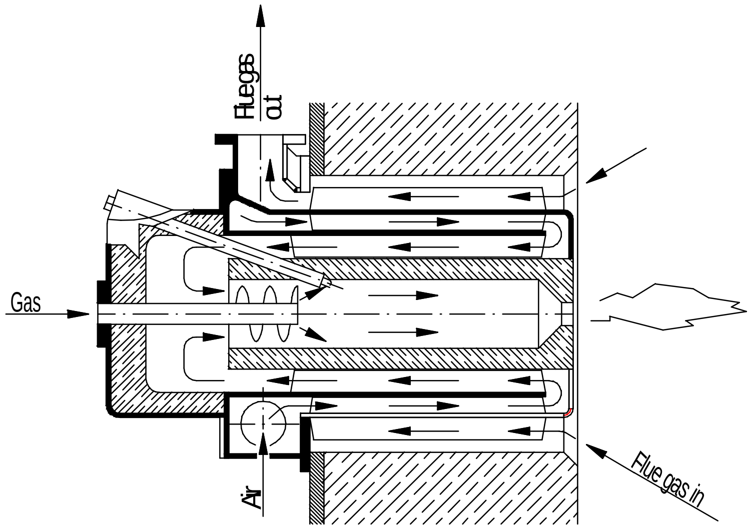

Fig. 1. TÜKI Developed Recuperative High Velocity Burner

The gas air-ratio had been adjusted to n=1,15-1,2. A sheet construction provided with thermocouples was placed on the bottom of furnace in order to determine the value of heat flux on that point versus both time of cycle

$$\tau_c=\tau_1+\tau_2 \tag{2}$$

and ratio of firing capacity

$$r=\tau_1/\tau_2 \tag{3}$$

where the indices 1 and 2 are concerning the firing by full resp. low capacity.

The sketch of the slot type furnace can be seen on **Fig. 2.**

The drawing shows the instrument for measuring of the heat flux on the bottom. There was applied metal slab at horizontal position. Because of it was embedded in fibre ceramic sheet, the role of heat conduction in perpendicular direction could be neglected.

The impact of the cooling pipe was eliminated by using of insulated umbrella.

The ratio of time of full and low capacities (r) was changed between 1:1 and 6:1. The full time of a cycle (τ_c) had been varied between 24 and 150 sec. The average heat flux during the heating up period from 200C° to 840C° was analysed as function of both parameter r and τ_c.

Regarding to the role of parameter r can be established, that the decreasing of this ratio hardly reduces the of average heat flux. Because of the lower r value is the fewer consumption of energy, the range of r<3 was investigated more thoroughly.

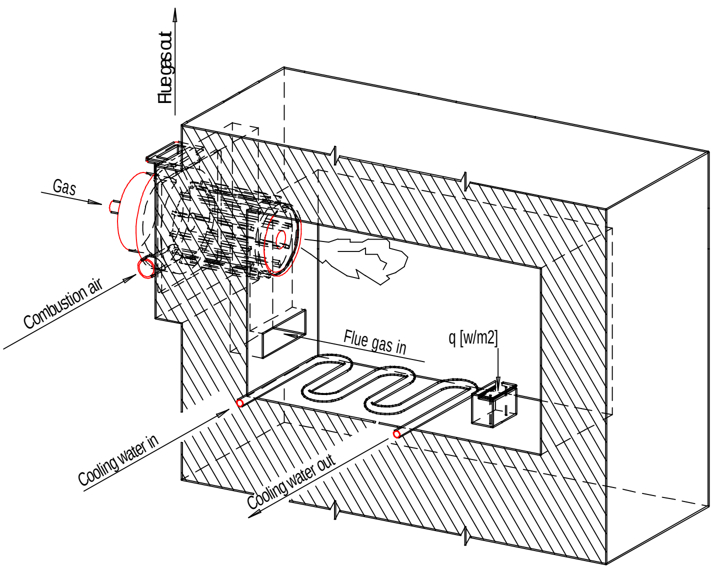

Fig. 2. Slot Type Investigating Furnace

Compared with the data of firing with full capacity ($r \to \infty$) it was established, that the average heat flux was reduced about 15-25% **Fig. 3.**

