International Research Cooperation on the Computer Study Programmes between VSB – Technical University Ostrava, Czech Republic and Silesian University of Technology, Poland

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Abstract *— The first scientific -research cooperation treaty between the Faculty of Electrical Engineering and Computer Science of VSB -TU Ostrava – Department of Electric Power Engineering and the Faculty of Material Science and Metallurgy of Silesian University of Technology, Gliwice – Department of Electrotechnology has already been ratified in 1994. Since 2001 the programme is resolved in terms of the "KONTAKT" international programme. The treaty supposes the realization of a common long -time research project named "Development of Programmes for Computer Aided Research in Electroheat". The basic element of the cooperation is the working out the design methods and function simulation of several types of electric furnaces and heaters which were used within a creation of six computer programmes. These programmes are able to calculate the electric, thermal and operation parameters of the ment ioned equipment. The programmes are also used for didactic purposes at the both of the universities. They were presented in several publications common for the employees of the both of cooperating departments*

Index Terms *— International Research, Computer Aided Design, Electroheat study*

COMPUTER PROGRAMME FOR INDIRECT HEATING

Introduction

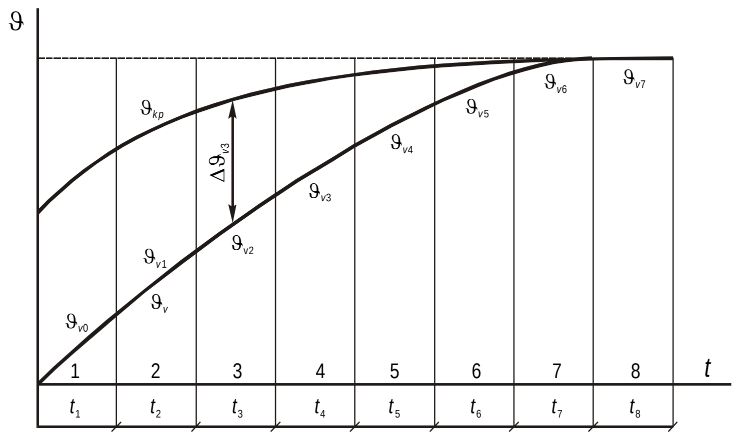
In the indirect-resistance furnace the conversion of electrical energy into heat takes place in the resistance heating element from which the heat is transferred thermokinetically (by means of convection, conduction, radiation and in a combined way) into the heated charge. The equipment of this type contains a chamber furnace stirring the charge and also heating elements. For practical purposes such as industrial resistance heating it is necessary to determine a time needed for it. Therefore there was designed a programme for the required time calculation.

Programme Algorithm

The period of heating t_n and changes in the temperature of the charge $\vartheta_v(t)$ can be determined by means of the graphic-analytical iteration method providing that we know the heating characteristic of the chamber of the furnace $\vartheta_{kp}(t)$ (Figure 1).

For the thermally steady state of the furnace, an assumption that ϑ_{kp} = const can be accepted. On the axis of time (Figure 1) arbitrary time intervals (steps) t_1, t_2, ..., t_i, ..., t_N will be plotted; however, equal intervals should be chosen best ($t_1 = t_2 = ... = t_i = ... = t_N$). The temperature of the charge is calculated for separate stages of the intervals: the initial temperature ϑ_{v0} is taken and ϑ_{v1} is calculated, in the next time step for the known temperature ϑ_{v1}, ϑ_{v2} is taken, etc.

FIGURE. 1
TEMPERATURE CHANGES IN THE CHAMBER OF THE FURNACE (ϑ_{KP}) AND IN THE CHARGE (ϑ_{V}).



