FACTORS INFLUENCING THE PRECISION OF OPTIMIZING THE VALUES OF DEFINITE SCALAR QUANTITIES ACCORDING TO THE ACCEPTED CRITERIA USED IN DESIGNING HEAT EXCHANGERS

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Abstract

The paper outlines the essential factors influencing the precision of optimizing the values of definite scalar quantities according to the criteria that are used in designing heat exchangers.

The paper refers to the method of designing heat exchangers of technical power systems in view of the required reliability of these systems described in the work [1].

Optimization is used for the velocity values of the flow of definite fluids through the heat exchanger and for the cooling fluid temperature T_2'' at the output of the definite heat exchanger, as they occur in significant relationships with definite scalar quantities in designing heat exchangers. The paper emphasizes divergences in the results of calculations of the above mentioned optimized values of definite scalar quantities on the example of designing a shell and tube condenser of marine steam turbine.

The criterion of optimizing the values of definite scalar quantities is the minimum of total costs $\min\sum_{i=1}^{n} K_i(\tau)$ in the time τ. The time is the set value τ_z and constitutes the period, in which the optimization is considered.

The paper presents the following factors: time assumption τ_z of the period, in which optimization is considered, price assumption of electrical energy KC_e consumed in order to pump the cooling water in time τ_z, assumption of the values of efficiency η_p of the pump of the cooling water in time τ_z, assumption of the values of the friction factor λ_{str2} of the inside surfaces of the condenser tube in time τ_z, at the cooling water flow, the selection of a model of the function determining the Nusselt number Nu_2 from the set of models that can be used in a given designing case, price assumption (the selection of a manufacturer) of heat exchanger area KC_A of a shell and tube condenser, assumption of the forecasted thickness δ_{os2} of fouling on the heat exchanger area from the side of the flow of the condenser cooling water in time τ_z.

Finally, the conclusions resulting from the paper's contents are presented.

Keywords: *optimization, heat exchangers, design*

1. Introduction

The aim of the paper is to show the influence of particular factors on the accuracy of rating the optimized scalar quantities values: velocity w_2 of the cooling fluid flow and temperature T_2'' of this fluid on the output of the heat exchanger according to the adopted criteria for optimization in designing heat exchangers. Then, to emphasize significance of particular factors while making designing decisions that concern the implementation of the values of these definite scalar quantities into computations. Computational examples refer to a shell and tube condenser of marine steam turbine with the water installation cooling this condenser. The paper considers models and algorithms contained in work [1].

The optimization presented in work [1] consists in balancing the overall costs $K_C(\tau)$ of the definite heat exchanger together with the installations connected with it (including the installations of pumps, fittings, pipes and other elements together with fluids exchanging heat), in time τ [1]:

$$K_C(\tau) = K_{Iwc}(\tau) + K_{Iinst}(\tau) + K_{Ewc}(\tau) + K_{Einst}(\tau), \tag{1}$$

where:
$K_{Iwc}(\tau)$ – investment costs of the definite heat exchanger, in time τ, PLN,
$K_{Iinst}(\tau)$ – investment costs of the installation of fluids exchanging heat of the definite heat exchanger, in time τ, PLN,
$K_{Ewc}(\tau)$ – operation costs of the definite heat exchanger, in time τ, PLN,
$K_{Einst}(\tau)$ – operation costs of the installation of fluids exchanging heat of the definite heat exchanger, in time τ, PLN.

Investment costs $K_{Iwc}(\tau)$ of the definite heat exchanger in time τ, according to work [2], refer to the whole operation period. These are the costs connected with the investment involving the heat exchange area and also other elements, which the definite heat exchanger is composed of, the costs of elements of the heat exchanger $K_{i,elwc}(\tau)$, including the costs $K_{mwc}(\tau)$ of assembling this exchanger and of depreciation in the situation when the investment is realized with our own funds.

The investment costs of the installation $K_{Iinst}(\tau)$ of fluids exchanging heat in the definite heat exchanger are analogous to the earlier indicated costs connected with the heat exchanger: the costs $K_{i,elinst}(\tau)$ of installation elements and the costs $K_{minst}(\tau)$ of the installation assembly.

