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Experimental Analysis of Heat-Mass-Exchange Progresses of Irrigators Cooling Stack

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ABSTRACT : In the article some results of experimental analysis of heat-mass-exchange progresses leaking spray cooler are carried out. The coefficients of heat exchange and mass exchange were found. For cooler the thermal coefficients of useful effect were found in accordance with the degree of coolness .The graphics of mass exchange dependence from the air speed in the inter piping area of spray cooler are brought out .The results of thermal balance of cooler's tests are shown.

KEYWORDS :coolers, spray cooler, water catchers, water supply reverse , eddy formation, sprayer

I.INTRODUCTION

By mathematical modeling of technological range of water cooling in coolers by theory the tangible and thermal balances for one quasi-section were be prepared. [1] For adequacy checkup of mathematical model we reviewed the real processes of heat mass exchange in the experimental cooler. [2]

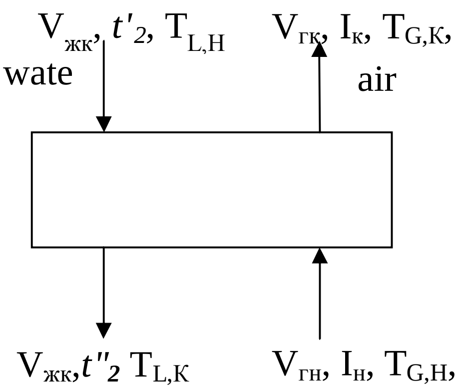

Figure1 Heat mass exchange processes in the cooler

Let the air pass through the cooler V, $м^3/с$, and besides its temperature changes from t_1 to t_2, humidity content from $x_н$ to $x_к$, кg/кg, and heat function in the thermal keeper (enthalpy) from I_H to I_K. Дж/кg. The quantity of water (the total consumption) is $V_ж$, $м^3/s$. The initial temperature of water t_1, the final temperature of water is t_2. As above-mentioned the experimental diagnoses are brought out that water carrying away by air stream constitutes no more than 1 % from total water quantity, proceeded into the installation. Therefore we may ignore the influence of carrying away in the balance equation.

For calculation of record heat mass exchange the equation of thermal balance was applied:

$$Vi_1 + Gct'_2 = Vi_2 + (G \pm \Delta W)ct''_2 + Q_{потерь} \qquad (1)$$

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Let's write the equation of tangible balance:

$$L_{ГН} + L_{ЖК} = V_{ГК} + V_{ЖК} \tag{2}$$

The mass air consumption $L_{ГН}$ in the installation enter:

$$L_{ГН} = V_{ГК} \cdot \rho_{ВЛ}\text{, кg/s} \tag{3}$$

Where $V_{ГК}$ - air consumptionm^3/s: $\rho_{ВЛ}$ - air solidity, кg/ m^3 (at temperature t_1).

The calculation of mass consumption of arid air in the installation G, kg/s:

$$G = \frac{V_{ГН}}{(I + X_H)}. \tag{4}$$

The quantity of evaporated water for the per unit of time (period) M, (кg/s):

$$M = C(X_K - X_H) \tag{5}$$

The dimension of mass consumption of water in the entry of the cooler, kg/s:

$$L_{ЖН} = V_{ЖН} \cdot \rho_{Ж}, \tag{6}$$

Where $\rho_{Ж}$ - water solidity, кg/m^3 (at temperature t_2); $V_{ЖН}$ - total consumption of water in the entry of the installation, m^3/s.

The calculation of water consumption in the exit of the cooler is $L_{ЖК}$, kg/s:

$$L_{ЖК} = V_{ЖК} - M, \tag{7}$$

From the equation of thermal balance of the cooler, applying the equation of heat irradiation, figure out the stream of the heat out coming from the installation's sides into environment

$$Q_{losses} = \alpha_{cp} F_{cp} (t_{cp} - t_3), \tag{8}$$

Where α_{cp}- summary coefficient heat irradiation into environment by radiation and convection Вт/m^{2}C; F_{cp}- square of installation surface, through which the heat is lost into environment, m^2; t_{cp}-medium temperature of the installation's sides of surface, °C; t_3-temprature of environmental air, °C.

