

**The „Gh.Asachi” Technical University of Iași**

**EXPERIMENTAL AND CFD TECHNIQUES  
FOR ENERGETIC OPTIMIZATION OF  
ELECTRIC FURNACES BY MODIFYING  
THE WORK SPACE GEOMETRY**

**RESEARCH REPORT**

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**The objectives and activities within the structure (II Annex) foreseen for the  
unique stage of year 2007**

**OBJECTIVES' NAME:**

1. The establishment of a representative scientific method for studying the energetic optimization of electric furnaces.

**ACTIVITIES' NAME:**

1.1. The elaboration of an initial data base regarding the industrial applications of heat transfer processes. Intervention possibilities on the processes.

1.2. The critical analysis of intensifying the transfer processes and the establishment of research directions for electric furnaces.

1.3. The establishment of theoretic method for economic efficiency of thermal installations.

1.4. The team-work analyze of partial results at finalizing each objective

## 1.2. The critical analysis of intensifying the transfer processes and the establishment of research directions for electric

### 1.2.1. The critical analysis of intensifying techniques of transfer processes

The critical analysis of intensifying techniques of heat transfer was realized by itself identification of the applied methods regardless the process specific.

Below there will be presented all the intensification techniques of heat and mass transfer processes such as

- Turbulence promoters
- Oscillations
- The increase of transfer surface
- The increase of turbulence degree of the medium
- By increasing the moving force (potential difference) of transfer process
- Other methods.

#### 1.2.1.1. The intensification of transfer processes by using turbulence promoters

The turbulence promoters induce a supplementary local turbulence which leads to increasing transfer speed.

*The intensification of energy transfer through surface turbulence promoters.* Heat transfer can be intensified by modifying the surface state pursuant to artificial roughness introduction. These realize a flow modification in limit layer which lead to increasing superficial coefficient of heat transfer but also friction coefficient. There are the following used roughness types: channel, rib, granular.

Ribs like channel type represent profiles mechanically processed in the heat exchange surface wall and are shaped as annular channels thread type with 1 till 6 beginnings, trapezoidal and triangular types or with other different geometries of the grooves. In figure 1 there are presented some thread type roughness.

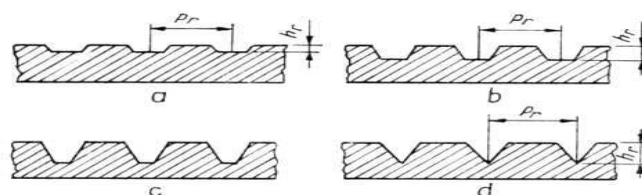


Figure 1. Thread type roughness:

a, c – Trapezoidal thread with a beginning; b – trapezoidal thread with 6 beginnings; d – triangular thread

Rib type roughness is realized as:

- Thin metallic bands welded longitudinally or transversal on the exterior of the pipes;
- Rectangular or triangular ribs transversal, helicoidally and lamellar processed on the exterior surface of spiral tubes;
- Free or welded wire rings on the exterior or interior surfaces.

In figures 2 and 3 it is presented this roughness type.

Granular roughness is asperities with different shapes and dimensions obtained through metallic surfaces friction with paper and diamond paste.

Some studies regarding the roughness effect of the thread type on the heat transfer in nuclear

reactors took to an efficiency criterion:  $E_r = \frac{\alpha_r f}{\alpha f_r}$ ; where  $\alpha_r$  and  $\alpha$  are convective transfer

coefficients, in roughness presence and in its absence;

$f$ ,  $f_r$  – friction coefficients for smooth pipe and for roughness pipe.

