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Mathematical Modeling of Cooling Process Water in the Packed Towers

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ABSTRACT: The results of the study, modeling of thermal processes lead to the intensification of heat and mass transfer and energy efficiency in process equipment packed tower evaporative cooling. It was the mathematical modeling of the dynamic line of the cooling process the water in the cooling tower and computer research statics calculation process in a packed device at different hydrodynamic structures.

KEYWORDS: cooling tower, simulation, system analysis, quasi unit, sprinkler, irrigation, heat and mass transfer, hierarchical stage, computer.

I.INTRODUCTION

The basis of the process line of rational water management schemes are water circulating cooling system where the cooling tower are used as cooling equipment [1]. Cooling towers are used in water recycling systems, where you need a steady cooling water at high specific hydraulic and thermal loads. Therefore, research, modeling of thermal processes that lead to the intensification of heat and mass transfer and energy efficiency in process equipment cooling tower evaporative cooling is important.

Process water cooling line consists of a set of objects. Imagine the whole process as a single unit with a plurality of input and output parameters, given the total amount of water fed to the dispenser and the total energy. For clarity, we represent in Figure 1

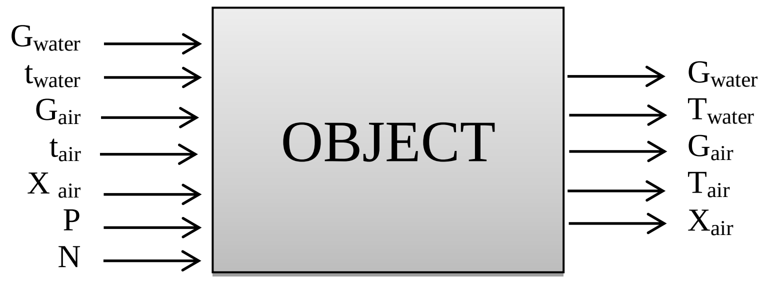

Fig. 1. Technological process.

Input parameters: G_{Water} - water consumption; t_{Water} - the initial temperature of the water; G_{air} - air flow; t_{air} - the initial temperature of the air; X_{air} - humidity; P - air pressure; N - energy.
Output parameters: G_{water} - water consumption; T_{water} - outlet water temperature; G_{air} - air flow; T_{air} - outlet air temperature; X_{air} - humidity.

For a better understanding of the process, look at each individually quasiunit [2, 3].The nozzle block (irrigator) [4] of the tower is in the form of layers of the module horizontally staggered rows of polymer longitudinal tubes. Pipes are fixed to the tube plates by passing them through the holes with the tube sheet is made of a polymeric material in the form of a rigid lattice, and the distance between the holes in a row and the distance between rows of holes equal to the diameter of the pipe. Tube sheet is made as a rigid lattice with holes spaced relative to each other in a staggered manner. Choosing the distance between the holes in a row and the distance between the rows equal to the diameter of the pipe allows you to create optimum air flow rate corresponding to the maximum intensification of heat and mass transfer and thus ensures its optimal aerodynamic drag.

When using the nozzle unit as the sprinkler water to be cooled in the cooling tower is sprayed on the sprinkler, and then it flows over the surface of the tubular elements and cooled by the counter air flow, while during operation a rigid block design allows to maintain the original configuration of the assembled unit, thus enhancing efficiency of heat and mass transfer in a cooling tower.

When using the nozzle unit water catchers as water drops which are carried along with the air flow, when passing multiple layers of tubular elements are deposited on the surface of the latter, going into larger droplets and flow back to the cooling tower basin. This prevents loss of water from the droplet entrainment.

Spray zone consists of a liquid and air (Fig. 2). Here comes the heat-mass transfer process. In this process, the greater the flow rate, the process is more efficient.

