Doctoral thesis abstract

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KOSZALIN UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

Department of Food Industry Processes and Facilities

Title: NUMERICAL ANALYSIS AND EXPERIMENTAL STUDIES OF THE FLOW OF BEER WORT IN A MODIFIED ROTATORY TANK

Author: Marta Stachnik

Supervisor: dr hab. inż. Marek Jakubowski, prof. PK

Auxiliary supervisor: dr inż. Monika Sterczyńska

Nowadays, Consumers are constantly looking for new experiences, and the market is responding by providing new types of beers. Raw ingredients other than barley malt significantly affect the production steps, particularly the filtration, clarification, boiling, and transport operations.

The boiling of wort with hops also generates hot trub, which is separated in a rotary tank. The development of new measurement techniques and computer tools allows for more extensive analysis and improvement of the separation conditions of said suspension.

This work introduces modifications to the bottom of the rotary tank to improve the clarification conditions of beer wort after boiling with hops. Using sections of the projection of the Ekman spiral on the surface, 5 baffles were constructed, which multiples (2, 3, 4, and 5) constituted geometrical forms modifying the bottom of the classical tank. The primary flow velocity distribution was measured using the PIV method and computer simulations. Rheological characteristics of wort and sediment were also determined.

Two phenomena occur in the rotary tank: vortex flow with free surface and sedimentation of hot trub. Initially, a three-phase computer model was built consisting of two continuous phases (air and wort) and a dispersed phase (sediment). An Euler-granular approach was used, a combination of free surface wort-air tracking and a granular model to describe the dispersed phase. The extended mathematical equations describing the flow in the tank include the contribution of each phase/fraction. Based on simulations, changes in the share of the dispersed fraction and the formation of a sediment cone in successive time steps were

investigated. Contrary to the experiment the computer model also allows for the analysis of the characteristics of the vertical secondary flow.

Preliminary calculations were performed for a classical tank. Due to the long computation time, the analysis of the effect of modifications on the flow was carried out through experimental PIV measurements. Based on the analysis of flow vector maps, five evaluation categories were defined: primary flow symmetrization concerning maximum velocity values; primary flow symmetrization concerning the location of maximum velocity values; stabilization of the central zone flow; reduction of primary flow velocity values; a decrease of central zone flow velocity values.

The greatest reduction of maximum values of primary flow velocity was observed in geometric forms constructed from shorter spiral fragments. The geometric configurations of the longest spiral fragment contributed to the least reduction of these values. In terms of the evaluation of the symmetrization of the position of the maximum values of the primary flow velocity, the smallest deviations were identified for the shortest spiral fragments, of which the variant located closest to the axis with three arms was the most favorable. In terms of the symmetrization of the maximum values of the primary flow velocity, each variant contributed to the worsening of the conditions in relation to the classic vats. However, in the category of position symmetrization, even the least favorable solution contributed to improved flow conditions relative to the classical vat. The most beneficial in terms of central zone stabilization were geometric forms made of the shortest spiral fragments, of which the best was the variant with three arms located closest to the axis. On the other hand, modifications of the bottom with spiral fragments positioned closer to the tank wall contributed to the impaired flow conditions in comparison with the classical tank. The most substantial reduction in central zone velocity was identified for geometric forms with the longest spiral fragments.

Vorticity values were also analyzed. Although the flow in the tank is considered as a rotation of a rigid body, local vortices were observed. The criterion λ_{ci}, which distinguishes vortex structures from the high shear flow region, was used to identify vortices. The lowest values of this criterion (compared as absolute values) were identified for the shortest fragments located closest to the axis. On the other hand, longer spiral fragments contributed to the development of local vortices of higher strength than in the classical vats. Experimental studies show that the shortest spiral fragments located closer to the axis in a 3 or 4 arm configuration generated more favorable primary flow conditions. On the other hand, longer spiral fragments contributed to the most prominent reduction in central zone velocity.

Computer simulations of selected modification variants were conducted for a low tank, where the height of the liquid column is equal to the radius of the tank. The longer spiral fragments generated the most favorable effect on the flow in the rotary tank, and the shortest elements created the least favorable. Therefore, the variant with the shortest spiral fragments had the lowest cone compaction. In contrast, the highest compaction developed in the variant with the longest spiral fragments. This was the opposite situation to the results obtained for the tank with the ratio H/D = 1. It was assumed that the selected height of the construction elements would not disturb the radially inward flow. Computer simulations proved that the bottom modifying baffles inhibited the near-bottom flow, which contributed to sediment aggradation around them.

The last part of this dissertation describes the results of measuring the rheological properties of hot trub from an industrial brewery. Four types of sediments, made from three combinations of raw materials (barley malt charge, 30% and 45% addition of unmalted barley), were compared. Two hot trubs were made from the same batch but differed in wort extract. The effect of temperature and shear rate on the change in viscosity values was evaluated. Wort viscosity values were measured at 20°C and as a function of temperature. The values from the experiments were input data for computer simulations.

The hot trub showed shear-thinning properties and considerable thixotropy. At each temperature, the highest apparent viscosity values were recorded for the sediment derived from the malted batch. On the other hand, the hot trub with 30% addition of unmalted barley had the lowest apparent viscosity values. Increasing the unmalted substitution by 15% and the extract to 16.1 and 18.2° slightly increased the apparent viscosity of the hot trub. The material showed the existence of yield stress. Its value decreased with increasing temperature, but not enough to interfere with sedimentation. Finally, a Cross model successfully represented the rheological properties of the hot trub.

The research suggests that the hot trub structure is influenced not only by the raw material input but also by the production scale. Consumers eagerly reach for craft or mini-breweries products. They are also looking for new flavors. Unusual raw materials, such as buckwheat or oats, are becoming popular. The change in the amount of protein and other compounds affects the settling and characteristics of the hot trub. Therefore, it is necessary to analyze sediment's cone formation, including its rheological parameters. Further research includes simulations and experiments taking into account different values of wort and hot trub viscosity. Additionally, a study of the influence of this parameter on primary and secondary flow, sedimentation, and hot trub cone formation in the rotatory tank is vital.

Keywords: rotary vat, hot trub, vortex flow, multi-phase flow, rheology

Marta Stachnik