area σ. A change in the internal energy of air δQ_{a1} in the packing layer with thickness dx depends on the rate of change in the air temperature and its mass. If we assume WKDW WKH HQWLUH YROXPH RI IUHH VSDFH LQ WKH SDFNLQJ LV ¿OOHG with air, then its mass in a layer of thickness dx can be expressed as $\rho_a A\varepsilon dx$, where ρ_a is the air density. Therefore, δQ_{a1} will take the form:

$$\delta Q_{a1} = \rho_a c_a A\varepsilon \frac{\partial T_a}{\partial t} dx,$$

where c_a is specific heat capacity, and T_a is the air temperature. Let us take for the positive direction of the $0X$ axis the direction which coincides with the direction of air movement through the packing. Then, the convec- WLYH K δQ_{a2} through the boundaries of the packing layer with a thickness dx can be expressed through the WHPSHUDWXUH JUDGLHQW DQG WKH PDVV ÀRZ UDWH RI DLU G_a^m

$$\delta Q_{a2} = -G_a^m c_a \frac{\partial T_a}{\partial x} dx.$$

:H ZLOO DVVXPH WKDW KHDW W DLU RFFXUV DW WKH ERXQGDU\ RI WKH OLTXLG ¿OP the packing material as a thin layer. If we assume that the entire packing surface is involved in heat transfer, then the KHDW WUDQVIHU DUHD ZLOO EH HTXDO WR WKH VXUIDFH DUHD RI WKH packing. For a layer with thickness dx, it will be $\sigma A dx$. As a result, the amount of heat δQ_{a3} transferred to air through the interface per unit of time can be written:

$$\delta Q_{a3} = \sigma A\alpha \cdot (T_w - T_a)\, dx,$$

where α LV WKH KHDW WUDQVIHU FRHI¿FLHQW, T_w is the temperature of water. Balance of thermal energy for air is:

$$\delta Q_{a1} = \delta Q_{a2} + \delta Q_{a3}.$$

Substituting the corresponding expressions, we obtain WKH LQKRPRJHQHRXV GLIIHUHQWL

$$\rho_a c_a \varepsilon A \frac{\partial T_a}{\partial t} + G_a^m c_a \frac{\partial T_a}{\partial x} = \sigma A\alpha \cdot (T_w - T_a) \qquad (1)$$

Let us consider the balance relations of thermal energy IRU WKH OLTXLG SKDVH 7KH DPR NLQJ layer depends on the regime of its flow. Under the assumption VXPSWLRQ RI LWV ¿OP OLNH QDW Q WKH packing layer with thickness of dx can be written in the form $\rho_w A\sigma h dx$, where ρ_w is the density of water, and h LV WKH WKLFNQHVV RI WKH ¿OP HWWHG SDFNLQJ 7KHQ D FKDQJH LQ WKH LQWHUQDO HQHUJ\ RI OLTXLG LQ the packing layer will take the form:

$$\delta Q_{w1} = \rho_w c_w \sigma A h \frac{\partial T_w}{\partial t} dx,$$

where c_w LV VSHFL¿F KHDW FDSDFLW\ RI WDQW KHDW δQ_{w2}, transferred through the boundaries of the packing layer by convection, considering the direction of water motion can be written as:

$$\delta Q_{w2} = G_w^m c_w \frac{\partial T_w}{\partial x},$$

where G_w^m LV WKH PDVV ÀRZ UDWH RI OL of heat δQ_{w3}, transferred through the interface per unit of WLPH LV HTXDO WR KHDW δQ_{a3}, then WKH IRUH LQ WKH ¿QDO IRUP WKH EDODQ can be written as:

$$\rho_w c_w \sigma A h \frac{\partial T_w}{\partial t} - G_w^m c_w \frac{\partial T_w}{\partial x} = -\sigma A\alpha \cdot (T_w - T_a) \qquad (2)$$

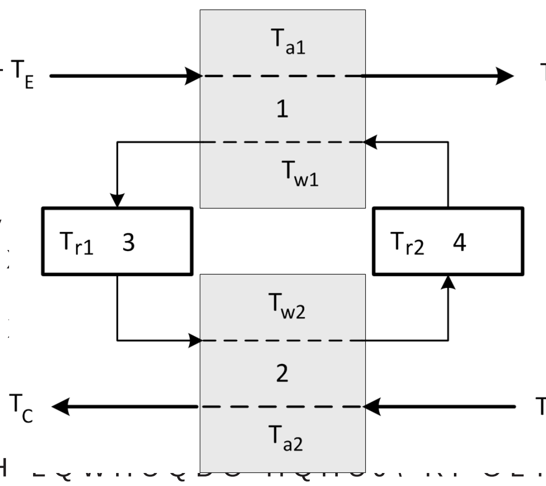
:DWHU ¿OP Note the surface of packing ma WHULDO YHORFLW\ RI DQG PDVV ÀRZ UDWH DUH PXWXDOO\ FRQQHFWHG E\ H

$$G_w^m = \rho_w u \sigma A h \qquad (3)$$

To take into account the effect of the amount of heat that can accumulate in the packing and increase the ther- PDO LQHUWLD RI WKH OD\HU LQVWH write:

$$\left(\rho_w c_w \sigma A h + \rho_p c_p A[1-\varepsilon]\right) \cdot \frac{\partial T_w}{\partial t} - G_w^m c_w \frac{\partial T_w}{\partial x} = -\sigma A\alpha \cdot (T_w - T_a).$$