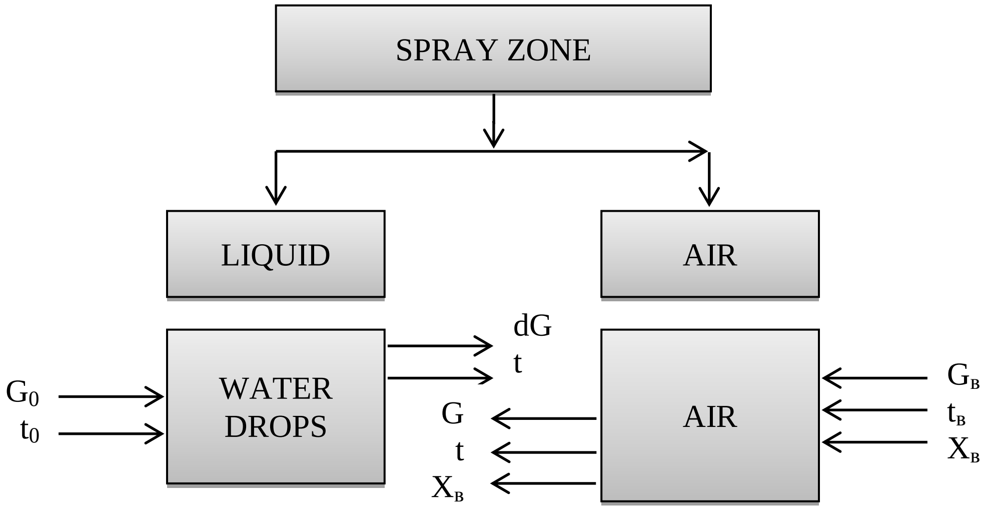

Fig. 2. Spray zone

Input parameters of water drops: G_0 - the initial flow of water drops; t_0 - the initial temperature of the water drops;
Output parameters of water drops: dG - water flow drops; t - water temperature drops;
Input parameters of air: G_{air} - air flow; t_{air} - air temperature; X_{air} - humidity;
Output parameters of air: G_{air} - air flow; T_{air} - air temperature; X_{air} - humidity.
Mathematical modeling of heat and mass transfer for the selected spray or packed zone j-th unit begins with the preparation of the heat balance in the unit:

$$\frac{\partial Qj}{\partial \phi} = q_{\text{в}J-1} - q'_{\text{в}} - \Delta q_j + \Delta q_{jair} \quad (1)$$

$$Q_j = m_j * e_j * t_j \ ;$$

Q_j-liquid heat in the j quasiunit.
$q_{\text{в}.j-1}$-the thermal energy, water coming in the jthquasiunit.
q_j –the thermal energy from the fluid leaving the jthquasiunit.
Δq_j -thermal energy is carried away by the evaporating liquid from the jthquasiunit.
Δq_{jair} –the thermal energy from the air in the jthquasiunit.
We turn to the mathematical description of the indicators considered above heat balance.
$q_{\text{в}j-1} = G_{j-1} * e * t_{j-1}$
G_{j-1} –water consumption ofjthunit;
e- heat capacity of the jthquasiunit;
t_{j-1} - the temperature coming into the jthquasiunit;
$q_j = G_j * c * t_j$
$\Delta q_{jm} = = \Delta G_j * i$
$\Delta q_{jair} = б * F_j(t_{airj} - t_j)$

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б-coefficient of heat transfer.
F_j-surface, which receives thermal energy which is delivered from the air in the jth quasi unit.
$t_{воз j}$ −air temperature entering the jth unit.
t_j −temperature of the jth quasi unit.
$\Delta G = в * F_j\ (X_{вн} - X_{air})$
ΔG −airflow.
в −mass transfer coefficient.

$$\frac{\partial mj*c*tj}{\partial \phi} = G_{j-1} * e * t_{j-1} - G_j * c * t_j - \left(в * F_j(x_{в.н} - x_{air})\right) * i + б * F_j\left(t_{air.j} - t_j\right); \quad (2)$$

$$\frac{\partial t}{\partial \phi} = G_{j-1} * e * t_{j-1} - G_j * c * t_j - \left(в * F_j(x_{в.н} - x_{air})\right) * i + б * F_j\left(t_{air.j}\right)/(m_j * c) \quad (3)$$

In this mathematical description of a number of indicators that require a special approach. In particular, this mass transfer coefficients в and the heat transfer б. To determine the values of these coefficients are used experimental approaches. Another, significantly affecting the calculation of the rate of the process is the actual and equilibrium moisture concentration in the air.

II.Equilibrium moisture concentration in the air.

When the heat-mass transfer of water phase and gas phase is determined by the equilibrium. Equilibrium by liquid phase has its own characteristics. The equilibrium concentration of water in the gas phase is characterized by three parameters:
t-temperature of the liquid phase;
P_0- pressure quasi apparatus;
X^*_{j-1}- equilibrium concentration of water vapor in the gas phase in terms of the state of the fluid.

