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INFLUENCE OF A WHIRLPOOL TILT ANGLES ON THE PLACEMENT OF A SUBSTITUTE SEDIMENT CONE

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Abstract. The article presents the results of the experimental research on the placement of the cone of substitute sediment at the bottom of the laboratory whirlpool tank with capacity of V=2 *hl* and diameter D=640 mm. The subject of the research was the influence of the whirlpool tilt angle on the process of forming the cone of break. Different tilt angles of the tank's inlet were also taken into account and, for each characteristic states of forming the cone of break were registered. The research led to finding a tilt angle beneficial in terms of movement of the cone of substitute sediment in comparison to cycling in a tank without any tilt.

Key words: cone of break, tank's bottom, whirlpool, rotating fluid flow

Introduction

After boiling, beer wort is pumped over to the whirlpool's tank (commonly known as the whirlpool) in order to filter out the, so-called, hot trub. This process takes advantage of the hot trub cone formation phenomenon, which is caused by the mixture's rotational flow and occurs just above the central part of the tank's bottom. This rotational flow is achieved by filling the tank via an inlet placed tangentially in the tank's wall (fig 1). In order to avoid retardation of the flow, no structural elements are placed inside the tank. Employing a whirlpool to separate hot trub from wort is the cheapest as well as prevailing method in the process of beer wort production. Yet, it should be borne in mind, pumping out the clarified wort carries the risk of transferring the sediment along with the semi-finished product.

Considering the processing technology, wort impurity may result in severe complications. Therefore, each whirlpool tank is equipped with outlets placed in its wall and joint for transferring out the clarified wort. The bottom outlet is used for final emptying. However, the production practice shows it is common (because of the cone diffusion) to close the bottom outlet's valve prematurely, in order to prevent the clarified wort from being tainted by letting sediment through the inlet.

In production plants, since the 1960s – when the whirlpool was first used, there have been two types of tank in use: slim (with H – height to D – diameter ratio noticeably above 1) and short (with the ratio way below 1). Each tank's structure is constantly a subject to modifications, usually related to the placement of inlets and outlets for the clarified wort and the separated sediment. This has been the case since the settling vat (an old solution), which was ineffective because it had a pipe attached to a float, right up to the contemporary solution as a collecting pipe connected to two outlets**.** Placing the outlets at multiple heights (above the sediment cone and near the tank's bottom) allows sequential emptying, which minimizes the risk of pumping out wort with hot trub (Briggs et al., 2004; Kunze, 2010).

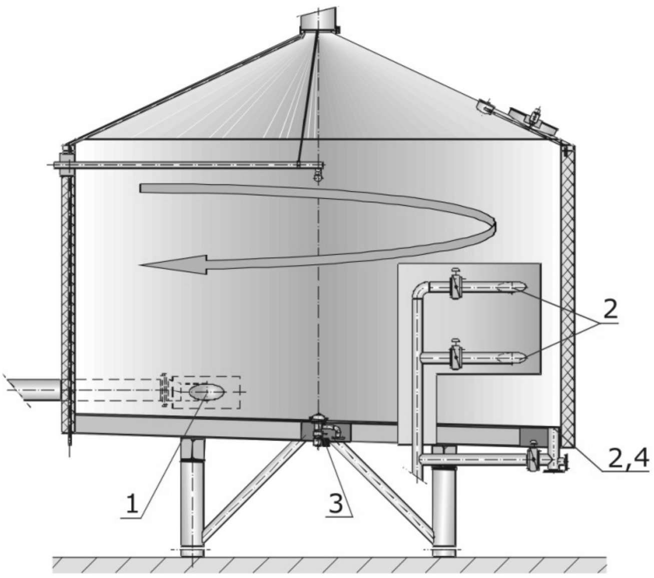

Figure 1. A diagram of a whirlpool vat's classic structure: 1 – wort inlet; 2 – wort cleared outlets; 3 – automatic trub discharger; 4 – trub outlet (by GEA–Huppmann)

Modifications of the tank's construction were also related to elements of its interior and the tilt angle of its bottom (about 1-2º). Many proposals of the bottom's shape were introduced: flat, with sediment cup, of cone shape (with either raised or lowered middle part) or with a diffuser (like in apparatus known as a kettle). However, most of those solutions have no influence on the hot trub cone formation (Jakubowski, 2008; Diakun and Jakubowski, 2009).