Coefficient heat irradiation α_{cp} is defined according to empiric dependence [3, 4]

$$\alpha_{cp} = 9.3 + 0.058 \cdot (t_{cp} - t_3). \tag{9}$$

Calculation of medium temperature of installation sides:

$$t_{cp} = \frac{t_1 + t_2}{2}. \tag{10}$$

Figure our enthalpy of water in the entry into the installation I_H, joule Дж/кg:

$$I_H = t_1 C_{ЖН}, \tag{11}$$

Where $C_{ЖН}$ - thermal capacity of water at temperature T_{LH}, joule /(кg*К).

Calculation of enthalpy of water in the exit from the installation I_K, joule/кg:

$$I_K = t_2 C_{ЖК}, \tag{12}$$

Where $C_{ЖК}$ - thermal capacity of water at temperature t_2, Дж/(кг*К).

Using the equation of thermal balance (1), count upon the heat, assigned from the water to the air:

$$Q = GI_K - GI_H \tag{13}$$

On the base of carried out experiments results gereralizing equations were received for calculation total coefficient of mass transfer β_x [5] for spray cooler of pipy type from compositional polymeric pipe $d_{нас}$=0.63 m.

We use the quotation for computation of the heat stream, transmissible from liquid into the air (gas-vapor blend) at transpiration cooling in the cooler for element *df*:

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$$dQ = \alpha\left(T_{GH} - T_G\right)dT + I_{\Pi}^{//} \cdot dV_{Ж},\tag{14}$$

Where $V_{ж}$- hydraulic cooler load (the quality of cooling water), м^3/с; $I_{\Pi}^{//}$- enthalpy of hydronic steam, ккал/кg· arid air; α-coefficient of heat irradiation,ккал/м^2*час*^{0}С.

In the next formula we determine the quantity of evaporating liquid:

$$dM = \beta_x\left(x^{//} - x\right)dt,\tag{15}$$

Where $x^{//}$ - humidity content of replete air,кg/кg; ; β_x -coefficient of heat mass transfer , concerning to margin of humidity content кg/m^2*hour (кg/кg).

Copying out the parity (14), with accounting (15) and correlation of Luis:

$$\frac{\alpha}{\beta_x} = C_{ВЛ}$$

We receive [6]:

$$dQ - \left[\alpha\left(T_{Lr} - T_G\right) + I_{\Pi}^{//}\beta_x\left(x^{//} - x\right)\right]dF = \beta_x\left[C_{ВЛ}\left(T_{Lr} - T_G\right) + I_{\Pi}^{//}\left(x^{//} - x\right)\right]dF\tag{16}$$

Where $C_{ВЛ}$ - thermal heat capacity of humid air, correlating for 1кg containing in it the arid air, ккал/град*кg.

Substitute in the formula (16) dimensions: $C_{ВЛ} = C_H + C_B x_e$ и $I_{\Pi}^{//} \approx r - C_{\Pi}T_{Lr}$,

Where C_{Π} - heat capacities of hydronic steam, ккал/кg*^{0}С; C_B -heat capacities of arid air, ккал/кг*^{0}С; r - heat of evaporation образования, ккал/кg.

Considering, that:

$$I_{\Pi}^{//} = C_B T_{Lк} + \left(r + C_{\Pi}T_{Lr}\right)x^{//},$$
$$I = C_B \cdot T_G + \left(r + C_{\Pi}T_G\right)x$$

And reforming, note in the form (14):

$$dQ = \beta_x\left(I_{\Pi}^{//} - I\right)dF.\tag{17}$$

Intergrating (17) we get:

$$Q = \beta_x\int_0^F\left(I_{/\Pi}^{//} - I\right)dF = \beta_x \cdot \overline{\Delta I_{cp}} \cdot F\tag{18}$$

Where $\overline{\Delta I_{cp}}$ - process effect of medium leading transpiration cooling ккал/кg.

For calculation we review process effect of medium leading transpiration cooling as medium logarithmetic dimension $\overline{\Delta I_{cp}}$:

$$\overline{\Delta I_{cp}} = \frac{\Delta I_G - \Delta I_M}{In\frac{\Delta I_G}{\Delta I_M}},\tag{19}$$

Where ΔI_Gи$\Delta I_м$- major and lesser residual enthalpies in the upper and lower sections of the cooler (pict.1).Herewith of dimension ΔI_Gи$\Delta I_м$ are defined: $\Delta I_G = I_{cpH} - I_H$, $\Delta I_M = I_{cpK} - I_K$

Where I_{cpH}-enthalpy of the air on the division of phases at temperature of liquid υ_H, joule/кg of arid air; I_H-enthalpy of the air in the core of gas phase at temperature of liquid air; I_{cpK}-enthalpy of the air on the division of the phases at the temperature of liquid υ_K, joule/кg of arid air; I – enthalpy of the air in the core of gas phase at temperature t_H, Дж/кg. of liquid air .