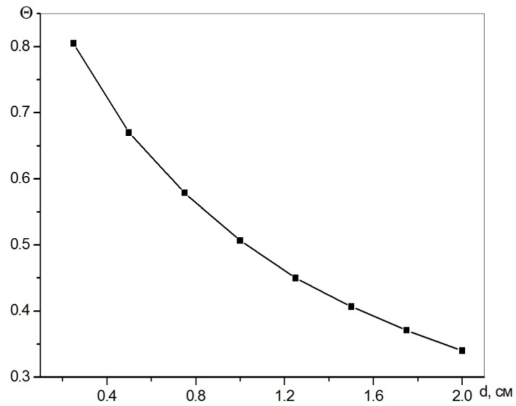
$ ÀRZFKDUW RI D UHJHQHUDWRU ZL columns, as well as two storage tanks is shown in Figure 3.



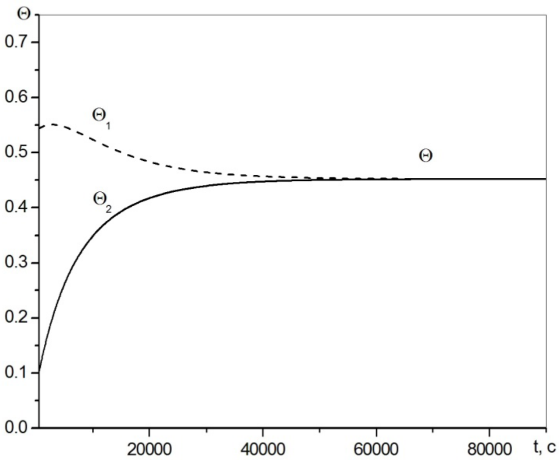
) L J X U H Flowchart of a regenerator with intermediate

 DOI: https://doi.org/10.30564/jcr.v3i1.3235

HG WKDW LQ WKH FRQVLGHUHG DLU UHJHQHUDWRU WKH HTXLOLEULX WHPSHUDWXUH HI¿FLHQF\ IRU ERW ... ZLWK WKH VDPH FROXPQ GHVLJQ HTXDO ... G DLU DQG ZLWKRXW WDNLQJ LQWR DFF ... I OLTXLG HYDSRUDWLRQ $ W\SLFDO ZD\ KRZ ... LHQ FLHV RI UHJHQHUDWRU FROXPQV D ... XP YDO ues over time is shown in Figure 4 according to the results RI FDOFXODWLRQV 8QGHU WKH WH ... H ZLOO IXUWKHU PHDQ WKH HTXLOLEULXP ... RI WKH regenerator $\Theta = \Theta_1 = \Theta_2$.



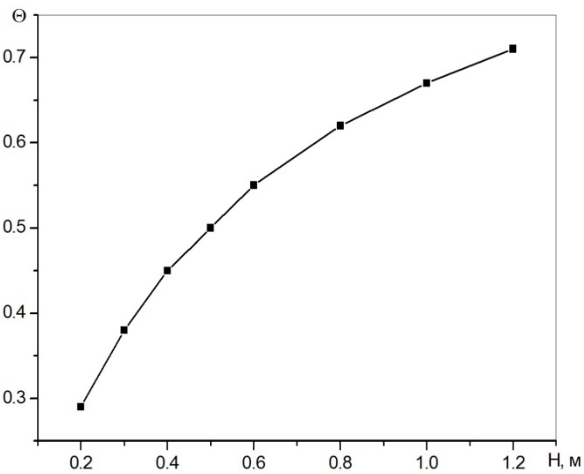
)LJXUH 7HPSHUDWXUH HI¿FLHQF\ YHUVX



)LJXUH $ FKDQJH LQ WKH WHPSHUDWXUH HI¿FLHQF\ RI WKH heating and cooling columns over time

Let us consider the influence of filling height on the temperature efficiency. According to calculations, an in FUHDVH LQ OHG WR DQ LQFUHDVH LQ HI¿FLHQF\ )LJXUH

This is caused by an increase in the area of the heat exchange surface S ZKLFK GHSHQGV RQ WKH SDFNLQJ KHLJKW LQ accordance with expression $S = A\sigma H$. Obviously, regen HUDWRU GLPHQVLRQV DFW DV WKH FRQVWUDLQW LPSRVHG RQ WKH height.



