ARTÍCULO CIENTÍFICO

CFD SIMULATION BASIS FOR AN INDUSTRIAL MALT GERMINATOR

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Abstract

Germination of barley follows a rigorous control of the operative conditions upon the grain, with the main parameters being the grain moisture, air humidity, temperature, air mass flow, and residence time. The unpredictable deviations yield undesirable characteristics of the product, such as over-germination, embryo death, and unachieved quality parameters. These problems come from the inhomogeneity conditions on the grain bed and its dependency on the ventilation system. This work presents a strategy for simulating an industrial germinator using the CFD technique. The system is a 2D computational domain with dimensions for industrial equipment. The grain bed is a porous system under elemental principles. The results demonstrated that the airflow through the porous medium generates an inverse effect on the temperature and turbulence after crossing the grain bed.

Keywords

Barley Germination, Simulation, porous medium, turbulence

Resumen

La germinación de malta es un proceso que controla las condiciones de la cebada, donde la humedad, temperatura, flujo de aire y tiempo son los parámetros controlables. Las desviaciones de los valores de control provocan problemas en la operación, como exceso de germinación, muerte del embrión e incumplimiento con estándares del producto. Estos problemas están ligados a la homogeneidad de las características de la cama del grano y dependen de la hidrodinámica del sistema de ventilación. Este trabajo presenta una estrategia para simular un germinador industria bajo la técnica de CFD. El sistema es un dominio computacional con las características de un equipo industrial. La cama de grano es un sistema poroso bajo consideraciones básicas. Los resultados indicaron que el flujo del aire en el lecho poroso influye inversamente con la temperatura y turbulencia al cruzar la cama de grano.

Palabras claves

Germinación, Simulación, medio poroso, turbulencia

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1. Introduction

Malt is a raw material for the brewing industry. The malt production from barley consists of three elemental stages: steeping, malting, and kilning. The steeping process promotes absorption, activating the enzymes within the kernel and increasing the inner water content to 42-47% (MacLeod and Evans, 2016; Cu et al., 2016). The malting stage takes between 3 and 5 days under controlled conditions to yield the growth of rootlets and acrospire, enzyme formation, and metabolic changes (Kunze, 2004; Finch-Savage & Leubner-Metzger, 2013). The malt kilning stops germination, reduces the water content, and yields the final color and flavor characteristics for the malt (Kunze, 2004; Bamforth, 2009). Particularly, germination is a delicate process that regulates water absorption in barley under controlled conditions of temperature, humidity, and airflow (Tian et al., 2010). Uncontrolled parameters modify malt quality and produce undesirable final aspects (Farzaneh et al., 2017).

Process analysis is a tool to predict and understand the operative conditions in a unit process. Computational Fluid Dynamics (CFD) is a numerical technique that reveals results for most of the food engineering processes (Kuriakose & Anandharamakrishnan, 2010; Sun, 2019). This technique has analyzed the brewing industry in some of its processes, such as mashing, lautering, and boiling (Jagiełło & Ludwig, 2024). Nevertheless, this technique has not been applied in the malting process. This work develops a CFD simulation for a circular malting box to explain the flow patterns through the grain bed and prevent inhomogeneity problems.

2. Metodology

The CFD methodology contains four stages: geometry development, meshing, model considerations, and solution. In this work, the first stage represented a central plane for the 2D geometry of a circular malting box, with the bed of grain as a porous medium. Figure 1 a) depicts the sizing of this computational domain. In meshing stage, the domain receives a mesh of 25,773 square-shaped elements with a skewness of 0.0055, which indicates a high mesh quality due to the orthogonal design. Nevertheless, the zone near to the inlet boundary presented a low orthogonal quality due to the wall shape. Figure 1 b) shows the mesh distribution in the domain. The development of the geometry and meshing was possible in the Design Modeler ® and Meshing Processor of ANSYS ®, respectively.