Considering the literature, one can conclude that the knowledge about the process and phenomena occurring in a whirlpool is incomplete. However, it is sufficient for creating structural designs to a limited extent. It is still necessary to seek new solutions and structural modifications through research on real-world models (Dürholt, 1988; Denk, 1998; Jakubowski and Diakun, 2006).

The aim of research

This article portrays experimental research on the impact of the whirlpool's tank's tilt angle on the position and formation of the sediment cone. The research also included multiple variants of tilt angle between the tank and its inlet, in order to determine the impact of the tilt's direction on the position and formation of the substitute sediment cone.

The workbench and an experiment setup

The research was carried out using a laboratory whirlpool. It's separation tank had the diameter of D=640 mm, nominal filling height of H=640 mm, capacity of V=2 *hl* and was made of polymethyl methacrylate (PMMA) made possible capturing images of the sediment cone during its formation with a camcorder and a camera. For the purpose of the experiment we used polystyrene (PS) particles, the specific gravity of which is g=1.023 $g{\cdot}cm^{-1}$. The only purpose of those particles is to visualize the phenomenon. There is no connection between the size of the seeding and the hot trub particles, however, their concentration was 1%, which meets the case of the separated mixture in a real-world scenario. Using the output images we determined the timing of occurrence of specific stages of the substitute sediment cone formation. The filling rate was constantly at u=1.7 $m{\cdot}s^{-1}$ and the inlet was at the height of h=160 *mm*=0.25D. This workbench had already been described in previous publications (e. g. Wiedro-Stempińska, 2012; Jakubowski et. al, 2013).

A part of the research plan was to perform a series of spins at different tilt angles of the laboratory whirlpool tank, which were: 2º, 4º, 6º, 9º, 12º and 15º. Different tilt variants of the inlet were also considered. The tank was filled so that the height to diameter H/D=1 ratio was satisfied. Every time a sediment cone formation was recognized, the spin was repeated two more times without altering the setup. We compared the results with the data obtained with a leveled tank.

The results and their analysis

The experimental research on the flow of the mixture separated in the laboratory whirlpool tank allowed performance of an analysis of the substitute sediment cone formation for each of the tilt variants.

As a result of the performed spins, we initially concluded that tilting the whirlpool tank towards its inlet enables substitute sediment cone formation above the central part of the tank's bottom. The cone's position is similar to the one present in the solutions currently used by breweries. Figure 2 presents examples of the substitute sediment cone's geometrical shapes when the tank is tilted towards its inlet. In the case of the 6-degree tilt angle (fig. 2b) a slight distortion of the cone's symmetry is present.

We were particularly focused on the position of the sediment cone when the tank was tilted away from its inlet. In this case, the substitute sediment cone formed much closer to the wall of the tank, yet it kept the torus shape. During the experiment we determined the timings of particular stages of the cone formation. Figure 3 presents the cone shifted towards the joint. Such a position was achieved by tilting the tank to 6 degrees. It may appear advantageous for the emptying process of such an apparatus in a brewery. Keeping the cone away from outlet may help minimize the risk of transferring the hot trub with the clarified wort. This would also reduce the loss of wort in the manufacturing process, caused by its impurity.

Figure 2. The final phase of forming the cone of sediment break (a formed cone of break - the end of cycling) next to the laboratory vat tilted to the inlet at: a) 2º; b) 6º

