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Numerical calculation of particle and air flow in a mixed flow grain dryer

Mixed flow dryers (MFD) are widely used in agriculture for the drying of various crops including maize and rice. As compared to other drying methods in the industrial drying, mixed flow dryers still have considerable potential for improving energy efficiency. The comparatively high primary energy consumption is mainly caused by uneven drying, which, in turn, is caused less by poor dryer control rather than by unfavorable dryer design. In order to optimize the processes in agricultural engineering, such as the mixed flow dryer, numerical methods are being increasingly used. Optimization of the dryer geometry provides a high potential to further increase the efficiency of MFD. In the following, the methods of Computational Fluid Dynamics (CFD) and the Discrete Element Method (DEM) are used to investigate the state of the art.

Keywords
Mixed-flow grain dryer, solids transport, air-flow, DEM, CFD

Abstract
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Mixed flow dryers (MFD) are used for the drying of different crops including maize and rice to make them storable for a long period. Although, convective heat is applied by horizontal arranged air ducts. The humidified air is dissipated from the dryer through staggered air ducts [1; 2; 3]. Convective drying of crops in mixed-flow grain dryers still has a potential to optimize the process, particularly the dryer apparatus. Design elements which are unfavorably constructed or arranged can cause broad residence time distributions as well as inhomogeneous drying. The result of inhomogeneous drying is over- and under-dried grain which causes high specific energy consumption as well as quality losses. To raise the product quality and reduce the energy consumption in future it is necessary to analyze particle mass flow and flow distribution of the drying air inside the dryer. The complexity of gas-solid-interaction (Concurrent-, Counter-, and Mixed-Flow) in the MFD requires the use of numerical methods.

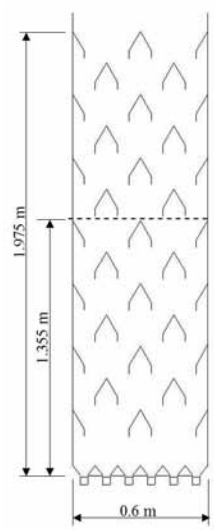
Numerical methods

The MFD which is analyzed consists of a vertical drying shaft, in which the inlet and outlet air ducts are horizontally arranged (**Figure 1**). The drying air flow is controlled by the staggered inlet and outlet air ducts. The humidified material is charged from the top of the dryer and flows vertically downwards by gravity. The discharge device on the bottom of the dryer regulates the product mass flow rate.

Discrete Element Method

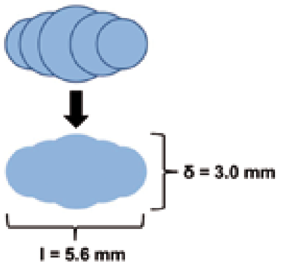
The discrete element method (DEM) describes the mechanical behaviour of the beds based on discrete structures (single particle). Compared to the finite elements or finite volume method the DEM works without any grid matrix. In the calculation the

Fig. 1



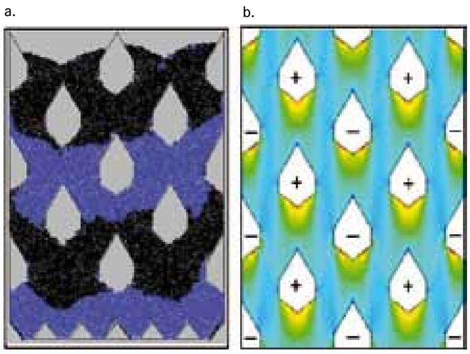
Schematic diagram of the investigated mixed-flow dryer

Fig. 2



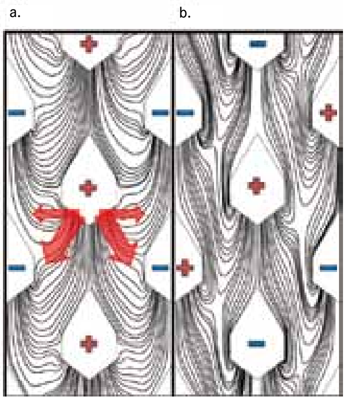
Model of a wheat grain

Fig. 3



Numerical investigation of a MFD with horizontal air duct arrangement
a.) solid mass flow with DEM b.) air flow with CFD