According to Raoult'slaw the partial pressure of water vapor depends on the molecular concentration or the molecular concentration of water vapor in the air is given by:

$$X^{*M}_{j-1} = \frac{P}{P_0} \quad (4)$$

In turn, the partial pressure of water vapor may be determined from a table of saturated water vapor state [6].
To determine the mass concentration of use equations depending on the molecular weight of the water concentration in the air:

$$m_в = x^M_в * M_в; \quad (5)$$

Equation depending on the molecular weight of the water concentration of the air:

$$m_в = x^M_{air} * M_{air}; \quad (6)$$

Equation molecular concentration in air of molecular water concentration in the air:

$$x_{air} = 1 - x^M_{water}; \quad (7)$$

The total mass of air is the sum of the air masses in the selected volume and water:

$$m_0 = m_{water} + m_{air}; \quad (8)$$

The water concentration in the air is determined by a conventional equation:

$$x_{water} = \frac{mв}{m0} \quad (9)$$

As is known, the molecular weight:

$$M_{water} = 18 \text{ и } M_{air} = 29{,}3$$

Then, after a mathematical transformation equation is obtained according to the mass concentration of water in air of molecular water concentration in the air:

$$x_в = x^M_в * 18/(x^M_в * 18 + 29 - x^M_в * 29) \quad (10)$$

$$x_в = x^M_в * 18/(29 - 11x^M_в).$$

When calculating the heat-mass transfer process using the mass fractions of the components, i.e.air and water. Considering the molecular weight of the components, it is possible to determine their mass concentration.
After processing tabular data by mathematical statistics definite regression equations for different changes in fluid temperature limits.

III.The partial pressure of water vapor in the heat and mass transfer system.

Information about the partial pressure of water vapor in the heat-mass transfer system we can obtain based on the table data on the properties of saturated steam and the temperature (Table 1). (Pressure - the second column, the temperature - the third column) [6].

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1.	0,6386	0
2.	0,9167	5
3.	1,2875	10
4.	1,7922	15
5.	2,4514	20
6.	3,3269	25
7.	4,4599	30
8.	5,9019	35
9.	7,7456	40
10.	10,0631	45
11.	12,9574	50

By processing tabular data we obtained an equation for a narrow range of variation of the fluid temperature from 5 ℃ to 40 ℃, and the calculation of the partial pressure of the fluid temperature can be performed using the formula:

$$P=0.0047t^2 - 0.027t + 1,$$

Dependence is shown in a graph (Figure 3.):

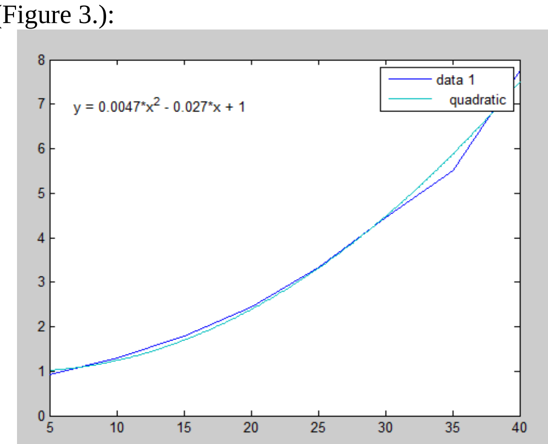

Fig. 3. Dependence

If the water temperature in the cooling tower 20 varies from 20 ^{0}C to 35 ^{0}C (rarely to 45^{0}C), the partial pressure dependence of the temperature can be characterized by a linear relationship:

IV.The actual concentration of water in the contacted air

The concentration of moisture in the air for the jth rate quasi unit characterized initial moisture concentration of the air in the air.

Air passing through quasi unit successively enriched with water vapor, whereby the concentration of water vapor in the air increases, thus increasing the air flow. You can use the equation:

$$G_{air} = G_{\text{в}0.} + \Delta G_1 + \Delta G_2 + \cdots \Delta G_{j-1} \quad (11)$$

If the initial humidity is known, the flow rate is easily determined in the incoming air. Consumption of water with the incoming air is:

$$G_{a\square r} = G_0 * x_0$$

For a more accurate calculation it would be desirable to rely on the average concentration of moisture in the air in the jth quasi unit. Vertical distribution of moisture in the air apparatus for an approximate calculation of heat and mass transfer process of the jth quasi unit can be taken constant. The concentration of vapor in the air for moisture included in the jth quasi unit air is determined by the ratio of water vapor in the air flow rate to the total air flow rate:

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$$X_{j.\text{в}} = \quad_{\text{в.п}} + \sum_{j=1}^{n} \Delta G_j \,/(G_{air\ 0} + \sum_{j=1}^{n} \Delta G_j) \quad (12)$$

After determining the concentration of water in the air for equilibrium and for actual conditions, you can continue to the definition of heat and mass transfer three-phase quasi unit.

