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Starch–gluten separation by shearing: Influence of the device geometry

E.E.J. van der Zalm, J.A.M. Berghout, A.J. van der Goot*, R.M. Boom

Food Process Engineering Group, Wageningen University, PO Box 8129, 6700 EV Wageningen, The Netherlands

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ABSTRACT

Wheat flour was separated into a gluten-enriched and a gluten-depleted (i.e. starch-rich) fraction within a conical shearing device. This paper describes the effect of the device geometry on the separation process. The gap distance between the two cones and the cone angle could be varied leading to a change in shear rate profile. The geometry influenced the aggregate formation and the following migration of the aggregates to the centre (of the cone).

This study confirms that the primary aggregation is mostly influenced by shear rate, while migration of the aggregates is influenced by shear stress. However, constraining the dough by the walls of the cones also influenced the inward migration of gluten. Gluten clusters were found in all cases, but their migration to the centre only starts when they become similar in size compared to the space between upper and lower cone. It is concluded that the separation mechanism consists of three steps, rather than two. The results indicate the importance of confining the dough in between the two cones. Obviously, restriction of the growth of the gluten aggregates is a prerequisite for gluten migration. It is therefore clear that not only the shear rate but also the exact configuration of the shearing device is important for separation. This insight may lead to significant optimisation of the process of separation by shearing.

The new insights were captured in a conceptual map with variables' shear rate, time and system geometry, which indicated in which regions only aggregation and in which regions only migration may be expected.

1. Introduction

Separation of agricultural products into their constituents is industrially and nutritionally important. The principles underlying separation processes are generally based on differences in density, particle size or solubility of the constituents. This is also the case in the current separation process for wheat flour into gluten and starch, as exemplified by the dough–batter washing process requiring large amounts of water and energy (Van der Borght et al., 2005).

Some years ago, a new separation mechanism for wheat flour was proposed, using a conical separation device (Peighambardoust et al., 2008; Van der Zalm et al., 2009b). The device consists of two cones of which one rotates. Dough is placed in between the cones, and undergoes simple shear deformation as a result. Separation is thought to be induced by differences in rheological behaviour of starch and gluten. The current hypothesis for the starch gluten separation during shear processing states that the separation consists of two steps. The first step is the aggregation of gluten into domains of mesoscopic scale upon continuous deformation. The stress onto the material limits the growth of aggregates, as too large stresses will cause the aggregates to break. In the second step, the gluten domains migrate to the apex of the cone, leading to a gluten-enriched fraction. A gluten-depleted fraction is observed in the outer regions of the shearing device. Here, the shear stress seems to play a positive role. The separation of wheat flour into starch and gluten is observed for a variety of flour types, salt concentrations and a broad range of process conditions (Van der Zalm et al., 2009a, 2009b; Van der Zalm et al., 2010). As far as the authors are aware of, no other industrial material is separated using the concept of shear-induced separation. However, on lab scale, migration of polymers in rotating cone-and-plate geometries was described in various studies (e.g. Agarwal et al., 1994) to be used as a novel separation and molecular weight fractionation technique. Dill (1979) explained the separation of large DNA molecules using force balance around an elongated DNA molecule. Due to the elastic nature of the DNA-molecule, shear forces will lead to a net inward force on the large DNA. The elastic properties of gluten might therefore be an important property in the shear-induced separation process described in this paper.

Until now, the influence of temperature, rotation rate and processing time was investigated, but the influence of shearing device geometry was not clarified yet. Previous devices were designed such

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* Corresponding author:Tel.: +31 317 480 852; fax: +31 317 482 237.
E-mail address: Atzejan.vanderGoot@wur.nl (A.J. van der Goot).

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that the shear rate was assumed to be equal over the height of the shearing device (Habeych et al., 2008; Manski et al., 2007; Peighambardoust et al., 2004). In that case, the gap distance of the shearing device at the centre of the cones should be exactly 0 mm. Nevertheless, the exact gap distance between the upper and lower cone in previous devices could not be measured. From previous experiments however, it is known that some material is present at the centre of the cone so the gap will not be exactly 0 mm. This will result in a non-uniform shear rate in the device. That explains why Peighambardoust et al. (2008) speculated that the resulting shear rate gradient could have an influence on the separation behaviour.

Therefore a new shearing device was developed to investigate the effect of gap distance at the centre of the cone and cone angles in more detail. Cones with different angles were used to create different spaces in between the cones, while a radial inhomogeneity in shear field was introduced by having a certain gap at the centre of the two cones. With this system the effects of shear rate and time, of which total deformation can be calculated, and system geometry on the separation mechanism were further elucidated. While the shearing device used gives the opportunity to verify and refine the hypothesis of separation that was formulated earlier. Moreover, it can be used to develop a first outline of a qualitative operating window, giving the combinations of geometry, shear rates and processing times that lead to good separation. Also the types of structures formed were investigated. The results may lead to further understanding of the separation principles.

This paper reports the influence of the exact geometry (overall gap space and increment of the gap from centre to rim of the device) on the principles and overall performance of the separation process and describes the new scientific insights resulting from the new experiments.

