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COMPUTER MODELING OF RATIONAL MODES OF LOCAL HEATING OF PLATE STRUCTURES IN GAS FURNACES

КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ РАЦІОНАЛЬНИХ РЕЖИМІВ МІСЦЕВОГО НАГРІВУ ПЛИТНИХ КОНСТРУКЦІЙ В ГАЗОВИХ ПЕЧАХ

The paper presents the results of a computational experiment aimed at developing rational modes of local heating of plate structures in gas furnaces. The traditional three-zone scheme with the allocation of the heating zone (the working space of the furnace), the thermal insulation zone (the areas where the product is in contact with the furnace lining) and the cooling zone (areas of the product outside the furnace), as well as the scheme with thermal insulation of zones outside the furnace (scheme A) and the introduction of buffer zones in the working space of the furnace (scheme B). A nonlinear mathematical model and a local-one-dimensional method of its implementation are used. It is established that scheme A provides a reduction in the heating time of the weld zone to a given temperature while reducing the temperature difference along the width of the heating zone, which is important from the point of view of organizing the technological process of local heat treatment. Scheme B further improves the specified characteristics of the technological process.

***Keywords**: computational experiment, mathematical model, local heat treatment, rational heating modes.*

Локальна термічна обробка великогабаритних конструкцій, виготовлених електрошлаковим зварюванням, є прогресивним ресурсозберігаючим технологічним процесом. Одним з основних етапів цього процесу є нагрів до заданої температури в умовах місцевого теплопідведення. У той же час закономірності внутрішнього і зовнішнього теплообміну в процесі місцевого нагріву за допомогою переносних газових печей вивчені ще недостатньо, що обумовлює актуальність даної роботи.

Метою дослідження є визначення на основі обчислювального експерименту можливих варіантів удосконалення технологічного процесу локальної термічної обробки плитних конструкцій у газових печах.

У роботі розглянута традиційна тризонна схема з виділенням зони нагріву (робочий простір печі), зони теплоізоляції (ділянки, де продукт контактує з футеровкою печі) і зони охолодження (ділянки продукту зовні печі), а також схеми з теплоізоляцією зон поза піччю (схема А) і введенням буферних зон в робочому просторі печі (схема Б). При проведенні обчислювального експерименту щодо традиційної схеми термообробки використана раніше розроб-

лена нелінійна математична модель, локально-одновимірний метод її реалізації та комп'ютерна програма. Для проведення обчислювального експерименту в двох інших випадках використовувалися відповідним чином модифіковані моделі, алгоритми і програми.

В результаті обчислювального експерименту встановлено, що теплоізоляція зон виробу, які розташовані поза піччю, призводить до значного зниження температурних перепадів як по всій зоні нагріву, так і в зоні шириною 0,3 м від зварного шва, що забезпечує якість технологічного процесу. Таким чином, можна стверджувати, що схема А дає переваги перед традиційною схемою локальної термічної обробки в газових печах. Зокрема, при використанні режиму термічної обробки за схемою А можна зменшити розміри газової установки для локального нагріву (знизити капітальні витрати на будівництво печі).

Схема Б додатково поліпшує задані характеристики технологічного процесу. Однак слід мати на увазі, що практична реалізація схеми Б пов'язана з переобладнанням печі і збільшенням витрат палива, тому в конкретних ситуаціях вона може не дати значного економічного ефекту. Остаточне рішення про застосування розглянутих схем в конкретних технологічних процесах вимагає проведення спеціальних розрахунків з використанням алгоритмів і програм, що використовуються в даній роботі.

***Ключові слова**: обчислювальний експеримент, математична модель, локальна термічна обробка, раціональні режими нагріву.*

Problem's formulation

Local heat treatment of large-sized structures made by electroslag welding is a progressive resource-saving technological process [1]. One of the main stages of this process is heating to a set temperature under conditions of local heat supply. At the same time, the regularities of internal and external heat transfer in this process have not yet been sufficiently studied, which requires further research in this direction. In particular, this concerns the influence of various schemes for organizing the technological process using portable gas furnaces [2].