In this three-phase quasi unit main active phases are liquid and gas phases. The solid phase, i.e. nozzle pipes, contribute to the improvement of heat and mass transfer, due to the increase of the contact surface and by increasing the rate of mass transfer, due to the increased turbulence flows.

Rolling in the gas phase water vapor determined by the classical equation of heat and mass transfer:

$$\Delta G = K_{vj} * V_j * (X_j^* - X_{j-1}) \quad (13)$$

This is the case when the contact area between the gas and liquid phases poorly correlated.
where: $К_v$ –mass transfer coefficient for the specific volume of the j[th] quasi unit;
V_j –quasi unit capacity;
X_j^* –equilibrium concentration in terms of the incoming fluid in the j[th] quasi unit;
X_{j-1} –the actual moisture concentration of the incoming gas stream into the j[th] quasi unit.

If the contact surface between the liquid and gas phases, it is possible to determine, it is possible to use other classical equation:

$$\Delta G_j = K_j * F_j * (X_j^* - X_{j-1}) \quad (14)$$

Mass Transfer Coefficients $К_{vj} и K_j$depend on many factors. Basically, there are two ways to determine the mass transfer coefficients:

1. The classic method. Mass transfer coefficients are determined based on the specific methods of the experiment, contributing to identify these factors through the use of criteria equations.

2. On the basis of experiments or in its original physical model by solving the mathematical procedure for the inverse problem. Here the definition of the dependencies of mass transfer coefficients of other factors established by comparing the results obtained with the mathematical and physical models.

$$t_i = (G_{j+1} * c * t_{j+1} - \Delta G_i + б * F * t_{\text{в}.j-1})/(G_0 - \sum_{j-n}^{j} \Delta G) * c + б * F) \quad (15)$$

$$X_j = \text{в}_j * F_j(X^* - X_{j-1})/m_j \quad (16)$$

$$\Delta G_{\text{в}} = G_{\text{в}j-1}(X_{j-1} - X_j) \quad (17)$$

$$X^* = \frac{P}{P0}; P = P_0 * X_{j-1}^{*M}; G_0 = \frac{G\text{в}}{X0}.$$

Implemented algorithmization contributing to the solution of the equation system. On the basis of a computer model algorithmization formalized.

In carrying out the process of evaporative cooling circulating water in the cooling tower is a limiting air phase. The volumetric mass transfer coefficient, $м^3/(м^2 \cdot h)$ orkg/($м^2 \cdot h$), determined by the formula [5,7]:

$$\text{в}_{xv} = Aq_{ж}\lambda, \quad (18)$$

A-the number of Merkel,

$$\text{Me} = \text{AH}\lambda^m, \quad (19)$$

where A is the coefficient characterizes the influence of nozzle design features on its cooling capacity, $м^{-1}$;
$\lambda = q_w/q_l$ - the ratio of the mass air flow and fluid, kg / kg;
H – height of the nozzle block, m;
m – exponent that characterizes the dependence of the volume mass-transfer coefficient by changing the mass of air speed.

When studying the process of evaporative cooling water in the experiment of [5] in accordance with the theory of similarity is necessary to provide a similar operation with hydrodynamic industrial cooling tower. Evaluation of cooling tower capacity is done by comparing the calculated temperature chilled water temperatures obtained in the tests, as well as mass transfer coefficients β_{xv}. It should be borne in mind that in the cooling capacity of the cooling tower and, accordingly, the value of β_{xv} affects the degree of uniformity of distribution of air and water on sprinklers, the degree of fragmentation in the water drops and the sprinkler in the film, i.e. the quantity of water contact surface with the air, the water temperature difference and the average temperature. In the experiments, we set the speed of the free cross-section of the cooling tower 0.5-2.5 m / s. Irrigation density corresponds 4,01ч7,61m^3 / h m^2. To measure the temperature of the thermocouple used with a microprocessor data processing system. The experiments were conducted in a pilot plant with sprinklers tube-type composite polymer. Material and heat balances of the fan cooling towers have been drawn up. Initially, the water cooling process was investigated in a hollow device and then experimented with a number of contact elements 8 in a single row. All experiments were conducted at a fixed density of irrigation and air speeds. Performance

