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THE INCREASE OF THERMAL EFFICIENCY FOR THE HEATING FURNACE

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ABSTRACT. The purpose of this paper was to evaluate the general thermal efficiency for a heating furnace of phosphatic porcelain, materialized in two different structures. One is the classical structure of these furnaces and the second represent a modified type-obtained by plating the inner side with ceramic fibers. The analyze is based on the finite element method (FEM) for the unstable heat transfer stage, supported by a COSMOS/M Geostar professional software package. The analyses reveal a major isolating effect of ceramic fibers and a real increasing of thermal efficiency up to 30% compared to the classic type of furnace.

1. Introduction

The general structural constructions of heating chamber's furnaces are well known in engineering practice [1,2,3] from many years. In the last decades, since 1980, many investigations [4,5,6] were developed for the increasing of heating furnaces' thermal efficiency. One of the main trends consists in the increasing of the general thermal transfer from the inner heating side to the porcelain products. This modality must to consider the heating diagram of the porcelain products both the cumbersome process of the proper heating and structural, phisical and chemical, changes of the products. Another way of approach for the increasing of the thermal efficiency is the one, which consider the equivalent thermal yield to be the quantity of heat consumed for the same quantity of product. This type of analysis leads the study towards constructive modifications of the heating furnaces, with favorable technical and economical implications. On this direction evolves the present study, which proposes that by modifying the basic structure of the heating furnaces of phosphatic porcelain, will achieve a decrease of lost heat energy. One of the most appreciate construction alternative used on the previous direction consist in using ceramic fiber in the structure of the furnaces' walls.

Because the process of heating of these products is an intermittent one, for which the usual known analytical methods are practically inapplicable or leads to major complications and the heat transfer stage is one unstable we've been using for the comparative analysis the finite element method (FEM) supported by a COSMOS/M Geostar professional software package.

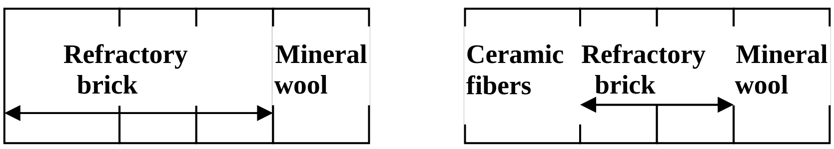
2. General analysis considerations

The main objective of this study is to analyze the efficiency of using ceramic fibers as a first inner layer of intermittent working heating furnaces. In this purpose it will be followed the temperatures, the heat transfer, thermal heating flux, during heating and cooling down. All these were achieved considering the whole process in an unstationary process. Further through calculations based on achieved thermal fluxes, the quantity of heat energy inside the furnace's walls, the whole heat input and the exterior heat energy losses, it can be evaluated the quantity of real total heat energy used by the process and implicitly it can be determined the global thermal yield. The classic structure of these furnaces – chamber, sidewalls, back walls, arch, etc.- is one multilayer. It is made from a combination of masonry, which combines different types of refractory bricks and other different isolation materials (Table 1). From the multitude of situations of building furnace's walls it has been chosen one of the most common classical, respectively one modified type obtained by plating the inner side of the walls with ceramic fibers (Fig. 1).

Table 1.

Physical and thermal parameters of refractory brick, ceramic fibers and mineral wool

Parameters		Refractory bricks			Mineral wool	Ceramic fibers KVF 151
		I 35 A 06	I 62A 08C	I 62A 11C		
T_{max} [^{0}C]		1200	1300	1500	130	1500
Density [Kg/m^3]		600	800	1100	250	140
Thermal conductivity [W/m ^{0}C] λ = f(T ^{0}C)	200				0,06	0,066
	400	0,209	0,279	0,488		0,095
	600	0,233	0,314	0,488		0,12
	800	0,291	0,326	0,488		0,18
	1000	0,326		0,477		0,25
Specific heat [J/Kg ^{0}C] c = f(T ^{0}C)	200	900	900	900	753	932
	400	980	980	980		
	600	1030	1030	1030		1162
	800	1063	1063	1063		
	1000	1093	1093	1093		1297,66
	1200	1120	1120	1120		
	1400	1134	1134	1134		



a. **b.**

Fig. 1. The equivalent structure for the walls of the furnace.
a. Equivalent structures for the walls of classic chamber furnace;
b. Equivalent structures for the walls of modified chamber furnace;

The following conditions are the most important from the heat transfer point of view:

- the heat transfer through the furnace's wall is determined by the unidirectional conduction in unstationary regime;
- relatively identical conditions for the convectiv and radiant heat transfer at the exterior of the wall for the classic type of furnace and as well as for the modifield type with ceramic fibers.

