The research work of a submersible washing machine with fluid activation by air bubbling from the outside of the laundered objects

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Abstract. The research aimed at improving the process of washing filled cylindrical cans in the production of tin cans is very relevant and of great importance in the food industry. So, a new two-section washing machine design is proposed. Tests performed at the machine under consideration. The results of experimental studies of the quality of surface cleaning metal cans were presented. The optimum operating mode of the washing machine was determined. The minimum energy consumption of the machine is \( E_{\text{min}} = 69 \cdot 10^{-3} \text{ W·h / pcs} \) at the optimal driving wheel speed \( n_{\text{opt}} = 31 \text{ min}^{-1} \). For comparison - for analogs the minimum energy intensity is \( E_{\text{min}} = 200 \cdot 10^{-3} \text{ W·h / pcs} \). As a result of experimental studies, it has been established that for the qualitative cleaning of the surface of filled cans, which corresponds to the requirements of the standard, the rotational speed of the drive wheel \( n_{\text{opt}} = 31 \text{ min}^{-1} \), temperature \( t = 74 \ldots 85 \degree \text{ C} \) and concentration of the washing solution \( c = 1.7 \ldots 3 \text{ g / l} \). When the capacity of the washing machine is increased to 100 pcs / min. it is required to increase \( n_{\text{opt}} = 31 \text{ min}^{-1} \) to \( n_{\text{max}} = 35 \text{ min}^{-1} \), with \( c = 1.7 \text{ g / l} \) and the temperature of the washing solution \( t = 72 \ldots 85 \degree \text{ C} \). At the same time, energy intensity increases by only 2%. The design features of the developed washing machine allow to reduce the power consumption of the cleaning process, and the productivity can be increased without loss of quality of cleaning the cans in comparison with existing washing machines.

1. Introduction
Every year, in the Russian market of tin cans appear more and more new trademarks, new manufacturers, which aspire to improve the quality of produced product and attract a buyer [1–3]. In this situation, the packaging and label of the goods are powerful means of promoting the goods on the market. Labels stick to clean, dry cans with no traces of fat on the surface. To take this into account, technological process of canning production included operation for degreasing cans with a washing machine [3]. 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[4].

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.

2. Experimental
Taking into account the flow of canning production, the results of the analysis of the dependence of the quality of cleaning on the type of relative movement of the cleaning object and the designs of
existing devices for washing cans, we proposed a two-stage washing machine with planetary movement of the cleaning object and activation of the liquid by air bubbling from the outside of the washed objects [5–8].

The machine (Figure 1) includes washing tanks 1 and 2 separated by a partition 3. Arched guides 4 and 5 is placed in them, driving wheels 7 and 11 with an elastic rim are symmetrically mounted on the shafts above each guide. Perforated pipelines (bubblers) are fixed on two lateral sides of guides 4 and 5.

The washing machine works as follows. Jars are fed into the guides 4 of the washing machine after canning. Cans roll forward and are completely immersed in the cleaning solution, fall into the gap between the elastic rim of the wheel 7 and the guide 4 and move due to the frictional force between the rubber rim of the wheel and the can in the direction of rotation of the wheel. Further, along the guide of the first bath, jars come out of the cleaning solution and fall on a convex arc-shaped section of the transition from one bath to the other. At the same time, the spent washing solution of the first bath drains from the cans and carries particles of contaminants with them. Then, the cleaning objects are fed to the guide of the second bath 2, arranged similarly to the first one. The technological process is repeated. The processed cans are sent to the autoclave basket or to another shop receiver.

Serial measuring and recording equipment and devices were used to register process parameters during the washing machine work. In the study of the process of washing the surfaces of tin cans with a washing machine, the factors that are independent of each other and which most influence the purification process, such as the temperature and concentration of the washing solution, the speed of the driving wheel, aroused the greatest interest. These factors were investigated by us during the technological testing of the device. All other factors either depend on the three above, or have little effect on the washing process. The method of A.K. Koshcheeva with the use of cotton strips is used.
as the feedback of the quality of purification. The essence of this method was to determine the area of the spot on the strips.