For example, for the third step t_3 the following equation can be written:

$$\alpha_3 S_v \Delta\vartheta_3 t_3 = m_v c_3 (\vartheta_{v3} - \vartheta_{v2}) \qquad (1)$$

where α_3 is the coefficient of heat transfer, S_v is surface of the charge, m_v is the weight of the charge and c_3 is the specific heat. The left side of (1) corresponds to the energy transferred to the charge in the interval t_3, and the right side to the heat accumulated in the charge. In that time the coefficient of heat transfer α_3 amounts to the following:

$$\alpha_3 = \alpha_{k3} + \alpha_{r3} = \alpha_{k3} + C_0 \varepsilon \frac{\left(\frac{\Theta_{kp3stř}}{100}\right)^4 - \left(\frac{\Theta_{v3stř}}{100}\right)^4}{\vartheta_{kp3stř} - \vartheta_{v3stř}} \qquad (2)$$

where $\vartheta_{kp3stř} = \frac{\vartheta_{kp2} + \vartheta_{kp3}}{2}$, $\vartheta_{v3stř} = \frac{\vartheta_{v2} + \vartheta_{v3}}{2}$, $\Theta_n = \vartheta_n + 273$ and C_0 is Boltzman's constant.

It follows from Figure 1 that the temperature difference $\Delta\vartheta_3$ is as follows:

$$\Delta\vartheta_3 = \frac{\vartheta_{kp2} + \vartheta_{kp3}}{2} - \frac{\vartheta_{v2} + \vartheta_{v3}}{2} = \frac{1}{2}(\vartheta_{kp2} - \vartheta_{v2} + \vartheta_{kp3} - \vartheta_{v3}) \qquad (3)$$

After introducing the dependence (3) into (1), we shall obtain the temperature of the charge in the time interval t_3:

$$\vartheta_{v3} = \frac{\frac{1}{2}\alpha_3 S_v t_3 (\vartheta_{kp2} - \vartheta_{v2} + \vartheta_{kp3}) + m_v c_3 \vartheta_{v2}}{\frac{1}{2}\alpha_3 S_v t_3 + m_v c_3} \qquad (4)$$

For the i^{th} time interval t_i, the temperature of the charge is determined as given below:

$$\vartheta_{vi} = \frac{\frac{1}{2}\alpha_i S_v t_i (\vartheta_{kp(i-1)} - \vartheta_{v(i-1)} + \vartheta_{kpi}) + m_v c_i \vartheta_{v(i-1)}}{\frac{1}{2}\alpha_i S_v t_i + m_v c_i} \qquad (5)$$

The specific heat itself c_i should be accepted for the mean value of the temperature of the charge

$$\vartheta_{vistř} = \frac{\vartheta_{v(i-1)} + \vartheta_{vi}}{2} \qquad (6)$$

After calculating the other temperatures of charges according to (5), we can draw the heating characteristic of the charge $\vartheta_v = f(t)$ and read the heating period, after which the charge will reach the final temperature as follows:

$$t_n = \sum_{i=1}^{i=N} t_i \qquad (7)$$

The plotting of temperatures of the charge and the period of heating will be considerably facilitated, if we assume that the temperature in the chamber of the furnace is constant, $\vartheta_{kp} = \vartheta_0 = const$ and the temperature of the charge changes according to a parabolic function given below:

$$t = k\vartheta_v^2 \qquad (8)$$

The coefficient α is constant (the mean value for the studied temperature range). Then the equation (1) will have the following form:

$$\alpha S_v(\vartheta_0 - \vartheta_v)dt = m_v c d\vartheta_v \qquad (9)$$

The temperature difference $\Delta\vartheta = \vartheta_0 - \vartheta_v$ varies in the interval of heating. For the adopted parabolic behaviour of the temperature, we can determine the mean value of temperature difference as follows:

$$\Delta\vartheta_{stř} = \frac{1}{3}(\vartheta_0 - \vartheta_{v0}) \qquad (10)$$

After introducing the dependence (10) into the equation (9) and with regard to the fact that the final temperature of the charge is $\vartheta_{vk} = \vartheta_0$, we shall obtain

$$t_n = \frac{3m_v c(\vartheta_{vk} - \vartheta_{v0})}{S_v(\vartheta_0 - \vartheta_{v0})} \qquad (11)$$