For really evaluating the impact of using ceramic fibers in the construction and upgrading the heating furnaces, we will consider the the analysis of heat transfer in real unstationary regime through the wall of a characteristic 4 m^3 chamber furnace in both constructive types: the classic one and the one upgraded with ceramic fibers (Fig. 2).

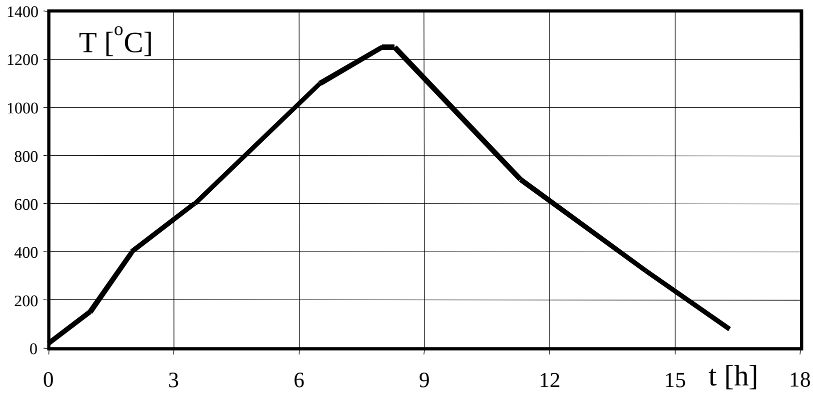


Fig. 2. Heating diagram for phosfathic porcelain.

We reduce the analysis to the conductive heat transfer through the furnace's walls because this is decisive for the global heat consumption of the furnace in both construtive types.

The main analysis assumptions:

- the temperature of all interior constructive elements of the furnace is known according to the heating diagram;

for the convectiv heat transfer between the outer sides' surface of the furnace and the environment it will be considered for partial coefficients of heat transfer the next general relations:

$\alpha \cong 7{,}1 + 0{,}057 \cdot T_e$ - transfer from plane wall to exterior environment;

$\alpha \cong 9{,}4 + 0{,}057 \cdot T_e$ - transfer from arch wall to exterior environment;

- heating cycle (Fig. 2) with a spread of 16 h 40‘, will be divided in 60” intervals resulting 500 steps until the end of the heating phase and 1000 steps until the end of the heating cycle;
- the MEF modeling and analysis will be achieved with square shapes (PLANE2D), 4 nodes and 0,025 m side bidimensional finite elements;
- because of the geometrical symmetry and the frontier conditions the MEF analyze model is considered only half of the transversal section of the furnace.

3. Numerical analysis

On the basic conditions and the previous presented context it has been achieved the unstationary regime heat transfer using MEF for two types of phosphatic porcelain chamber furnaces (Fig. 3):

- Type I (Fig. 1. a) classic solutions of the furnace;
- Type II (Fig. 1. b) a modified solution by which the interior walls and the arch are plated with a layer of type KVF 151 ceramic fiber with a thickness of 50 mm. Simultaneous complying the initial thickness of the fire place, under the plane fire place made by refractory bricks I 65 A 11C, a layer of 25 mm of ceramic fibers was introduced.