The operation costs $K_{Ewc}(\tau)$ of the definite heat exchanger, in time τ include: the costs $K_{czwc}(\tau)$ of cleaning heat exchange areas of the definite heat exchanger, the costs $K_{rwc}(\tau)$ of preventive replacements of particular elements of the heat exchanger, the costs of surveys and repairs of the heat exchanger and the costs $K_{pwc}(\tau)$ of diagnosing the exchanger during its operation in the technical energy system. The operation costs $K_{Einst}(\tau)$ of the installation of fluids exchanging heat in the definite heat exchanger, in time τ include: the costs $K_{finst}(\tau)$ of installation operation (the costs of pumping fluids exchanging heat, including the costs of electrical energy and fluids), the costs $K_{rinst}(\tau)$ of surveys and repairs of technical installations and the costs $K_{pinst}(\tau)$ of diagnosing the installations during the operation of the technical energy system.

The adopted criterion for optimizing values of the indicated designing scalar quantities is the minimum sum of the overall costs $min\sum_{i=1}^{n} K_i(\tau)$ in time τ. Time τ is the set value τ_z and it constitutes the period, in which optimization is considered; and it results from the adopted criterion in the optimization of the technical energy system, in which the definite heat exchanger occurs.

In order to calculate $min\sum_{i=1}^{n} K_i(\tau_z)$ in time τ_z, the following dependences were determined:

$$K_C(\tau_z) = f(w_2),\ K_C(\tau_z) = f(T_2''). \tag{2}$$

Limitations in the velocity w_2 of the definite fluid, in this optimization, are maximal and minimal values of the quantity $[w_{2,min}, w_{2,max}]$. The minimum value $w_{2,min}$ results from the relationship between the velocity of the definite fluid flow and fouling settlements on the heat exchange area, the maximal value $w_{2,max}$ results from the relationship between the velocity of the definite fluid flow as well as erosion and cavitation [1].

Limitations in temperature T''_2 of the cooling fluid on the output of the heat exchanger are maximal and minimal values of this quantity $[T''_{2,min}, T''_{2,max}]$. The minimal value $T''_{2,min}$ is limited by the value of temperature on the input of the heat exchanger, whereas the maximal value $T''_{2,max}$ results from the relationship between the cooling fluid temperature and precipitations of fouling (salt) on the heat exchange area [1].

The rated optimal values of the distinguished quantities, i.e. the velocity $w_{2,opt}$ of the cooling fluid flow and the optimal temperature $T''_{2,opt}$ of this fluid on the output of the exchanger, are again implemented into designing as another feedback after checking if they are contained in the earlier defined intervals $\left[w_{2,min}, w_{2,max}\right]$ and $\left[T''_{2,min}, T''_{2,max}\right]$. Next, the repeat designing computations for the definite heat exchanger are made and its overall costs are rated in the set time τ_z. The ultimate values of the optimized scalar quantities are accepted in designing the definite heat exchanger after meeting the distinguished designing conditions, which refer to particular features of the heat exchanger, including the desired reliability value $R_{wc}(t_z)$ of the heat exchanger, in the set time (life) t_z, definite maximal dimensions $L_{wc\max,j}$ of the heat exchanger and its maximal weight $G_{wc\,max}$ together with fluids exchanging heat [1].

The expansion of the equation (1) in relation to the condenser of marine steam turbine together with the installation is the following dependence [1]:

$$K_C(\tau_z)=\left(\frac{d_w}{d_z\alpha_1}+\frac{d_w\delta_s}{d_{sr}\lambda_s}+\frac{d_w^{0.2}v_2^{0.8}}{0{,}023\,\mathrm{Pr}_2^{0.4}\,\lambda_2}\frac{1}{w_2^{0.8}}\right)\dot{Q}_2(KC_A)\frac{\ln\dfrac{T_1-T'_2}{T_1-T''_2}}{T''_2-T'_2}+\sum_{i=1}^{m}K_{i,elwc}(\tau_z)+K_{mwc}(\tau_z)+K_{czwc}(\tau_z)+K_{pwc}(\tau_z)+K_{rwc}(\tau_z)+$$

$$+\sum_{i=1}^{m}K_{i,elinst}(\tau_z)+\frac{\dot{Q}_2\tau_z(KC_e)}{2c_{p2}\,(T''_2-T'_2)\,\eta_{p2}}\left(\frac{l}{d_w}\lambda_{str\,2}+\xi'+\xi''\right)w_2^2+\frac{\dot{Q}_2w_{2k}^2\tau_z(KC_e)}{2c_{p2}\,(T''_2-T'_2)\,\eta_{p2}}\left(2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str\,2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)+K_{pinst}(\tau_z)+K_{rinst}(\tau_z).\quad(3)$$

where:

$c_{p,2}$ – specific heat at constant pressure p, J/kgK,
d_w – inside diameter of the condenser pipes, m,
d_{winst} – inside diameter of the installation pipes of the water cooling the condenser, m,
d_z – outside diameter of the condenser pipes, m,
T_j' – temperature of the j-th fluid on the input of the condenser, K,
T_j'' – temperature of the j-th fluid on the output of the condenser, K,
l – length of the condenser pipes, m,
l_{inst} – length of the installation of the water cooling the condenser, m,
$\dot{Q}_2$ – heat flow of the water cooling the condenser, W,
α_1 – heat transfer coefficient of taking heat from the condensing steam to the pipes walls of the condenser, W/m^{2}K,
w_{2k} – velocity of the cooling water flow through the input stub pipes to the condenser, m/s,
δ_s – thickness of the pipe wall of the condenser element, m,
η_{p2} – efficiency of the water pump cooling the condenser,
λ_s – thermal conductivity of the element wall of the heat exchange area, W/mK,
$\lambda_{str2inst}$ – friction resistance factor, at the flow of the cooling water, of the inside surfaces of the condenser installation,
λ_2 – thermal conductivity of fluid of the water-cooling the condenser, W/mK,
$\lambda_{str\,2}$ – friction resistance factor, at the flow of the cooling water, of the inside surfaces of the condenser pipes,
v_2 – coefficient of kinematic viscosity of fluid of the water cooling condenser, value for the mean temperature in the core of the flowing water, m^2/s,
$\xi_{i,elinst}$ – local resistance coefficient of the i-th element of the water installation cooling the condenser,
ξ_k – local resistance coefficient of the input stub pipe through which the cooling water flows to the condenser,
ξ' – local resistance coefficient at the input of the cooling water to the condenser pipes,
ξ'' – local resistance coefficient at the output of the cooling water from the condenser pipes,
τ_z – set time of the condenser operation in the engine room of a ship, h.

2. Factors influencing the accuracy of rating the values of optimized scalar quantities in designing shell and tube condensers of marine steam turbines

The set time τ_z of the period, in which optimization is considered. For design computations, one can adopt the time necessary to clean the condenser, then the time, which results from the calculated annual overall costs of the technical energy system, or the total operation time of the condenser. Implementing the set time τ_z into the design computations is essential from the point of view of the following relationships. Firstly, between the time τ_z and the costs of electrical energy KC_e, which result mainly from both the costs of fuel and the technical condition of the ship engine room. Secondly, from the relationship between the time τ_z and the value of efficiency η_p of the pump of the cooling water in time τ_z. Next, from the relationship between the time τ_z and the value of the friction resistance factor $\lambda_{str\ 2}$, at the flow of the cooling water, of the inside surfaces of the condenser pipes. Here, there is a problem of selecting the forecasted values of the above-mentioned scalar quantities, which in turn affects the accuracy of rating the values of the optimized scalar quantities. The selection of the function model determining the Nusselt number Nu_2 from the set of models that can be used in a given designing case. The exemplary set of such models is presented in work [1]. It must be emphasized that there is a divergence of the rated results for the value of the Nusselt number Nu_2, which affects the accuracy of rating the value of the heat transfer value α_2, and consequently the accuracy of rating the values of the optimized scalar quantities. For the computational example, the following models were implemented:

$$Nu_2 = 0.023\,\mathrm{Re}_2^{\ 0.8}\,\mathrm{Pr}_2^{\ 0.4}\text{, where: } \mathrm{Re}_2 > 10\,000,\ 0.7 < \mathrm{Pr}_2 < 100,\ \frac{l}{d_w} > 60\ [3], \tag{4}$$

$$Nu_2 = 0.023\mathrm{Re}_2^{0.8}\,\mathrm{Pr}_2^{\frac{1}{3}}\text{, where: } \mathrm{Re}_2 > 10\,000,\ 0.7 < \mathrm{Pr}_2 < 160,\ \frac{l}{d_w} > 60\ [4], \tag{5}$$

$$Nu_2 = 0.032\,\mathrm{Re}_2^{0.8}\,\mathrm{Pr}_2^{0.37}\left(\frac{l}{d_w}\right)^{-0.054}\text{, where: } 10\,000 < \mathrm{Re}_2 < 500\,000,\ 0.7 < \mathrm{Pr}_2 < 370\ [4]. \tag{6}$$

Another factor is assumption of the price of heat exchange area KC_A of the condenser in the designing stage. The price of pipes depends mainly on the current stock exchange prices of materials, i.e. for instance copper, and also on competitive commercial offers of companies manufacturing pipes. For these reasons, the price can be the subject to changes in time, which in turn affects the accuracy of rating the optimized values.

