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To cite this article: Yulia Kibartene *et al* 2022 *J. Phys.: Conf. Ser.* **2211** 012019

Studies of Dynamic Processes and Simulation Results in the Exchange of Energy in Energy Components

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Abstract. The paper presents some results of numerical simulation of processes for the problem of stabilization of thermal regimes at dynamic exchange of thermal energy in the energy components of generation, cogeneration, trigeneration (polygeneration with H_2C), described by aperiodic links with delay and perturbations. The results of the research are presented in relative values for the comparison of the open-loop heat exchange system with perturbations and for the control options by deviation of the output coordinate, as well as by perturbation and by their combination. In particular, in the form of graphical dependences of the output temperature, dynamic perturbation and control action for five predetermined variants of parameters of dynamic links with the calculated duration of processes of 200 seconds. This makes it possible to study the stabilizing properties of heat exchange equipment when they are used in similar technologies for coal-fired, gas-fired or other thermal power plants, as well as for industrial process thermal equipment. The simulation tool MatlabSimulink was used.

1. Introduction

Technological processes of heat energy devices with elements of industrial heat generation, including cogeneration or trigeneration plants, as well as H_2C, are characterized in almost all applications by exchange of thermal energy with the transfer of heat energy from more heated bodies or heat carriers to less heated bodies or through them to liquid (such as water) or gas (steam-gas) streams [1,2,3,4,5,6,7,8]. These processes of heat energy transfer occur in technical objects through the use of special devices - heat exchangers. They can be implemented in the form of various in size and volume devices, and can have a very diverse design. At the same time, the principle of operation remains the same. To study the operation of a HE, as one of the main types of heat power and heat engineering equipment, let's consider a generalized in some sense model of a HE, the flow diagram of which is shown in Fig. 1. Once again, let's note that the presented model, despite of its simple design, fully reflects all processes, which can be transferred to equipment of any size and thermal capacity with sufficient degree of reliability.

The task of this research is to analyze the possibilities of applying the MatlabSimulink [3,7] simulation tool to visualize the results of calculations of the dynamic properties of HE stabilization on the example of HE described by aperiodic models with delays and control and perturbation correction links.

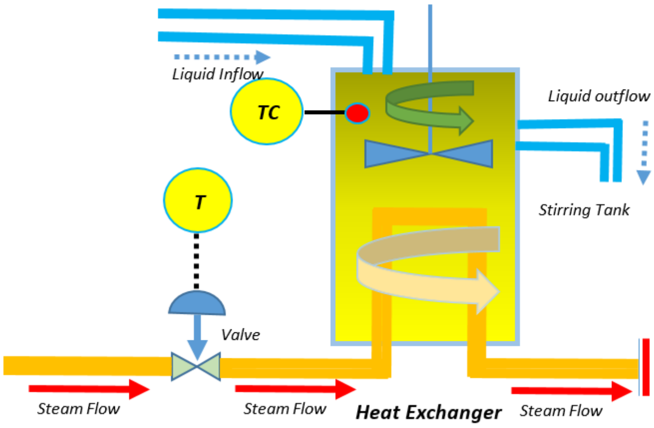
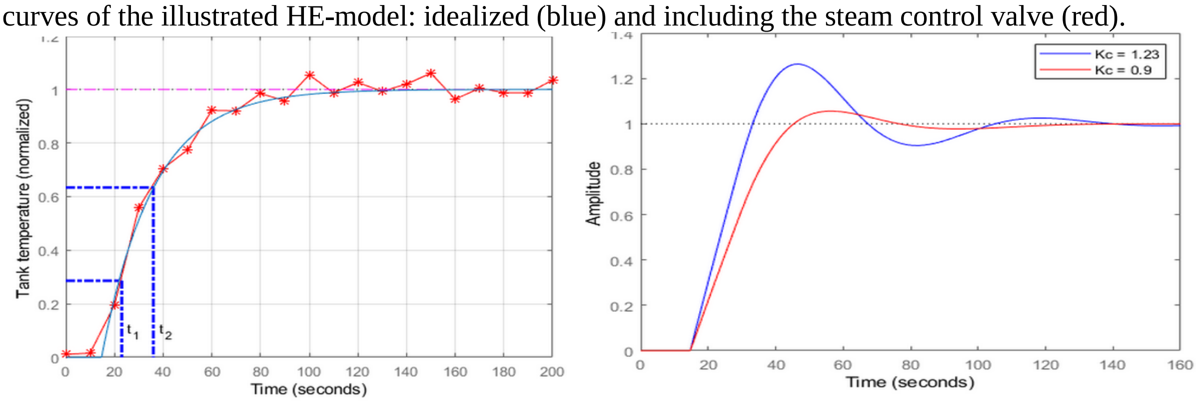


Figure 1. Process diagram of the calculated illustration model of the HE.

2. Basic technological scheme of the energy heat exchange (HE) unit

Structurally, in Fig. 1 is shown: the steam flow in the steam line; the control valve with the ability to control at a given temperature; the working tank of the HE; a device for mixing the working fluid to equalize the degree of heating of all layers of the working fluid, including near-wall and near-bottom layers of fluid; the working tank of the HE by pipelines: «in» - cold working fluid and «out» - the heated as a result of HE fluid. The main task is to stabilize the heat exchange process with constancy of the specified temperature mode of the heated working liquid at the outlet of the HE working tank. Note also that the cooling process can be provided similarly, i.e. temperature reduction with its stabilization. Technological process is as follows. Hot steam flow passing through the heating pipeline inside the working tank of the exchanger gives its energy and heats the cold liquid inside the working tank to a certain temperature. The heating process is monitored by a temperature sensor. By regulating the flow of steam using a valve, as well as the volume of the flowing fluid, we provide the set temperature parameters. Figure 2 shows a continuous line with breaks (red) of the process of heating the working fluid from the cold state and its exit to a stable value of the output temperature. The broken lines are associated with the operation of the heating steam valve through the steam line. For certainty, the time duration of the process in question is taken as 200 seconds, with the first reaching the calculated steady-state temperature value of 80 seconds at the calculated value of the net lag of 10 seconds. The temperature measurement and the effect on the control valve are carried out after 10 seconds. Such time durations are quite realistic for the thermal equipment in use. Figure 2 shows comparative acceleration curves of the illustrated HE-model: idealized (blue) and including the steam control valve (red).