Analysis of recent research and publications

The study of the thermal state of products of different geometries in the process of local heating is devoted to the works of a number of domestic and foreign scientists, in particular I.N. Manusov, M.M. Bilyaev, V.A. Soroka, G.F. Alekseev and others [2]. In their works, analytical methods for solving one-dimensional linear problems of thermal conductivity within the framework of two-zone models were mainly used. There are also attempts to use numerical-analytical schemes for calculating welded plate systems [3], as well as the use of finite-difference schemes to study the regularities of local heat treatment of low-carbon steel [4]. The study of the full cycle of local heat treatment of large-sized structures in gas furnaces according to various technological schemes, taking into account the two-dimensional nature of heat transfer and nonlinearities of the process, is devoted to the works [5—9]. In these works, modeling algorithms based on finite-difference methods are used using in some cases a modified method of elementary heat balances. In particular, in the works [6, 8, 9], one of the stages of local heat treatment according to the traditional scheme was considered, namely local heating of the weld zone of the slab structure. In the work [8], along with the traditional scheme, a modified scheme with heating buffer zones was used. The full cycle of local heat treatment (heating + exposure + cooling) according to a given schedule was considered in the works [5, 7]. In general, the analysis of recent studies and publications indicates the feasibility of further studies of the full cycle of local heat treatment, taking into account various schemes of organization of the technological process.

Formulation of the study purpose

The purpose of the study is to determine possible options for improving the technological process of local heat treatment of plate structures in gas furnaces on the basis of a computational experiment.

Presenting main material

The traditional scheme of local heating of products in gas furnaces involves the allocation of three different areas, on the surface of which the conditions of heat exchange with the external environment will be different (Fig. 1), i.e. a three-zone model of local heat treatment is used (zone 1 — the product in the working space of the furnace, zone 2 — the surfaces of the product are in contact with the lining of the furnace; zone 3 — the product outside the furnace).

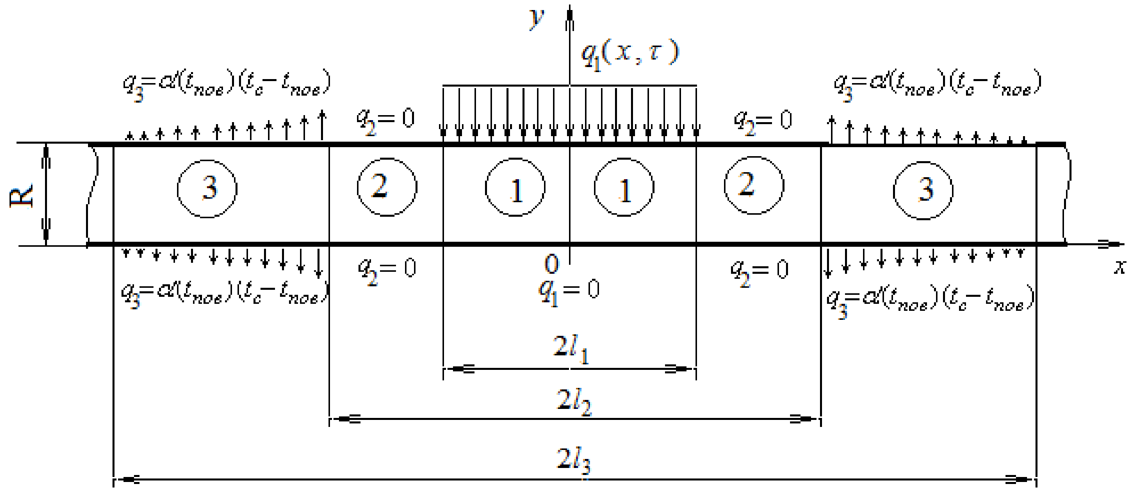

Fig. 1. Traditional thermal scheme of local stove heating [9]

Along with the traditional scheme, consider the other two. The first scheme (scheme A) provides for thermal insulation of areas of the product that are outside the stove (Fig. 2).

