Determination of the Optimal Parameters of the Metal Can Washing Machine

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Abstract. This article reflects the results of experimental studies on determining the can surface cleaning quality. Two-stage washing of can surfaces was performed based on the results of the factor-at-a-time experiments. It furnished a number of dependences of cleaning quality on the detergent concentration at different washing solution temperatures, as well as on the washing solution temperature at various solution concentrations at fixed washing machine drive wheel rotation frequency. Based on the findings of the studies carried out, it was proved that the cleaning quality indicators increase sharply when the washing solution concentration ranges between 1 and 3 g/L. The optimum temperature providing high-quality cleaning of the can surface as per the standard ranges between 65 and 85°C, and the optimal rotation frequency of the washing machine drive wheel is 20-35 min^{-1}.

1 Introduction

Canned products are consumed in large volumes in Russia. Canning allows food to be stored in airtight containers for a long period of time, for which reason the canning industry plays a significant role in the process of supplying food to the country's residents.

Russian agroindustrial organizations and companies are large consumers of fuel and energy resources, which indicates that even a relatively small increase in the technological equipment productivity enables vast opportunities to save considerable amounts of energy resources across the industry.

For this reason, research aimed at improving the process of washing filled cylindrical cans at the canned food production is quite relevant and plays an important role in the food industry. The importance of this kind of work is confirmed, for example, by the fact that the energy cost rapidly increases and has a significant negative impact on the cost of the final product [1-5].

It was proved that the specific energy consumption per unit surface to be cleaned is 0.1...0.3 kWh/m2 for high-pressure jet cleaning, 2.2...6 kWh/m2 for low-pressure jet cleaning, and 0.2...1.8 kWh/m2 for submersible cleaning. Great prospects can be seen in the use of high-pressure and submersible cleaning as the methods with a minimum energy intensity level [6-9].

Can washing machines, which do not extensively use highly effective detergents with a high SAS content, are actively distributed in the canning industry; there is a limitation in operating temperature due to the occurrence of cavitation in transfer and delivery pumps; they are very complex in terms of design and service; they practically do not use intensification methods [10-15].

Submersible machines are available today, which are generally used by repair enterprises to remove persistent contamination from complicated-geometry parts, however they are hard to maintain, and operate on a batch basis [14-16].

The use of the abovementioned washing machines in the food industry for washing the outer surface of metal cans is disadvantageous due to the fact that their use suggests high energy and metal consumption, as well as the cost of cleaning.

The need for many different elements that make liquid perturbate around the object being cleaned results in a more complicated design of the machines, as well as the increase in energy intensity and the cost of cleaning. Nevertheless, such washing liquid flows can be created in a much simpler and more efficient way, by giving the object being cleaned the eccentric motion and activating the liquid by bubbling from the outside. This is the principle, on which the operation of a submersible washing machine, developed in the premises of Mari State University, is organized [16].

2 Materials and Methods

In order to analyze the can washing process, an experimental washing machine has been developed that performs the working process depending on the two-stage cycle.

The designed structural and technological scheme of the washing machine for washing filled cylindrical metal cans is shown in Fig. 1 *a, b*.

It belongs to continuous machines. In this case, the object being cleaned is guided along the guides 4 and 5 of the bath sections 1 and 2, and gains eccentric motion in the washing solution due to the action of the drive

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wheels with an elastic rim 7 and 11 with a diameter of D = 0.71 m. Due to such motion, the object experiences both the friction against the liquid and its pressure.

At the same time, unsteady highly turbulent liquid flows are also formed around the object, which have a hydromechanical effect on the contaminated surfaces. Existing contamination is exposed to a combination of surface tangential and frontal forces of liquid resistance. According to the results of hydrodynamic studies, it was found that the surface tangential and frontal forces are inherently complex, in spite of the fact that they are variable both depending on the magnitude and on the direction.

Accordingly, the contamination of the object being cleaned is exposed from the side of the washing solution to a very complex “shaking” and “scraping” mechanical impact. At the same time, this kind of highly effective mechanical impact enhances the degree of influence of the thermophysical and chemical qualities of washing liquids.

The perforated pipeline systems 14 supplying air (bubblers) to the guides from two sides ensure activation of the washing solution at the can surface. The process of physico-chemical interaction accelerates during the movement of the washing solution at the surfaces being cleaned. Numerous bubbles are formed within the specified zone, which begin to burst upon contact with the object being cleaned, thereby applying high pressures on the contaminated surfaces, and thus intensifying the cleaning process.