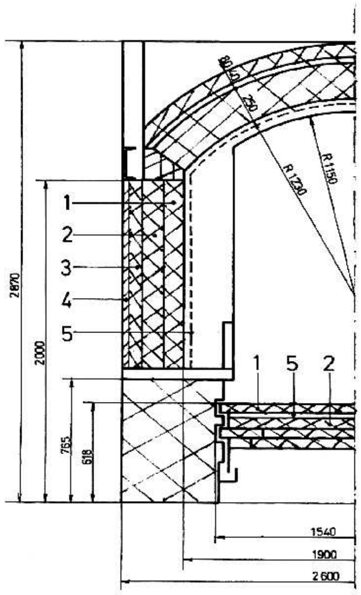
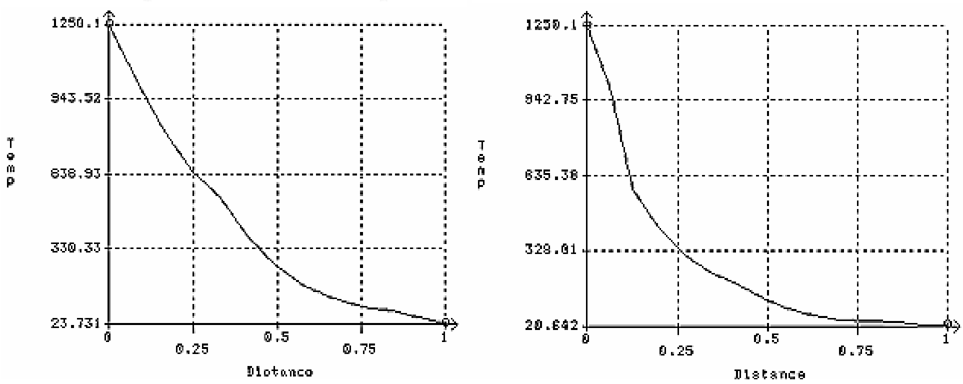


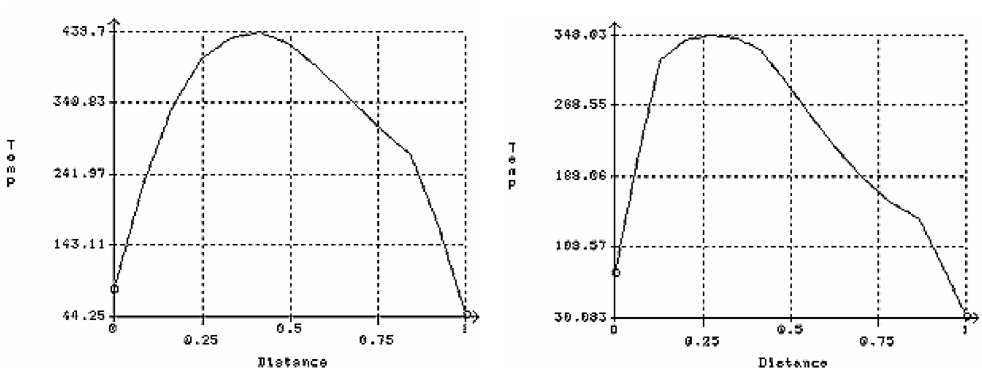
Fig. 3. The main constructive structure of heat furnace.
1-Refractory brick type I62A 11C;
2- Refractory brick type I35A 06;
3- Refractory brick type ID 06;
4- Refractory brick type I62A 11C;
5-Ceramic fibers layer ;



a. **b.**

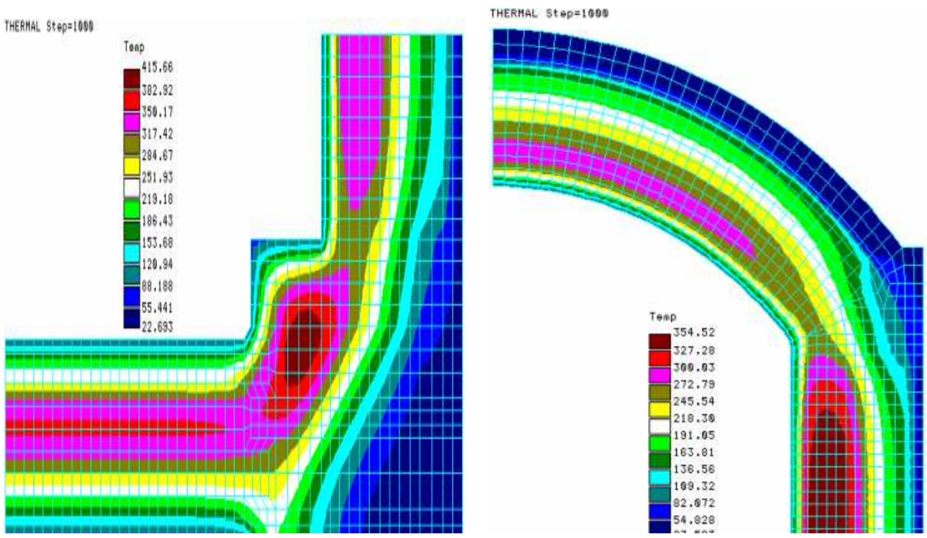
Fig. 4. General temperature distribution through the plane wall of the furnace at the end of the heating phase only. **a.** Classic furnace; **b.** Modified furnace by ceramic fibers;