(A) (B)

Figure 2. Comparative curves of acceleration: (A)- illustrative HE-model idealized (blue) and taking into account the operation of the steam supply control valve (curve with kinks, red) and (B)-processes

of the heat exchanger without considering the operation of the control device (blue) and optimized for the speed of technical optimum (red) [2,3].

It should be noted that without the participation of regulating devices, such as the specified steam supply valve, the processes will have uncontrolled nature and may have quite arbitrary dependence of the output coordinate - temperature. There may be an oscillating character with a very significant amount of overshoot. Figure 2 (B) shows curves of HE-processes of the HE without regard to the regulator and optimized for "technical optimum" (TO) in terms of speed with speed not more than 5,0 values of the control time constants and the value of overshooting not more than 5%. The process of setting the automatic control system to "symmetrical optimum" (SO) is also possible; in this case, better response time will be achieved with control time of about 3.0 values of time constants, but the overshoot will reach a value comparable to 50% of the steady-state value. Figure 2 shows curves which are roughly comparable with the above mentioned criteria for optimum processes.

3. Mathematical model of the controlled HE-process

Figure 3 shows a block diagram of the unchangeable part of the illustration model of the HE, in which the thermal processes are described as an open-loop dynamic system (DS). This diagram has two control (setting) inputs and one output. At the output of the presented structure there is an output parameter - the temperature at the HE outlet. The inputs of this system: the first input (V) - determines the setpoint control of the steam valve; the second input (d) - determines the influence of external disturbing influences.

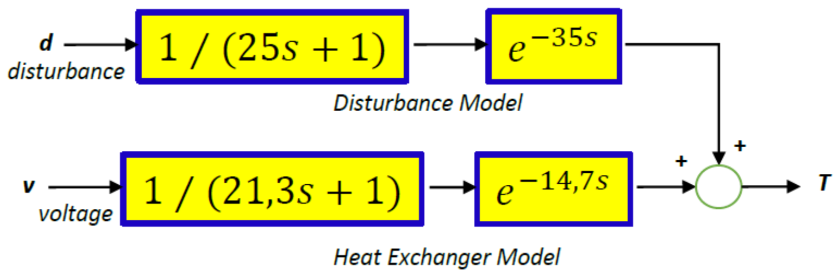
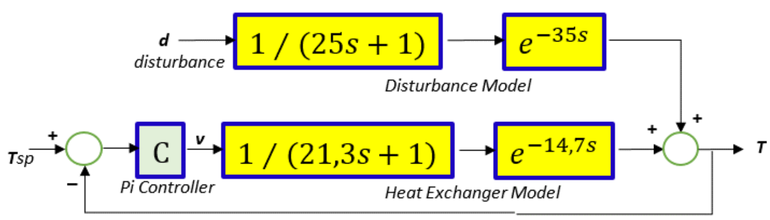
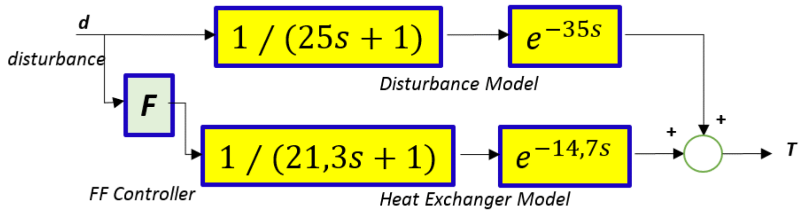


Figure 3. Schematic diagram of the unchanged part of the illustration model of the HE as an open DS.

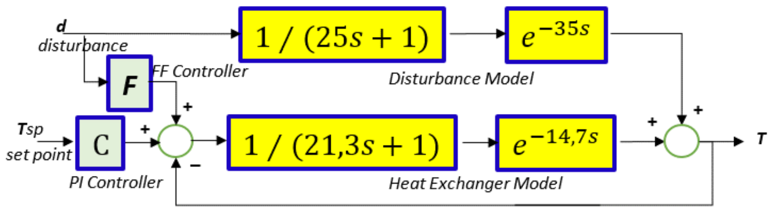
The signal transmission on both the first and second inputs is characterized by an aperiodic process and a "pure lag" value. These quantities are different for each input and have well-defined values, determined by the design parameters of the HE-setting unit. A general view of the DS structure is shown in Figure 4. In this structural diagram shown in Figure 4(A), a regulating element is additionally introduced for sequential correction of the control signal, which carries out, together with the introduced unit negative feedback, stabilization of the output parameter and improvement of the dynamic regulating properties of the HE-process system.



(A)



(B)



(C)

Figure 4. Block diagram of the illustration model of HE as DS: (A) - with a closed negative-type coupling on the output parameter; (B) - with a series-controlled controller compensating the disturbing influences; (C) - with combined control and series-parallel correction and compensation of the influence of disturbing influences.