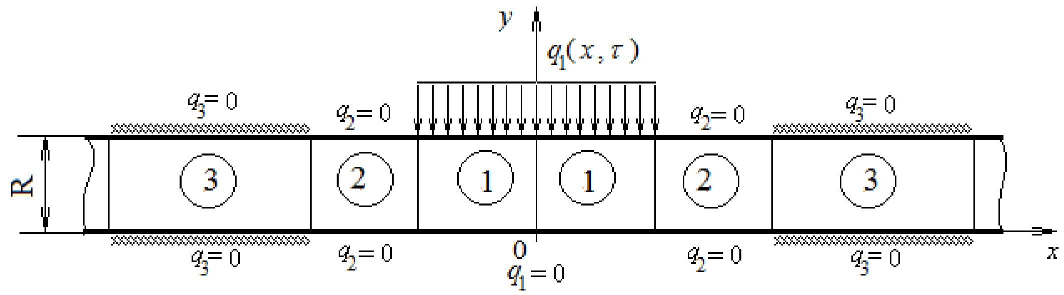

Fig. 2. Local heating scheme with thermal insulation of zone 3

Note that in scheme A, the heat exchange conditions in zones 2 and 3 will be the same, which gives grounds to use a two-zone model of local heating. This fact is used in scheme B, where, in addition to thermal insulation of sections of the product that are outside the furnace, it is planned to introduce buffer zones in the working space of the furnace with an increased heat flux density (Fig. 3).

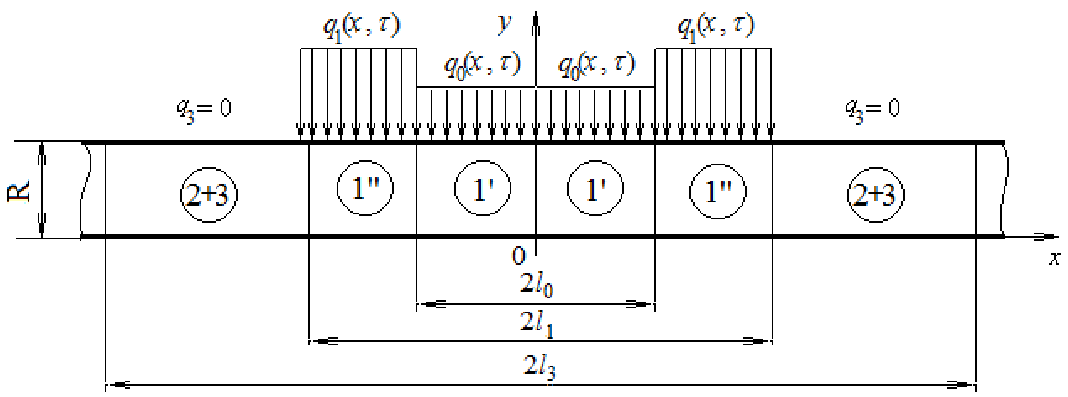

Fig. 3. Local heating scheme with buffer zones

In scheme B, in accordance with the conditions of heat exchange with the external environment, zone 1 is divided into two zones (zone 1' and zone 1"), and zones 2 and 3 are combined into one zone (zone 2+3).

A mathematical model and an algorithm for solving the problem in accordance with the traditional scheme (Fig. 1) with a known law of heat supply $q_1(x,\tau)$ are given in the paper [9]. At the same time, a two-dimensional nonlinear mathematical model and a local-one-dimensional method of its implementation with the involvement of a modified method of elementary heat balances were used to derive difference ratios at boundary points. According to the same algorithm, it is possible to simulate the thermal state of products using scheme A (it is enough to take into account that $q_3 = 0$).