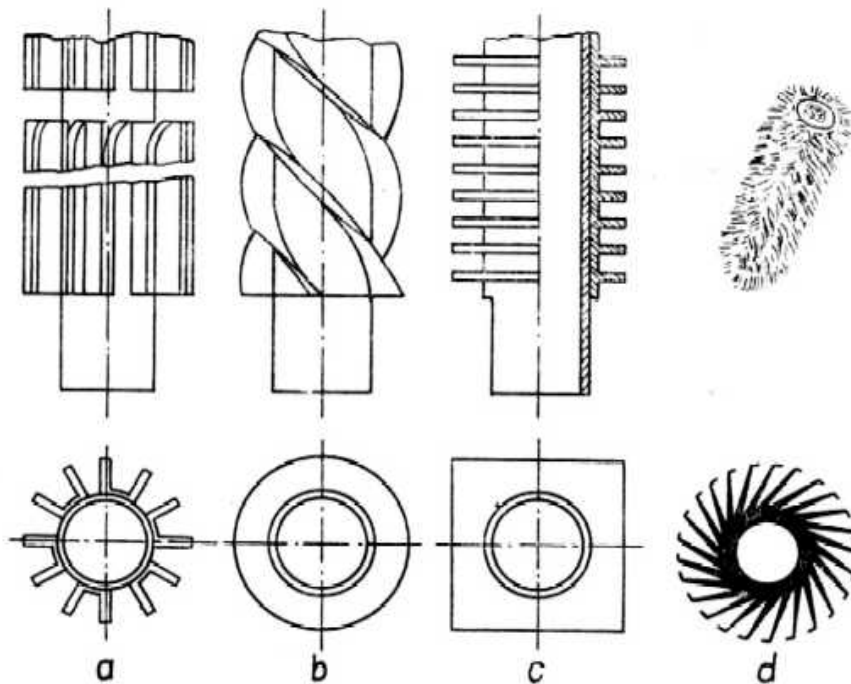


Figure 2. Tubes with exterior ribs

a – longitudinal; b – helicoidally; c – radial; d - lamellar

For the same studies regarding the thread type roughness shows that maximum efficiency is get at the value:  $p_r / h_r = 23 \dots 28$ ; where:  $p_r$  is channels' step;  $h_r$  – roughness height.

This criterion permits the comparison of the different roughness types..

**The intensification of energy transfer through turbulence shifting promoters of the fluid.** The intensification of heat transfer is made with shifting promoters which create an artificial turbulence within the mass of the fluid.

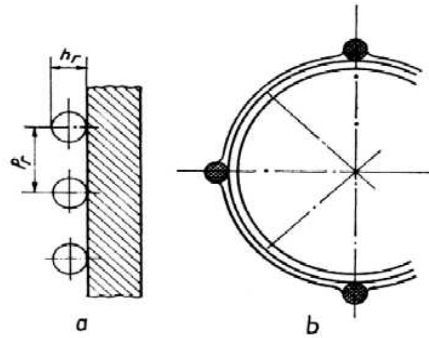


Figure 3. Exterior roughness

a – welded wire curl; b – free fibers

In figure 4 there are presented some promoters types by their montage within the pipes. These are:

- Plane curls;
- Swirling paddles;
- Conical surfaces;
- Twist metallic bands.

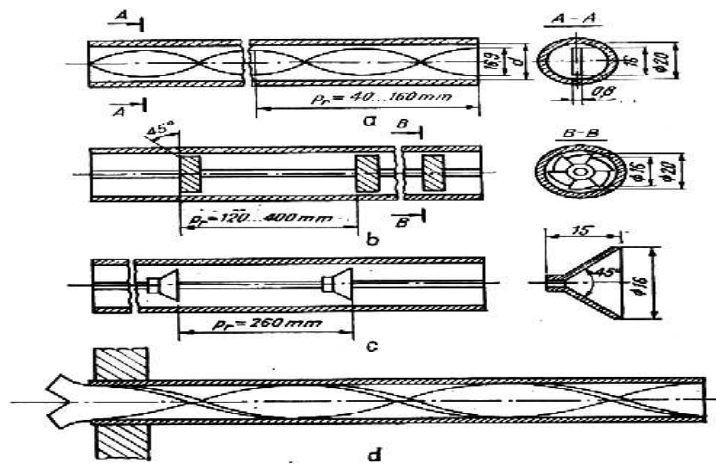


Figure 4. Turbulence promoters mounted in the pipes

a – plane curl; b – Swirling paddles oriented under a  $45^\circ$  angle towards flowing current; c – conical surfaces; d – twist metallic bands.