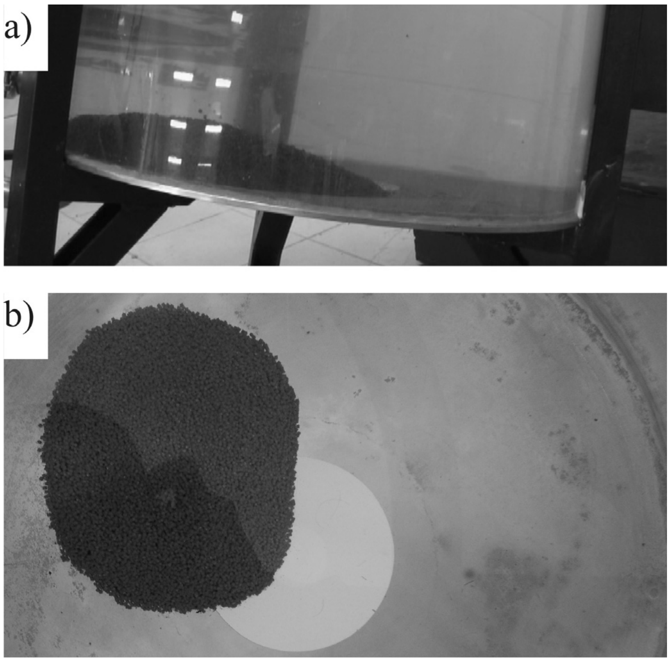

Figure 3. The final phase of forming the cone of substitute sediment (a formed cone of break – the end of cycling) next to the laboratory vat tilted towards the inlet-opposing wall at 6º: a) an overview of the cone; b) top-view of the formed cone of substitute sediment

When comparing the timings of particular stages of the substitute sediment cone formation we also used the data obtained with the leveled tank (fig. 4 – the dashed line). Those measurements had been described in detail in the previous publications (Jakubowski et. al, 2013). We recognized such characteristic stages: the sediment begins to form a torus, the torus is formed (and begins to form a cone), the sediment cone is spinning, the sediment cone is fully formed, the end of spinning.

It should be noted that the sediment cone always begins to form earlier, if the tank is tilted. A similar situation takes place in the 3rd and 4th stage of forming the substitute sediment cone. The tilt had no impact on the timing of the full stop and full formation stages.

As a part of the research we also performed measurements for tilt angles higher than 9 degrees. It resulted in major distortions of the rotational flow, thereby making it impossible to recognize and capture any stages of cone formation. Initially, the sediment occupied the entire available space. Next, something alike the torus formation stage was recognized, but it was unstable and lacked symmetry. After closing the inlet's valve, the substitute sediment once again scattered throughout the volume of the dispersion medium. The mixture was slowing down quickly, thereby causing the sediment to settle at the bottom of the tank, in the form of flat and irregular shapes resembling a diffused cone (fig. 5a, 5b, 5c).

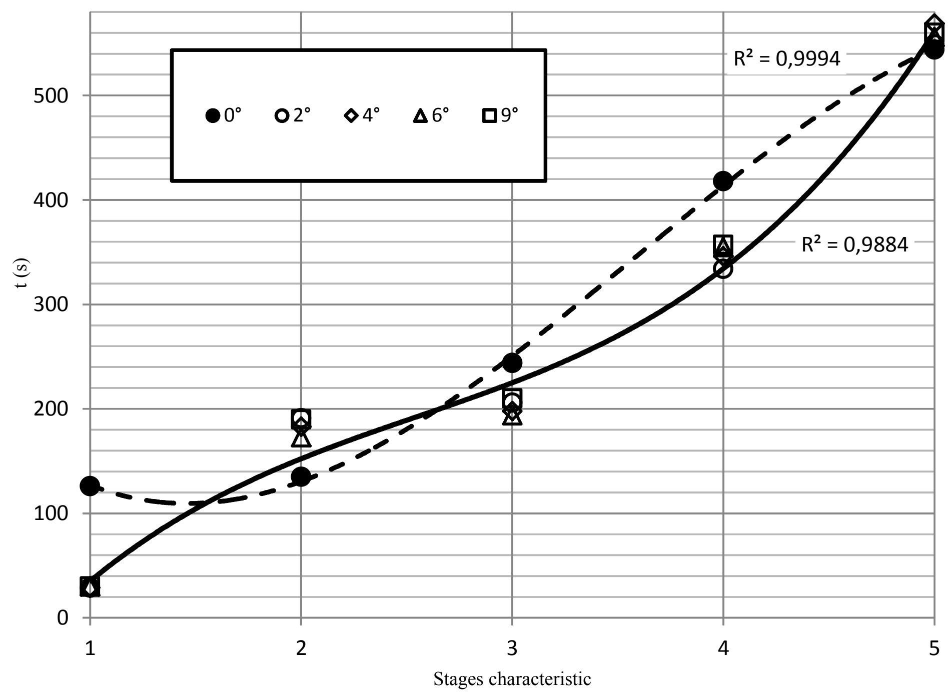

Figure 4. The timing of states characteristic for the cycling in a vat tilted towards the inlet–opposing wall (on the ordinate: 1 – the beginning of forming a torus; 2 – closing the torus; 3 – the rotating cone; 4 – the cone in a standstill; 5 – full standstill, the cone is formed

