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Simulation and experimental research on the flow inside a whirlpool separator

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ABSTRACT

The whirlpool settling vat is the prevalent separator in brewing, employed to remove hot trub in the process of wort boiling. During this process, the so-called tea leaf effect is present, i.e. the accumulation of the separated trub into a cone shape in the centre of the container. This phenomenon is the result of rotational flow of the separated mixture. This study presents simulation analysis and experimental research on the subject of flow in a whirlpool cycling vat. The creation process for a simulation model is presented, as well as its analysis employing CFD (Computational Fluid Dynamics), along with verification research using PIV (Particle Image Velocimetry). The results obtained by means of a computational simulation have been compared to the output of PIV. A way to implement scale-model research results in real-world objects, using dimensionless numbers, has been suggested.

1. Introduction

A cycling vat, commonly designated in the industry as a whirlpool (Fig. 1a), is a separator used in brewing to filter out hot trub after wort boiling (Kunze, 2010). It is a cylindrical reservoir, filled up through a tangent inlet placed in its wall. Due to gravitational sedimentation, along with an aggregate of secondary flows caused by rotational flow, the separated trub forms a cone in the centre of the tank. The phenomenon of cone formation is considered a paradox, because centrifugal force is not causing the trub particles to travel to the outer part of the tank, but in contrast, to accumulate in the centre of the tank (Fig. 1b). It was described by Albert Einstein, who named it the “Tea leaf effect” (Einstein, 1926). Whirlpool is an effective apparatus for filtering out suspended solids and could be implemented in other fields of the food industry. Apart from the primary and secondary (forming the trub cone) flows, there are other rotational flow types present, e. g. Taylor eddies near the tank’s wall and a planetary vortex tube. These flows have been portrayed in a diagram (Fig. 2a)

The rotational flow of a fluid in a vat’s tank and the phenomenon of secondary flows (Fig. 2a) formation are highly complex in terms of mathematical specification. The introduced set of equations describing flows in a whirlpool, which takes into account the presence of dispersed phase, are not suitable for analytical solving. Yet, it is possible to carry out analysis by means of Computational Fluid Dynamics. “Jakubowski and Diakun 2007” presents the results of simulation analysis of a simplified, 2-dimensional model, assuming axial symmetry of the flow. As part of that work, the simulation of the secondary flow phenomenon, responsible for the formation of the cone of hot trub, was proven possible. This study is an extension to that research, adding experimental research and full 3-dimensional analysis of flow. In terms of mathematical specification, a method has been suggested, which takes into account the influence of dispersed phase on the flow.

2. Material and methods

What is presented below is a concept for the mathematical specification of a two-phase flow, which takes into account mixture swirl and the influences of the dispersed phase on the flow. The subsequent paragraph presents the software for CFD computation, as well as the workbench for experimental PIV research.

2.1. The mathematical model

The process of separating wort (dispersion medium) and hot trub (dispersed phase) begins at the stage of filling up the tank.

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Nomenclature

c_d	mass density of dispersed phase (kg m^{-3})	m_{dc}	mass transfer between phases (if the particles do not dissolve, then: $m_{dc} = 0$) (kg s^{-1})
D	whirlpool diameter (m)	μ	laminar viscosity (Pa s)
D_{md}	diffusion coefficient of dispersed phase in a fluid (m s^{-2})	μ_T	turbulent viscosity (Pa s)
d_d	average diameter of particles (m)	n	normal to surface unit vector (–)
δ_w	distance between wall and grid (m)	p	pressure (Pa)
$\mathbf{F}$	additional volumetric forces (N kg^{-1})	ρ	density (kg m^{-3})
f_d	coefficient of flow resistance for dispersed phase (–)	σ_T	Schmidt number (–)
g	gravitational acceleration (m s^{-2})	ϕ_c	volumetric share of continuous phase (–)
H	whirlpool filling height (m)	φ_d	volumetric share of dispersed phase (–)
$\mathbf{I}$	identify matrix (–)	u	velocity (m s^{-1})
K	dimensionless number (in general) (–)	u_0	normal velocity on inlet (m s^{-1})
k_v	von Karman constant (–)	u_τ	friction velocity (m s^{-1})
L_T	turbulence length scale (m)	$\mathbf{u}_{slide}$	velocity in-between phases (m s^{-1})
l_{Tk}	turbulence intensity (–)		