In practice the highest efficiency is get by using the devices with swirling paddles at numbers  $Re < 10^4$ .

Also by placing the turbulence promoters on the exterior surface of the interior tube circular space, there are increases of heat flow about 60% in regard to the case without turbulence promoters.

#### **1.2.1.2. The intensification of transfer processes through oscillations**

This consists in superposition of some oscillatory moving over the normal moving of the fluids. They are created by using pulsations, mechanic, sonic and ultrasonic vibrations.

The oscillations applied to fluids are vibrations applied to the apparatus or in contact solid surface with the fluid or the pulsations applied to fluid medium.

##### *The use of vibrations for energy transfer intensification*

In heat transfer of Monophasic fluids mostly the horizontal cylinders and vertical surfaces were submitted to vibrations. The researches showed that the most convenient vibrations which lead to increasing the heat transfer coefficients are those applied to forced convection. The obtained effects are diverse by varying from transfer coefficient diminishing till its increasing about 300% and the phenomenon depends on the system and the vibration intensity which is defined as the product between amplitude ( $a$ ) and oscillation frequency ( $\nu$ ). When vibration intensity is very big it also appears cavitations phenomenon. In this case it is produced a significant loss of heat transfer.

##### *The use of pulsations for energy transfer intensification*

In order to produce pulsations in the fluid there are used pulsation generators which can be flow switcher and piezoelectric transducers. These realize the pulsation of 1 Hz until ultrasounds of  $10^6$  Hz.

Numerous researches were made for determining the sound effect on heat transfer from a horizontal cylinder to air.

The sound field was axially or transversal oriented towards horizontal or vertical surfaces. Thus, heat transfer coefficients, at free convection in liquids, can rise from 30% till 450% by the use of sounds and ultrasounds.

This transfer way is much more expensive than the use of forced convection (for example a simple agitator).

##### *The use of vibrations and pulsations in mass transfer intensification*

The oscillations use leads to mass transfer processes intensification (extraction, dissolution, sublimation) or in the operations with simultaneous heat and mass transfer (evaporation, correction, drying). Also for mass transfer, the intensification is realized both through decreasing transfer

resistance as a result of turbulence increase in limit layer and fluid volume, and by increasing contact surface between phases. .

The intensification of mass transfer processes through vibration was realized for film fluid columns, column fillings, columns with continuous phase and a disperse phase bubble type, drops, solid particles and columns with agitation devices.

The vibrations applications to the filling columns determine mass transfer intensification because it realizes a uniform distribution of the liquid in the filling, a uniform cover of contact surface, relatively high flow speeds of the phases, high speed gradients at interface and turbulence in liquid film.

### **1.2.1.3. Heat transfer intensification by surfaces extension**

The extension of heat exchange surface is used as an intensification method of convection processes for the fluids that realize small convection coefficients like gases. According to Newton relation  $Q = \alpha S (t_p - t_f)$ , for a given difference between the wall and fluid temperature and a low value of  $\alpha$  coefficient, the increase of heat flow  $Q$  can be done by increasing surface  $S$ .

The extension of heat exchange surface makes with the help of some ribs with different geometric shapes (longitudinal, radial, acicular, etc.) attached to a support surface (basic) made of the same material with support wall or of different materials.

The calculus of the ribs is based on the following simplifier hypotheses:

- thermal regime is constant in time;
- thermal conductivity of ribs material  $\lambda = \text{const.}$ ;
- the rib is cooled by a fluid with uniform temperature  $t_f = \text{const.}$ , convection coefficient is constant on the entire rib surface,  $\alpha = \text{const.}$ ;
- the temperature of rib's base is uniform, there are no contact heat resistances between rib and support wall;
- the thickness of the rib is small comparing to its height so that temperature gradients can be neglected;
- there are no interior heat sources in the rib,  $q_v = 0$ .