The number of holes in the bubbler, their diameter and the distance between their centers are determined depending on the mixing intensity. The reasonable number of holes in the arcuate bubbler has been determined and is 36, and thus the diameter of the holes is 2.5 mm and the distance between their centers is 21.5 mm. The minimum pressure in the air supply system for bubbling, in which all the holes of the arcuate bubbler are involved, is 0.5 MPa.

During the process of entering the convex arcuate sector *D* of the transition from one bath to another (Fig. 1 *b*), the spent washing solution of the first bath 1 begins to drain from the cans and contaminated particles are carried away. At that, film streams are formed on the surface of the carried-out objects, which are characterized by increased values of tangential friction stresses, which contribute to the intensification of the cleaning process.

In order to heat the washing solution with the hot steam jets, the baths are equipped with the radiators connected to the steam supply.

All the above hydromechanical effects combined with the physical and chemical parameters of the washing solutions allow for intensive, uniform and high-quality cleaning of the outer surface of cylindrical cans.

The implementation of kinematic link between the wheels of baths 1 and 2 in the form of a V-belt transmission process 12 with a gear ratio of 0.86 allows to provide higher performance level of bath 2 than that of bath 1, thus eliminating jams of cans and ensuring uninterrupted production line operation.

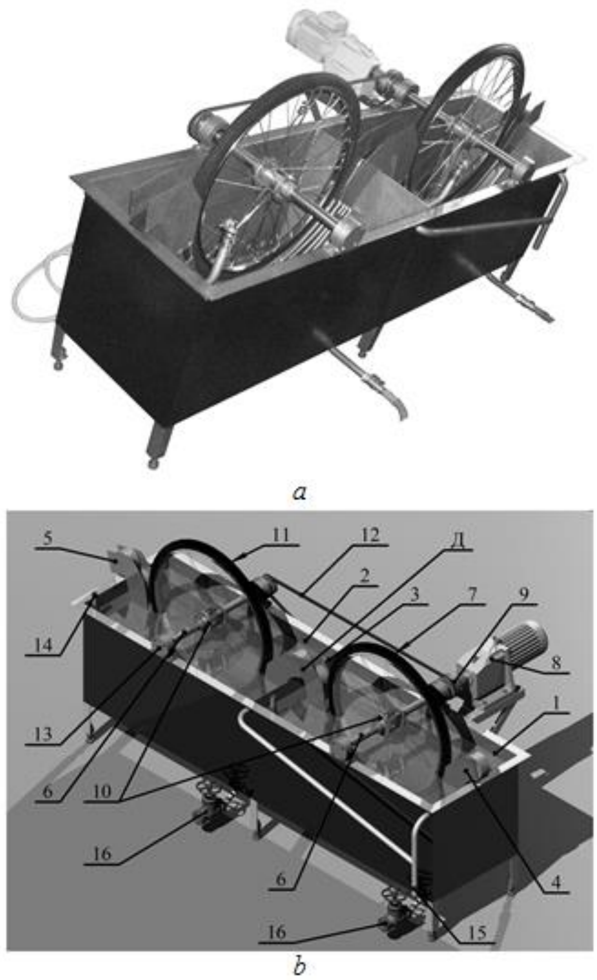

Fig. 1. General view of the can washing machine: a - general view; b - machine in operation; 1, 2 - washing baths; 3 - partition; 4, 5 - guides; 6 - shafts; 7 - drive wheel; 8 - gear motor; 9 - coupling; 10 - nave; 11 - idle wheel; 12 - V-belt transmission; 13 - bearing housing; 14 - bubbler; 15 - overflow pipe; 16 - drain pipes.

In order to ensure smooth, stepless process of adjusting the washing machine electric motor shaft speed, which is adjusted for line performance, the Telemecanique Altivar 31 frequency converter is installed in the gear motor.