The assumption of the forecasted thickness of fouling δ_{os2} on the heat exchange area from the side of the flowing water cooling the condenser in time τ_z affects the accuracy of rating the values of the optimized scalar quantities mainly because of resistances of the water flow cooling the condenser that are changeable in time τ_z.

3. The influence of factors determining the accuracy of rating the values of optimized scalar quantities in designing shell and tube condensers of marine steam turbines – computational examples

The computational examples were based on the models (7) and (8), which resulted from the dependences (2) and (3) [1]:

$$w_{2,opt,i} = \exp\left[\frac{1}{2.8}\ln\left(\frac{0.8 d_w^{0.2}\nu_2^{0.8}\left(KC_A\right)c_{p2}\left(T''_2 - T'_2\right)\eta_{p2}}{\Delta T_{sr}\,0.023\,\mathrm{Pr}_2^{0.4}\,\lambda_2\tau_z\left(KC_e\right)\left(\frac{l}{d_w}\lambda_{str2} + \xi' + \xi'' + 2\xi_k + \frac{l_{inst}}{d_{winst}}\lambda_{str2inst} + \sum_{i=1}^{m}\xi_{i,elinst}\right)}\right)\right], \tag{7}$$

$$T''_{2,opt,i} = T_1 - \exp\left[-1-\frac{\tau_z (KC_e) w_2^2\left(\frac{l}{d_w}\lambda_{str2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}{2c_{p2}\,\eta_{p2}\left(\frac{1}{d_z\alpha_1}+\frac{\delta_s}{d_{sr}\lambda_s}+\frac{\nu_2^{0.8}}{0.023 d_w^{0.8}\,\mathrm{Pr}_2^{0.4}\,\lambda_2 w_2^{0.8}}\right)d_w (KC_A)}\right]. \quad (8)$$

The following values of definite scalar quantities resulting from the dependence (3) were assumed in order to show exemplary differences in the computational values of the optimized scalar quantities.

Computational assumptions: d_z=0.02 m, d_w=0.015 m, d_{winst}=1.146 m, kind of material of pipes Cu Zn20 AI2 [5] λ_s=100.38 W/mK, l=8 m, l_{inst}=80 m, T_1=333 K, T'_2=293 K, on the basis of [6] α_1=300 W/m^{2}K, on the basis of [7] ξ'=15, ξ''=18, ξ_k=16, $\lambda_{str2inst}$=0,05, $\sum_{i=1}^{m}\xi_{i,elinst} = 54$, next [8] $c_{p,2}$=4049 J/kgK, Pr$_2$=6.1, ν_2=0.868∗10^{-6} m^2/s, λ_2=0.58175 W/mK. Referring to the literature [8,5] the following limitations of the velocity of the flow of the cooling water $w_{2,opt}$=[1, 3] and the temperature [9] $T''_{2,opt}$=[294, 313] were assumed.

The first example: the set time τ_z of the period, in which the optimization is considered. The following values of times were assumed: $\tau_{z,1}$=720h, $\tau_{z,2}$=8640h, $\tau_{z,3}$ =129600h, later KC_e=0.0001678 [PLN/Wh], KC_A=818.5 [PLN/m^2], η_{p2}=0.75, λ_{str2}=0.026 and then they were entered into the dependences (7) and (8). The following computational results were obtained: $w_{2,opt,1}$=2.84 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.17 m/s, $T''_{2,opt,2}$=332.64K, $w_{2,opt,3}$=0.44 m/s, T''_2=332.65K.

The second example: price assumption of electrical energy KC_e consumed in order to pump the cooling water in time τ_z. The following prices were assumed on the basis of the prices of the electrical energy on the Balancing Market [10]: $KC_{e,1}$=0.00008 [PLN/Wh], $KC_{e,2}$=0.0001678 [PLN/Wh], $KC_{e,3}$=0.00025 [PLN/Wh], and $\tau_{z,2}$=8640h, etc. as above. The following computational results were obtained: $w_{2,opt,1}$=1.52 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.17 m/s, $T''_{2,opt,2}$=332.64K, $w_{2,opt,3}$=1.01 m/s, T''_2=332.64K.