It should be noted that the parameters of the invariant part of the DS describing the dynamic properties of the HE process depend on many design parameters of the particular HE apparatus, as well as the parameters of the fluids or gases involved in the HE energy. In this regard, the calculated parameters adopted as an example for research can be modified without loss of adequacy of models and assumed solutions according to the parameters of the specific HE processes and HE apparatuses under study. Figure 4(B) shows a variant of the HE-process modeling scheme, described by an open-loop control structure with a series-connected input control signal regulator, which compensates for perturbing influences. This structure essentially demonstrates the principle of perturbation control. For this purpose, an additional control controller is introduced into the unchangeable part of the system, the input of which is taken as the control signal stabilizing the output temperature of the HE-apparatus. The output is connected to the input of the DS dynamic link describing the heating process. The structure and transfer function of this controller is also determined by the parameters of the desired dynamic processes. The control structure shown in figure 4(C), which implements the principle of combined control with a direct corrective control channel and compensation of disturbing influences, has more complete possibilities.

4. Digital computational models of the heat exchange process and results of computer simulation

In order to analyze the dynamic processes that would best provide the desired characteristics of the HE processes, we will use the DS digital model, which is fully adequate to the physically proceeding processes in the HE apparatus. The schematic of the digital model is given in the MatlabSimulink simulation system and is presented in Fig. 5.

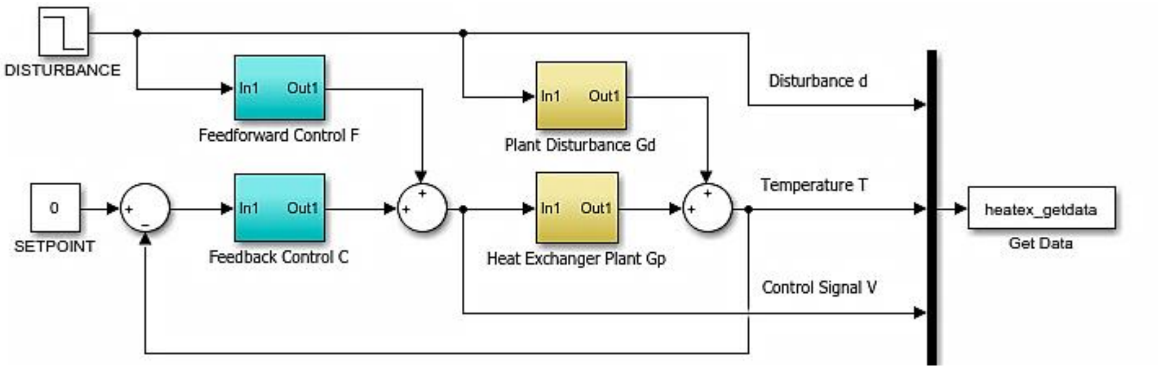
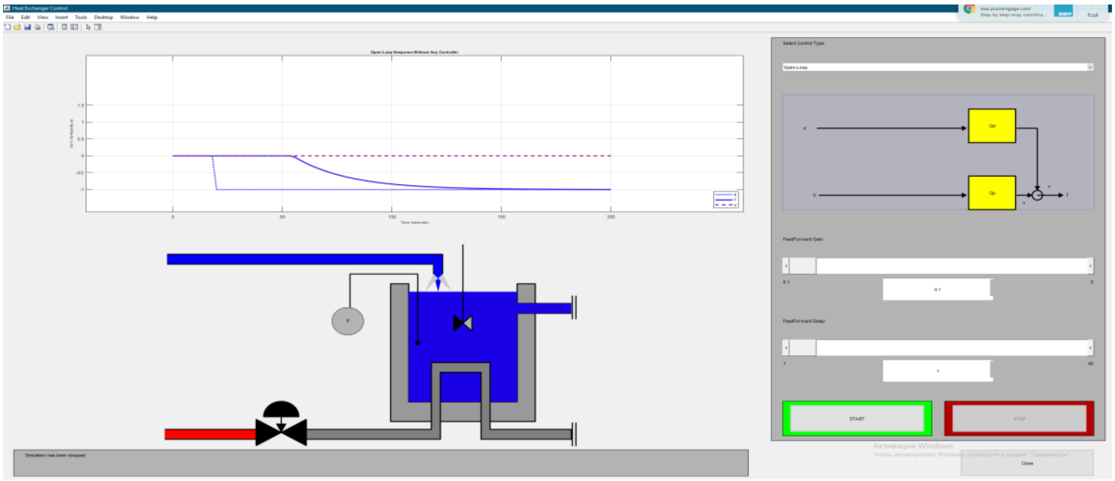


Figure 5. Schematic of the HE model as DS in the MatlabSimulink simulation system [3,7].

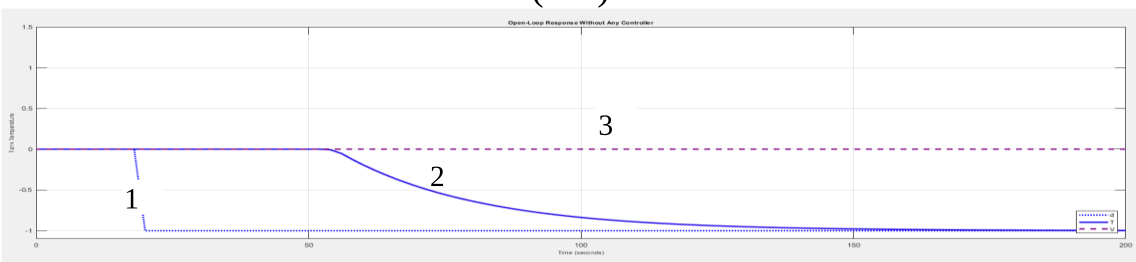
Figure 6 shows a mnemonic and structural diagram for calculating HE parameters and results of the calculations for the following variations of the correcting link parameters (from left to right): (A)-direct channel (DC) parameters (gain/lag - 0.1/1.0); (B)-direct channel parameters (gain/lag - 1.0/1.0); (C)- DC parameters (gain/lag - 2.0/1.0); (D)- DC parameters (gain/lag - 2.0/10.0); (E)- DC parameters (gain/lag - 2.0/40.0). In this DS diagram, which simulates HE-energy processes, the control actions are carried out through two control channels: the direct control channel (DC) and the disturbance channel.