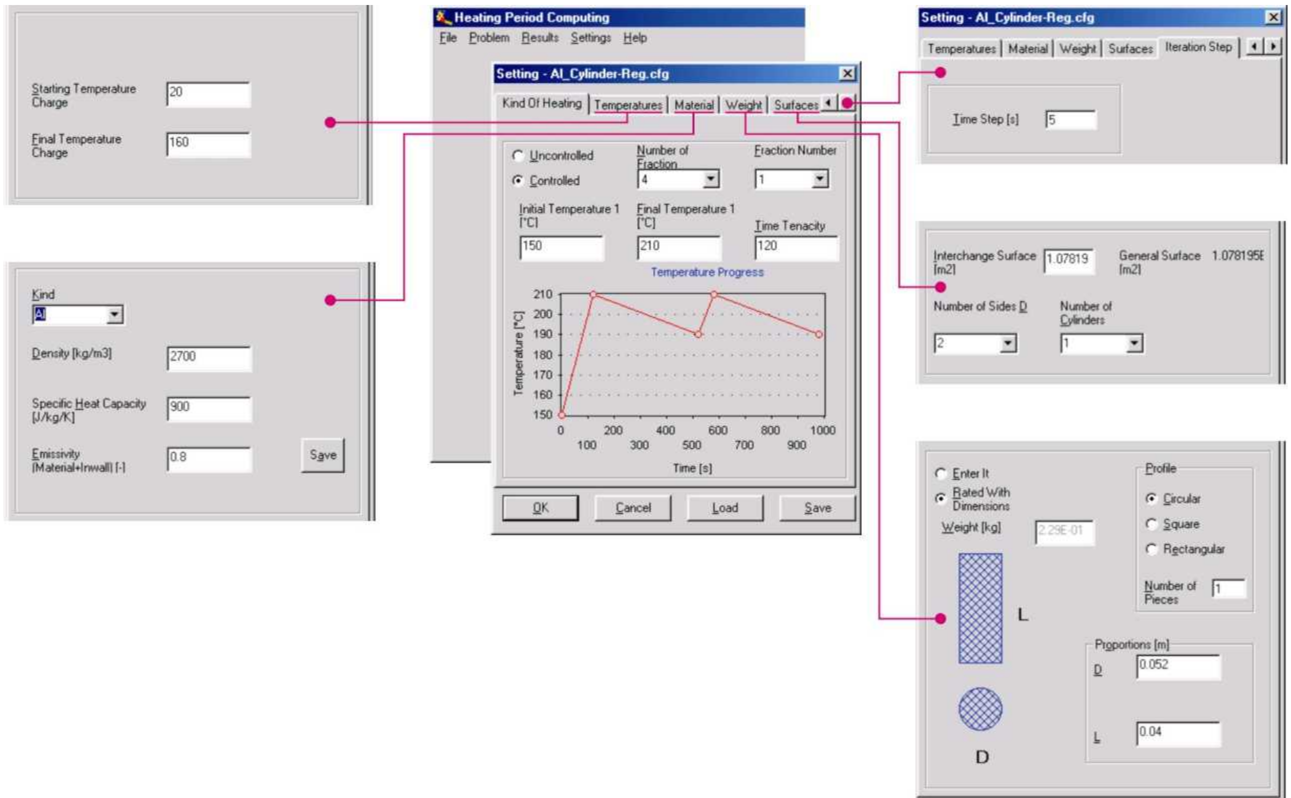
Purpose of the Programme

The Program allows determining of the time required for the heating of charge in the indirect-resistance furnace and displaying of temperature progress of the charge in time dependence. Computation is pursued by iterative-analytic method according to principles showed above and under these initial conditions:

- The temperature in the chamber of the furnace is defined by the temperature curves or it is constant
- The coefficient of heat transfer by convection is $\alpha_k = 15$ W.m^{-2}.K^{-1}