To determine the area of the spot on the indicator cotton strip, was used the program "AreaS", developed by the Samara State Agricultural Academy by Permyakov A.N. The error in determining the area does not exceed 0.001%.

The program of experimental studies included several stages and consisted of preliminary single-factor and complete three-factor experiments. Levels and intervals of variation of factors are given in the Table 1.

| Coded factor Identification | The name of the factor, unit of measurement | The level of factor | The interval of variation |
|----------------------------|---------------------------------------------|--------------------|--------------------------|
| x₁                         | Solution temperature, °C                    | 65                 | 75                       | 85                       | 10                       |
| x₂                         | Concentration of washing solution, g/l      | 1                  | 2                        | 3                        | 1                        |
| x₃                         | Drive wheel rotation speed, min⁻¹             | 25                 | 30                       | 35                       | 5                        |

In order to study the influence of the speed of rotation of the driving wheel, the temperature and concentration of the solution individually on the quality of cleaning the outer surface of the cans, one-factor experiments were conducted in which the temperature and the concentration of the washing solution were changed at fixed frequencies of rotation of the driving wheel of the washing machine. Experimental studies were conducted with bubbling the washing solution. The pressure in the air supply system for bubbling was kept constant at 0.5 MPa. The diameter of the holes on the arcuate bubbler was 2.5 mm. The experiments were carried out three times.

3. Results and Considerations

Analysis of the results of single-factor experiments showed the following.

1. With the increase in the speed of rotation of the drive wheel of the washing machine at a constant temperature of the cleaning solution, the quality of cleaning meets the requirements of the standard at a lower concentration of the washing solution. At a frequency of \( n = 15 \text{ min}^{-1} \) and a temperature of 85 ° C, the concentration of the washing solution must be at least 3.5 g / l. The same quality of cleaning is achieved at a concentration of 1 g / l of washing solution, its temperature is 85°C and the driving wheel speed \( n = 35 \text{ min}^{-1} \);

2. As the speed of the drive wheel of the washer increases, the required quality of cleaning is achieved at a lower solution temperature. At \( n = 15 \text{ min}^{-1} \), the minimum temperature of the cleaning solution is 68 ° C at a concentration of 5 g / l. The same cleaning quality is achieved at a solution temperature of 48 ° C, a concentration of 5 g / l and \( n = 35 \text{ min}^{-1} \).

3. The quality of cleaning intensively increases with an increase in the concentration of the cleaning solution from 1 g / l to 3 g / l. Further increase in the concentration of the detergent solution improves the quality of the cleaning very slightly.

The orthogonal central composition plan of the three-factor experiment is realized in the study, which makes it possible to obtain an adequate dependence of the cleaning quality on the investigated factors: the temperature of the washing solution is \( t, ^{°}C (x_1) \), the concentration of the washing solution is \( C, g/l (x_2) \), the drive wheel rotation speed \( n, \text{min}^{-1} (x_3) \). For the feedback function, the quality of cleaning is accepted - K, % (Y).

After implementing the plan of experiment and processing the results, a regression equation was obtained that was tested for adequacy according to the \( F_{0.95} \) Fisher's criterion:

\[
Y = 4.969 + 1.501 \cdot x_1 + 14.378 \cdot x_2 - 0.015 \cdot x_1 \cdot x_3 + 0.139 \cdot x_2 \cdot x_3 - 1.012 \cdot x_2^2 + 0.038 \cdot x_3^2.
\]
To study the effect of factors on the optimization criterion $Y$, two-dimensional sections of the response surface were used (Figures 2–4).