We consider the medium residual as arithmetical mean, as ΔI_Gи $\Delta I_м$ differ less than in twice:

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$$\overline{\Delta I_{cp}} = \frac{\Delta I_G + \Delta I_M}{2}.$$

Contradiction between arithmetical mean and medium log residuals of enthalpies does not exceeds 4 % [6].

Defining experimentally the coefficient of mass transfer β_x, herewith we use equation (18), according to [7, 8] in the form of:

$$\beta_x F = \frac{Q}{\overline{\Delta I_{cp}}} \qquad (20)$$

We incorporate experimental records referring to mass-exchange at evaporating cooling of water in cooler in the form empirical dependence for total coefficient of mass-exchange [9]:

$$\beta_{vx} = A q_{ж}^{n} (\lambda)^{m} \qquad (21)$$

Where A, m, n- constants, depending from types of nozzles; $q_{ж}$- solidity of irrigation, м^3/(м^2/ч);$\lambda = \frac{G}{V_ж}$

For interrelation coefficients of mass-transfer in gas phase we write Luis correlation

$$\frac{\alpha_v}{\beta_{vx}} = C_{pr} \cdot \left(\frac{Sc_r}{\Pr_r}\right)^{0.5}, \qquad (22)$$

Where C_{pr}- thermal capacity of the air; Sc_r- value of Shmid; Pr_r- value of Prudtle

For the air we use correlation $\left(\frac{Sc_r}{\Pr_r}\right)^{0.5} \approx 1.$

We write the formula of medium thermal effectiveness factor for cooler in liquid phase:

$$\eta_{ж} = \frac{t_1 - t_2}{t_1 - t_4} \cdot 100\%, \qquad (23)$$

Where t_1- temperature of water in the entry into the cooler, ^oC, t_2- temperature of water in the exit from the cooler, ^oC t_4-temperature of wet thermometer in the entry into the cooler, ^oC (theoretical limit of liquid cooling) .

Usage is defined by that it shows the grade approach of the process to the balance state. In the theory thermal effectiveness=100 % means that, for evaporating water cooling process, gas and liquid streams in the exit from the installation have equilibrium parameters of temperature and equal to the of wet thermometer.

In practical processes thermal effectiveness is always less than 100 %. It occurs by complex hydrodynamics of gas and liquid, irregularity of allocation of streams and many other factors.

Experiments on the experimental installation of the cooler were carried out with spray coolers of pipy type from compositional polymeric pipe with reticulate sprayer.

As a result of handling of experimental records empiritic equations were received for calculation of total coefficient of mass transfer for the cooling with spray cooler from polymeric pipes by height H=1,0 м were received:

$$\beta_{vx} = 1.04 \cdot q_{ж}^{1,02} \lambda^{0,79} \qquad (24)$$

Where где $q_{ж}$-irrigation solidity, м^3/(м^2*ч); $\lambda = \frac{G}{V_ж}$

The research experiments water cooling in the experimental installation with spray cooler in two regimes with working fan and idle fan were carried [10]. Experiments results on process research of water cooling in the experimental installation with different water consumption and at different climatic conditions are shown in tables 1-11.

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Table 1

Research results experimental cooler working with fan

№ experiments time	t_1 ^{0}C, water temperature supply into the cooler	t_2 ^{0}C, temperature outcoming water from the cooler	t_3 ^{0}C, temperature of the environment air	t_4 ^{0}C, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
8^{40}	38	23	35	21	27	0,88
11^{10}	41	25	40	22,5	23	0,86
13^{00}	43	26	42	23,5	26	0,87
15^{30}	40	26	39	22,5	25	0,91
19^{10}	39	24	38	22	24	0,88

Table 2
Research results experimental cooler working without fan

№ experiments time	t_1 ^{0}C, water temperature supply into the cooler	t_2 ^{0}C, temperature outcoming water from the cooler	t_3 ^{0}C, temperature of the environment air	t_4 ^{0}C, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
8^{40}	38	27	35	21	27	0,64
11^{10}	41	27	40	22,5	23	0,75
13^{00}	43	28	42	23,5	26	0,76
15^{30}	40	28	39	22,5	25	0,68
19^{10}	39	28	38	22	24	0,64

