EXPERIMENTAL AND NUMERICAL STUDIES OF CONVECTION FLOW IN A CYLINDRICAL-CONICAL FERMENTING TANK

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Summary: In this paper the experimental and numerical investigations of the convection flow in a real cylindrical-conical fermenting tank for beer production are described. The experimental investigations were conducted using a two-dimensional ultrasonic Doppler velocity measurement method to measure the flow field during a real fermentation process in opaque wort. In further investigations the fermentation process was simulated with a model-fluid by heating and cooling the outside of the fermenter. In a numerical study the convection flow of the simulated fermentation process was analysed.

INTRODUCTION

Today the fermentation, maturation and storage of beer during the manufacturing process are mostly carried out in cylindrical-conical fermenting and storage tanks. These tanks are made of stainless steel with separated cooling spirals for the different processing steps. The fluid mechanics inside of these tanks has not been recorded satisfactorily from a scientific point of view.

Optimal conditions, i.e. the homogeneous distribution of yeast particles, during fermentation, maturation and storage are achieved by means of controlling the transport mechanisms regarding momentum, heat and mass transfer. The multiphase flow in the tank generated by the fermenting process is three-dimensional and turbulent. The medium “wort” is composed of several phases and components. In the wort, heat and mass transfer processes take place and there is an interrelationship between the biological matter and the carrier liquid.

EXPERIMENTAL ARRANGEMENT

For the analysis of the fluid mechanics inside the fermenting and storage tank a model tank was developed, which was equipped with eight separately controlled cooling zones. The volume flows in these zones were adjustable to the various test conditions and process requirements. The cooling energy was supplied by a chiller with a power of 10 kW. The cooling medium was a glycol/water mixture, which was able to supply the eight cooling panels with a temperature down to minus 7 °C. For the simulation of the fermentation process, these zones could be heated by means of a heating unit, so that different temperature levels in the zones outside the model tank to simulate the process with a model fluid could be obtained. The test facility can work in two different modes: a real fermentation and storage process mode and a mode that simulates the real process by means of a model fluid. This experimental simulation mode allows the comparison with the numerical simulation. For controlling the test facility, a software was created on the basis of the software tool “HP-VEE” with a view to managing the continuous data logging of temperature and volume flows during the fermentation, maturation and storage processes. For the velocity field measurement inside of the fermenting tank an ultrasound Doppler measuring technique is used. The operating principle of this measurement technique is to use ultrasound pulse waves to detect the Doppler frequencies in 128 measurement volumes along the measurement axis. The spatial information of these measurement volumes is determined by the time delay between pulse emission and echo reception. The velocities at each measurement volume are calculated from the Doppler frequencies. For the measurement of two-dimensional velocity fields it is necessary to measure two velocity components at one spatial point in order to calculate a vector. In the intersection point of measuring lines of two transducers the velocity vector can be determined. For this reason a measurement field with a vertical and horizontal arrangement of 16 transducers was installed.