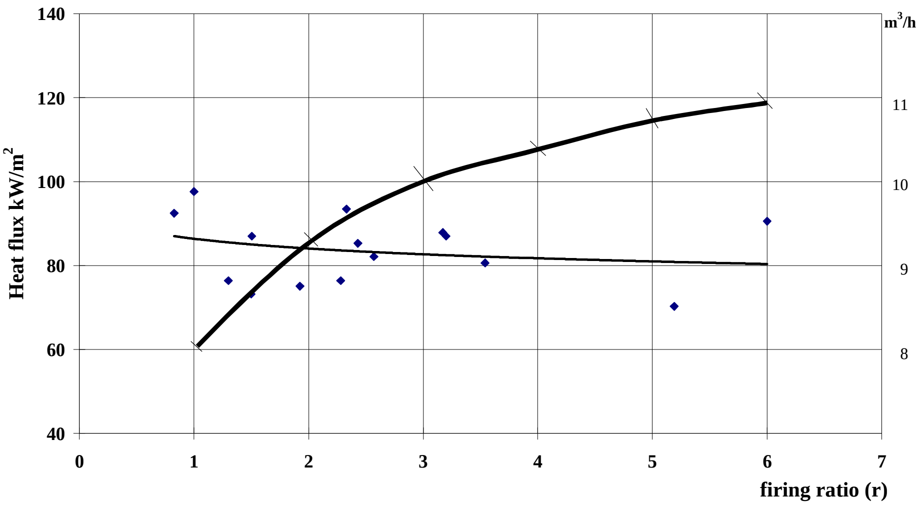

Fig. 3. Heat Flux Versus Ratio of Firing

The energy consumption versus r function is illustrated by the thick line of diagram.

The impact of parameter τ_c is unambiguous. The shortening of the cycle time results significant growing of heat fluxes **Fig. 4.**

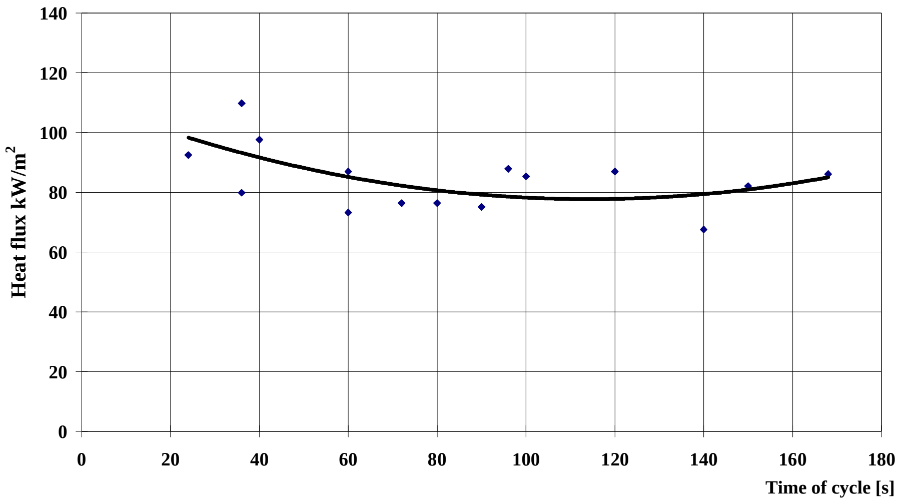

Fig. 4. Heat Flux Versus Time of Cycle τ_c

This relationship can be led back on the above mentioned transient phenomenon. The very first phase of actual system of heat transfer results much higher Nu number see (Eq.1.) During the next phase there was carried out a serie of experimental investigation of modified circumstances.

- The pilot furnace had been changed.
- The operating temperature exceeded 1 000°C.
- By choosing steel block of ∅90×100 mm, the heating through phenomenon could be analysed too.