When using scheme B, more significant changes should be made to the algorithm associated with the need to take into account buffer zones. However, the general approach to the modeling process remains the same, and therefore the modified algorithm is not considered in this work.

For the implementation of modified algorithms, a program was developed in the environment of the PascalABC.NET programming system, using which a computational experiment was conducted. The basic version of the object of study is characterized by the following parameters: plate thickness R = 0.2 m; zone lengths $l_1 = 0.5$ m, $l_2 = 0.8$ m, $l_3 = 1.6$ m; plate material — steel 20; initial temperature $t_0 = 20$ °C, ambient temperature (zone 3) $t_c = 20$°C. Heat flux density in the heat supply zone $q_1 = 0{,}7 \cdot 10^4$ W/m²; heat flux density in zone 3 is given by the formulas

$$q_3(x,\tau) = \alpha(t_c - t(x,R,\tau)),$$

$$\alpha = 5{,}67 \cdot 10^{-8} \cdot \varepsilon_m \left[T_n{}^3 + T_n{}^2 \cdot T_c + T_n \cdot T_c{}^2 + T_c{}^3\right] + 2{,}55 \cdot \sqrt[4]{T_n - T_c},$$

where ε_m is the degree of blackness of the surface; $T_n = t(x,R,\tau)$ +273; $T_c = t_c + 273$.

Difference grid parameters: $\Delta x = 0.05$ m; $\Delta y = 0.05$ m; $\Delta\tau = 60$ s (sec).

When using scheme A $q_3(x,\tau) = 0$, the rest of the parameters remain unchanged.

Fig. 4 shows the dynamics of changes in the temperature difference on the surface of the stove using the traditional scheme ($\Delta t_1, \Delta t_3$) and scheme A ($\Delta t_2, \Delta t_4$). At the same time Δt_1 , they Δt_2 characterize the temperature difference over the entire heating zone ($\Delta t = t(0,\tau) - t(l_1,\tau)$) , and Δt_3, Δt_4 characterize the temperature difference in a zone $l_1^* = 0.3$ m wide from the plane of symmetry of the working space of the stove ($\Delta t = t(0,\tau) - t(l_1^*,\tau)$).

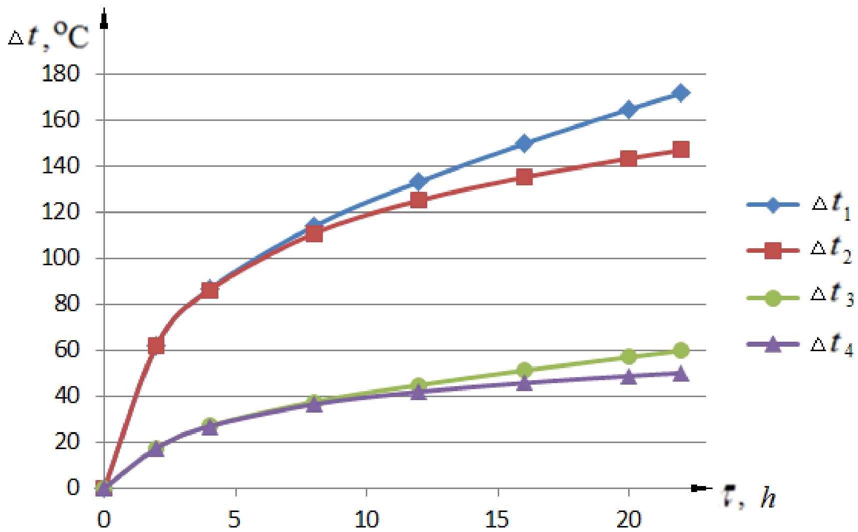

Fig. 4. Temperature changes on the surface of the product

Note that temperature differences on the surface of the product are important, since according to the conditions of the technological process of heat treatment of welded joints, they determine the quality of the process.