The study found out that a number of factors can significantly influence the cleaning quality indicators and the process intensity level in the designed washing machine. These factors include temperature, washing solution (type and concentration), driving wheel rotation frequency (kinematic parameters - linear and angular velocities and accelerations of the object being cleaned - are interconnected with this factor), process duration, liquid activation through the implementation of air bubbling from the outside of the objects being washed, kinematic and dynamic viscosity of the liquid detergent, shape and dimensions of the bath for a given liquid, type, composition, level and degree of contamination resistance. Nevertheless, during the study of the process of washing the surfaces of tin cylindrical cans in a two-stage submersible washing machine with the eccentric motion of the object being cleaned, the most interesting factors are those independent of each other and, to the maximum extent, affecting the process, particularly, temperature and concentration of the washing solution, drive wheel speed, which we studied during the technological tests of the machine. All other factors either depend on the three presented factors, or are insignificant, and they do not influence the washing process at all in certain situations.

In order to study the nature of separate influence of the driving wheel speed, temperature and concentration on the outer surface cleaning quality, the factor-at-a-time experiments were carried out, in which the temperature and concentration of the washing solution changed at fixed washing machine drive wheel speed.

Experimental studies were carried out with bubbling of the washing solution. The same pressure was maintained within the air supply system for bubbling at a constant level with an average value of 0.5 MPa. In this case, the diameter of holes on the arc-shaped bubbler reached 2.5 mm. The experiments were carried out with three replications.

3 Results and Discussion

Two-stage washing of can surfaces was performed based on the results of the factor-at-a-time experiments. It provided characteristic dependences of cleaning quality on the detergent concentration at different washing solution temperatures, as well as on the washing solution temperature at various solution concentrations at fixed washing machine drive wheel rotation frequency. The dashed horizontal line on the Figure shows the cleaning quality level that meets the requirements of the standard K ≥ 93 % [16].

The following relations can be identified by analyzing the obtained diagrams (Figs. 2 and 3):

1) in the case of increasing the washing machine drive wheel rotation frequency at a constant temperature of the washing solution, its concentration level is reduced, within which the required cleaning quality is achieved, which also meets the requirements of the standard (Fig. 2). In the case of a speed of 15 min^{-1}, the washing solution concentration is 3.5 g/L with a temperature of 85°C. Similar cleaning quality can be achieved if the washing solution concentration is 1 g/L at a temperature of 85°C and a speed of 35 min^{-1}.

2) with an increase in the washing machine drive wheel speed at a constant washing solution concentration, the temperature decreases, which ensures the achievement of cleaning quality that meets the requirements of the standard (Fig. 3). In the case of a speed of 30 min^{-1} the minimum temperature will be 60°C at a concentration of 5 g/L. Similar cleaning quality can be achieved at a temperature of 48 °C with a concentration of 5 g/L and a frequency of 35 min^{-1}.