The third example: efficiency η_p of the pump of the cooling water in time τ_z. The following efficiencies of the pump were assumed: $\eta_{p2,1}$=0.9, $\eta_{p2,2}$=0.75, $\eta_{p2,3}$=0.6, and $\tau_{z,2}$=8640h, $KC_{e,2}$=0.0001678 [PLN/Wh], etc. as above. The following computational results were obtained: $w_{2,opt,1}$=1.25 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.17 m/s, $T''_{2,opt,2}$=332.64K, $w_{2,opt,3}$=1.08 m/s, T''_2=332.64K.

The fourth example: the friction factor λ_{str2} of the inside surfaces of the condenser tube in time τ_z, at the cooling water flow. On the basis of [7] the following values of this factor were assumed: for new pipes $\lambda_{str2,1}$=0.023, for an old pipe $\lambda_{str2,2}$=0.04, etc. as above. The following computational results were obtained: $w_{2,opt,1}$=1.17 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.15 m/s, $T''_{2,opt,2}$=332.64K.

The fifth example: selection of a model of the function determining the Nusselt number Nu_2 from the set of models that can be used in a given designing case. After implementing the models (4), (5), (6) into the model (3) and the appropriate transformations the following dependences were obtained:

$$w_{2,opt,2} = \exp\left[\frac{1}{2.8}\ln\left(\frac{0.8 d_w^{0.2}\nu_2^{0.8}(KC_A)c_{p2}(T''_2 - T'_2)\eta_{p2}}{\Delta T_{sr}\,0.023\,\mathrm{Pr}_2^{1/3}\,\lambda_2\tau_z (KC_e)\left(\frac{l}{d_w}\lambda_{str2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}\right)\right], \quad (9)$$

$$T''_{2,opt,2} = T_1 - \exp\left[-1-\frac{\tau_z (KC_e) w_2^2\left(\frac{l}{d_w}\lambda_{str2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}{2c_{p2}\,\eta_{p2}\left(\frac{1}{d_z\alpha_1}+\frac{\delta_s}{d_{sr}\lambda_s}+\frac{\nu_2^{0.8}}{0{,}023 d_w^{0.8}\,\mathrm{Pr}_2^{1/3}\,\lambda_2 w_2^{0.8}}\right)d_w (KC_A)}\right], \quad (10)$$

$$w_{2,opt,3}=\exp\left[\frac{1}{2.8}\ln\left(\frac{0.8d_w^{0.2}\nu_2^{0.8}(KC_A)c_{p2}(T''_2-T'_2)\eta_{p2}}{\Delta T_{sr}0.023\,\mathrm{Pr}_2^{0.37}\left(\frac{l}{d_w}\right)^{-0.054}\lambda_2\tau_z(KC_e)\left(\frac{l}{d_w}\lambda_{str2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}\right)\right], \quad (11)$$

$$T''_{2,opt,3}=T_1-\exp\left[-1-\frac{\tau_z(KC_e)w_2^2\left(\frac{l}{d_w}\lambda_{str2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}{2c_{p2}\eta_{p2}\left(\frac{1}{d_z\alpha_1}+\frac{\delta_s}{d_{sr}\lambda_s}+\frac{\nu_2^{0.8}}{0{,}023d_w^{0.8}\,\mathrm{Pr}_2^{0.37}\left(\frac{l}{d_w}\right)^{-0.054}\lambda_2w_2^{0.8}}\right)d_w(KC_A)}\right]. \quad (12)$$

The figures were implemented as in the first example and the following computational results were obtained: $w_{2,opt,1}$=1.17 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.22 m/s, $T''_{2,opt,2}$=332.64K, $w_{2,opt,3}$=1.34 m/s, T''_2=332.64K.

The sixth example: price assumption (selection of a manufacturer) of heat exchanger area KC_A of a shell and tube condenser. The following values of KC_A were assumed taking into account the stock exchange prices of copper [11] and the assumed costs of pipe production on the level of 40% of the copper price: $KC_{A,1}$=734 [PLN/m^2], $KC_{A,2}$=903 [PLN/m^2], $KC_{A,3}$=818.5 [PLN/m^2]. The remaining figures were implemented as in the first example and the following computational results were obtained: $w_{2,opt,1}$=1.12 m/s, $T''_{2,opt,1}$=332.64K, $w_{2,opt,2}$=1.17 m/s, $T''_{2,opt,2}$=332.64K, $w_{2,opt,3}$=1.21 m/s, T''_2=332.64K.