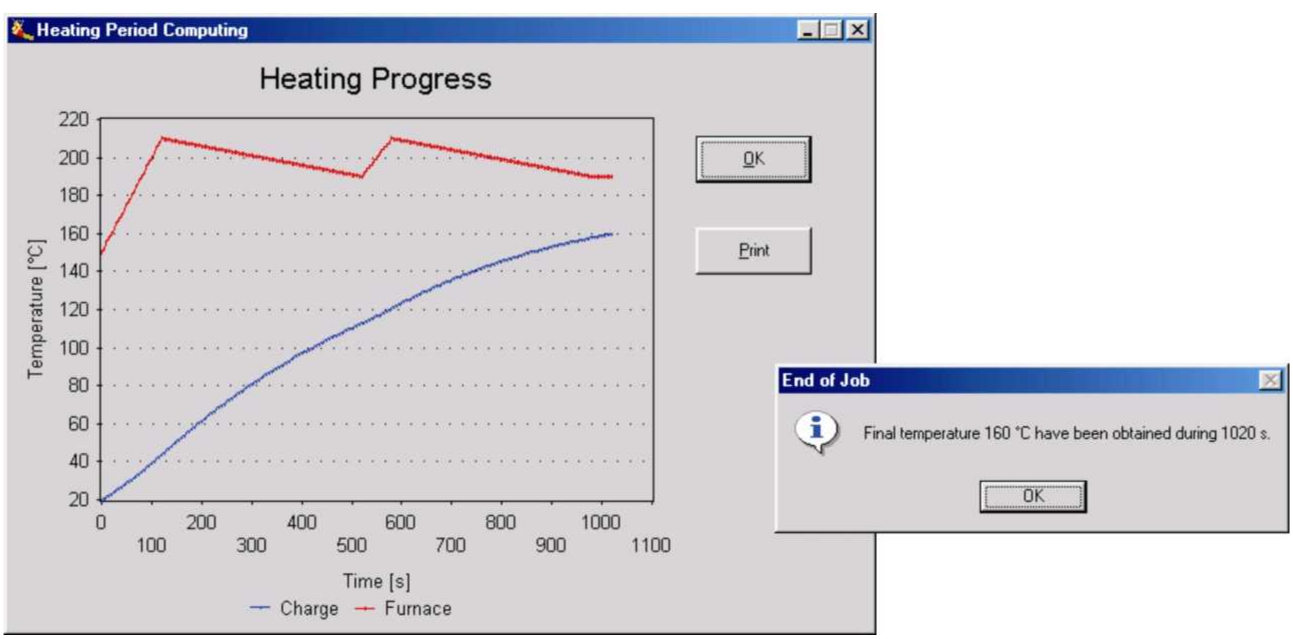
Inputs for computation are weight of material, size of interchange surfaces, the temperature in the chamber of the furnace and initial and final temperature of the heated material. Necessary material constants are saved in program database, which is possible to be complemented furthermore. Resultant temperature progress curve of the heated material is able to be displayed either in the form of table or sharply by graph. The structure of the programme including the main windows and parameter gaps is showed in Figure 2.

FIGURE. 2
THE STRUCTURE OF THE PROGRAMME – WINDOWS OF SETTINGS.



The conclusions of calculation are presented either graphically (the heating progress) either in numbers (the time needed to reach the final temperature). They are showed in Figure 3.

FIGURE. 3
THE CONCLUSIONS.



COMPUTER PROGRAMME CONFURNACE

Introduction

Electrical efficiency η_{el} of the devices used in induction heating depends, among others, on heated metal electric conductivity – it decreases with the conductivity growth. Overall efficiency (electrothermal efficiency) of crucible induction furnaces, commonly used for metal melting, is relatively small in comparison to the one of resistance furnaces. In case of non-ferrous metals melting it is only 55 to 60 %, which is the reason of excessive energy consumption.