The calculation curves below have the following designations: curve 1 (dotted line) - shows the dependence of the applied disturbing influence (signal "d" on Fig.3, 4 and 5); curve 2 (solid line) - shows the calculated temperature dependence (signal "T" on Fig.3, 4 and 5) of the fluid at the HE outlet (fluid temperature in the HE tank); curve 3 (discontinuous line) shows the calculated dependence of the control (correction) signal applied to the HE (signal "v" in Fig.3, 4 and 5). The coordinate axes of the calculated curves are indicated in the figures below as follows. The horizontal axis (abscissa axis) - shows the calculation time of a total duration of 200.0 seconds with gradations: 0.0; 50.0; 100.0; 150.0 and 200.0 seconds. The vertical axis (ordinate axis) shows, in relative units, the values of the calculated parameters (indicated by numbers 1, 2, and 3) with gradations: -1,0; -0,5; 0,0; 0,5; 1,0 и 1,5. At performance of calculations the mathematical method of numerical solution of the differential equations ODE45 [4] with variable automatically varying step of integration has been used; the reached set value of a relative error of calculations is accepted equal to 10,0E-6; the set value of solution time is accepted equal to 200,0 seconds.It should be noted, in this system [3,7] different "Solvers" (ode) with application of mathematical methods of solution of differential equations both with constant integration step and with variable integration step are also available for use.

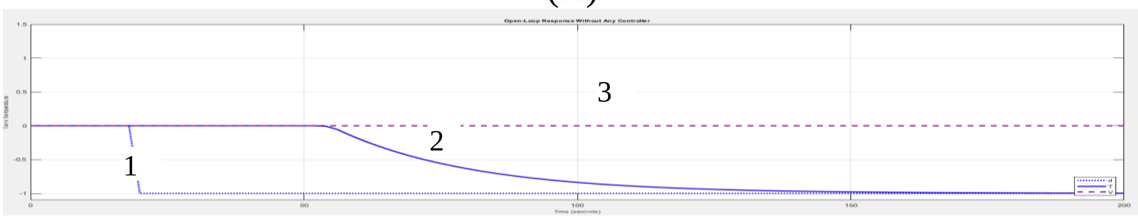
The comparative (visual) comparability of the calculation results must be ensured by the parameters of the input and correction circuits of the digital dynamic HE model adopted in advance. The figures 6, 7, 8 and 9 below are screen copies (screenshots), which, nevertheless, sufficiently illustrate the possibilities of rapid visual analysis of calculation results.


START
STOP

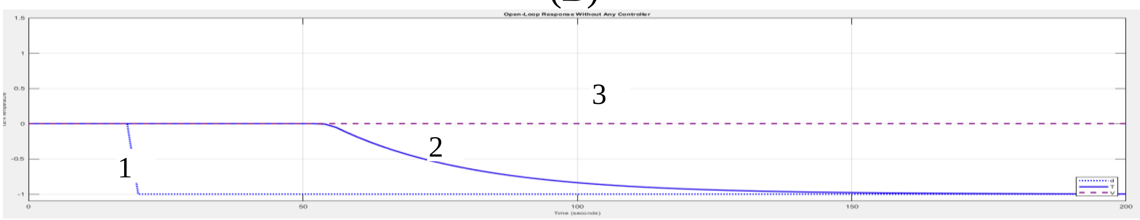
(AA)


Open-Loop Response Without Any Controller
1
2
3
Time (seconds)

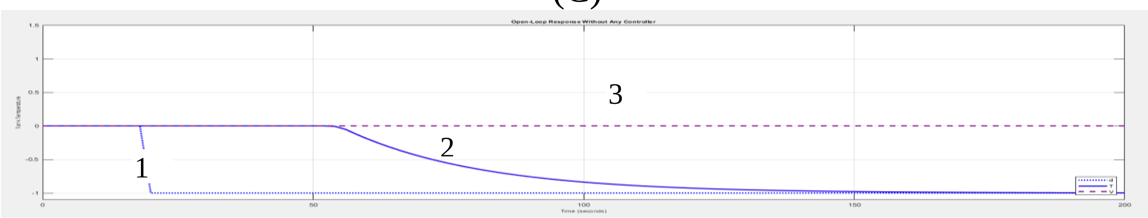
(A)


1
2
3

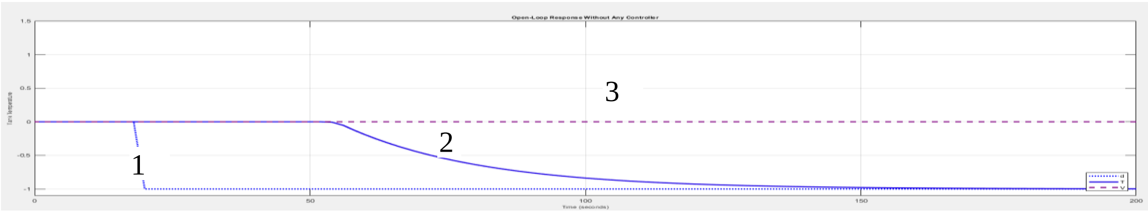
(B)