Table 3
Research results experimental cooler working with fan

№ experiments time	t_1 ^{0}C, water temperature supply into the cooler	t_2 ^{0}C, temperature outcoming water from the cooler	t_3 ^{0}C, temperature of the environment air	t_4 ^{0}C, temperatureмof wet thermometer.	φ % Airrelationalhumidity	$\eta_ж$
8^{25}	38	24,5	35	21	27	0,79
11^{00}	42	25	41	23,5	24	0,91
13^{05}	46	25,5	45	25,5	30	0,91
15^{30}	45	26	44	22,5	25	0,84
17^{40}	41	26	40	23,5	24	0,85

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Table 4

Research results experimental cooler working without fan

№ experiments time	$t_1{}^0C$, water temperature supply into the cooler	$t_2{}^0C$, temperature outcoming water from the cooler	$t_3{}^0C$, temperature of the environment air	$t_4{}^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
8^{25}	38	26	35	21	27	0,70
11^{00}	42	28	41	22,5	23	0,71
13^{05}	46	28	45	23,5	26	0,80
15^{30}	45	28	44	22,5	25	0,80
17^{40}	41	27	40	22	24	0,73

Table 5

Research results experimental cooler working with fan

№ experiments time	$t_1{}^0C$, water temperature supply into the cooler	$t_2{}^0C$, temperature outcoming water from the cooler	$t_3{}^0C$, temperature of the environment air	$t_4{}^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
The8^{00}	30	24	30	21	27	0,66
10^{00}	31	25	36	22,5	23	0,70
12^{00}	32	25	42	23,5	26	0,58
14^{00}	35	25	44	22,5	25	0,80
16^{00}	33	24	42	22	24	0,81

Table 6

Research results experimental cooler working without fan

№ experiments time	$t_1{}^0C$, water temperature supply into the cooler	$t_2{}^0C$, temperature outcoming water from the cooler	$t_3{}^0C$, temperature of the environment air	$t_4{}^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
8^{00}	30	26	30	21	27	0,44
10^{00}	31	27	36	22,5	23	0,47
12^{00}	32	27	42	23,5	26	0,58
14^{00}	35	28	44	22,5	25	0,56
16^{00}	33	27	42	22	24	0,54

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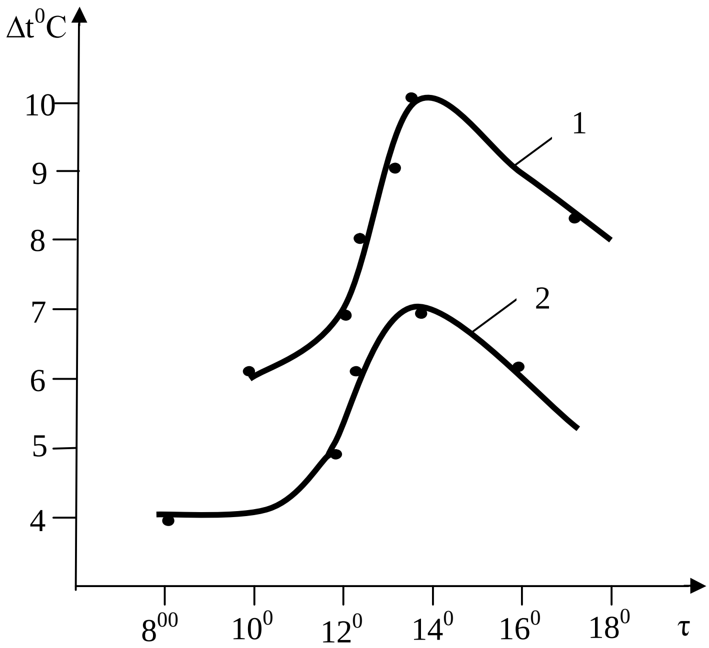

Picture. 2 Curve of transitive process, showing instability dependence of cooled water during twenty-four hours (1,2- at switched-on and off-stream fan)

Table 7
Research results experimental cooler working with fan

№ experiments time	$t_1{}^0C$, water temperature supply into the cooler	$t_2{}^0C$, temperature outcoming water from the cooler	$t_3{}^0C$, temperature of the environment air	$t_4{}^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
9^{00}	30,5	24	36	21	27	0,68
11^{00}	31	25	42	22,5	23	0,70
13^{00}	35	25	44	23,5	26	0,86
15^{00}	32	24,5	43	22,5	25	0,78
18^{30}	32	24	42	22	24	0,8