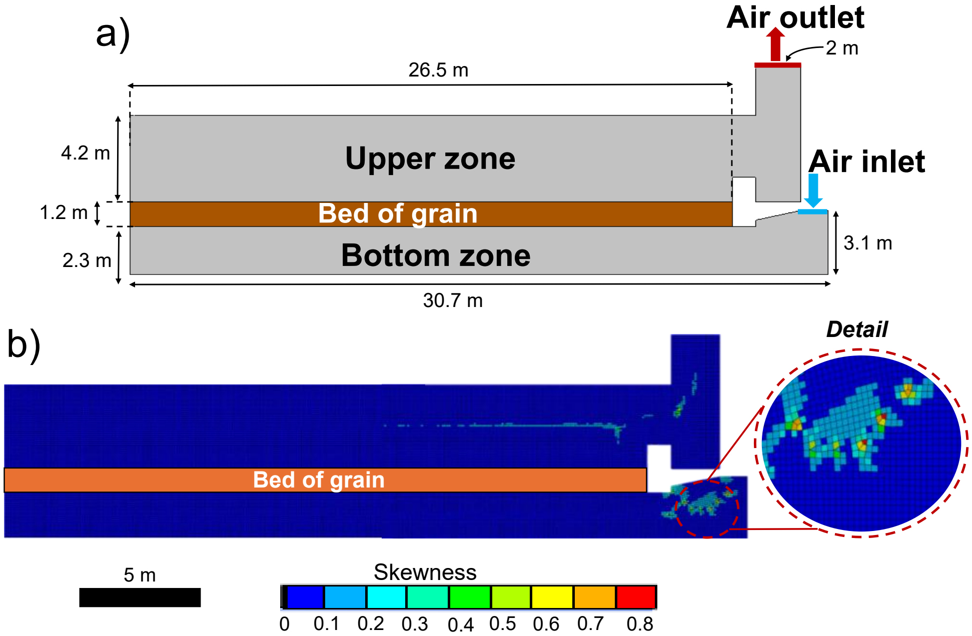

Figure 1. Plane view of a germination system: a) sizing description and b) meshing.

The system core is composed of a bed of grain with a density of 691.85 kg/m^3, a porosity of 0.43, an interfacial area of 800 m^{-1}, and a viscous inertial resistance factor of 698 (Carrera Rodríguez et al., 2011). The airflow is considered an ideal gas (1.225 kg/m^3 at 17°C) with a mass flow rate of 25 kg/s in the inlet boundary and mass conservation for the outlet boundary. The κ-ε Realizable turbulence model was applied to this case, considering vorticity and wall effects, as well as turbulence generation. Table 1 contains the governing equations for this isothermal scenario. Finally, the solution applied the Coupled algorithm by considering the second-order upwind interpolation scheme and hybrid initialization (solving the Laplace equation for the system).

Table 1. Governing equations for this case study.

Description	Equation
Mass conservation	$\frac{\partial v_i}{\partial x_i}=0$
Momentum conservation	$\rho\left(\frac{\partial v_i}{\partial t}+\frac{\partial v_i v_j}{\partial x_j}\right)=-\frac{\partial P}{\partial x_i}+\mu\frac{\partial^2 v_i}{\partial x_j^2}+g_i\rho$
Kinetic turbulence energy conservation	$\rho\left(\frac{\partial \kappa}{\partial t}+\frac{\partial v_i \kappa}{\partial x_i}\right)=\frac{\partial}{\partial x_j}\left((\mu+\mu_t)\frac{\partial \kappa}{\partial x_j}\right)+2\mu_t\frac{\partial v_i}{\partial x_j}\left(\frac{\partial v_i}{\partial x_j}+\frac{\partial v_j}{\partial x_i}\right)-\rho\varepsilon$
Turbulence dissipation rate conservation	$\rho\left(\frac{\partial \varepsilon}{\partial t}+\frac{\partial v_i \varepsilon}{\partial x_i}\right)=-\frac{\partial}{\partial x_j}\left(\left(\mu+\frac{\mu_t}{1.3}\right)\frac{\partial \varepsilon}{\partial x_j}\right)+2.88\mu_t\frac{\varepsilon}{\kappa}\frac{\partial v_i}{\partial x_j}\left(\frac{\partial v_i}{\partial x_j}+\frac{\partial v_j}{\partial x_i}\right)-1.92\rho\frac{\varepsilon^2}{\kappa}$
Nomenclature	v: velocity, x: coordinates, P: pressure, g: gravity, μ: viscosity, ρ: density, μ_t: turbulence viscosity (0.09ρκ^2/ε), i and j: indexes of coordinates.