1
2
3

(C)


1
2
3

(D)

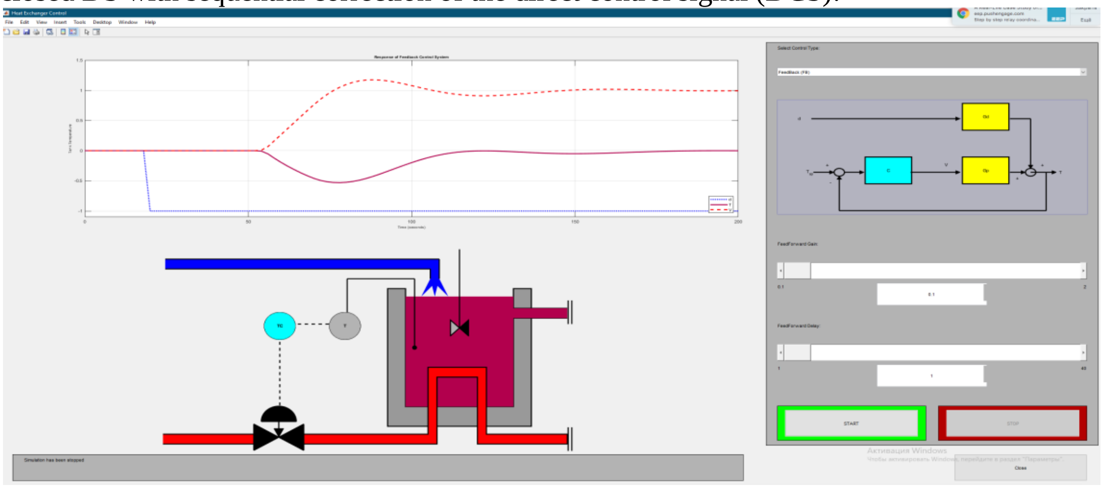


(E)

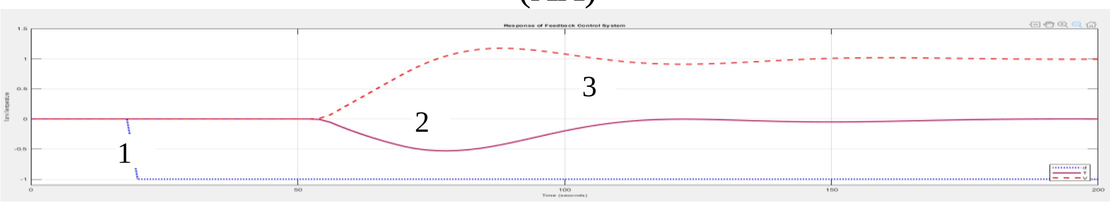
Figure 6. Graphical user interface (GUI) to study HE (AA) processes as an open DS in the MatlabSimulink and results of the calculations (A)-(E).

Similar designations are adopted for all other calculation curves. The above studies and calculations show that in the open state the DS describing the HE-energy processes according to the model shown in the figure does not satisfy the above requirements with respect to the stability of the expected HE-processes. Therefore, in order to investigate the possibilities of improving the regulating properties of the HE-energy system, we will perform further studies.

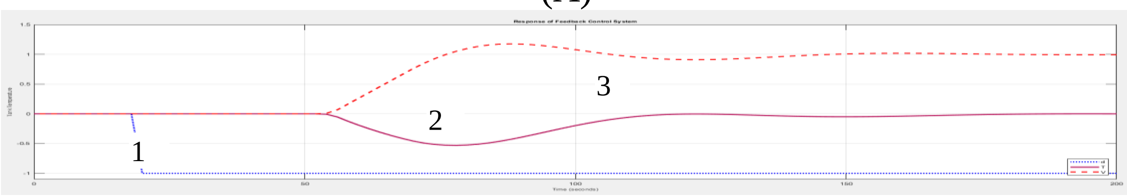
Figure 7 shows a mnemonic diagram and a block diagram for calculating the HE parameters with the introduction of a stabilizing output temperature feedback and computational curves of HE processes as a closed DS with sequential correction of the direct control signal (DCS).



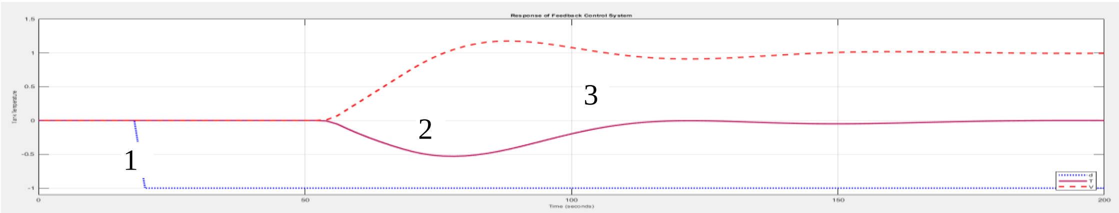
(AA)



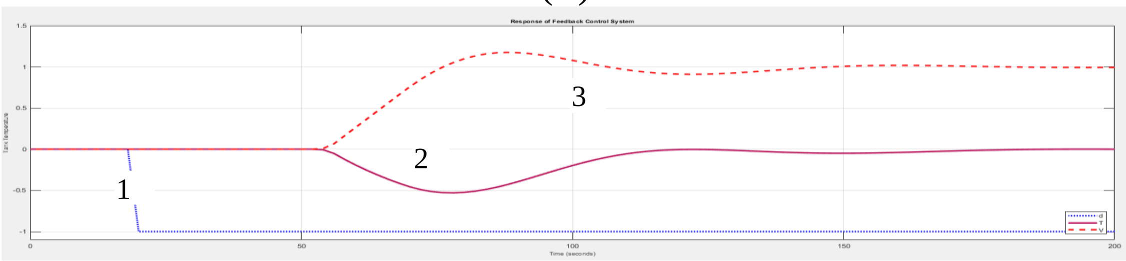
(A)



