An analysis on pre-frying of French fries under well-defined oil flow

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Introduction

Conventional pre-frying systems are not optimised towards homogeneous product quality, which can be partly related to the poor distribution of oil flow and the varying oil velocities in the packed bed of French fries. A better design and controllability might be realized by changing the manner by which oil is contacted with the fries

Objective & Approach

In this study we investigate an alternative frying system with well-defined oil flow from bottom to top through a packed bed of French fries.

- The minimum fluidization velocity at the onset of frying was observed and compared to the Ergun equation.
- The mobility of the fries during frying was quantified using the entropy of mixing through image analysis.
- For the quality distribution of the fries, the final water content was used as an indicator.

Experimental setup

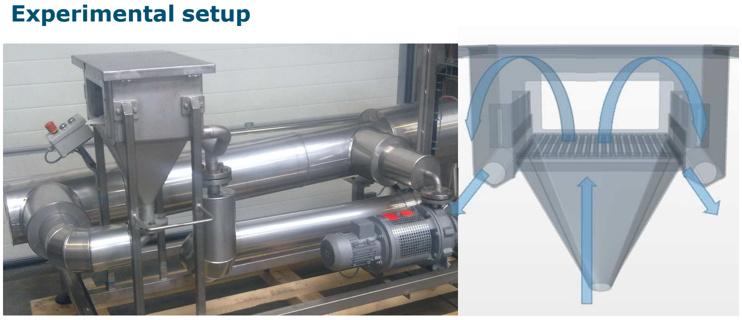

Figure 1. Left: Pilot cross-flow frying unit with pump, heating unit and frying section. Right: Frying section with oil entering from below, flowing via a perforated plate into the bath, and leaving the system via the sides.

The Ergun equation, modified for non-spherical particles, was used to estimate the minimum fluidization velocity of French fries during frying

Figure 2. Deposition of 2 coloured layers of fries with 16 grid cells to determine the degree of mixing in terms of mixing entropy

$$u_m = \frac{150 * (1-\varepsilon_m) * \nu}{2 * 1.75 * \overline{\varphi} * \overline{d_p}} * \left(\sqrt{1 + \frac{4 * 1.75 * \overline{\varphi}^3 * \overline{d_p}^3 * \varepsilon_m{}^3 * (\overline{\rho_s} - \rho_f) * g}{150^2 * (1-\varepsilon_m)^2 * \nu^2 * \rho_f}} - 1\right)$$

Here u_m is the minimum fluidization velocity, ε_m the void fraction, ν the kinematic viscosity, φ the sphericity of the particles, d_p the relative diameter of the particles, ρ_s and ρ_f the densities of the solid and fluid phase respectively, and g is the gravitational constant.

Results

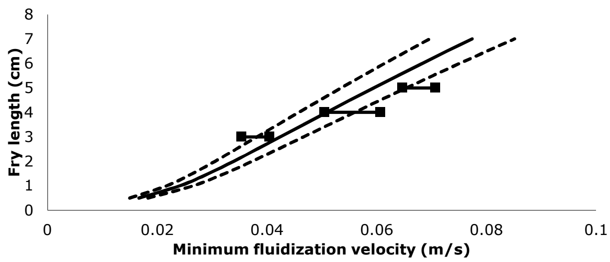

Figure 3. Fry length plotted against the minimum fluidization velocity calculated using the Ergun equation. The dotted lines indicate a 10% relative error. The connected blocks represent the maximum flow rate at which no fluidization was observed and the minimum flow rate at which fluidization was observed for the fry lengths of 3, 4 and 5 cm.

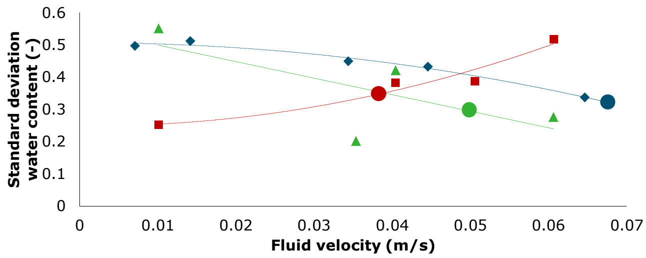

Figure 4. Standard deviations for the water content at different oil flow velocities for 3 (■), 4 (▲)and 5 (◆) cm fries. Lines are drawn to guide the eye. The larger spheres indicate the minimum fluidization velocities for the different fry lengths.

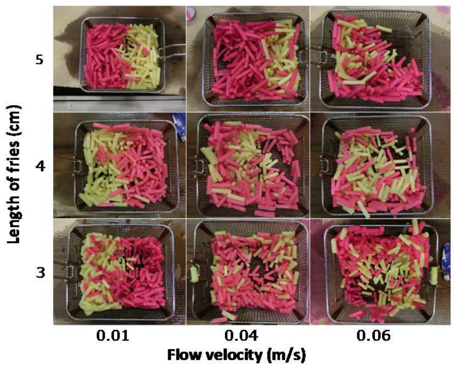

Figure 5. Pictures visualizing the amount of mixing after 1 minute of frying at different oil flow rates and fry lengths of 3, 4 and 5 cm.

Conclusions

- Initial fluidization velocities of French fries could be predicted with the Ergun equation with a 10% margin of error.
- 5 cm fries showed a decreasing trend in quality variation while this was not visible for the 3 and 4 cm fries.
- Higher quality variations at 3 and 4 cm probably coincide with their higher degrees of mixing, as they are more susceptible to flow instabilities and local eddies
- This suggests optimum operation at high oil velocities while preventing fluidization.

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