Determination of optimal technological parameters of a washing machine on the basis of its energy studies

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Abstract. It is necessary to study supplied power of all modes for more precise determination of optimal mode of tin cans surface washing. The following parameters are defined: effective power that is expended only for washing, effectiveness factor of power use. Dependence of power expenditure, energy output and effectiveness factors of power use on rotational rate of the washing machine’ driven wheel are determined. Following the results of research, optimal technological parameters of the washing machine are determined. According to the results of research, the following optimal parameters are defined: necessary cleaning quality with optimal rotation rate of the driven wheel can be reached with temperature (74…85°C) and concentration of washing solution of 1.7…3 g/l. If it is necessary to increase production capacity from 88 to 100 cans per minute, it is important to increase rotation rate of the driven wheel from 31 to 35 r/min. Concentration of solution should be minimal due to optimal rotation rate and constitute $c = 1.7$ g/l. Energy output also increases by 2% that is not significant increase in comparison with increase of machine production capacity. Quality of cans surface cleaning will be $K \geq 93\%$ with temperature from 72 to 85 °C.

1. Introduction

Quality of cans cleaning, labour capacity, industrial standards, and cost price of canned food production depend on excellence of technology and washing machines.

A large number of modern washing machines work in an irrational regime and are energy and metal consuming, so their use is unprofitable. Consequently, the development of new efficient machines and the improvement of existing washing machines in the canning industry is great reserve to reduce energy consumption, materials and cost of the whole production process of canned food.

Therefore, research aimed at improving the washing process filled cans in the production of canned food are very relevant and have great importance in the food industry.

Appliance of submersible cleaning as the less energy-demanding method is more prospective according to the criteria of specific energy costs on a unit of the surface being cleaned.

When the washing machine is used, the same degree of cleaning of the products can be obtained with different modes (for different combinations of factor values). As the speed of the wheels increases, the intensity of the process increases. However, the costs also increase - the required power, the pressure in the bearings increase, that is, the operating mode of the machine deteriorates from the point of view of force analysis. Therefore, the main goal of experimental research is the determination of the optimum technological parameters of the washing machine.
The optimization task was the choice of such a combination of values of the investigated factors, which ensure the quality of treatment required by the standard, at which energy consumption will be the least.

2. Experimental

It is necessary to study supplied power of all modes for more precise determination of optimal mode of tin can surface washing [1–3].

Let us consider power structure and determine effectiveness. To get cleaning physical impact of washing fluid on the object in submerged washing machines, it is necessary to coerce rotational movement to the wheels with the help of which eccentric motion of the objects being washed is carried out. Energy necessary for this process is consumed on rotation of the wheels, displacement of the objects being washed, on passage of washing fluid’ hydrodynamic resistance to the wheels rotation and the objects being washed, and on passage of friction force in bearings. Because of the comparative low frictional force in the bearings of the examined machine, they were not taken into account. Only energy consumption for passage of hydrodynamic resistance of washing fluid to movement of the objects being washed is useful among above listed expenditures [4–7]. Effective power mostly expended on cleaning (fluid physical impact on contamination) is represented by the following Equation:

\[ N_{ef} = N_{ttl} - N_{flwhl} - N_{whlcan} + N_{ohl} \]  

where \( N_{ttl} \) is total output consumed on wheel rotation and object being washed in washing fluid; \( N_{flwhl} \) is power expended on wheel rotation without cans displacement in fluid; \( N_{whlcan} \) is power expended on wheel rotation and cans displacement in the empty bath; \( N_{ohl} \) is power expended on wheel rotation without cans displacement in bath without washing fluid.

Then effectiveness factor of power use can be found from the Equation

\[ \eta = \frac{N_{ef}}{N_{ttl}} \]  

The meter Mercury 230 AR-01R3 was used to measure required power of washing machine drive and its components.

On the Figure 1 there are graphs of power and its components change depending on rotation rate of the driven wheel of the washing machine. These graphs are based on the results of power in three drive electromotor phases by the meter Mercury 230 AR-01R3 in studied modes during washing of tin can surface and their continuous displacement.