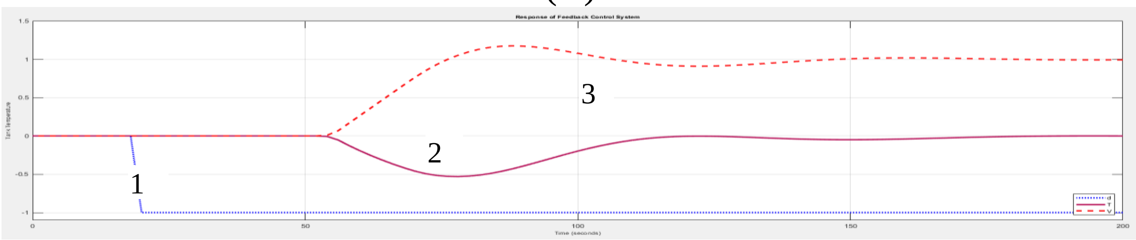
(B)



(C)



(D)

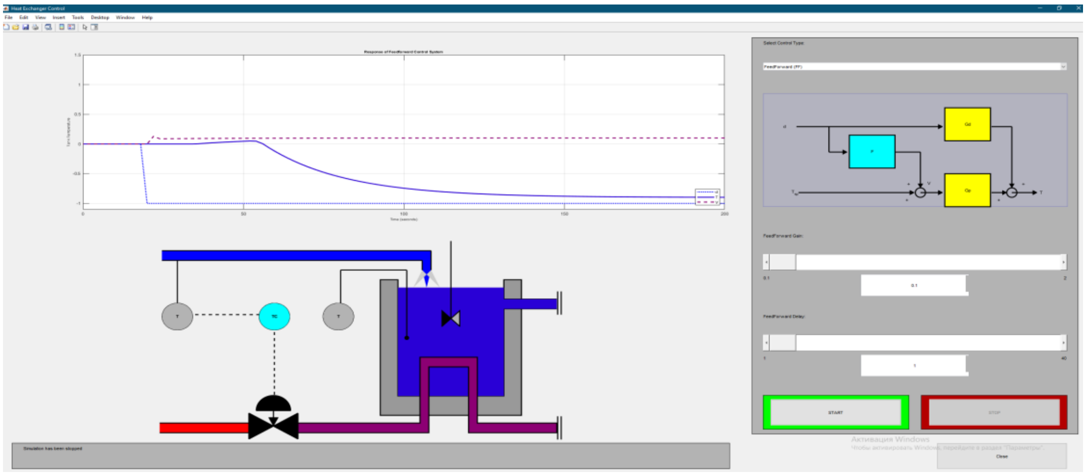


(E)

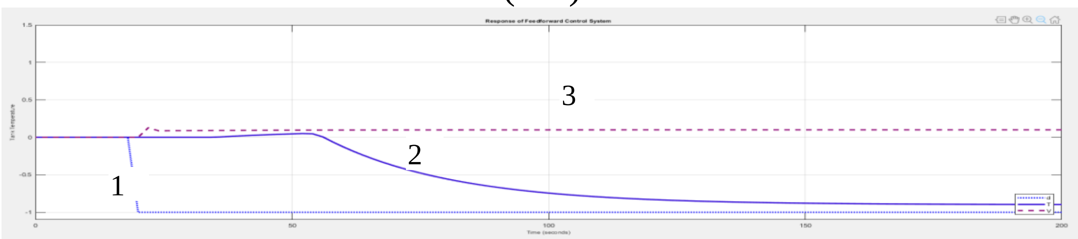
Figure 7. GUI (AA) for the study of HE processes as a closed DS with sequential correction of the DCS in the MatlabSimulink and computational curves (A)-(E).

In this scheme, which simulates HE-energy processes, the control actions are carried out by two control channels: the channel of direct regulation and the channel of disturbing influences. In this case, in addition to the direct control channel, a serial correcting element with the structural scheme of a standard PI-regulator is introduced. The mathematical description is given above. Parameters of the controller in the process of research have the possibility to change within wide limits. In addition, a unit negative feedback is connected to the serial correcting link to ensure stability of output coordinates.

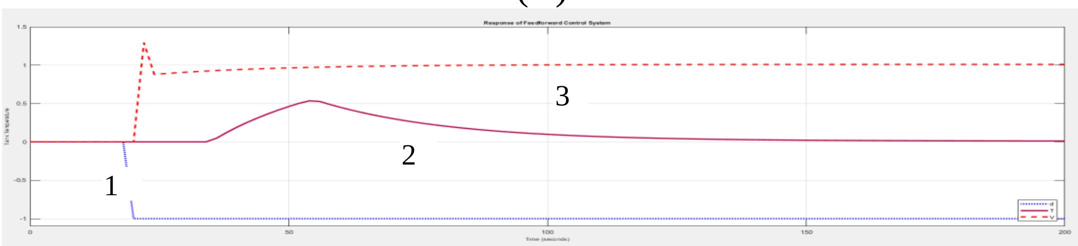
Figure 8 shows the GUI mnemonic diagram for the study of HE processes as an open DS with correction of disturbing influences and calculated curves of HE processes as an open DS with correction of disturbing influences. To study the dynamic processes of the HE-apparatus, this scheme also provides the change of two parameters.



