Defoamer centrifugal pump (with foam separator) for pumping highly disperse liquids

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Abstract

Foam in technological processes is formed during intensive mechanical, chemical and thermal processes causing gas release. In many cases, the formation of foam and its effect on the technological process is unfavorable. Liquids which contain plant cellular juices (e.g. obtained in processing of potatoes, sugar beets, fruits, vegetables), hydrolyzed natural raw materials (cereal flours, soybeans, corn), molasses, distillers' decoction have the highest tendency to form foam. Substrates and post-fermentation liquids prepared from the above mentioned raw materials, containing products of autolysis of microbial cells, have high foaming properties. Good foaming properties are also demonstrated by milk proteins similar in structure to those easily adsorbed on the surface of casein-β phase boundary.

Foam is not a metastable system and, while remaining in apparent equilibrium, undergoes slow decay. Since foam undergoes spontaneous degradation, which is unacceptable in the conditions of the technological process due to its long duration, it is necessary to take actions preventing and eliminating the foam that has formed.

In industrial practice, two methods of foam destruction are most commonly used, i.e. physical actions in which sudden pressure changes, shearing, compression, impact or ultrasound forces are used to destroy foam, and chemical methods, which involve the addition of a defoaming agent (inhibitor) to the liquid to reduce the intensity of foam formation or to eliminate foam that has already occurred, or the addition of an anti-foam agent to the liquid before the occurrence of foam.

Chemical vaporization methods, although widespread, have a number of disadvantages, the most important of which is that it is not an additive that is inert to the course of reactions occurring in the vaporized liquid and causes contamination which cannot be acceptable for technological reasons. The dilemma therefore arises as to whether chemical defoamers are production aids or whether they should be considered as food additives. Currently in the food industry, with the growing awareness of industrial methods of food production, there is a search for products free of chemicals, even despite the manufacturers' declarations of their indifference to health, while retaining all the valuable properties. Therefore, the share of mechanical foam removal methods will increase. This is especially true for food producers who focus on high quality of the so-called pure products they offer.

Having the above in mind, the subject of the research undertaken within the work is the aspect of the mechanical method of removing the gas phase (foam) from technological liquids in the food industry. The aim of the work was to design, construct and experimentally verify the working parameters of a device liquidating foam with the mechanical method, capable of pumping liquids containing up to several tens of percent of a gaseous phase with simultaneous separation into a liquid phase subjected to further technological processes and a gaseous phase separated and removed from the hydraulic system.

The paper is divided into two parts: theoretical and research.

The theoretical part describes the mechanism of foam formation and its types depending on the volume fraction of the gas phase and indicates the negative factors of foam influence on the technological process in the food industry. It discusses the effects of basic physicochemical properties of liquids on pump performance such as specific gravity, viscosity, incompressibility, evaporation, and the ability of liquids to dissolve or release gases. In addition, the work describes the liquid-gas two-phase flow in the suction pipe of a centrifugal pump which had nine flow patterns identified and distinguished. These patterns determine the efficiency and volume contribution of the gas. The paper also describes the mechanism of blocking the centrifugal pump depending on the gas phase contribution.

Chapter 6 describes the mechanical process of foam destruction based primarily on the use of shear force, centrifugal force, and rapid changes in pressure and impact.

The research part describes the construction and principle of operation of the designed device and two test stands used for flow and foam destruction efficiency tests.

The pump was designed and built as a frame mounted pump unit and consisted of three main sections: hydraulic (casing with impellers and baffle), bearing unit with stuffing box seal and electric motor to drive the pump. The hydraulic section consists of a chamber divided by a baffle with hole(s) and two rotors mounted on a common shaft. The first (separating and pumping) rotor separates the foam and pumps out the liquid, the second rotor, in a three or two-stage destruction process, mechanically breaks up the formed foam and removes air and residual liquid. Two or three stage process of foam destruction is realized by suitable configuration of working elements of the pump i.e. the partition dividing the pump chamber and the impeller destroying the foam. The designed baffles (3 types) and foam destroying rotors (2 types) allowed to configure three sets of working elements, labelled as Set I, Set II and Set III, respectively, which were tested on bench and during CFD(Computational Fluid Dynamics)simulations.