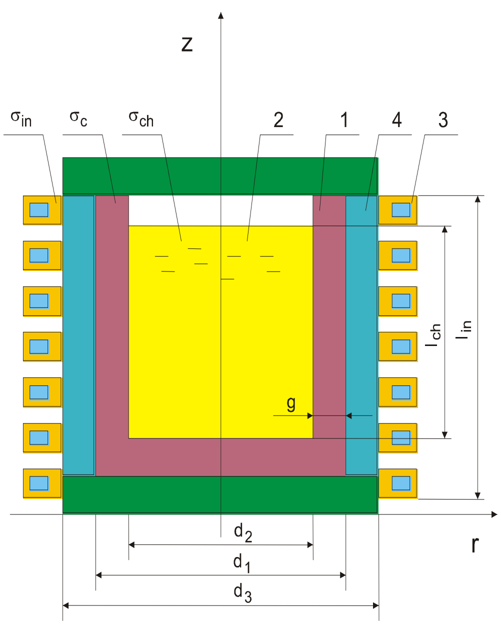
The way to improve this situation is changing induction heating method – from the direct one (in traditional furnace with ceramic crucible) to intermediate one (in conducting crucible (Figure 4a)). High electrical efficiency is obtained by proper choice of crucible material (graphite, cast iron, cast steel), its wall thickness and supply current frequency (Figure 4b). The scientists of the Department of Electrotechnology at the Silesian University of Technology have elaborated complex computational method enabling the calculation of basic electrical, thermal and operating parameters of induction furnaces with conducting crucibles, useful in computer aided designing. Methods based on the uni - dimensional analysis of electromagnetic field and temperature were used. They ensured very short calculation time and possibility of taking quick and proper decision on the basis of multi - variant analysis.

Such methods were earlier applied in computer programmes:

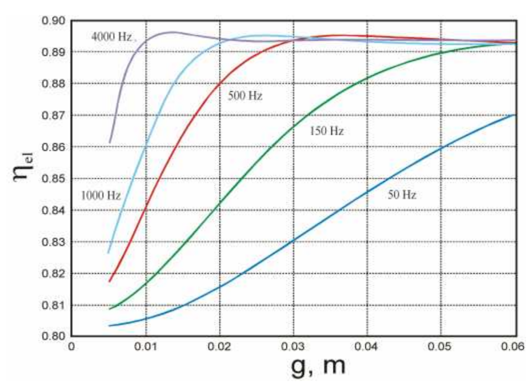
- PIT – for aiding the design of induction furnaces with ceramic crucibles,
- PIK – for aiding the design of channel – type induction furnaces,
- NISC – for aiding the design of through induction heaters to cylindrical charges.

Detailed description of these programmes and servicing instructions were presented in monograph [2].

FIGURE. 4
MODEL OF INDUCTION FURNACE WITH CONDUCTING CRUCIBLE (A) (1 – CONDUCTING CRUCIBLE, 2 – LIQUID METAL, 3 – INDUCTOR, 4 – HEAT – INSULATING LINING) AND DEPENDENCE OF ELECTRICAL EFFICIENCY UPON CRUCIBLE THICKNESS FOR DIFFERENT CURRENT FREQUENCY OF THE INDUCTOR ($\sigma_c = 0.9\ 10^6$ S/m, $\mu_c = \mu_0$, $d_2 = 0.5$ m) (B) [3].



a)



b)

Programme Algorithm

CONFURNACE programme, the simplified algorithm of which was presented in Figure 5 was made in Object Pascal (Delphi environment). In order to create user interface, standard visual elements, accessible in Delphi libraries, were used: system dialog boxes for operating files, dialog boxes with editing fields, drop-down list boxes and buttons for data input and output. Text editor with basic formatting possibilities, used to chaining, edition, record/readout and printing reports from calculations was also added. Programme handling is fully intuitive and compatible to the handling of other programmes existing in Windows operating systems. Access to particular computational modules takes place by choosing an option from the menu by the mouse or from the keyboard. In dialog boxes, numerical data are entered into editing fields and approved by an appropriate key, which results in performing necessary calculations and at the same time entering the next editing field. Exemplary dialog boxes are shown in Figures 6a – 6c. Figure 6d illustrates the way of presenting some computational results, like for example determined temperatures on the boundary of particular furnace elements: crucible, heat – insulating material, inductor. The results of different computational versions can be added to the report, creating full record of calculations. Final or fragmentary results can be also saved in separate file on a disc and then read-in again in order to continue or modify the calculations. The programme has many data bases, like for example data bases with properties of melted metals, standard parameters of supply sources, materials used to make crucibles, heat – insulating and refractory materials, dimensions of conductors and condenser parameters. To handle these data bases Borland Database Engine (BDE) was used. Browsing, adding, editing and record deletion is possible. Furnace design, which will be considered completed may be added to the project database.