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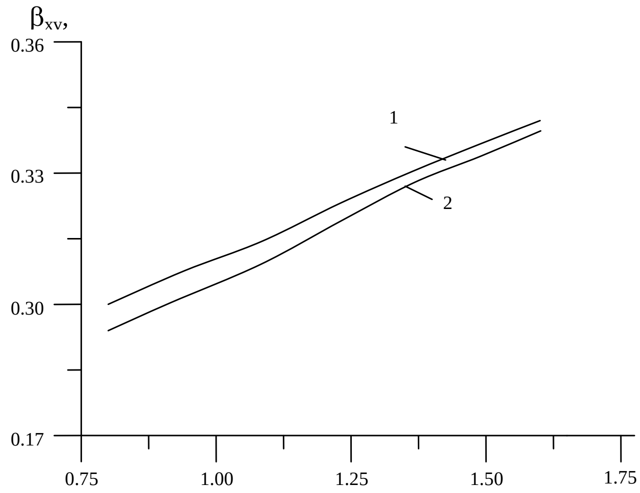
characteristics were chosen close to the industrial cooling towers. Maximum experimental error of ± 15%, the average error of ± 7-8%. All experiments were carried out ten times at fixed air and water costs. The results with the greatest differences from the average (15%) were not considered. As a result, it found that satisfactory accuracy is achieved during the 4-5 experiments. The research results of water evaporative cooling process in a pilot plant with tubular tower sprinklers at different air speeds and the same irrigation densities were processed and obtained empirical expressions for the calculation of the volumetric mass transfer coefficient for cooling towers:

$$\beta_{vx} = 1.04 \cdot q_{ж}^{1,02} \lambda^{0,79} \tag{20}$$

Based on calculations by the formula (20) were built according to the coefficient of mass transfer (Fig. 4) of the air speed. As seen from the graph (Fig. 4) with increasing gas velocity increases mass transfer coefficient. This is due to an increase in the degree of the gas nozzle flows layer turbulence, which explains the greater agitation of the air due to the location of the pipes in staggered rows and increase the contact surface of the phase due to the intense fragmentation of liquid droplets drops reduce leakage.

Fig. 4. Dependence of the mass-transfer coefficient of air velocity when irrigation densities 1. 6м^3/м^{2}h; 2. 7м^3/м^{2}h.



V. Computer simulation of the dynamic process line of the cooling water in cooling towers.

Based on a computer model of the tower was made up of the material balance system with all incoming and outgoing parameters in which the temperature is regulated.

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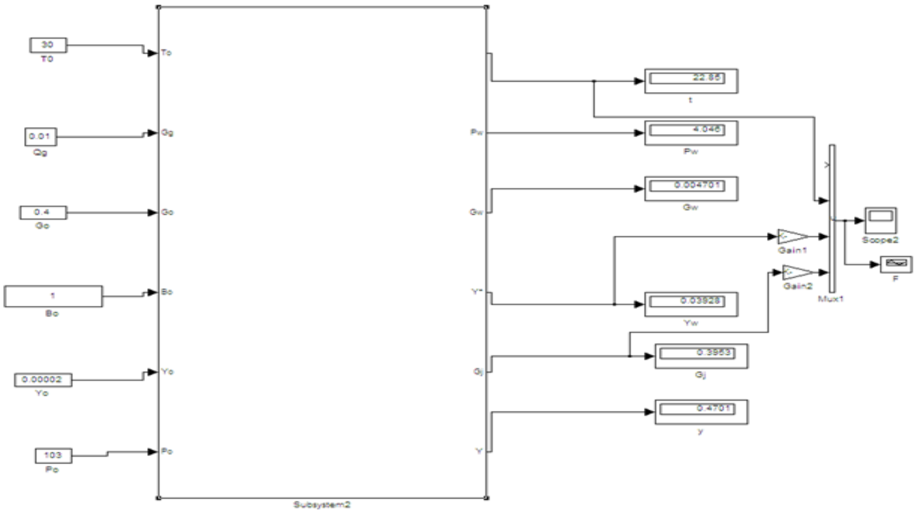
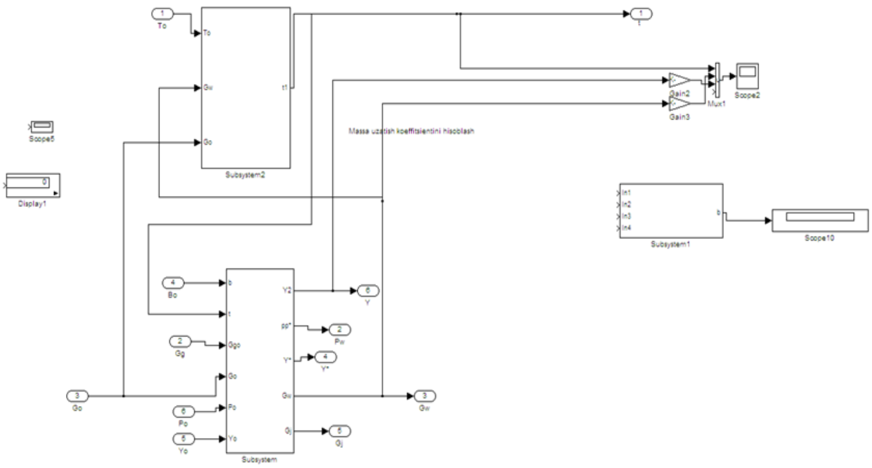