Based on these hypotheses heat transfer through rib will be unidirectional conduction with convection.

*The variable transversal section rib.* It is considered a rib with variable transversal section  $S = S(x)$  and variable perimeter  $P = P(x)$ , in contact with a fluid with temperature  $t_f = \text{constant}$  and its convection coefficient  $\alpha = \text{constant}$  (figure 5.). In a certain transversal section, including its lateral perimeter, the rib's temperature is the same:  $t = t(x) > t_f$ .

The temperature of rib's base is  $t_0 = \text{constant}$ .

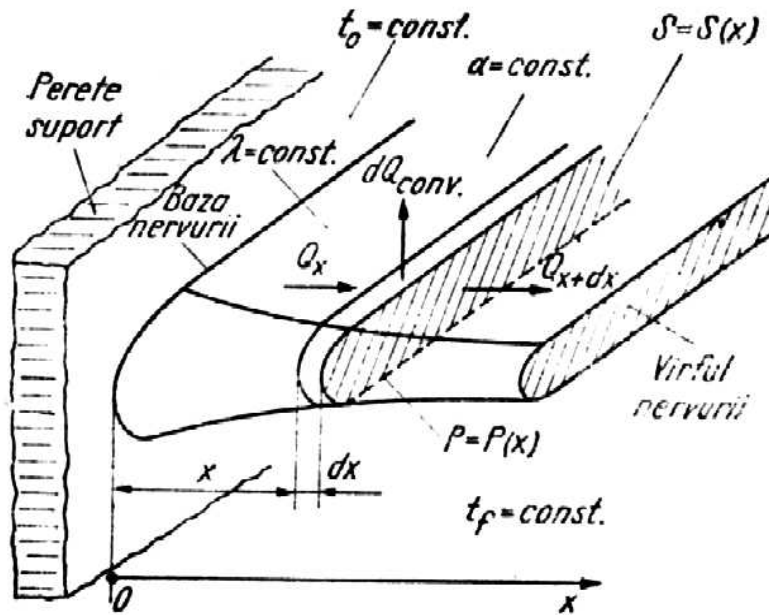


Figure 5. Longitudinal rib with variable transversal section

For volume element of  $dx$  thickness from the rib it can be written the next thermal balance:

$$Q_x = Q_{x+dx} + dQ_{conv}, \quad (1)$$

where:  $Q_x$  is heat flux that crosses  $x$  plan;

$Q_{x+dx}$  – heat flux that crosses  $x+dx$  plan;

$dQ_{conv}$  – heat flux transmitted to the fluid through convection.

It is obtained the differential equation after the balance calculus:

$$\frac{d^2 t}{dx^2} + \frac{1}{S} \frac{dS}{dx} \frac{dt}{dx} - \frac{\alpha P}{\lambda S} (t - t_f) = 0. \quad (2)$$

If we introduce variable exchange  $\theta = t - t_f$ , where  $\theta$  represents temperature excess between wall

and fluid in  $^{\circ}\text{C}$ , and the report is noted as  $m^2 = \alpha P / \lambda S$ , ( $\text{m}^{-2}$ ); where:  $m = m(x) = +\sqrt{\frac{\alpha P}{\lambda S}}$ , ( $\text{m}^{-1}$ ).

The differential equation gets the general form

$$\frac{d^2 \theta}{dx^2} + \frac{1}{S} \frac{dS}{dx} \frac{d\theta}{dx} - m^2 \theta = 0. \quad (3)$$

*The constant transversal section rib.* For this type belongs the straight rib with constant thickness with rectangular profile. (figure 6.) For it,  $S = \text{const.}$ , so that differential equation has the form