Chapter 12 discusses the results of the tests carried out to verify the numerical model used in the calculations so that it most closely matches the actual operating conditions and so that simulations can be carried out for the pump as a whole consisting of both impellers together with the inter-chamber baffle. The obtained results confirmed the correctness of the numerical model and gave rise to further research work.

Sections 12.2.3, 12.2.4, and 12.2.5 contain the results of flow tests and simulations for several configuration sets of pump operating elements. The points of proper work of the configured sets were determined, i.e. the volume flow ($\dot{Q}$) and pressure (p_2) at the pump outlet for which the condition of correct operation of the pump is met, i.e. outflow of liquid at the outlet free of gaseous phase. The results show that in the case of the volume expenditure $\dot{Q}$the best results were obtained for set II - 13.4 m^3/h, followed by set III - 11.7 m^3/h. For Set I, the average flow is 39% of the Set II flow and is 5.3 m^3/h. Analysis of the pump outlet pressures (p_2)shows that they are comparable for each of the configuration sets which results from the dependence of discharge pressure on the speed of the rotor blade tip which in turn, for the same outer diameter of the rotor and the same rotor speed, is constant for all cases. Moreover, the paper determines dependence of the volume flow ($\dot{Q}$) on the size of the borehole or the baffle opening (d_p) for selected pump outlet pressures (p_2) for particular sets of configurations of working elements of the pump. The relationship is linear - for all outlet pressures (p_2) flow ($\dot{Q}$) increases with decreasing dimension d_p. The smaller diameter d_p the thicker the water ring in the separating-pumping and thus the greater volume of liquid is pumped per unit of time.

Section 12.3 investigates the propensity of the designed pump to produce so-called secondary foam. It shows that the application of the chemical method through the addition of inhibitors changes the properties of the liquid causing a decrease or disappearance of the tendency to form foam. At the same time, the applied methods of mechanical foam destruction do not change the physical and chemical properties of the liquid. Thus, there is no reduction in the ability to form foam once the liquid has passed through the separator. This can lead to secondary foaming, the skimming device will circulate the foamed liquid without blocking the flow. This process will be so dynamic that foam will form at the outlet of the device. The test liquid was a solution of beetroot juice used in a beetroot drying plant for borscht powder. The average volumetric flow rate was $\dot{Q} \approx 13{,}4\, m^3/h$assumed earlier and the pressure at the outlet was $p_2 \approx 0{,}90 bar$. Beet juice with a volume of 89 dm3 was pressed 15 times through the measuring system. It has been proven that for fixed pump operating conditions there is no secondary foam effect.

Section 12.4 examines and compares the foam destruction effectiveness of the pump configuration sets. The test liquid was apple juice, turbid, directly pressed, and the destruction efficiency was evaluated by measuring the rise time of the liquid, in 100 ml increments, to a final volume equal to 400 ml escaping from the outlet port of the destruction module and flowing into the measuring vessel. At the same time, the height of the liquid was measured, not the foam collecting on the surface of the liquid. The results of the tests indicated that the fastest growth of liquid in the measuring vessel, and thus the best foam destruction efficiency for all pressures of compressed air affecting the intensity of primary foam formation was achieved in the tested configuration set II, in the process of three-stage foam destruction.

Chapter 13 provides general and specific conclusions. The assumed aim of the work has been achieved. Comparison of the obtained parameters of the pump operation for three sets of configurations of working elements of the pump showed that the best parameters were demonstrated by set II, both in terms of volumetric flow ($\dot{Q} = 13{,}4\, m^3/h$)volume flow, as well as the stability of the discharge pressure (p_2) and foam destruction rate. The design of the subsequent pump series sizes will be based on the II configuration set of the pump operating elements.