Fig. 5. A computer model of heat mass exchange of the cooling tower process.

Computer model of cooling tower heat mass transfer process is shown in Fig. 5. The input parameters are: the initial flow rate of the incoming gas G_{g0}, initial temperatureT_0,, pressure in the device, the flow rate, the initial gas humidity. Output parameters: indicative consumption output gasG_g,exponential temperatureT_e, unit pressure *P*, the flow rate *G*.

Fig. 6. Elements of the model: calculation block heat and mass transfer between liquid and gas phases; unit calculation



of mass transfer and equilibrium conditions

Fig. 6 shows the elements of the model. Block calculate heat and mass transfer between the liquid and gas phases, includes two blocks and a number of elements, performs registration required output parameters. The upper block is carried fluid temperature calculation based on the initial temperature T_0, the evaporation of moisture in the packed zone *Gв* and the initial flow rate G_0.

Lower unit - unit of calculation of mass transfer and equilibrium conditions. Input parameters are: mass transfer coefficient B_0, initial gas flow rate G_{g0}, pressure P_0. The output parameters are: the equilibrium partial pressure P_w, the equilibrium moisture concentration in the air Y_w, output fluid consumption G_w, the actual concentration of moisture in the air G_j.

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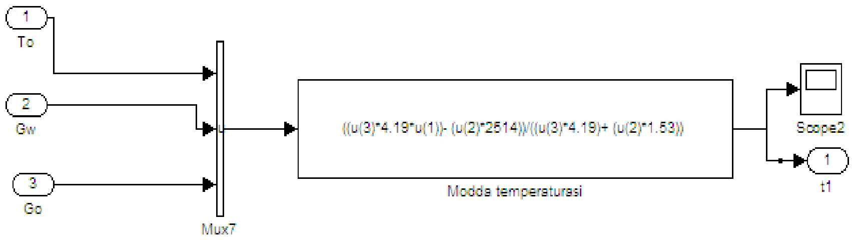

Fig. 7. A computer model of the calculation cooling liquid temperature unit

Fig. 7 shows a computer model of the unit calculating the temperature of the coolant. Performs a solution of the ordinary algebraic equation derived from the heat balance of the liquid phase. The input parameters are: initial temperature$t_0$is denoted U1, consumption of evaporated moisture $G_{в}$, denoted by U2 initial flow rate is G_0, denoted by U3. This heat energy of the gas phase can be included, occurring due to heat exchange between the liquid and gas phases.

Fig. 8. The inner part of the conditions of equilibrium and heat and mass transfer

