contain the amount of water necessary to maintain the processes. The second heat tank is designed to store the water required to carry out process 4.2, and its volume should be as large as the amount of water needed for the process. The design presented in Fig.1 can provide for the processes involved in the technological regulation. The task of process control is to determine the controlling variables ensuring minimum costs (water, vapor) the scheme.

MATHEMATICAL MODEL

It is assumed that for each of the four stages cooling will be carried out by certain dependence of the change of cooling water flow with time. This assumption provides a possibility to use models of the processes with ordinary differential equations. These equations describing the processes of heat- and mass transfer are:

1. An equation describing the change of the temperature of the mixture in reactor F_H when a flow of $CW20$ or $CW5$ of certain flow rate F_{Wi} - is described by an equation for each time interval:

$$\frac{dT_{Fi}}{dt}=\frac{(\Phi_{Wi}-1)}{\Phi_{Wi}}\frac{(F_{Wi}Cp_{Wi})}{V_F Cp_F}\left(T_i^{in}-T_{Fi}\right),\forall i\in(1\div 4) \quad (1)$$

where:

- $T_i^{in}=x_i T_{W20}+(1-x_i)T_{W5}$, $x_i=\{0\vee 1\}$,
- $\Phi_{Wi}=\left|\frac{T_{Fi}-T_i^{in}}{T_{Fi}-T_i^{*}}\right|=\exp\left(\frac{UA}{F_{Wi}Cp_{Wi}}\right)$, A is the heat exchange surface of the serpentine in $\left[m^2\right]$,
- U is the total coefficient of heat transfer, in $\left[kWm^{-2}K^{-1}\right]$,
- Cp_F, Cp_{W20}, Cp_{W5} in $\left[kJm^{-3}K^{-1}\right]$,
- $Cp_{Wi}=x_i Cp_{W20}+(1-x_i)Cp_{W5}$, Cp_{W20} and C_{pw5} are the specific heat capacities of $CW20$ and $CW5$.
- The flow rate of the cooling water through the serpentine is F_{wi} [m^3/s].

2.The temperature at the serpentine outlet is determined for each time interval by the equation:

$$T_i^{*}=\frac{(\Phi_{Wi}-1)}{\Phi_{Wi}}T_{Fi}+\frac{1}{\Phi_{Wi}}T_i^{in},\quad \forall i\in(1\div 4) \quad (2)$$

The solution of equation (1) was to be found under initial condition $T_{Fr}(0)$, where $T_{Fr}(0) = T_{str}(0)$, at $i=1$ and $T_{Fr}(0) = T_{Fri}(0)(t_{i-1})$ at $i>1$. It should be taken into account that the temperature of the water flowing out of the serpentine T_i^{*} must be lower than that of the material contained in the fermenter T_{Fri} i.e. $T_{Fi}\geq T_i^{*}$.

3. The volumes of the tanks $S1$, $S2$, SW and their temperatures for each time interval are described by:

$$\left.\begin{aligned}&\frac{dV_{S1}^i}{dt}=y_i^{S1}F_{Wi}\\ &Cp_{Wi}V_{S1}^i\frac{dT_{S1}^i}{dt}=y_i^{S1}F_{Wi}Cp_{Wi}\left(T_i^{*}-T_{S1}^i\right)\end{aligned}\right\},\ \forall i\in(1\div 4) \quad (3)$$

At initial conditions $V_{S1}^i(0)=V_{S1}^{(i-1)}\left(t_{(i-1)}\right)$, $T_{S1}^i(0)=T_{S1}^{(i-1)}\left(t_{(i-1)}\right)$ and at $i=1$ for the first time interval – 1 $V_{S1}^i(0)=0$, $T_{S1}^i(0)=T_i^{in}$.

$$\left.\begin{aligned}&\frac{dV_{S2}^i}{dt}=y_i^{S2}F_{Wi}\\ &Cp_{Wi}V_{S2}^i\frac{dT_{S2}^i}{dt}=y_i^{S2}F_{Wi}Cp_{Wi}\left(T_i^{*}-T_{S2}^i\right)\end{aligned}\right\},\ \forall i\in(1\div 4) \quad (4)$$

At initial conditions $V_{S2}^i(0)=V_{S2}^{(i-1)}\left(t_{(i-1)}\right)$, $T_{S2}^i(0)=T_{S2}^{(i-1)}\left(t_{(i-1)}\right)$ and at $i=1$ for the first time interval – $V_{S1}^i(0)=0$, $T_{S2}^i(0)=T_i^{in}$.

$$\left.\begin{aligned}&\frac{dV_{SW}^i}{dt}=y_i^{SW}F_{Wi}\\ &Cp_{Wi}V_{SW}^i\frac{dT_{SW}^i}{dt}=y_i^{SW}F_{Wi}Cp_{Wi}\left(T_i^{*}-T_{SW}^i\right)\end{aligned}\right\},\forall i\in(1\div 4) \quad (5)$$

At initial conditions $V_{SW}^i(0)=V_{SW}^{(i-1)}\left(t_{(i-1)}\right)$, $T_{SW}^i(0)=T_{SW}^{(i-1)}\left(t_{(i-1)}\right)$ and at $i=1$ for the first time interval $-V_{SW}^i(0)=0$, $T_{SW}^i(0)=T_i^{in}$, $y_i^{S1}=\{0\vee 1\}$, $y_i^{S2}=\{0\vee 1\}$, $y_i^{SW}=\{0\vee 1\}$ depending on the that whether the corresponding heat tank is filled during the given time interval or not.

4. Cooling flow values $F_{Wi}(t)$ with time. In general the flow through the cooling serpentine can be presented by the expression:

$$F_{Wi}(t)=\left.\begin{aligned}&sign\left(F_{MAX}-F_i(t)\right)+\\ &\left(1-sign\left(F_{MAX}-F_i(t)\right)\right)F_{MAX}\end{aligned}\right\},\forall i\in(1\div 4), \quad (6)$$

at

$$F(t)_i=A_i+(B_i-A_i)\exp(-C_i t),\quad \forall i\in(1\div 4), \quad (7)$$

Where $sign(.)=1$ when $\left(F_{MAX}-F_i(t)\right)\geq 0$ and $sign(.)=0$ at $\left(F_{MAX}-F_i(t)\right)<0$. The values of the coefficients A_i, B_i, C_i should be determined.

Another possible method for controlling the cooling water flow is at a constant flow rate within the intervals. This method is comparatively easy for implementation, but the effectiveness of each method should be compared. In this method the values of the coefficients are $A_i=0$, $B_i\geq 0$ and $C_i=0$ for each $i\in(1\div 4)$.