The seventh example: assumption of the forecasted thickness δ_{os2} of fouling on the heat exchanger area from the side of the flow of the condenser cooling water in time τ_z. After the appropriate transformations of the model (3) the following dependences were obtained:

$$w_{2,opt,i}=\exp\left[\frac{1}{2.8}\ln\left(\frac{0.8d_{w,os2}^{0.2}\nu_2^{0.8}(KC_A)c_{p2}(T''_2-T'_2)\eta_{p2}}{\Delta T_{sr}0.023\,\mathrm{Pr}_2^{0.4}\lambda_2\tau_z(KC_e)\left(\frac{l}{d_{w,os2}}\lambda_{str2,os2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}\right)\right], \quad (13)$$

$$T''_{2,opt,i}=T_1-\exp\left[-1-\frac{\tau_z(KC_e)w_2^2\left(\frac{l}{d_{w,os2}}\lambda_{str2,os2}+\xi'+\xi''+2\xi_k+\frac{l_{inst}}{d_{winst}}\lambda_{str2inst}+\sum_{i=1}^{m}\xi_{i,elinst}\right)}{2c_{p2}\eta_{p2}\left(\frac{1}{d_z\alpha_1}+\frac{\delta_{os1}}{d_{sr}\lambda_{os1}}+\frac{\delta_s}{d_{sr}\lambda_s}+\frac{\delta_{os2}}{d_{sr}\lambda_{os2}}+\frac{\nu_2^{0,8}}{0.023d_{w,os2}^{0.8}\,\mathrm{Pr}_2^{0.4}\lambda_2w_2^{0.8}}\right)d_w(KC_A)}\right]. \quad (14)$$

The following values of the definite scalar quantities were assumed for computations using the dependences (13) and (14): inside diameter $d_{w,os2}$ of the condenser pipe decreased by the assumed thickness of fouling δ_{os2}=0.5 mm from the inside of the pipe, the friction factor λ_{str2}=0.04 of the inside surfaces with fouling of the condenser tube in time τ_z, at the cooling water flow, and $\tau_{z,2}$=8640 h, then on the basis of [11] the values of proper thermal resistance on both heat exchange areas $r_{os1,2}$=0.000176 m^{2}K/W for computations using the dependence (14). The remaining figures were implemented as in the first example and the following computational results were obtained: clean heat exchange area $w_{2,opt,1}$=1.17 m/s, $T''_{2,opt,1}$=332.64K, heat exchange area with fouling $w_{2,opt,2}$=1.14 m/s, $T''_{2,opt,2}$=332.64K.

4. Conclusions

On the basis of the computational examples presented in the paper it is possible to conclude that:

- the biggest differences between the computational results occur while rating the optimal value of the velocity $w_{2,opt}$ of the water flow cooling the condenser,
- the most essential factor conditioning the accuracy of rating the optimal value of the velocity $w_{2,opt}$ of the water flow cooling the condenser is to assume in a designing process of a condenser the value of the set time τ_z, which results from the adopted criterion in the optimization of the technical energy system, in which the definite condenser appears due to the following relationships: between the time τ_z and the electrical energy costs KC_e, which are the results of both fuel prices and the technical condition of the ship engine room and between the time τ_z and the efficiency η_{p2} of the pump of the water cooling the condenser, because it is difficult to select the proper (forecasted) values of KC_e and η_{p2} in the designing stage,
- another factor conditioning the accuracy of rating the optimal value of the velocity $w_{2,opt}$ of the water flow cooling the condenser is to select the function model determining the Nusselt number Nu_2 from the set of models that can be used in a given designing case,
- the other factors, i.e. assumptions of the following values: the friction factor $\lambda_{str\,2}$, the price of heat exchange area KC_A of the condenser, the forecasted thickness of fouling δ_{os2} on the heat exchange area from the side of the flow of the water cooling the condenser in the time τ_z, do not have any significant influence on the computational results $w_{2,opt}$ in relation to the above mentioned factors,
- all the rated values of the temperature $T''_{2,opt}$ of the cooling water on the output of the condenser are bigger than the maximal value of the temperature $T''_{2,max}$ from the previously determined interval, which means that for the optimal value of the temperature $T''_{2,opt}$ the value $T''_{2,max}$ is assumed, which results from the relationship between the temperature of the cooling fluid and fouling (salt) on the heat exchange area of the condenser. On the other hand, the factors conditioning the accuracy of rating the optimal value of this scalar quantity in this case do not have any essential significance in designing the condenser.

While designing a condenser of ship steam turbine, it is possible to determine the interval of the optimal values of the velocity $w_{2,opt}$ of the water flow cooling the condenser, which is contained within the definite limitations, and then to make a deliberate choice of the value $w_{2,opt}$ from the interval of permissible computational results taking into account the conditions, in which this condenser will be used.

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