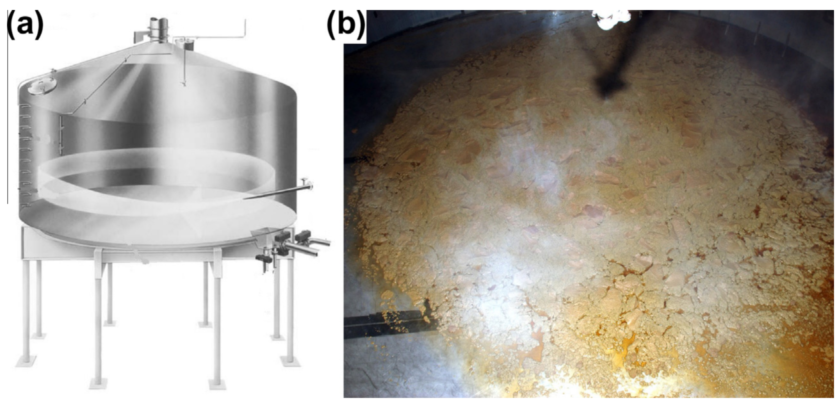

Fig. 1. Whirlpool: (a) general view of an industrial tank (Bamforth, 2009), (b) hot trub cone after the separator has been emptied (the picture presents a GEA-Hupmann whirlpool of 1050 hl capacity).

Once the tank is filled to its operational level (nominal), the swirling stage begins – the so-called whirlpool stand. The mixture, constantly under the separation process, flows with uniformly retarded rotational motion. Considering the premise, the rotational flow inside a whirlpool ought to be regarded as in unsteady state (Dürholt, 1988).

In this case, the equation of velocity balance assumes the following form:

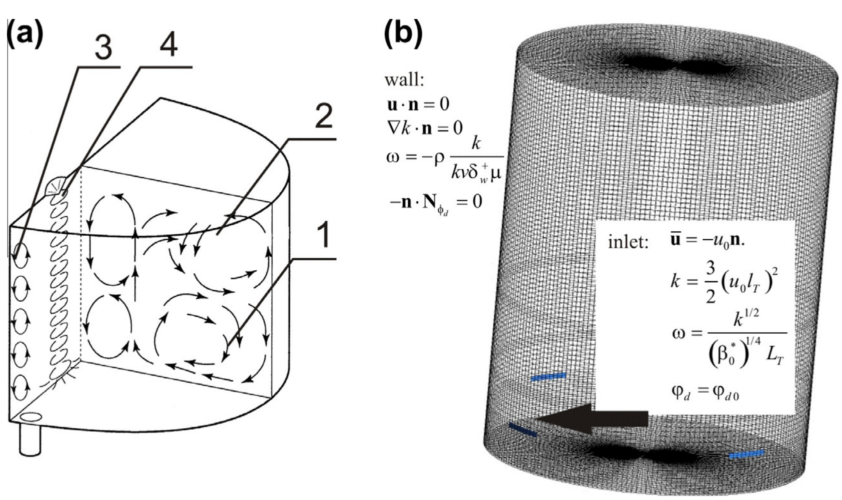

Fig. 2. Whirlpool: (a) schematic diagram of secondary flows: 1 – secondary flow, 2 – torus eddy, 3 – Taylor eddy, 4 – planetary eddy (in accordance with Denk and Dürholt, 1991); (b) geometrical model with the finite elements grid and boundary conditions for the mathematical model.