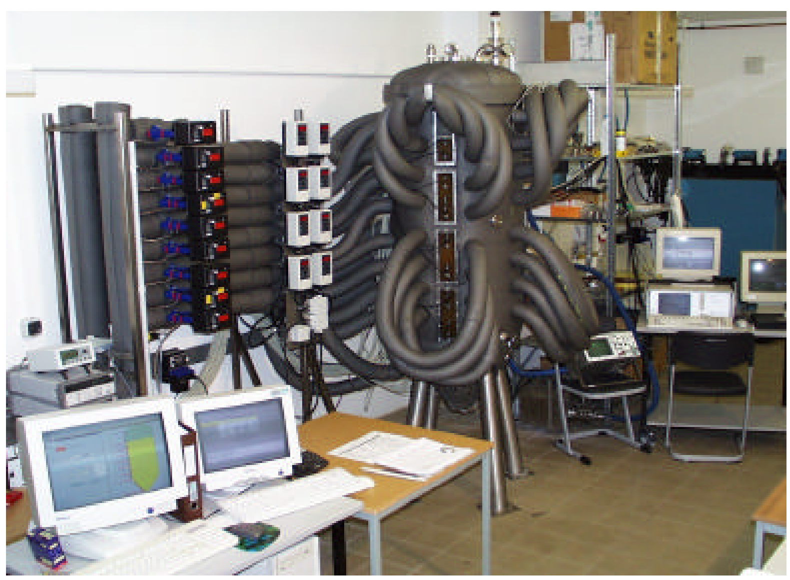

Figure 1: Experimental arrangement

PRESENTATION OF RESULTS

Experimental results

The flow field was measured continuously several times during the eight days of fermentation. The temperature in the cooling zones was set at 5 °C in order to achieve a constant temperature (8 °C) of the interior of the fermenting tank in compliance with the fermenting procedure. In figure 2, an example of the velocity field taken on the 8th day of fermentation is shown. The heat transfer of the fermenting heat took place in the upper two cooling zones. On the first day of fermentation, no convection areas had developed inside the tank. Velocities of 15 mm/s were measured. In the bottom part of the tank, an upward flow, with a velocity of about 4 mm/s, was observed through the windows. On the third day of fermentation the flow activity strongly increased due to the increase of the fermentation process. On the fifth day the velocity field was nearly symmetrical. In the upper part of the tank, a radial flow directed at the cooling zones was detected. In the central area an upward flow was measured with velocities up to 130 mm/s. The warmer liquid in the cone area rises to the upper part, turns to the cooling zones, and sinks at the border area of the tank back to the bottom part due to the fact of continuity. This re-flow is not very intensive. Video recordings show that even at the end of the fermentation process (8th day) a very turbulent three-dimensional flow in the upper part of the tank, below the foam, occurs. In the bottom part a constant downward flow with a velocity of about 4 mm/s could be observed. Inside this flow precipitate yeast agglomerates were observed.

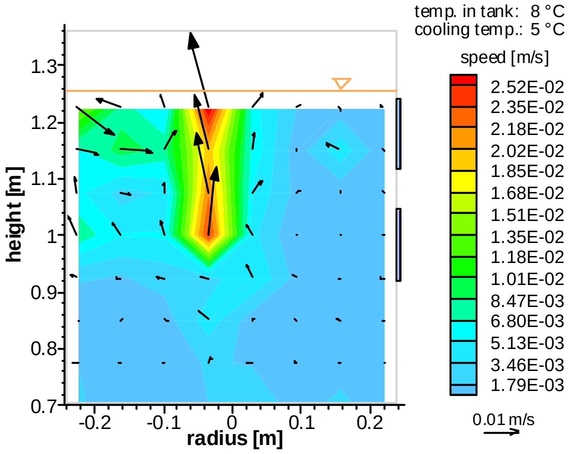

Figure 2: Measurement of velocity field (8th day)

Numerical results

The numerical simulation of heat and momentum transfers in the model fluid in the fermenting tank was conducted by means of the CFD software tool "Fluent". Water was used as the model fluid, because it is single-phase and incompressible. The geometry of the tank assumed was three-dimensional. The real local heat input through the yeast particles was neglected and substituted by a heated cone wall, with the heat dissipation taking place in the upper two cooling zones. In figure 3 the computed flow field of a simulated fermentation is presented. Mass transfer is neglected in the present computation. A comparison between the computation and the simulated fermentation showed that the numerical results offer a good prediction of the flow fields observed in the experimental simulation.

Further experimental investigations will aim at increasing the accuracy of measuring by means of collecting more experimental data. In addition, the influence of rising CO_2-bubbles during fermentation on the velocity measurements will be investigated.

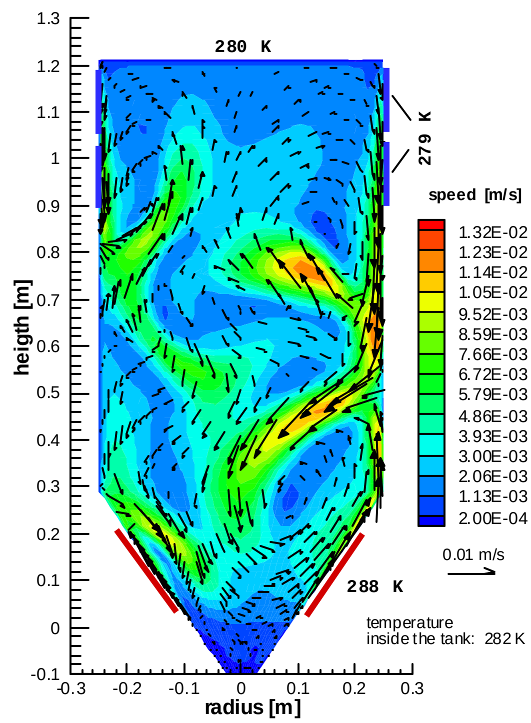

Figure 3: Computation of simulated fermentation

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