For a comparative and facial evaluation of the temperature variation through the thickness of side walls, at the end of the heating phase, on the base of MEF analyses are rendered the distributions for both types of analyzed furnaces (Fig. 4). From Figure 4 it comes out the favorable effect of the presence of ceramic fibers emphasized by the severe heat drop on the thickness of the fibers' layer thus the maximum temperature of the brick masonry doesn't exceeds 600 ^{0}C. The favorable isolating effect of the ceramic fibers is much more obvious from Figure 5, at the end of the whole heating cycle.



a. **b.**

Fig. 5. General temperature distribution through the plane wall of the furnace at the end of the whole heating cycle. **a.** For classic furnace; **b.** For modified furnace by ceramic fibers;



a. **b.**

Fig. 6. FE mesh and temperature distribution through the main parts of the heating furnace. **a.** Through the fireplace and sidewalls. **b.** Through the arch and sidewalls.

In fact, this favorable isolating effect of the presence of ceramic fibers can be appreciated more directively representing on the same diagram the maximum temperature distribution in assembly parts of the two types of furnaces.

Based on the previous diagrams (Fig. 4-7), derived by the FE analysis, it can be evaluated the conductive thermal flux throughout the main constructive elements of the furnace. In t he conductive thermal fluxes, also like in the case of temperatures distribution, it comes out that the maximum isolation effect of the presence of the ceramic fibers appears at the sidewalls and the arch of the furnace.

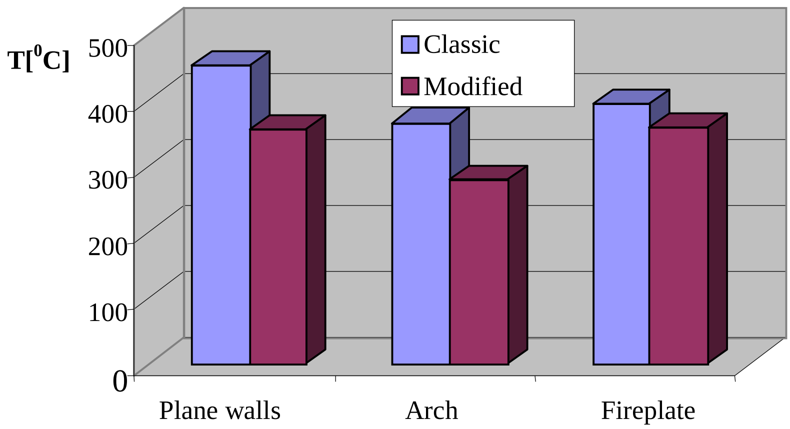


Fig. 7. Distribution of the maximum temperature in the two types of furnaces at the end of whole heating process.

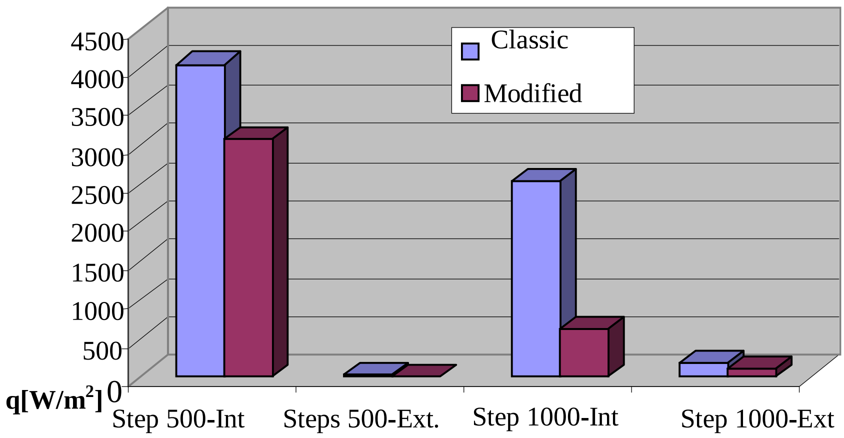


Fig. 8. Thermal flux throught the plane sidewalls.

