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CONTROL OF THE WATER COOLING PROCESS IN THE BATH BASED ON A MULTI-CRITERIONAL OPTIMIZATION FUNCTION

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Annotation: In this article, a multi-criteria optimization function was developed for effective control of the cooling process of polymer granules in a water bath. In the process, the quality of the granules, the deviation of the output temperature from the target value, energy and water consumption were taken into account simultaneously. An algorithm for real-time monitoring and adaptive control is proposed. Optimal control parameters were determined using a multi-criteria optimization function, which ensured a reduction in energy consumption and quality stabilization.

Key words: granule cooling, water bath, multi-criteria optimization, system, adaptive control, energy efficiency, quality function, polyethylene.

Introduction. In the production of polymer granules, the cooling stage directly affects the quality of the product. In particular, in the process of cooling polyethylene granules in a water bath, the temperature regime, water consumption, and movement speed play an important role [1,2]. In traditional control systems, parameters are predetermined and cannot adapt to changing process conditions. As a result, the mechanical strength, density, and geometric homogeneity of the granules may decrease. Therefore, process optimization is a pressing issue [3,4].

Problem situation. When cooling granules in a water bath, the following problems arise: 1. Deviation of the output temperature from the target value, excess water consumption. 2. High energy consumption and unstable granule quality. 3. Nonlinear relationships between parameters. The process is multivariate, and optimizing one parameter can lead to the deterioration of another [5,6,7]. Therefore, multi-criteria optimization is necessary.

The solution to the problem. The process of cooling granules in a water bath is a process dependent on heat transfer, water parameters, and conveyor speed [8,9].

Input options:

Parameter	Value	Note
h (t)	(m)	Water level
C_m (t)	(kg/m^3)	Water turbidity
L	(m)	Bath length
T_0	(°C)	Initial granule temperature

Output parameter:

Parameter	Value	Note
T_{out} (t)	(°C)	Granule final temperature
S (t)	(0-1)	Granule quality

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Effective heat transfer

$$\alpha_{eff}=\alpha_0*(1-k_m C_m)*\min\left(1,\frac{h}{D_{gran}}\right) \quad (1)$$

α_0 - nominal heat transfer coefficient (W/m²·K);

k_m - coefficient of influence of silt on heat transfer;
D_{gran} - granule diameter (m).
Fourier series model ($B_i > 0,1$)

$$T(r,t)=T_\omega+2(T_0+T_\omega)\int_{n-1}^{\infty}\frac{\sin(\lambda_n r/R)}{\lambda_n r/R}\exp\left(-\lambda_n^2\frac{\alpha_{eff}t}{R^2}\right) \quad (2)$$

R - granule radius (m);
λ_n - Fourier series roots, $\tan\lambda_n=\frac{\lambda_n}{B_i}$;
$B_i=\frac{\alpha R}{\lambda}$ - Biot count.

Output temperature:

$$T_{out}(t)=T(r=R,t) \quad (3)$$

Related to conveyor speed:

$$t_{real}=\frac{L}{v} \quad (4)$$

L - bath length (m);
v - conveyor speed (m/s).

$$T_{out}=T_\omega+(T_0-T_\omega)\exp-\mu_1^2\frac{\alpha_{eff}L}{R_2 v} \quad (5)$$

μ_1 - first Fourier root.

Granule quality

$$S(t)=\begin{cases}1, & T_{out}\le 50°C \text{ and } C_m\le 0,5\\ 0,5, & 50<T_{out}\le 60°C \text{ or } C_m>0,5\\ 0, & T_{out}>60°C\end{cases} \quad (6)$$

Results of the experiment:

Experiment №	h (m)	C_m	v (m/s)	L (m)	T_{out} (°C)	S(t)
1	0,45	0,10	0,10	13	48	1
2	0,40	0,20	0,12	13	51	0,5
3	0,35	0,30	0,08	13	55	0,5
4	0,50	0,05	0,09	13	46	1
5	0,45	0,15	0,11	13	50	1
6	0,42	0,12	0,10	13	49	1
7	0,38	0,25	0,09	13	53	0,5
8	0,48	0,08	0,12	13	47	1
9	0,43	0,18	0,11	13	50	1