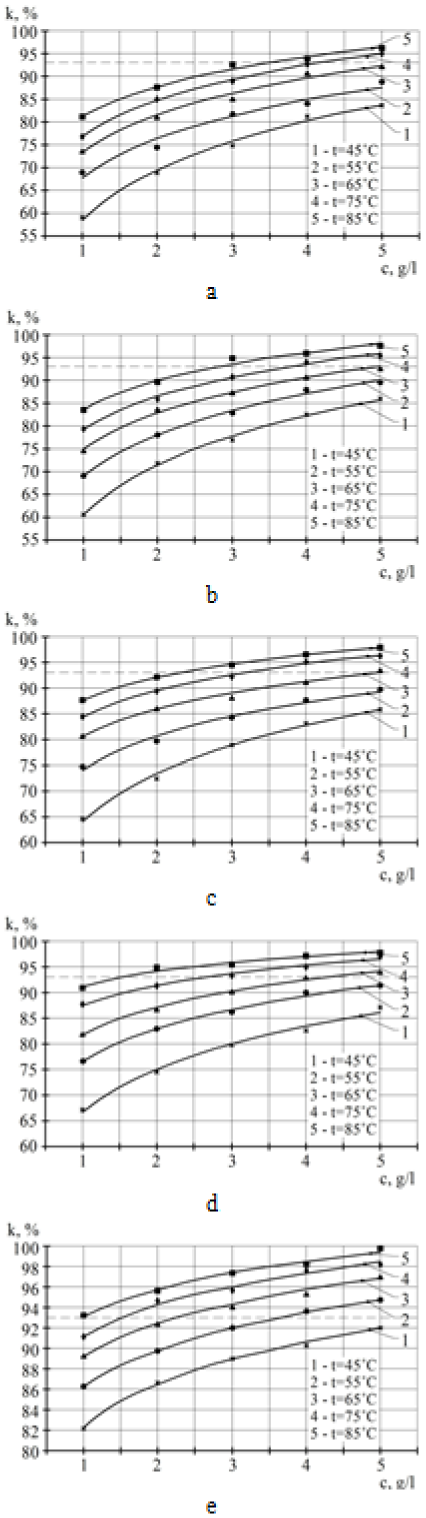

Fig. 2. Dependences of the can surface cleaning quality on the washing solution concentration at various temperature modes t (a - washing machine drive wheel speed n_1=15 min^{-1}; b - n_1=20 min^{-1}; c - n_1=25 min^{-1}; d - n_1=30 min^{-1}; e - n_1=35 min^{-1}): 1 – t=45 °C; 2 –t=55 °C; 3 – t=65 °C; 4 – t=75 °C; 5 – t=85 °C.

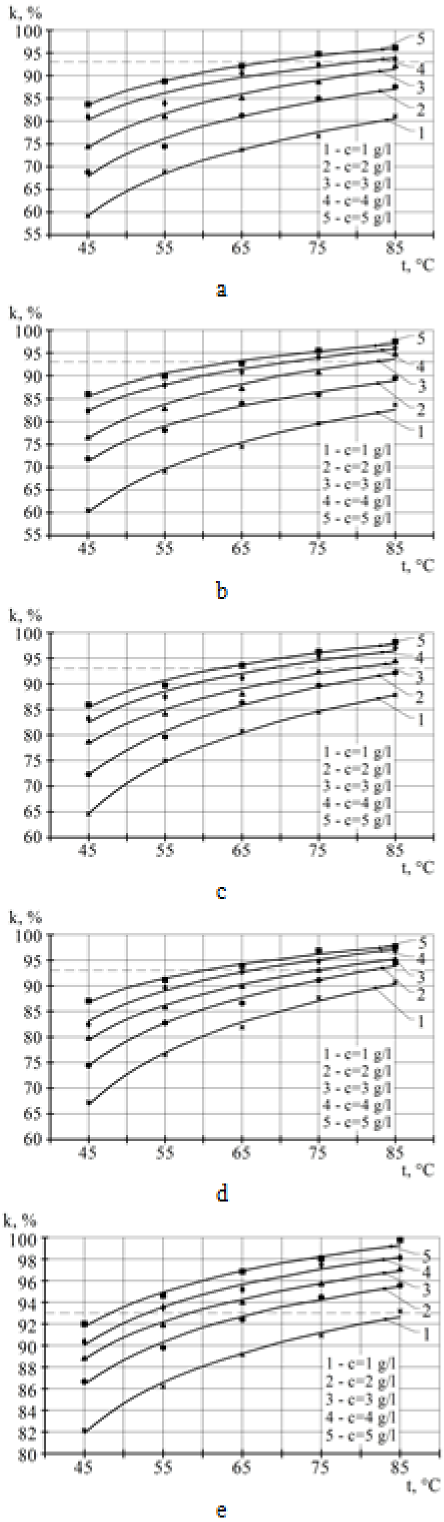

Fig. 2. Dependences of can surface cleaning quality on the washing solution temperature at various solution concentrations *c* (a - washing machine drive wheel speed n_1=15 min^{-1}; b - n_1=20 min^{-1}; c - n_1=25 min^{-1}; d - n_1=30 min^{-1}; e - n_1=35 min^{-1}): 1 – *c*=1 g/L; 2 – *c*=2 g/L; 3 – *c*=3 g/L; 4 – *c*=4 g/L; 5 – *c*=5 g/L.

3) the cleaning quality indicators increase sharply at a concentration of 1 to 3 g/L. As part of a further increase in the washing solution concentration over 3 g/L, the cleaning quality indicators improve very slightly;

4) the optimum temperature that provides high-quality cleaning of the can surface that meets the requirements of the standard lies within the range of 65...85°C, regardless of the washing machine drive wheel speed.

4 Conclusions

The following optimal parameters were identified in accordance with the results of the conducted studies:
- the cleaning quality indicators increase sharply at a concentration of 1 to 3 g/L. As part of a further increase in the washing solution concentration over 3 g/L, the cleaning quality indicators improve slightly;
- the optimum temperature that provides high-quality cleaning of the can surface that meets the requirements of the standard lies within the range of 65...85°C;
- as appears from the results of the studies, the optimal washing machine drive wheel speed ranges between 20 and 35 min^{-1}.

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