# Mathematical Modeling of the Process of Condensation, Removal and Temperature Fields When Using Secondary Thermal Resources

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ABSTRACT

The article considers the modeling of the process for studying the heat and mass transfer of sludge in a gas jet and develops an acceptable mathematical model for the installation of forced removal and condensation of the vapor-air mixture and calculations in an integrated automatic design system of the ChemCad type. The mathematical model consists of five equations. The numerical solution of the system gives the temperature distribution in the drop during its separation into components.

**Keywords:** steam-air mixture, sludge, system of equations, water-air mixture, mathematical model.

Obviously, when the slabs are cooled by the sprayer flow of the water-air mixture, the processes of evaporation and condensation of water vapor from the composition of the steam-air mixture take place. Currently, the steam-air mixture is released into the atmosphere without cooling and purification, which is unacceptable because the condensate has an acidic environment.

An acceptable mathematical model of the installation for the forced removal and condensation of the vapor-air mixture was created on the basis of mathematical modules used in the process of modeling and calculations in an integrated automatic design system of the ChemCad type. The use of elements of the ChemCad system made it possible to trace the chemical transformations occurring in water, to identify the quantitative and qualitative composition of the steam-air mixture, condensate and water entering the circulating water supply system at various parameters of the water-air mixture and ambient air. To reduce the temperature and trap harmful substances, a unit for forced removal and condensation of the steam-air mixture from slab secondary thermal resources of the metallurgical industry has been developed.

The purpose of creating a mathematical model was not only to describe the ongoing processes, but also in an attempt to identify the main patterns of physicochemical processes occurring in this case, and to develop recommendations for preventing harmful environmental consequences of emissions of products of the interaction of water and impurities in it with the high-temperature surface of the slab.

The use of ready-made software packages greatly simplified the procedure for creating a mathematical model and made it possible to standardize methodological approaches to solving similar problems for metallurgical and similar processes associated with water and water-air cooling. The creation of a mathematical model was preceded by a fairly extensive examination of the composition of material flows, heat engineering and physico-chemical features of the slab cooling process in the secondary cooling zone of metallurgical enterprises.

An urgent problem is the development of a safe technology for the separation of sludge components based on the use of secondary thermal resources of a metallurgical enterprise and does not require the use of chemicals.

To study the heat and mass transfer of sludge in a gas jet, a mathematical model for calculating the temperature field of a sludge drop has been developed. The actual composition of the sludge taken directly from the secondary settling tanks varies within the following limits: water: 23 - 37%, oil: 15-31%, solid component: 38 - 60%.

The material components are separated in a gas jet at a temperature that boils the oil in the sludge. A spherical particle passes successively through the stage of heating up to the boiling point of water. Then moisture evaporates from the surface, and the evaporation front moves towards the center of the particle. The heat for water evaporation is supplied through the layer of the “sludge-oil” mixture, which gradually warms up to the oil boiling point ($\mathrm{T}_{\text{кип}1} = 159^0\mathrm{C}$). After the material reaches the temperature $\mathrm{T}_{\text{кип}1}$, the oil begins to evaporate. As the corresponding fractions boil away, the temperature of the particle rises, and the oil evaporation front moves to the center. The heat for oil evaporation is supplied through the dry layer of the solid component by thermal conduction. It is assumed that the temperature profile of the material corresponds to the stationary temperature distribution of the spherical wall.

Heating, evaporation of water and oil and heating of the solid residue are described by a system of equations:

$$c_1\rho_1\frac{\partial t_1(r,\tau)}{\partial \tau}=\frac{\partial}{\partial r}\left(\lambda_1\frac{\partial t_1(r,\tau)}{\partial r}\right)+\frac{2\lambda_1}{r}\frac{\partial t_1(r,\tau)}{\partial \tau}, \quad r<\xi\ ; (1)$$

$$c_2\rho_2\frac{\partial t_2(r,\tau)}{\partial \tau}=\frac{\partial}{\partial r}\left(\lambda_2\frac{\partial t_2(r,\tau)}{\partial r}\right)+\frac{2\lambda_2}{r}\frac{\partial t_2(r,\tau)}{\partial \tau}, \quad \xi<r<r_{\text{к}}\ (2)$$

$$-\lambda_1\frac{\partial t_1(\xi,r)}{\partial r}=-\lambda_2\frac{\partial t_2(\xi,r)}{\partial r}-W^p\cdot\rho\cdot r_n\frac{d\xi}{d\tau}$$
(3)

Initial conditions: $t_1(r,0)=t_2(r,0)=t_o$; $\xi=r_k$

Border conditions:
$t_1(r,0)=t_2(r,0)=t_o;\quad \xi=r_k\cdot q_{\text{пов}}=\alpha_{\text{к}}[t_r-t_2(r_{\text{к}},\tau)]$

The boiling point of oil at a given temperature

$$\mathrm{X}=\frac{\Delta m_{\text{ж}}}{m_{\text{жо}}}=\frac{(u_o-u)}{u_o}=1{,}08\cdot10^{-5}\cdot t^2-3{,}6\cdot10^{-3}\cdot t+0.3146,$$

$$\frac{d^2\,t_2(r,\tau)}{dr^2}+\frac{2}{r}\frac{dt_2(r,\tau)}{dr}=0, \varepsilon\le r\le r_{\text{к}}, t_2(\varepsilon,\tau)=T_{\text{кип}1} \quad (4)$$

Initial conditions:

$$-\lambda_c\frac{dt_3}{dr}\bigg|_{r=r_{\text{к}}}=\alpha_{\text{к}}\left(\mathrm{T}_{\text{г}}-\mathrm{T}_2|_{r=r_{\text{к}}}\right), -\lambda_2\frac{\partial t_2(\varepsilon,\tau)}{\partial r}=-\lambda_c\frac{\partial t_3(\varepsilon,\tau)}{\partial r}-L\rho_\varepsilon\frac{d\varepsilon}{d\tau} \quad (5)$$

Here $t_1(r,\tau)$ and $t_2(r,\tau)$ are the current temperature before and behind the moisture evaporation front; $t_3(r,\tau)$ - current temperature of the solid layer; $\lambda_1,\lambda_2,\lambda_3$ - thermal conductivity coefficients before and after the moisture evaporation front and dry solid layer; $c_1, c_2$ are the heat capacity of the material before and after the moisture evaporation front; $\rho_1,\rho_2$ - density before and after moisture evaporation, r - current coordinate; ξ - the current coordinate of the moisture evaporation front, ε - the current coordinate of the oil evaporation front; $W^p$ - humidity per working mass; r_n is the heat of evaporation of moisture; L - the heat of evaporation of the oil; $q_{\text{пов}}$ - the heat flux density on the droplet surface; $\alpha_{\text{к}}$ - heat transfer coefficient; $t_{\text{г}}$ - the temperature of the flow around the particle; $r_{\text{к}}$ - the radius of the drop; $\rho_\varepsilon$ - hard layer density; $\Delta m_{\text{ж}}$ - the amount of evaporated oil; $m_{\text{жо}}$ - initial oil content; $u_o, u$ - initial and current oil concentration, equal to the ratio of the mass of the liquid to the mass of the dry solid component; t - the current boiling point of the oil.

The first two equations describe the heating of a spherical particle before and after the moisture evaporation front. The third determines the position of the evaporation front. The fourth equation describes the temperature field of the outer layer without oil. The fifth equation determines the position of the oil evaporation front.

The numerical solution of the system gives the temperature distribution in the drop during its separation into components.

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