Fig. 4



CFD simulation of air flow in a MFD with
a.) horizontal and b.) diagonal air duct arrangement

flow behaviour of the bulk material is specified with Newton's law to the particles and a force-displacement law at the contacts between them. The mechanical behaviour of an assembly of particles is described by tracing the movement of individual particles. The DEM was introduced by Cundall [4] and then applied to soils by Cundall and Strack [5]. DEM computes the particle flow numerically by an explicit time integration scheme with suitable boundary and initial conditions. In this work a commercial software, called PFC 2D©, is used to simulate the solid mass flow in MFD on a discrete way. To describe the real behaviour of wheat particles, clumps formed out from spheres which are connected (**Figure 2**) were used. Every clump has an ellipsoidal shape and a length of 5.6 mm and a high of 3 mm. The mechanical properties of the clumps correspond to those of grain by Mühlbauer [6].

Computational Fluid dynamics

The common used method for CFD calculations is the Finite Volume Method (FVM). This method calculates the fluid flux properties of the investigated system by the conservation laws for mass, momentum and energy. The turbulence production and dissipation is described by the Reynolds Stress Tensor after the Reynolds Averaged Navier Stokes (RANS) theorem. To describe the turbulence, we used the two equation SST (Shear Stress Transport) Model after Menter [7]. To discretize the differential equations a grid matrix, called mesh, is created. After the mesh creation, boundary and initial conditions are defined for the borders of the control system and the conservation equations are approximated to the mesh by the Gaussian Integral Theorem.

By the calculation of the air flow in MFD, the bed is considered as a porous medium. Therefore the porosity is determined for bulk grain after the work from Matthies [8] and the specific pressure drop is determined by the Ergun equation.

The flow velocity at the entry of the inlet ducts was experimentally determined. The investigations were made for two typical air ducts arrangements of mixed flow dryers. The first configuration is called horizontal-, the second configuration diagonal configuration. In the first configuration rows of inlet and outlet air ducts are arranged sequentially in a horizontal way, in the second configuration the inlet and outlet air ducts are arranged sequentially in a diagonal way.

Results

Solid mass flow

The simulations of the solid mass flow in a mixed flow dryer (**Figure 1**) with particles like grain, show a velocity profile over the width of the dryer. The particle flow through the center of the dryer (center region) is faster than the particle flow at the side walls (wall region) (**Figure 3,** a.). The unequal distribution shows the influence of the wall friction and the half air ducts positioned directly at the side walls. Different particle velocities lead to different residence times in the dryer [9]. The consequence is an uneven residence time distribution of the particles and therefore an uneven moisture distribution which causes over- and under-drying of the grain.

Air flow

The investigations of the air flow for the horizontal configuration shows, that the inlet air from an inlet-air duct (+) will be distributed to the 4 surrounding outlet-air ducts (-) (**Figure 4,** a.), in which the air-stream to the lower outlet-air ducts is higher than to the upper one.

At the diagonal configuration of the air ducts it becomes apparent that the air-stream will be distributed in a non-equal way to the surrounding outlet-air ducts (-) (**Figure 4,** b.). That causes a configuration of low flow and high flow areas. Hence, the maximal air velocities during the diagonal configuration is higher, than in the horizontal configuration. The different residence times of the particles between center and wall region in the dryer (**Figure 3,** a.) result in a moisture distribution at the discharge device of the dryer. These effects were increased by the different flow velocities in the dryer (**Figure 3,** b.).

Conclusion

To avoid extra drying costs (energy demand) and economic losses by over-drying or formation of mold and toxins during storage, caused by under-drying, it is necessary to optimize the drying process in mixed flow dryers. The results obtained generate a basic concept for the development of a new dryer geometry which will allow the adaption of the air flow to the particle flow: In regions with lower particle velocity the air flow will be decreased and in regions with higher particle increased. An aimed comparison of the traditional with the new developed dryer geometry should demonstrate the advantages and disadvantages of both systems.

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