The spins should be repeated for the tilt variants recognized as advantageous, this time with the tank leveled and only its bottom tilted.

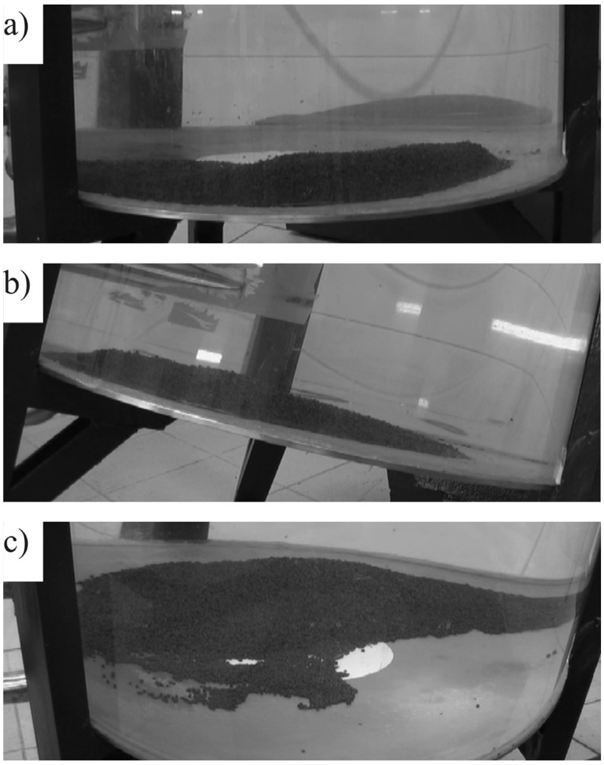

Figure 5. The final phase of forming the cone of substitute sediment (a formed cone of break – the end of cycling) next to the laboratory vat tilted towards the inlet-opposing wall at: a)10º; b)12º; c)15º

Conclusions

1. The measured timings of the characteristic cone formation stages show that tilting the whirlpool vat's tank away from its inlet causes advantageous shift of the position of the sediment cone, but only at slight angles (not greater than 9 degrees). Going beyond this value made it impossible to recognize the cone formation stages. The particles settled across the bottom of the tank shortly after the filling.
2. Tilting the tank towards the inlet resulted in minor impact of the position of the substitute sediment cone, shifting it slightly towards the wall of the tank of the laboratory whirlpool.

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WPŁYW KĄTA POCHYLENIA ZBIORNIKA KADZI WIROWEJ NA POŁOŻENIE STOŻKA OSADU ZASTĘPCZEGO

Streszczenie. W artykule przedstawiono wyniki badań eksperymentalnych dotyczących umiejscowienia stożka osadu zastępczego na dnie zbiornika laboratoryjnej kadzi wirowej (tzw. whirlpoola) o pojemności V=2 *hl* i średnicy D=640 mm. Przedmiotem badań był wpływ kąta pochylenia zbiornika kadzi wirowej na formowanie się stożka osadu. Dodatkowo uwzględniono warianty odchylenia zbiornika względem otworu wlotowego. Dla poszczególnych wariantów zarejestrowano występowanie stanów charakterystycznych formowania się stożka osadu. Przeprowadzone doświadczenia pozwoliły stwierdzić, iż istnieje wariant pochylenia zbiornika whirlpoola, który jest korzystny ze względu na przemieszczenie uformowanego się stożka osadu zastępczego w odniesieniu do wirowania w zbiorniku niepochylonym.

Słowa kluczowe: stożek osadu, dennica zbiornika, whirlpool, ruch wirowy cieczy

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