**Figure 2.** The two-dimensional section of the response surface characterizing the dependence of the cleaning quality ($Y$) on the factors $x_1$ (the temperature $t$ of the washing solution) and $x_3$ (the frequency $n$ of rotation of the driving wheel) for a fixed value of the factor $x_2$: a - at $x_2 = -1$ ($C = 1$ g/l); b - at $x_2 = 0$ ($C = 2$ g/l); c - at $x_2 = 1$ ($C = 3$ g/l).

**Figure 3.** A two-dimensional section of the response surface characterizing the dependence of the purification quality ($Y$) on the factors $x_1$ (washing solution temperature) and $x_2$ (concentration $C$ of the washing solution) for a fixed value of $x_3$: a - at $x_3 = -1$ ($n = 25$ min$^{-1}$); b - at $x_3 = 0$ ($n = 30$ min$^{-1}$); c - at $x_3 = 1$ ($n = 35$ min$^{-1}$).

**Figure 4.** The two-dimensional section of the response surface characterizing the dependence of the cleaning quality ($Y$) on the factors $x_2$ (concentration $C$ of the washing solution) and $x_3$ (the frequency $n$ of rotation of the driving wheel) for a fixed value of the factor $x_1$: a - for $x_1 = -1$ ($t = 65$ °C); b - at $x_1 = 0$ ($t = 75$ °C); c - at $x_1 = 1$ ($c = 85$ °C).

On the basis of the analysis of two-dimensional sections of the response surfaces [1], it can be noted that the washing machine provides the required quality of cleaning cans at speeds of rotation of the driving wheel 30 ... 35 min$^{-1}$, the temperature of the washing solution 75 ... 85 °C and the concentration of the solution is 1 ... 2 g/l.

To obtain the appropriate quality standard for cleaning, in our case power from 361.5 W to 417 W
corresponding to the rotation speed of 30 min\(^{-1}\) and 35 min\(^{-1}\) of the driving wheel is required. At the same time, theoretically and experimentally determined efficiency coefficients of power use \(\eta\) will be in the range 0.24 ... 0.26 [2]. For comparison, for submerged washing machines of vibration type \(\eta = 0.1 ... 0.2\), and for jet washers \(\eta = 0.05 ... 0.10\).

The minimum energy consumption of the machine is \(E_{\text{min}} = 69 \cdot 10^{-3}\) W·h / pcs at the optimal driving wheel speed \(n_{\text{opt}} = 31\) min\(^{-1}\) [2]. For comparison - for analogs the minimum energy intensity is \(E_{\text{min}} = 200 \cdot 10^{-3}\) W·h / pcs.

As a result of experimental studies [1], it has been established that for the qualitative cleaning of the surface of filled cans, which corresponds to the requirements of the standard, the rotational speed of the drive wheel \(n_{\text{opt}} = 31\) min\(^{-1}\), temperature \(t = 74 ... 85\) °C and concentration of the washing solution \(c = 1.7 ... 3\) g / l. When the capacity of the washing machine is increased to 100 pcs / min. it is required to increase \(n_{\text{opt}} = 31\) min\(^{-1}\) to \(n_{\text{max}} = 35\) min\(^{-1}\), with \(c = 1.7\) g / l and the temperature of the washing solution \(t = 72 ... 85\) °C. At the same time, energy intensity increases by only 2%.

The design features of the developed washing machine allow to reduce the power consumption of the cleaning process, and the productivity can be increased without loss of quality of cleaning the cans in comparison with existing washing machines.

4. Conclusion

As a result of statistical processing of the experimental data, a mathematical dependence of the quality of cleaning cans on the main independent factors of the washing process was obtained, which makes it possible to determine the optimum technological parameters of the washing machine.

The required quality of cleaning the surfaces of cans is achieved at a drive wheel speed of 31 min\(^{-1}\), the temperature of the washing solution is 74 ... 85 °C and the concentration of the washing solution is 1.7 ... 3 g / l. At the same time, the energy intensity of the process does not exceed \(69 \cdot 10^{-3}\) W·h per one can.

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