Table 8
Research results experimental cooler working without fan

№ experiments time	$t_1{}^0C$, water temperature supply into the cooler	$t_2{}^0C$, temperature outcoming water from the cooler	$t_3{}^0C$, temperature of the environment air	$t_4{}^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
9^{00}	30,5	26	36	20	66	0,42
11^{00}	31	27	42	20,5	63	0,38

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13^{00}	35	28	44	21	66	0,5
15^{00}	32	27	43	22	69	0,5
18^{30}	32	26	42	22	69	0,6

Table 9
Research results experimental cooler working with fan

№ experiments time	$t_1\,^0C$, water temperature supply into the cooler	$t_2\,^0C$, temperature outcomingwater from the cooler	$t_3\,^0C$, temperature of the environment air	$t_4\,^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
11^{00}	30	24	24	20	66	0,6
12^{00}	33	26	25	20,5	63	0,56
14^{00}	36,5	29	26	21	66	0,48
15^{00}	35	28	26	22	69	0,53
16^{00}	34	27	25	22	69	0,58

Table 10
Research results experimental cooler working with fan

№ experiments time	$t_1\,^0C$, water temperature supply into the cooler	$t_2\,^0C$, temperature outcoming water from the cooler	$t_3\,^0C$, temperature of the environment air	$t_4\,^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
12^{00}	36	27	25	22	69	0,64
13^{00}	36	27	26	22	69	0,64
14^{00}	36	27	26	22	75	0,64
15^{00}	30	24	26	23	76	0,85

Table 11

Research results experimental cooler working with fan

№ experiments time	$t_1\,^0C$, water temperature supply into the cooler	$t_2\,^0C$, temperature outcoming water from the cooler	$t_3\,^0C$, temperature of the environment air	$t_4\,^0C$, temperatureмof wet thermometer	φ % Airrelationalhumidity	$\eta_ж$
10^{00}	40	34	24	22	83	0,33
11^{00}	40	34	24	22	83	0,33
12^{00}	40	34	26	22	75	0,33
13^{00}	40	34	26	22	69	0,33
14^{00}	31	25	27	23	69	0,75
15^{00}	31	25	26	23	76	0,75
16^{00}	31	25	26	23	76	0,75

Outgoing results of experimental researches of temperature and relational humidity of the air in the process of evaporating water cooling on the experimental installation with pipy spray coolers at different speeds of the air and constant irrigation solidity are shown in table 12.

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Table 12
Experimental research results at different speeds of the air and constant irrigation solidity

Experiment number	1...7	8..14	15... 21
Air speed , м/s	1,07	0,82	0,72
Irrigation solidity , $м^3/м^2$*c	4,93	4,93	4,93
Temperature of the air on the entry , ^0C	17,2	17,2	17,3
Temperature of the air on the exit , ^0C	21.1	20.6	20.4
Temperature of the air on the entry , ^0C	36	38	40
Temperature of the air on the exit , ^0C	26	28	28
Thermal effectiveness with liquid	0,71	0,6	0,72
Coefficient of heat irradiation , Вт/ $м^2$*к	928,8	621	530,4
Coefficient of mass transfer , кg/м*s	0,8	0,5	0,4

In consequence of small phase contact surface and small time of surroundings low process effectiveness of water cooling becomes apparent.

In table 13 the results of generalized experimental researches process of evaporating cooling of water on the experimental cooler installation with pipy spray coolers are brought out.

Table 13
Results of generalized experimental researches

Experiment number	1...4	5...7	8...10	11...12	13,14	15,16
Air speed , м/s	1,7	1,82	1,72	1,84	2,1	2,1
Irrigation solidity, $м^3/м^2$c	4,93	6	7	11	16	20
Temperature of the air on the entry , ^0C	29,2	29,2	29,3	29,4	30	30
Air humidity , %	31.7	31.6	33.4	34	32	32
Temperature of the air on the entry , according to wet thermometer , ^0C	21	21	22	22	22	23
Temperature of water on the entry , ^0C	40	41	40	40	39	39
Temperature of water on the exit , ^0C	28	29	31	30	28	29
Thermal effectiveness with liquid	0,82	0,64	0,6	0,55	0,64	0,62
Coefficient of heat irradiation , Вт/ $м^2$*к	928,8	621	530,4	586,7	601,3	501,2
Coefficient of mass transfer , кg/м*s	0,95	0,75	0,64	0,76	0,68	0,78

On the base of experimental records there were coefficient dependence from mass transfer constructed (picture 3) and the thermal effectiveness (picture 4) in liquid speed from the air speed in the experimental cooler with pipy nozzle. As is known from table (picture 3), the coefficient of mass transfer is increased. It is connected with increasing of turbulence of gas stream in the nozzle layer, which is explained by big eddy formation on the account pipes location in chess order and increase of surface phase contact on the account more intensive braking liquid drops and decrease drops slip into spray coolers.