The sketch of the bath type pilot furnace can be seen on the **Fig. 5.**

It was applied the ROREG regenerative gas burner operating by preheated air of 570°C. Its capacity was changed between 125kW and 42 kW. The air factor was adjusted to n=1,2.

There was investigated 13 version of cycle of time (see table 1.)

The heating up process was finished, when the temperature of score achieved the value of 1 000°C. The analysis of tests proved, that the lower cycle of time is the shorter time of heating up process. From point of view of temperature uniformity seem the tests of smaller ratio of firing capacity (r<3) somewhat more convenient.

Comparing for instance the test Nr 5 with the basic test Nr 1 can be established, that

- the time of heating up period is about 5,5% longer
- the energy consumption is 23% lower
- the maximum difference of temperature within the block is reduced from 95°C to 57°C.

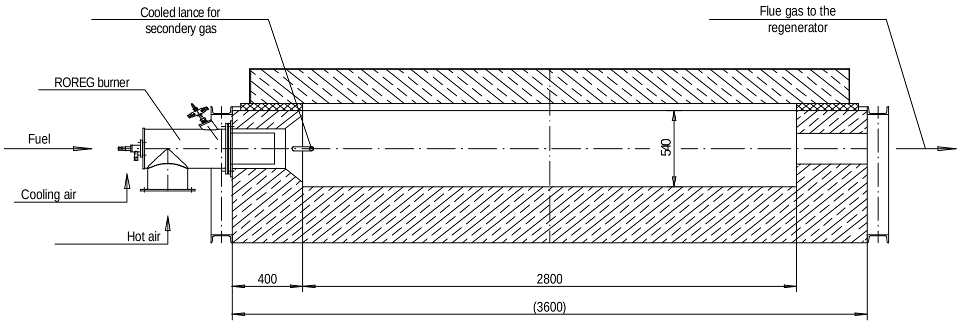

Fig. 5. Sketch of Bath Type Pilot Furnace

The same tendency was learned at the other trials too.

These results justified the earlier consequences with referency to improved heat transfer of firing of changing capacity.

Nr.	Firing capacity		Temperature		Heating up time [sec]	Ratio of energy consumption
	full [sec]	low [sec]	score [°C]	surface [°C]		
1	cont.	0	1000	1095	740	1,000
2	60	30	1000	1084	783	0,770
3	60	20	1000	1103	723	0,825
4	60	15	1000	1100	693	0,860
5	48	24	1000	1057	780	0,770
6	48	18	1000	1071	744	0,825
7	48	12	1000	1080	716	0,860
8	36	18	1000	1102	731	0,770
9	36	12	1000	1100	700	0,825
10	36	9	1000	1105	669	0,860
11	24	12	1000	1088	720	0,770
12	24	8	1000	1094	700	0,825
13	24	6	1000	1108	650	0,860

Table 1. Data of Heating up Processes and Energy Consumption at Different Tests

Theoretical analysis

It was elaborated a mathematical model based on the heat flux measured. On behalf of this model can be evaluated the role of the impulse-type firing taking into account the heating through i.e. heat equalisation phase as well.

The heating through process had been investigated by one dimensional heat conduction’s model.

The computation was carried out with parameter of unalloyed steel.

The heat flux values were taken over from the experimental investigation of heat flux measurement. The heating up period was analysed until the temperature of surface achieved the value of 830C°. The **Fig. 6 and 7** are demonstrating the surface and score temperature as function of firing ratio.