)LJXUH 7HPSHUDWXUH HI¿FLHQF\ YHUVXV ¿OOLQJ KHLJKW

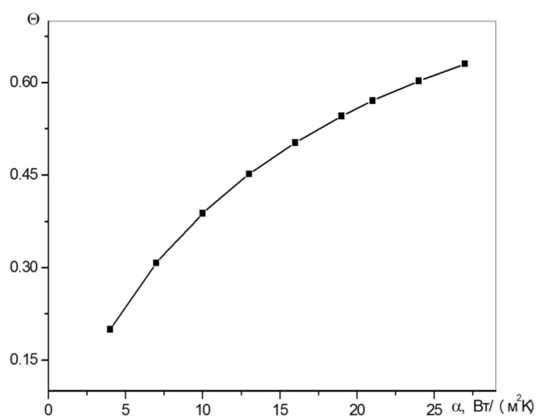
With a decrease in the packing diameter and retention RI DOO RWKHU SDUDPHWHUV DQ LQFUHDVH LQ HI¿ciency took place (Figure 6), and the rate of its growth increased with a decrease in the diameter. This dependence of temperature efficiency is associated with an increase LQ WKH VSHFL¿F VXUIDFH RI WKH ¿OO packing diameter, according to:

$$\sigma = \frac{6\cdot(1-\varepsilon)}{\Phi\cdot d} ,$$

where Φ is the shape factor, and ε is porosity.

With an increase in the temperature efficiency of the UHJHQHUDWRU ZLWK DQ LQFUHDVH LQ ... crease in the size of the packing, an increase in hydraulic losses should be taken into account.

Calculations showed that it is possible to increase the WHPSHUDWXUH HI¿FLHQF\ RI WKH UHF VL¿FDWLRQ RI KHDW WUDQVIHU SURFH 7KH FDOFXODWHG GHSHQGHQFH RI WKH ¿OO on the heat transfer coefficient on the contact surface is presented in Figure 7.



)LJXUH 7HPSHUDWXUH HI¿FLHQF\ YHUVXV FRHI¿FLHQW

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Let us consider the influence of the flow characteristics of air and liquid heat carrier on the temperature efficiency of the regenerator. The influence of the liquid flow rate on the efficiency at a constant air flow rate through the columns of 60 m^3/h and a column height of 0.4 m is shown in Figure 8.

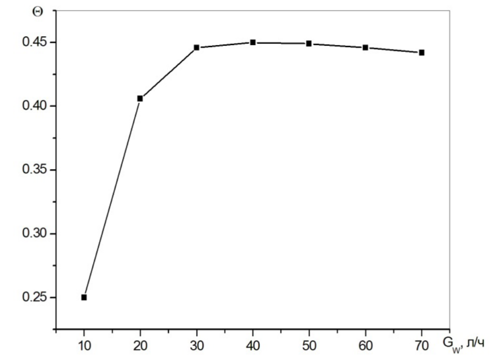

Figure 8. Temperature efficiency versus water flow rate

In the studied range of liquid flow rates, the temperature efficiency increased to the maximum value, and with a further increase in the flow rate, its slight decrease occurred. The maximum value of efficiency was observed at liquid flow rate G_w 30, which corresponds to the equality of water equivalents:

$$G_w^m c_w = G_a^m c_a \quad (5)$$

The calculated dependence of the temperature efficiency of regenerator on the air flow through the columns for liquid flow rate of l/h at different heights of filling in the columns is shown in Figure 9.

The dependence of efficiency at each filling height had a maximum, and with an increase in the height, the value of maximum efficiency increased, and the position of maximum approached its value at the air flow rate obtained from the equality of the water equivalents of air and water. With a decrease in the filling height, the heat transfer surface decreased, the value of maximum decreased and its position shifted towards the lower air flow rates through the columns.

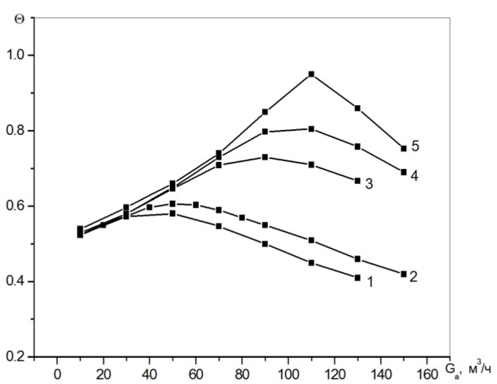

Figure 9. Temperature efficiency versus air flow rate for filling height H m m m m

Main Conclusions

A computational model of heat transfer of a new air-to-air regenerative heat exchanger with an intermediate liquid heat carrier for room ve tested in this work.

When analyzing the influence of v temperature efficiency of regener significant increase in its effici packing diameter is shown.

As a result of calculations, it was found that with a decrease in the filling height, the ciency shifted towards a decreas its value determined from the lents of liquid and air

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