3. Results and Considerations

An empirical dependence between expended power and rotation rate of the driven wheel with approximation validity of \( R^2=0.9963 \) was defined on a personal computer with the help of the programme Excel after results processing of power measurement in three drive electromotor phases:

\[ y = 204.36 \cdot e^{0.1426x} \]  

On the basis of the graph (Figure 1) it may be concluded that with increase of the driven wheel’ rotation rate quality of cleaning and energy consumption also increase. Energy consumption increases more intensively as dependence is exponential. That is why there should be an optimal mode of the washing machine (in relation to energy consumption) to achieve technologically planned cleaning quality.

The optimal mode of the washing machine was defined on the basis of received relevant regression equation of cleaning quality depending on studied parameters from the plan of three-factor experiment. It shows that power from 361.5 to 417 W corresponding to 30 and 35 r/min is necessary to receive cleaning quality relevant to the standard. Graphs on the Figure 1 show that damaging components of expended power \( (N_{ohl} \cdot N_{flwhl} \cdot N_{whlcan}) \) increase with increase of rotation rate \( n \), but less intensively than total output \( (N_{ttl}) \).
Dependence of energy consumption on rotation rate of the washing machine’s driven wheel. 

That is why effective (useful) power (\(N_{\text{ef}}\)) found with the help of the equation (1) and expanded mostly on passage of hydrodynamic pressure increases quite intensively. Relation of this effective power to total output, according to the equation (2), shows effectiveness of power use.

Effectiveness factor of power use of the washing machine can be considered according to the graph (Figure 2).

The analysis of the results shows that effectiveness factor in the optimal mode of the washing machine with eccentric motion of the objects being washed and fluid turbulization by air barbotage from the outer side of the cleaned objects is \(\eta = 0.23 \ldots 0.26\). For comparison: the factor of submersible washing machines of vibration type is \(\eta = 0.1 \ldots 0.2\), and it is \(\eta = 0.05 \ldots 0.10\) in jet-type washing machines [1].

Research showed that equal quality of cans surface cleaning can be achieved due to different combinations of values of studied factors. That is why the optimization task is to find such a combination of these values due to which energy consumption would be at a minimum level.

Required power is found from the dependence of expanded power on rotation rate of the driven wheel \(N_{\text{ttl}} = f_1(n_1)\) (Figure 1).

On the Figure 3 there are received values of machine capacity depending on rotation rate of the driven wheel found theoretically and experimentally. \(W_{\text{exp}}\) is defined on the basis of data represented in the Table 1.
Table 1. Results of capacity measurement due to different rotation rate of the driven wheel

| Rotation Rate of the Wheel \( n_i \), r/min | Machine Capacity \( W \), pcs/min | Arithmetic Mean Value \( W \), pcs/min |
|---------------------------------------------|---------------------------------|---------------------------------|
| Repetitions | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 15           | 45.55 | 45.11 | 45.39 | 44.54 | 45.87 | 45.21 |
| 20           | 54.55 | 57.53 | 56.08 | 60.48 | 62.02 | 57.99 |
| 25           | 75.42 | 75.14 | 75.99 | 76.58 | 78.74 | 76.36 |
| 30           | 84.69 | 88.82 | 91.74 | 89.22 | 82.25 | 87.21 |
| 35           | 98.68 | 99.59 | 93.53 | 97.72 | 100.84 | 98.01 |

Therefore, experiments approved validity of theoretical measurement.

From the graph (Figure 3) it can be seen that machine capacity increases on empirical dependence with increase of rotation rate of the driven wheel

\[
y = 13.48x + 32.519. \tag{4}
\]

Energy output can be found with the help of the Equation (5).

\[
E = \frac{N}{60}W, \tag{5}
\]

where \( N \) is required power, \( W \); \( W \) is machine capacity, \( n/\text{min} \); \( E \) is energy output of washing process, \( \text{W} \cdot \text{h/pcs} \).

The least expenditures for achieving planned quality level of cleaning and factors parameters providing these expenditures are found after solving this equation on minimum for different combinations of values.