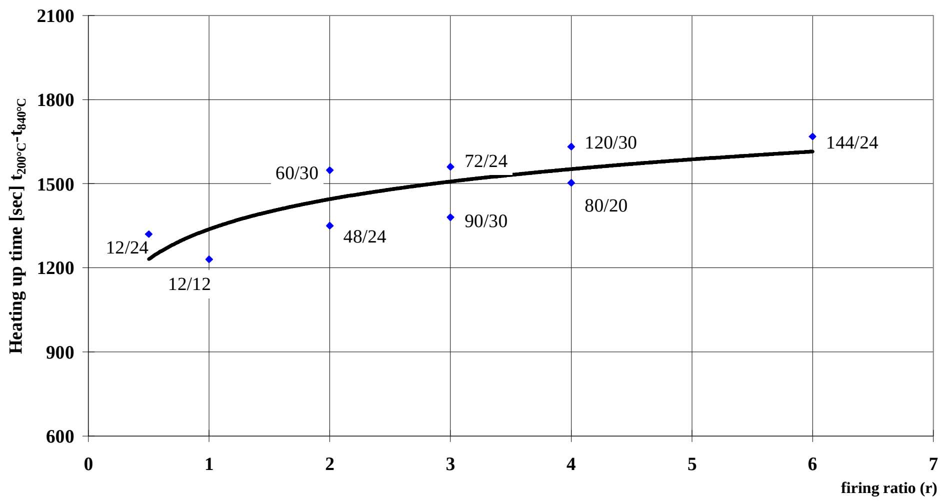

Fig. 6. Heating up time of surface element versus ratio of firing capacity r

The heating up time of surface is depending on the above mentioned parameters according to the impact on the heat flux. In the case of the score is the role of parameter r practically neglectable. It means that the effect of equalisation during the periods of firing with changing capacity is able to compensate the strongly variable values of the heat flux.

In order to approximate the heat transfer phenomenon of firing by changing capacity theoretically too, it was carried out a calculation of following simplified model.

It is based on the trials with steel block, carried out within the pilot furnace of **Fig. 5.** In the first phase was defined the flue gas temperature as function of the wall temperature with condition of empty furnace.

The temperature of wall was measured in range of 1 100 - 150C°. The shorter time of cycle was the smaller fluctuation of wall – and similarly of the flue gas temperature. The heat balance equation has taken into account

- the forced convection
- the radiative heat exchange between flue gas and wall
- the heat losses (wall and flue gas).

The present calculation doesn't include the impact of radiation of flame.

The knowledge of data of temperature made possible the calculation of heat transfer onto the surface of charge tested experimentally.

Its surface temperature was taken over from the testing data. The calculation concerned the time period of 0-700 sec.

In order to evaluate the impact of firing of changing capacity there was chosen the test Nr. 5. (r=2; τ_c=72 sec). The heat acceptance of steel blocks was calculated by equation

$$Nu=C\cdot Re^{0,8} \quad (4)$$

resp by the Stephan - Boltzmann law applicated on radiation of both solid and gaseous medium. The results of calculation can be seen on **Fig. 8.**

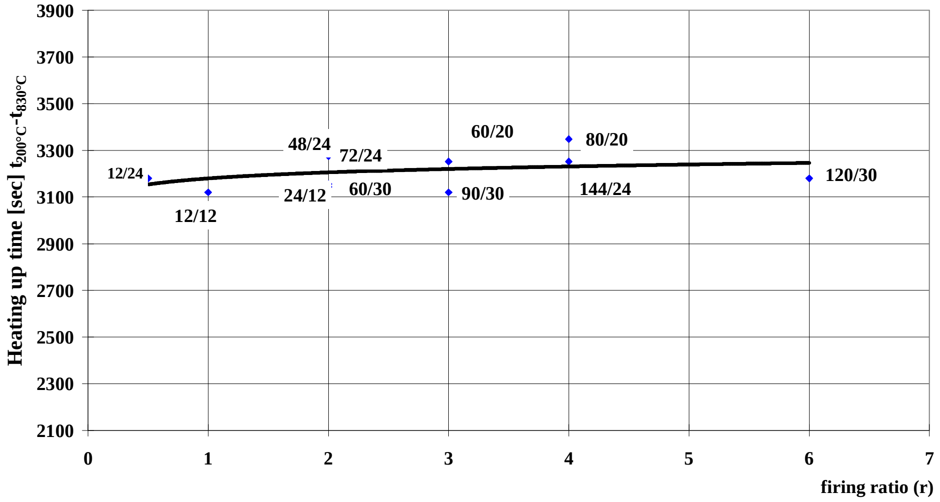

Fig. 7. Heating up Time of Score Element Versus Ratio of Firing Capacity

The column diagram makes possible the comparing of impulse type firing -48 sec full capacity and 24 sec low capacity periodically repeated – with the same of stable full capacity.