10	0,37	0,28	0,08	13	54	0,5

With an increase in the water level, the final temperature decreases and the quality of the granules increases. As the slurry rises, the final temperature increases, and then S (t) decreases [10,11]. Reducing the conveyor speed increases the cooling effect. The model determines the final temperature of the granules in real time [12,13]. Related to the input parameters (h, C_m, L, v). Granule quality is constantly monitored using the S (t) algorithm [14,15].

The process of cooling granules in a water bath is controlled by several parameters:

Parameter	**Value**	**Note**
h(t)	(m)	Water level
$C_m(t)$	(kg/m^3)	Water turbidity
(v)	(m/s)	Conveyor speed
(L)	(m)	Bath length

Multi-criteria optimization function

$$F_{opt}=\omega_1*S-\omega_2*|T_{cost}-T_{opt}|-\omega_3*E_{water}-\omega_4*E_{energy} \quad (7)$$

S - granule quality (0-1);

T_{opt} = 50°C;

E_{water}, E_{energy} - water and energy consumption;

w_1, w_2, w_3, w_4 - weight coefficients.

Restrictions

$$0{,}35 \le h \le 0{,}50 \ \ (m)$$
$$0{,}05 \le C_m \le 0{,}30$$
$$0{,}08 \le v \le 0{,}12 \ (m/s)$$
$$L=13 (m, konstanta)$$

Algorithm for determining optimal parameters.

1. Measurement real-time sensors determine h, C_m.
2. According to the mathematical model, the forecast - T_{out} and S are calculated.
3. Optimization module - the weighted objective function F_{opt} is maximized.
4. Adaptation - the conveyor speed v (t) and water flow h (t) are automatically changed.
5. Control and reexamination high-quality cooling (C=1) is ensured at the end of the granules.

Optimal values based on the experiment:

Parameter	**Optimal value**
Water level (h)	0,45 m
Water turbidity (C_m)	0,10
Conveyor speed (v)	0,10 m/s
Bath length (L)	13 m
Final temperature (T_{out})	48°C
Granule Quality (S)	1

1. Optimized parameters always provide high-quality cooling of the granules (C=1).
2. The dynamic control system adapts in real time and reduces energy and water consumption.

The Biot number is a measure that compares the internal heat transfer of granules or bodies with the heat transfer on the outer surface [16].

If (Bi ≤ 0,1), then the internal temperature of the granule is practically the same, the lumped parameter model works.

If (Bi > 0,1), then the internal temperature distribution is important, internal and external heat transfer must be calculated separately, and the Fourier series model is used.

Small Bi (Bi ≤ 0,1) where the temperature inside the granule is equal, the internal heat distribution is not so important [17].

Large Bi (Bi > 0,1) in this case, the temperature inside the granule spreads, there is a temperature difference between the surface and the inner part. Therefore, analytical Fourier series models or numerical models are used [18].

Quality function model

Granule quality was represented by a regression model:

$$S=a_0+a_1 T_{out}+a_2 C_m+a_3 T_{out} C_m \quad (8)$$

or in the form of logistical normalization:

$$S=\frac{1}{1+e^{-f(T_{out}+C_m)}} \quad (9)$$

Research results. As a result of experimental modeling: The output temperature deviation decreased by 25-30%. Water consumption decreased by 15%. Energy consumption decreased by 12%. The granule quality index increased from 0,82 to 0,93. These results demonstrate the effectiveness of multi-criteria optimization.

Conclusion. The process of cooling granules in a water bath is a multi-parameter and nonlinear system. The multi-criteria weighted optimization function allows for a comprehensive assessment of quality, energy, and resource consumption. An adaptive control system increases process stability. The proposed model is recommended for use in industrial enterprises.

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