2. Materials and methods

2.1. Wheat flour

Separation experiments were performed with Soissons wheat flour (Meneba, Rotterdam, The Netherlands) from a single wheat cultivar. The flour used had a protein content of 11.2% (w/w) and a moisture content of 14.5% (w/w). Farinograph water absorption of the Soissons flour was 53.5% on 14% moisture basis (AACC-method 54-21). Water absorption of the flour is determined in combination with 2 w% NaCl (Merck, Germany) which is added on top of the sample. The dough formed had a stability time of 14 minutes, a peak time of 23.5 min and a tolerance index of 30 BU.

2.2. Shearing device

A new shearing device was developed in-house and used for all the experiments presented here. The shearing device, principally based upon the concept of a rheometer, applies a well-defined deformation to the material. The device used is an improved version of the devices made and described earlier (Manski et al., 2007; Peighambardoust et al., 2008; Peighambardoust et al., 2004). The device was developed to study the influence of simple shear deformation on breakage and structure development in a number of biopolymer systems (Van den Einde et al., 2004; Van der Goot et al., 2008). In this respect, it differs from current structuring devices like extruders and kneaders that apply a complex flow pattern, so multiple types of forces, to a material (Jongen et al., 2003). A schematic drawing of the shearing device is given in Fig. 1. The diameter of the upper cone is 0.13 m, the diameter of the lower cone 0.138 m and the hypotenuse of the lower cone 0.094 m. The upper cone is the static cone that can be replaced by a cone with another cone angle (0°, 2.5°, 5° and 7.5°). The bottom cone is the rotating one. The space between the cones is filled by the dough. This shearing device has modifications in the closing system. Even though cone–cone or cone–plate systems are usually designed to have the same shear rate everywhere in the system, this study shows the potential of an inhomogeneous shear field through the creation of a gap between the two cones. The gap between the cones can be adjusted and monitored during the process. The gap distance in the tip of the cone can be changed from 0, 1, 2 to 3 mm with the help of some spacers. The shearing device is connected to a Brabender Do-corder 330 unit (Brabender OHG, Duisburg, Germany).

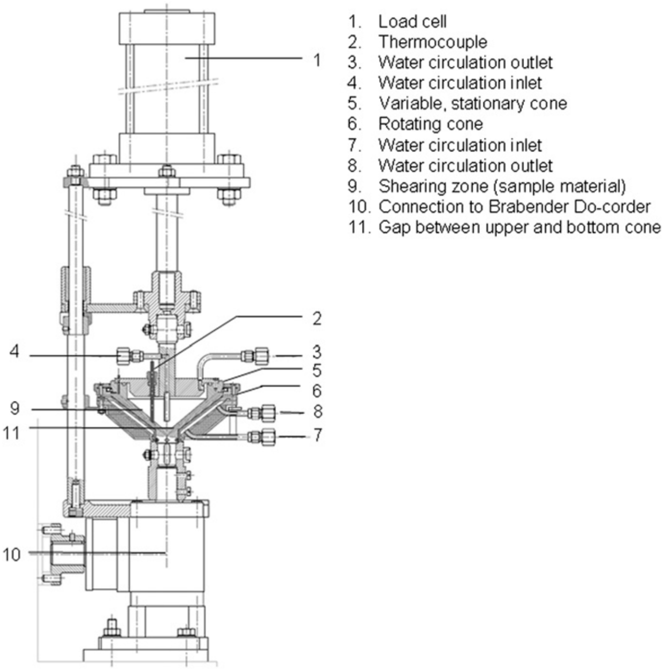

Fig. 1. Overview of the shearing device.

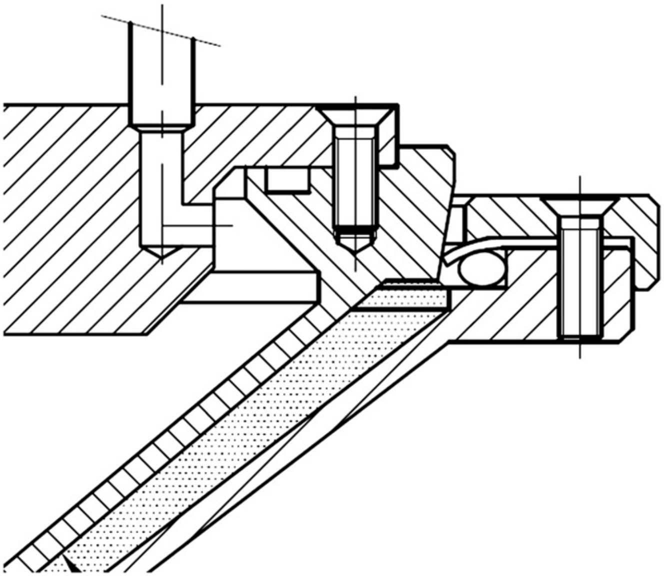

Fig. 2. Closure system for the shearing device.

In earlier experiments, the closure of the system during operation was found to be crucial. The closing system used here is an improved design compared to previous versions of our shearing devices. A flexible PTFE (Teflon) ring closed the space by pressing onto the lower cone. Fig. 2 describes the closing in more