3. Results

This analysis evaluates the airflow parameters through the bed of grain: velocity and turbulence kinetic energy, κ. The high velocity values were near the inlet and outlet boundaries. In the bottom zone, the obstruction effect of the floor produced a sudden change in direction and the airflow accelerated on the floor. In response, the kinetic energy allows a spatial distribution of the velocity before the bed of grain. The flow through the bed presented linear patterns. At the upper zone, the air patterns changed direction by the ceiling, and the response was a global spatial distribution toward the outlet boundary. The narrowing shape of the upper zone accelerates the airflow until it leaves the system. Figure 2 shows the airflow patterns.

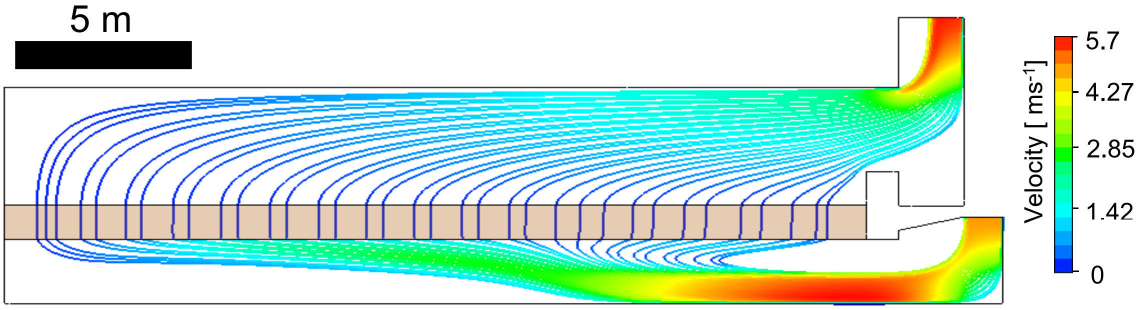

Figure 2. Velocity profile with stream lines for the case study.

The behavior of the κ parameter did not totally concur with the velocity response. The high turbulence region was at the bottom zone over the high-velocity zone. This response came from a secondary flow pattern along the airflow distribution, before the bed of grain. Similarly, the left region in the bottom zone increased the κ parameter. Both turbulence regions responded to the flow distribution before getting to the bed of grain. Finally, the upper zone presented high turbulence zones at the outlet boundary and on the bed of grain.

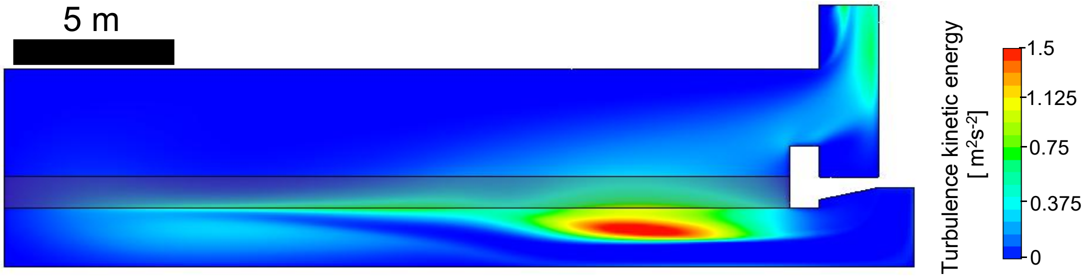

Figure 3. Profile for the kinetic energy turbulence.

4. Conclusions

The application of the CFD tool to the industrial mating process described the airflow. In principle, the bed of grain influenced the flow pattern before crossing it. The air distribution in the bottom zone generated turbulence regions due to secondary flows from the wall obstructions. The upper zone followed the flow patterns through the bed of grain. This description is remarkable for keeping homogeneous conditions throughout the bed of grain. Therefore, the CFD application in germination is suitable for predicting and maintaining desirable conditions to guarantee the quality of malt.

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