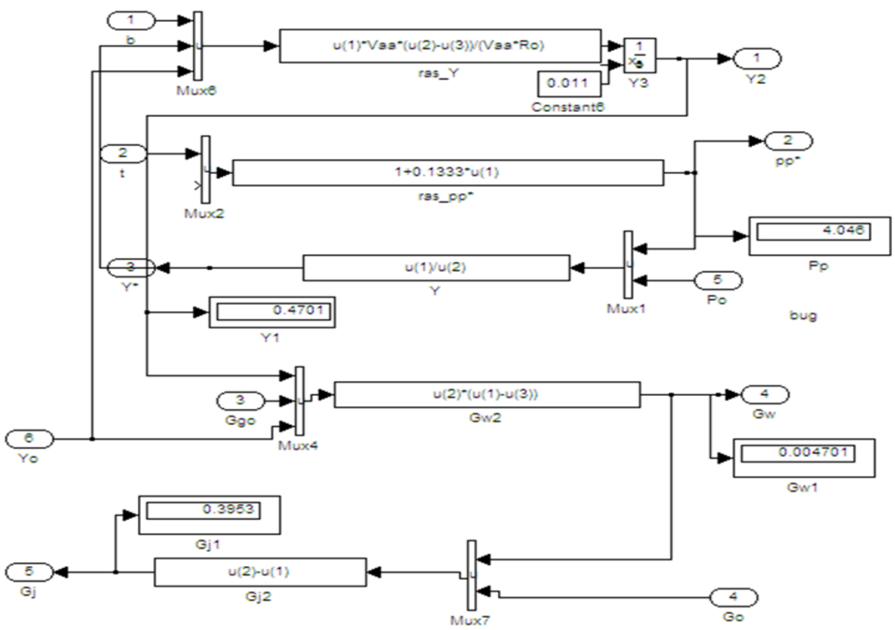

Fig. 8 shows the internal part of the conditions of equilibrium and heat and mass transfer.

1 - the block of calculation taking into account the evaporated moisture equilibrium two-phase state. In the block, due to the evaporation of moisture, based on classical mass transfer procedure calculated moisture turning into a gas phase. The block includes the value of mass transfer coefficient symbol U1. The value of the equilibrium concentration of U2

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air moisture and the amount of the actual concentration of U3. In block 2 shows up the right side of an algebraic equation, and then integrated into the integration bloc. 3 - the block of calculation of the equilibrium partial pressure. Performs calculation of the equilibrium partial pressure in the air. Here comes the value U1 and temperature hysteresis dt-U2.

3 - unit for calculating the equilibrium concentration of water in the gas phase The equilibrium partial pressure enters in the block and the actual pressure U1 with U2 designation.

4 for calculating the actual flow of moisture concentration in the gas phase. It sas the input parameters on the value of U1 evaporated moisture of the initial gas flow system U2 and U3 of the initial humidity.

5 - unit for calculating the flow of water coming out, has the input parameters of the flow rate of the evaporated moisture U1 and U2 on the initial water flow.

Fig. 9 shows a transition curve showing the time dependence of temperature. Over time, the dynamics of the water temperature decreases.

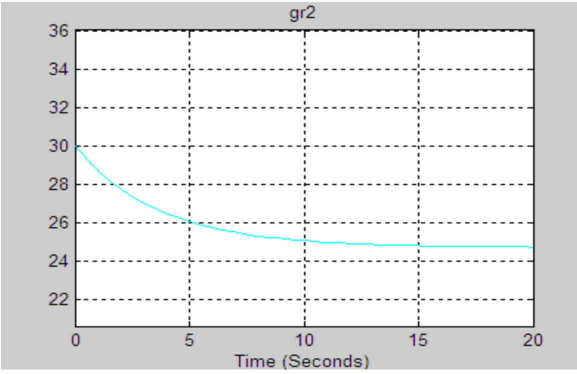

Fig.9 Transient curve.

VI.The calculation of the statics of the cooling line process water in cooling towers

After formalizing the computer model, there is opportunity to study the process with different initial conditions and the determination of appropriate indicators of the process. Adopted by the initial conditions: inlet water temperature of 300 ° C, water flow rate of 0.4 kg / s of air flow of 0.1 kg / s, the initial humidity of 0.0002 kg / kg.

To get started in Fig. 10, 11, 12 are estimates: for working volumes apparatus Vo = 0.5 and Vo = 0.1; for different values of mass transfer coefficients; for packing machines, spray-packed, and spray-packed with hydrodynamic structure double-celled ideal mixing streams.