From Fig. 4, it can be seen that the thermal insulation of the zones of the product that are outside the furnace leads to a significant reduction in temperature differences both throughout the heating zone and in the zone 0.3 m wide from the plane of symmetry of the furnace working space. Thus, it can be argued that Scheme A provides advantages over the traditional local heat treatment scheme in gas furnaces. In particular, when using the heat treatment mode according to scheme A, it is possible to reduce the size of the installation for local heating (reduce capital costs for the construction of the furnace).

The use of scheme B leads to certain features of the formation of temperature fields compared to scheme A. Fig. 5 shows the distribution of temperatures along the length of the product for several moments of time (curves 1, 2 — $\tau = 1$ hour, curves 3, 4 — $\tau = 5$ hours, curves 5, 6 — $\tau = 12$ hours) for scheme A (curves 1, 3, 5) and scheme B (curves 2, 4, 6). It can be seen that when using circuit A, as in the case of the traditional circuit [8], the temperature curves on the surface of the product are smooth with an inflection point at the boundary of the furnace working space. When using Scheme B, the nature of the temperature curves is more complex, especially in the areas corresponding to the buffer zone. At the initial stage of heating (curve 2), even an increase in temperature is possible as you move away from the weld.

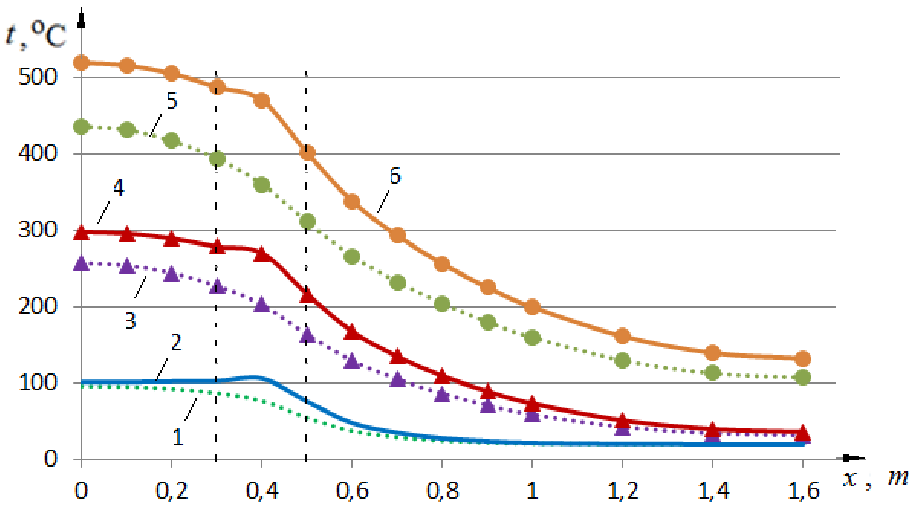

Fig. 5. Temperature fields on the surface of the product

The efficiency of using scheme B is illustrated by Fig. 6a), which shows the dynamics of temperature changes on the surface of the plate in the center of the weld (*x=0, y=R*) when using scheme A (in Figure t_1) and scheme B (in Figure t_2 and t_3). At the same time, the t_3 line corresponds to the case when the heat flux density in the buffer zone is twice the flux density in the main heating zone ($Q_1=2Q_0$), and the t_2 line corresponds to the case when $Q_1=1.5Q_0$.

From Fig. 6,a it can be seen that the heating process up to 600 °C when using scheme B is much faster, and the speed increases with an increase in the density of heat flux in the buffer zone. This is due to the fact that the buffer zone inhibits the outflow of heat to the zones outside the furnace and contributes to a more active accumulation of heat around the weld.

Fig. 6,b shows the change in temperature difference on the surface of the plate in a zone 0.3 m wide from the weld when using heating modes according to scheme A (Δt_1) and scheme B ($\Delta t_2, \Delta t_3$). It can be seen that the use of modes according to scheme B provides more uniform heating of the board in the areas adjacent to the weld. Presence on the curve Δt_3 areas where the temperature difference takes negative values confirms the previously indicated effect of temperature increase as it moves away from the weld due to the introduction of a buffer zone.