The difference is small. It means that in this case can be achieved specific energy saving of 23% without significant increasing of heating up time (less than 2%).

In the reality this result has to be modified, because of

– the impact of radiation of flame isn't neglectable

In case of charge of large mass will be its cooling effect much stronger. The low capacity period probably has to be reduced in order to keep the prescribed temperature of technology.

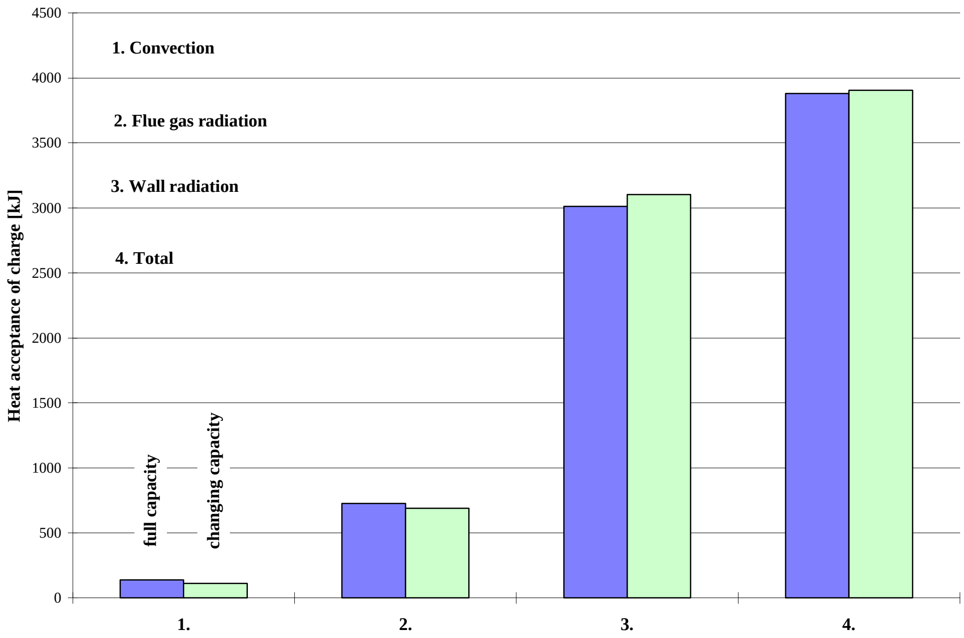

Fig. 8. Heat Acceptance of Charge During 700 Sec at Firing With Full and Changing Capacity

Conclusion

There was investigated the impact of firing by changing capacity on the heat transfer at the surface of charge within the furnace. The evaluating of experimental testing showed, that through applying of firing with changing capacity in case of short cycle time - τ_c<60 sec-the heat transfer on the surface can be realised by 10-15% reduced energy consumption compared with traditional full capacity firing. The series of trials were carried out at furnace temperature of 840C° and 1 150C°. The range of saving of energy was at both cases 10-15%.

The first phase of theoretical calculation was directed to the heating through process.

The evaluation of results proved, that the total heating up process – including the heat equalisation period too – carried out by saving of energy more than of 10% without increasing of time namely without reduction of productivity. According to the results of the second phase, the heat acceptance of change remains unchanged. The energy saving can exceed the value of 15%. Because of the simplifying of the model it will be in the reality somewhat smaller, harmonising with the results of experimental investigations.

The research work is going on. In the next phase will be investigated the application of process of impulse type firing in case of industrial circumstances.

Acknowledgement

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