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0. \tag{4}$$

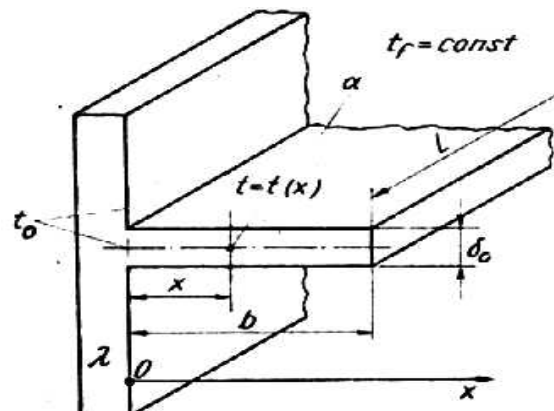


Figure 6. Longitudinal rib with rectangular profile – calculus elements for real rib

Where, with the figure notations,  $m = \sqrt{\frac{2\alpha}{\lambda\delta_0}}$ , iar  $\theta = t - t_f$ .

*The optimum profile rib.* Usually, the ribs are made of materials with high thermal conductivities or corrosion resistant, both cases being very expensive. That is why it is searched the accomplishment of some ribs with minimum metal consumption for a certain quantity of heat.

The problem consists in determining the longitudinal profile of the rib so that unitary thermal flow transmitted through conduction remains constant from where it results that  $d\theta/dx = C_1 = \text{const}$ . So, we have  $\theta = C_1x + C_2$ , respectively a linear variation of the difference between lateral surface and fluid temperatures.

The only longitudinal rib that has a linear distribution of temperature difference  $\theta$  is concave parabolic rib (figure 7.) which fulfills the condition of minimum material consumption.

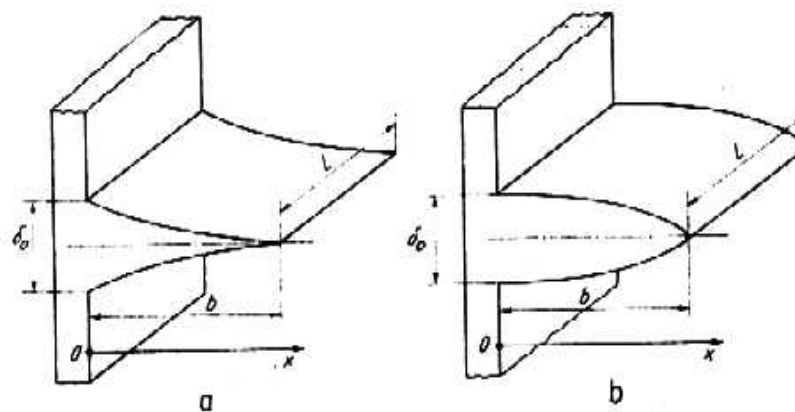


Figure 7. Longitudinal rib with concave (a) and convex (b) parabolic profile

Technologically the execution of a longitudinal concave rib is difficult. In addition this profile has a low mechanical resistance. Taking into consideration that weight difference between a concave rib and a triangular one is very small, the latest being easy to realize, it can be accepted for practice use a triangular rib as an optimum form. Also from resistance motives the triangular rib is modified as a trapezoidal rib.

*Radial ribs.* In the general case of a radial rib with a certain profile, the differential equation of temperature distribution in the rib is similarly fixed by getting

$$\frac{d^2\theta}{dr^2} + \frac{1}{r} \frac{d\theta}{dr} + \frac{1}{y} \frac{dy}{dr} \frac{d\theta}{dr} - \frac{\alpha}{\lambda y} \theta = 0, \quad (5)$$

where  $y = y(r)$  is rib's thickness variable with  $r$  radius.

*Acicular ribs (bar type).* Acicular ribs are longitudinal ribs bar type with finite dimensions of transversal section small in comparison with rib's height.

### ***1.2.2. The determination of research directions***

The determination of research directions realized through analytic analysis of intervention possibilities on heat processes at average temperatures.

The researches will be directed towards theoretical and practical research of electric furnaces and the simulation of industrial heat processes.

Particularities concerning the efficiency of heat transfer will be detailed at point 1.3.