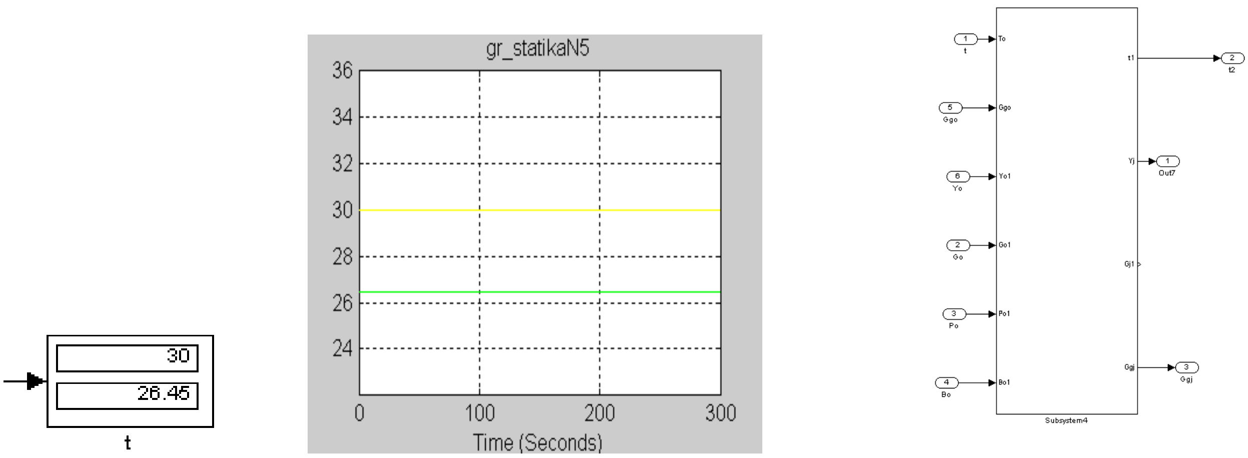

Fig. 10. Calculation of the static process in the packed unit with a hydrodynamic structure of the single-cell flow of ideal mixing (at Vo = 0.5; Bo = 1)

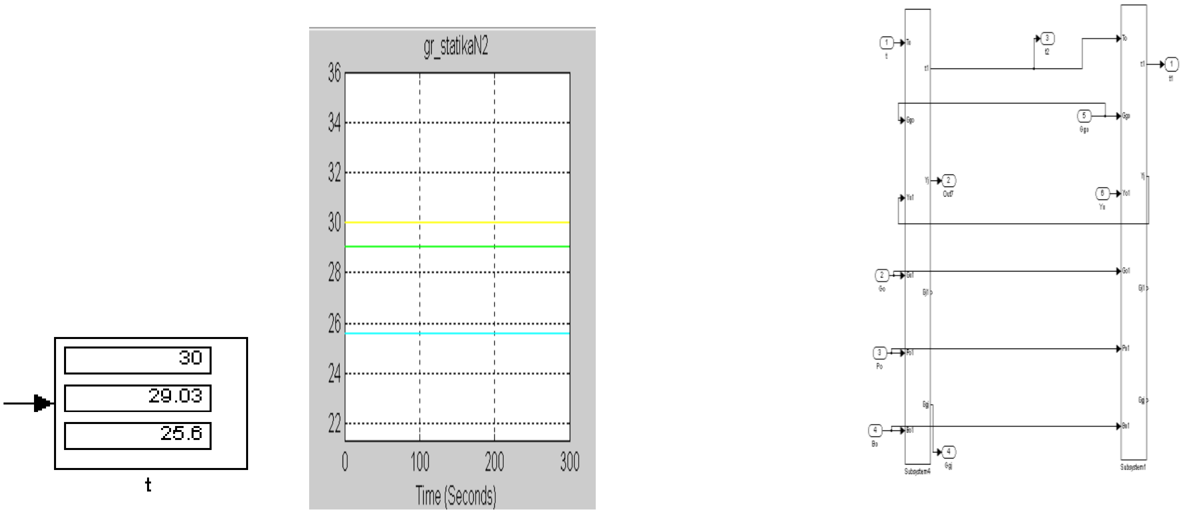

Fig. 11. Calculation of the static spray process, and a packed unit with a hydrodynamic structure ideal mixing flow (at Vo=0.5; Bo=1 n=2)

at Vo=0.1 at Vo=0.3 at Vo=0.5

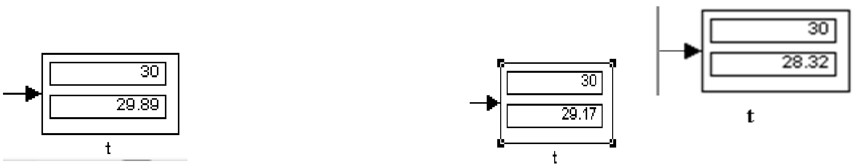

Fig. 12. Calculation of the static process in the packed unit with a hydrodynamic structure of ideal mixing with different quantities packed area streams (+it's possible to bring data from laboratory experiments)

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