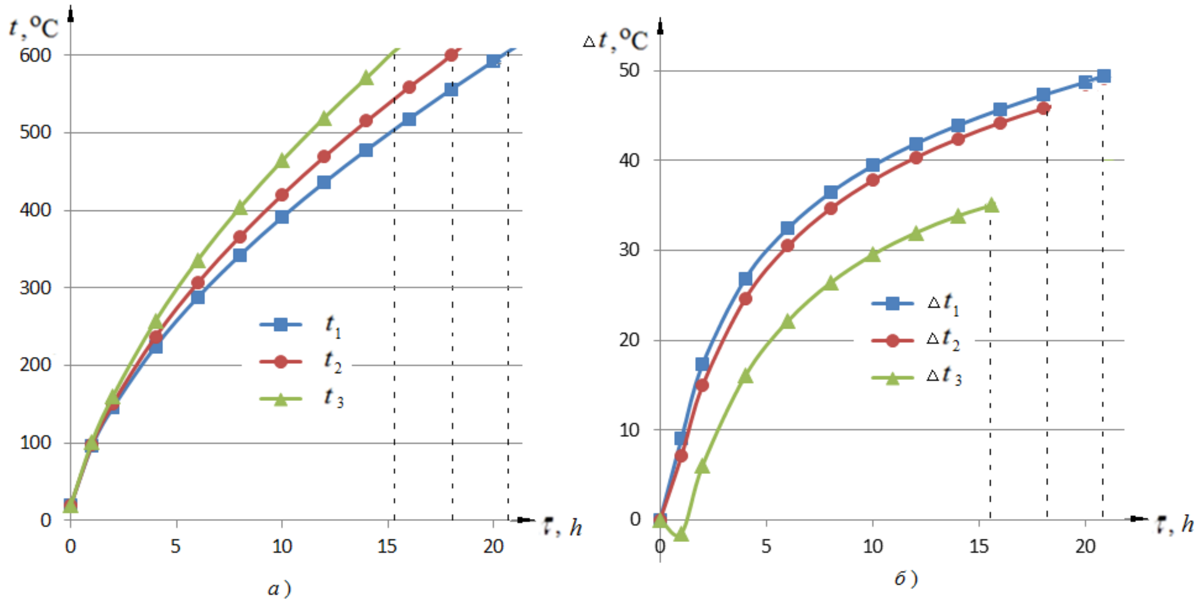

Fig. 6. Comparison of heating modes according to schemes A and B

It should be noted that the given data are of a qualitative nature, that is, they unequivocally indicate the advantages of organizing the process of local heat treatment according to scheme A compared to the traditional scheme of organizing the technological process in gas furnaces and illustrate the advantages of using scheme B compared to scheme A. However, it should be borne in mind that the practical implementation of scheme B is associated with the re-equipment of the furnace and an increase in fuel consumption, therefore, in specific situations, it may not give a significant economic effect.

Conclusions

To ensure rational modes of local heat treatment of plate structures in gas furnaces, schemes for organizing the technological process with thermal insulation of product areas outside the furnace (scheme A) and using buffer zones with increased heat flux density in the furnace working space (scheme B) are proposed. The computational experiment on these schemes was carried out using a two-dimensional nonlinear mathematical model and a local-one-dimensional method of its implementation.

The results of the computational experiment indicate that the use of scheme A provides a significant improvement in the technological process by reducing temperature differences in the limited area around the weld while reducing the duration of the heating period. The use of scheme B further improves the specified characteristics of the technological process, but in specific practical situations it may be economically unjustified due to the increase in the cost of organizing the process.

The final decision on the application of the considered schemes in specific technological processes requires special calculations using the algorithms and programs used in this work.

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