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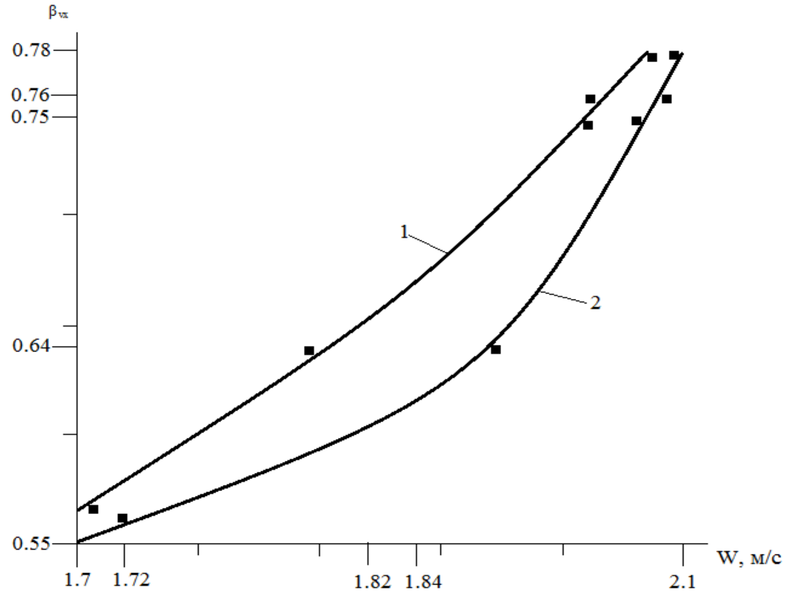
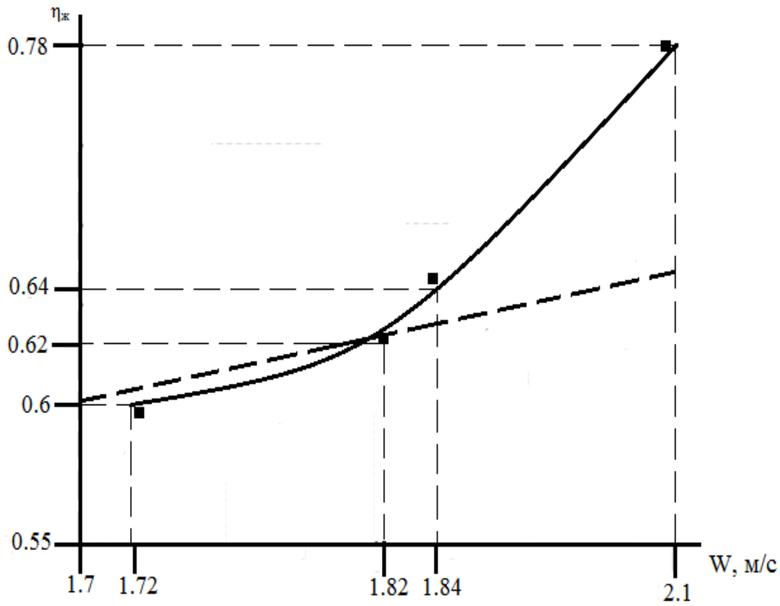


Picture 3. Dependence of mass transfer from the air speed:

At irrigation solidity1. - 6 м^3/м^{2}час; 2. - 7 м^3/м^{2}hour



Picture 4.Thermal effectiveness dependence from the air speed

At irrigation solidity**q$_ж$**- 6 м^3/м^{2hour}; ---- calculation on mathematical model

From the diagram (picture 4) we can see, with increase of the air speed thermal effectiveness is increasing with liquid phase. With increase of liquid consumption significance of thermal effectiveness is decreasing . It is

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connected with at increasing liquid consumption in the cooler the heat $Q = I \cdot c_p (T_H - T_K)$, acts more and the air consumption remains constant. At speed increase of the air in 1,5 times the thermal effectiveness increases in 1,33 times at maximum liquid consumption and at minimum liquid consumption in 1,19 times.

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