On the Figure 4 there is a graph of energy output change depending on rotation rate of the driven wheel. Minimal energy consumption corresponds to the optimal value of rotation rate \( n_{opt1} \). In this case \( E_{min} = 68.9765 \cdot 10^{-3} \text{W} \cdot \text{h/pcs}, n_{opt1} = 30.6 \text{ r/min} \).

![Figure 3. Theoretical (---) and experimental (-----) dependence of machine capacity on rotation rate of its driven wheel.](image)

Productive capacity of the washing machine for the cans No. 8 will be \( W = 88 \text{ pcs/min} \) with rotation rate of the driven wheel \( n_{opt1} = 30.6 \text{ r/min} \).

From the regression Equation (6) a two-dimensional section of resonance surface can be made. It characterizes dependence of cleaning quality on temperature of washing solution and its concentration with a fixed value of optimal rotation rate of the driven wheel \( n = 30.6 \text{ r/min} \) (Figure 5).
\[ Y = 4.969 + 1.501x_1 + 14.378x_2 - 0.015x_1x_3 + 0.139x_2x_3 - 1.012x_2^2 + 0.038x_3^2. \]  

(6)

From the analysis of dependence (Figure 5), it is seen that necessary cleaning quality with optimal rotation rate of the driven wheel can be reached due to different combinations of temperature (73.5…85 °C) and concentration of washing solution (1.73…3 g/l). Therefore, increase of requirements to the quality of cans surface leads to considerable expenditure of washing solution per liter of water and to increase of washing solution temperature. Moreover, concentration in the area of good cleaning increases quite intensively. That is why absolute purity of cans surface is inappropriate from the point of view of economy of can goods production.

**Figure 4.** Dependence of energy output on rotation rate of the driven wheel.

With increase of rotation rate of the driven wheel by 14.38% (from 30.6 to 35 r/min) energy output increases only by 1.92% (from 68.9765·10^{-3} to 70.3·10^{-3} W·h/pcs). Production capacity also increases by 13.64% (from 88 to 100 pcs/min) that is important for cans production.

Committing concentration of washing solution \( c = 1.73\text{g/l} \) that is minimal due to optimal rotation rate, we make a two-dimensional section of resonance surface from the regression Equation (6) that characterizes dependence of cleaning quality on temperature of washing solution and rotation rate of the driven wheel (Figure 6).

**Figure 5.** A two-dimensional section of resonance surface that characterizes dependence of cleaning quality \( Y \) on factors \( x_1 \) (temperature of washing solution, \( t \)) and \( x_2 \) (concentration of washing solution) with a fixed value of factor \( x_3 \) \( (n=30.6\text{ r/min}) \).

**Figure 6.** A two-dimensional section of resonance surface that characterizes dependence of cleaning quality \( Y \) on factors \( x_1 \) (temperature \( t \) of washing solution) and \( x_3 \) (rotation rate of the driven wheel, \( n_1 \)) with a fixed value of concentration \( x_3 \) \( (c=1.73\text{ g/l}) \).
From analysis of dependence (Figure 6) it is seen that cleaning quality can increase to $K \geq 93\%$
with concentration of solution $c = 1.73\, g/l$, temperature from $72\, ^\circ C$ to $85\, ^\circ C$
and with rotation rate of the driven wheel from $30.6\, r/min$ to $35\, r/min$.

4. Summary
According to the results of research, the following optimal parameters are defined: necessary cleani
ng quality with optimal rotation rate of the driven wheel can be reached with temperature $(74\ldots85\, ^\circ C)$ and
concentration of washing solution of $1.7\ldots3\, g/l$.

If it is necessary to increase production capacity from 88 to 100 cans per minute, it is important to
increase rotation rate of the driven wheel from $31$ to $35\, r/min$. Concentration of solution should be
minimal due to optimal rotation rate and constitute $c = 1.7\, g/l$. Energy output also increases by $2\%$
that is not significant increase in comparison with increase of machine production capacity. Quality of cans
surface cleaning will be $K \geq 93\%$ with temperature from $72$ to $85\, ^\circ C$.

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