(AA)



(A)



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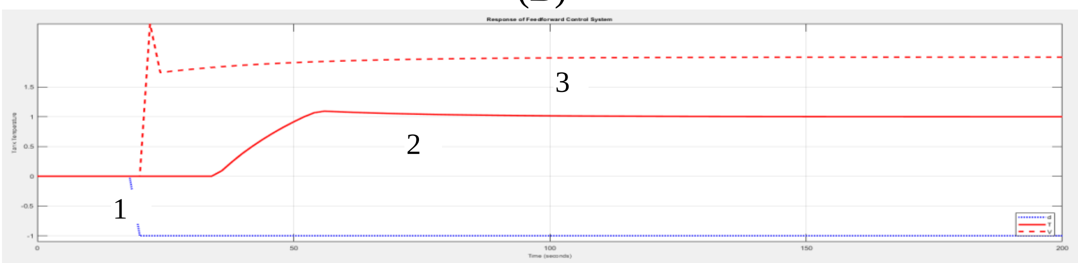

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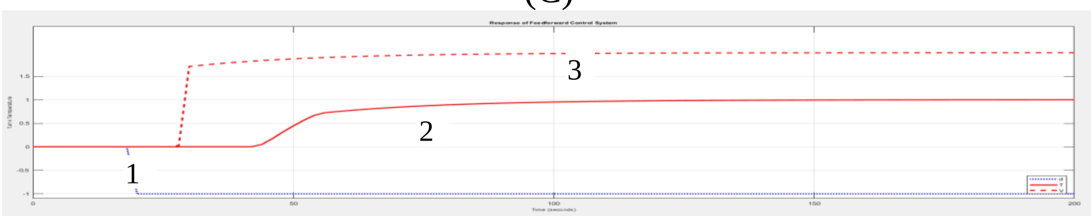

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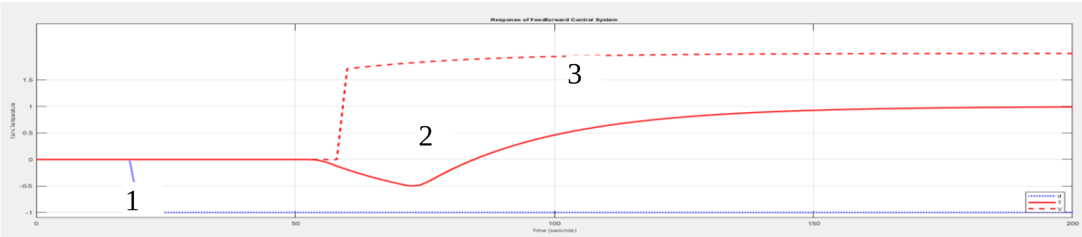
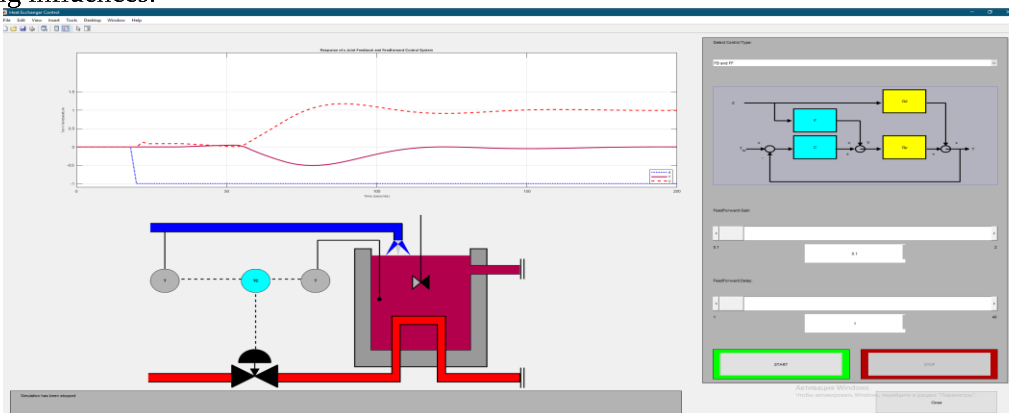


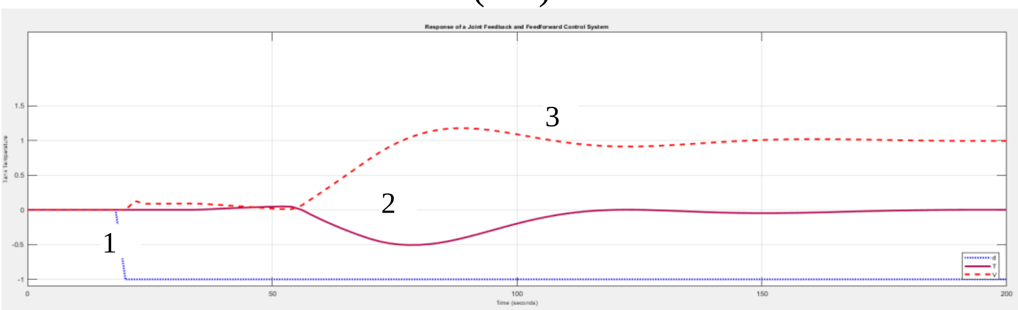
(E)

Figure 8. GUI (AA) for the study of HE processes as an open DS with correction of disturbing influences in the MatlabSimulink and computational curves (A)-(E).