CONFURNACE programme enables:

- calculation of the most important electrical, thermal and operating parameters of the furnace,
- making calculations for many variations of furnace design and choosing the best solution,
- record and readout of data and calculation results on every stage of work,
- using as a help data bases for the best choice of materials and furnace elements,
- modification and complementation of data bases,
- generating reports for every calculation stage,
- editing text of the report, its record, readout and printout.

Access to database is possible for any stage of calculation. The user is informed about errors in data entry and going beyond the range of recommended parameters. The programme, therefore, has features characteristic for design aiding programmes. Students using that programme can observe the influence of changes in furnace dimension, kind of crucible material, properties of heat-insulating materials, supply current frequency and many other factors, on basic operating parameters: energy consumption, efficiency and melting productivity.

FIGURE. 5
ALGORITHM OF FURNACE PARAMETERS CALCULATION IN CONFURNACE PROGRAMME.

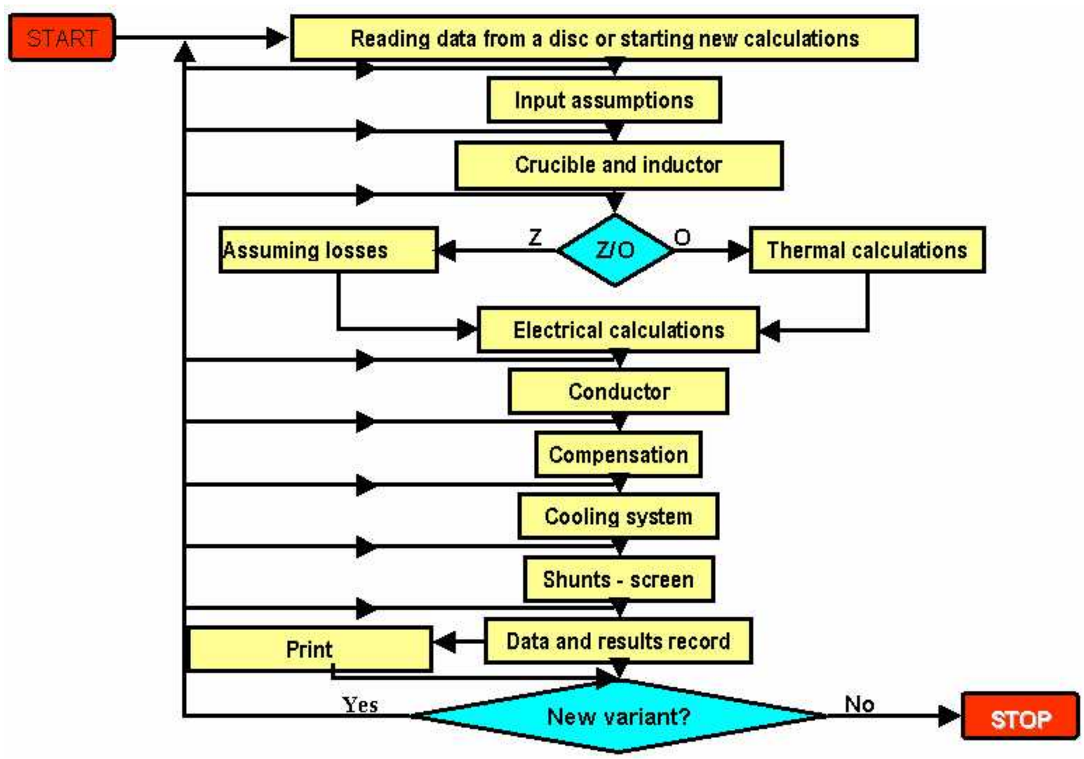
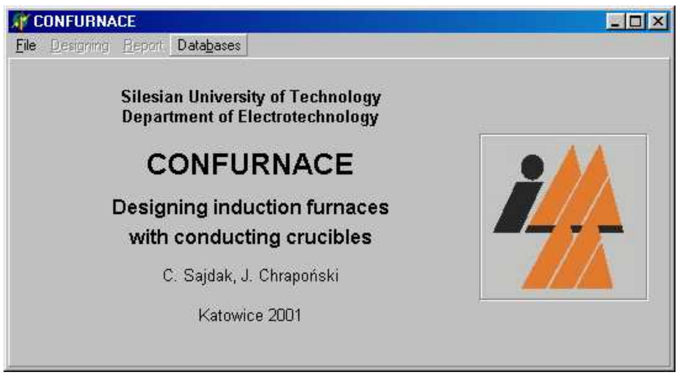
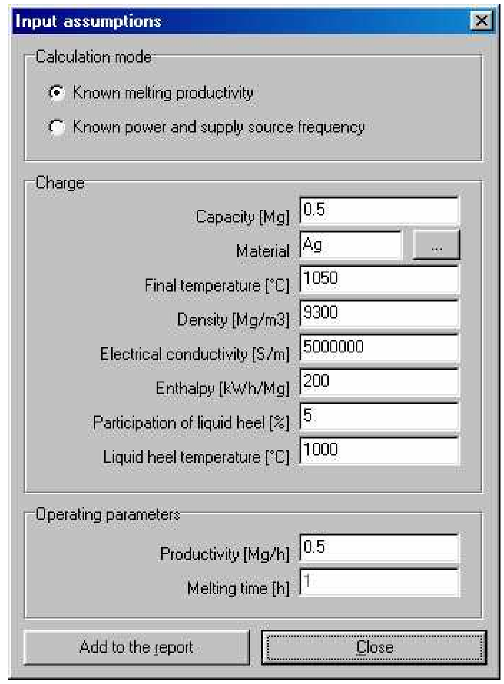