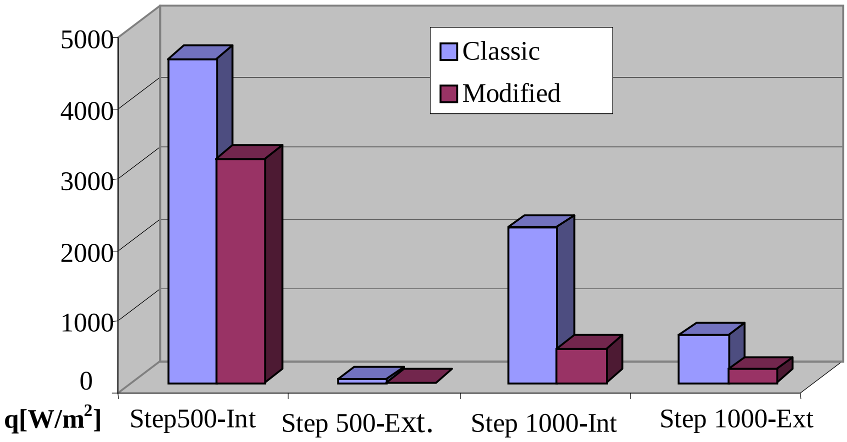


Fig. 9. Thermal flux throught the arch.

Based on modeled values by FE (Fig. 8-10) it can be specified that the presence of ceramic fiber leads to a smaller conductive flux up to 25% for the side walls and and 30% for the arch compared to the classic type of furnace. The great isolating effect of ceramic fibers is much more important for the cooling period (between step 500→1000) of the heating cycle because a conservation of heat accumulated in the furnace's structure is assured so at the beginning of a new heating cycle it will be needed a smaller quantity of heat for resuming the cycle.

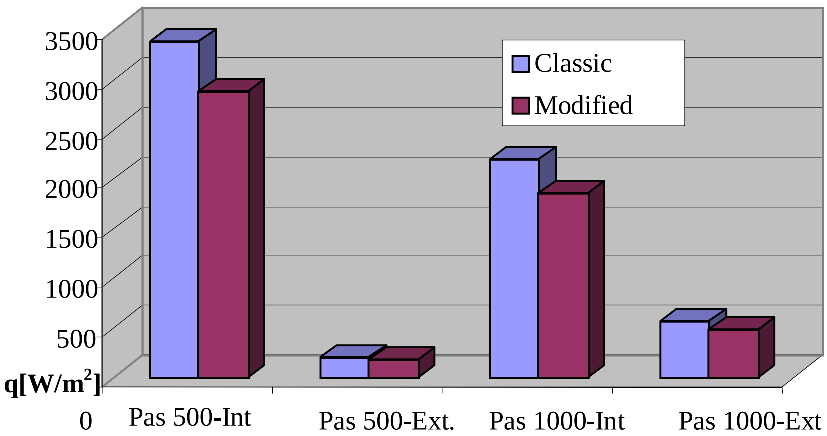


Fig. 10. Thermal flux throught the fireplate

For the particular considered furnace (Fig. 2) at the end of the whole heating cycle (step 1000) it cames out 75% less thermal fluxes on sidewalls and 78% for the arch. So it can be concluded that all the heat losses (towards outside and inside) from the accumulated in the furnace 's walls on the modified type are much smaller than the classic type of furnace. This status determines a significant reduction of heat quantities consumed for heating the products in a new stage of resuming the porcelain heating process.

4. Conclusions

By using almost identical analysis models with real furnaces the study reveals the major advantages of usage of ceramic fibers for construction or for upgrading chambers furnaces of heating porcelain. Although the quantitative evaluations are obtained for a particular type of chamber furnace it can be highlighted the following general favorable effects:

- the decrease of temperature gradient on the thickness of the furnace's walls;
- the decrease of thermal conductive flux through the furnace walls;
- a very good conservation of accumulated heat;
- the increase of general thermal yield of the process.

The precision and the efficiency of the FE method justified this kind of approaches, which with relatively small efforts leads to spectacular economic and thermal results.

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