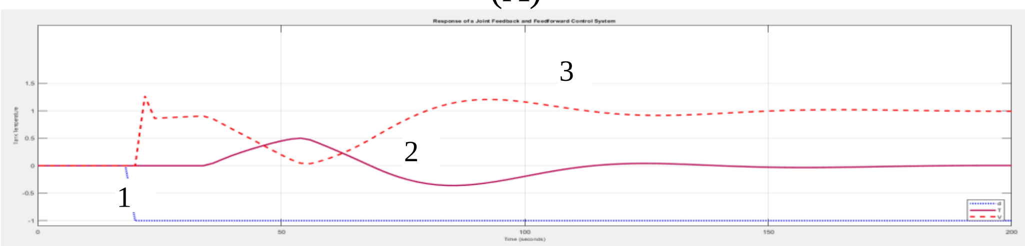
Figure 9 shows a mnemonic diagram and a block diagram for calculating the HE parameters and computational curves of HE processes as a closed DS with sequential correction of the direct control signal and correction of disturbing influences. In this scheme, the additional control actions are carried out by two control channels: DC-regulation with serial correction and unit feedback on the input parameter and a parallel correcting direct channel, which carries out direct parallel correction of disturbing influences.



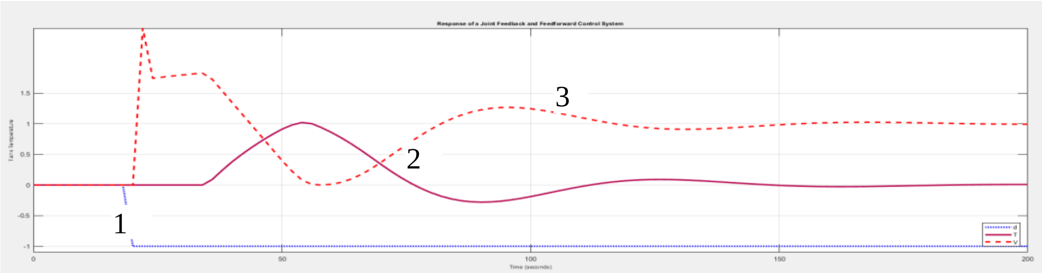
(AA)



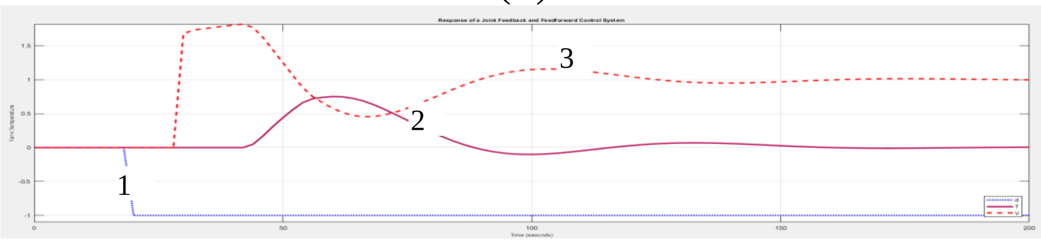
(A)



(B)



(C)



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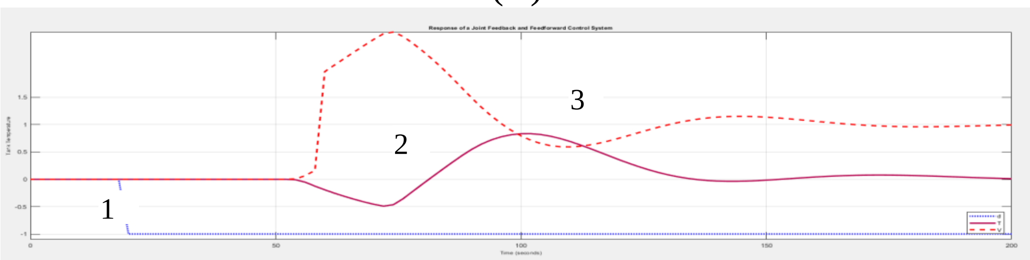

(E)

Figure 9. GUI (AA) for studying HE processes as a closed DS with sequential correction of the direct control signal and correction of disturbing influences in the MatlabSimulink and computational curves (A)-(E).

5. Conclusions

It is obvious that changing the parameters of the correction circuits leads to changes in the dynamic characteristics with different degrees of output coordinate control time, the value of overshooting, the values of oscillation of control processes, as well as the statism of the output characteristics of the object under study, which carries out the process of HE. When performing calculations, it is assumed that the achieved accuracy of the solution of the differential equations describing the specified thermal processes is determined by the established relative error of the mathematical method of solution and the step of integration, and is no more than 10.0E-6. On all of the above calculation curves, the time of the calculation process is 200.0 seconds.

References

[1] Zimmerman R D and Murillo C E 2019 *Matpower* (Software) 10.5281/zenodo.3236535
[2] Currie J and Wilson D I 2012 *Foundations of computer-aided process operations* **24** 32
[3] Wotao Y Gurobi Mex: A MATLAB interface for Gurobi, URL: http://convexoptimization.com/wikimization/index.php/gurobi_mex, 2009–2011
[4] Optimization Toolbox Users's Guide, The MathWorks, Inc., 2016 [Online] Available: https://www.mathworks.com/help/releases/R2016b/pdf_doc/optim/optim_tb.pdf
[5] Roqueta J M and Márquez M 2007 *Trigeneration: The heat useful in the production of cold*
[6] Borelli D, Devia F, Schenone C and Spoladore A 2015 *Energy Procedia* **81** 505–15
[7] MIT (Massachusetts Institute of Technology), The Future of Coal in a Carbon Constrained 2007 World, http://mit.edu/coal

[8] Gani R, Cameron I, Lucia A, Sin G and Georgiadis M 2012 *Process Systems Engineering, 2. Modeling and Simulation. In Ullmann's Encyclopedia of Industrial Chemistry* (Atlanta: Cancer Society)
[9] Watson H A, Khan K A and Barton P I 2015 *AIChE J.* **61** 3390–3403