FIGURE. 6

(A) BANNER PAGE OF THE PROGRAMME; (B) DIALOG BOX „INPUT ASSUMPTIONS“; (C) DIALOG BOX „CRUCIBLE AND INDUCTOR DIMENSIONS“; (D) BOX „THERMAL CALCULATIONS – LATERAL SURFACE OF THE FURNACE“



a)



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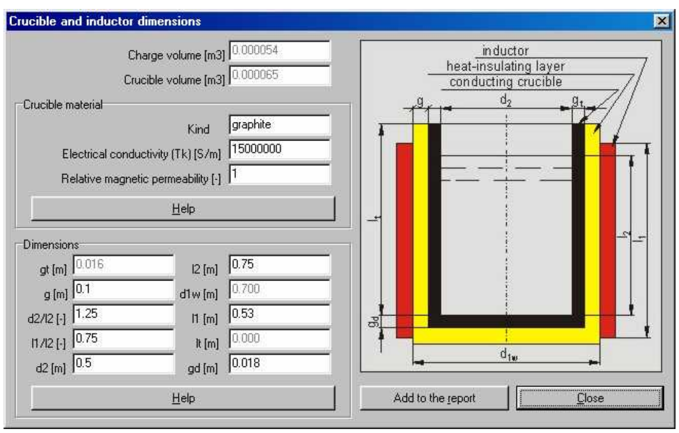

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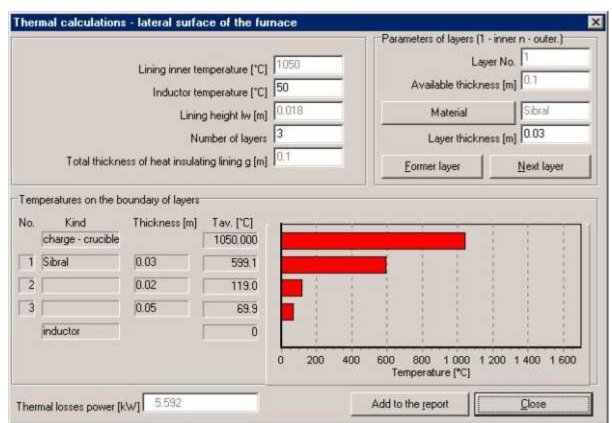

d)

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