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Transformation of Funnel Flow Silos for Concentrates into Mass Flow Silos

Optimised Inserts with the Help of the Finite Element Method

To prevent spoilage in concentrate silos, a concept for outflow in a mass flow must be developed. In the original funnel flow silos mass flow was attained through subsequent cone in cone installation. To optimise the cone in cone system the Finite Element Method (FEM) was used. Results were tested in a large silo plant.

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Keywords

Concentrate silo, mass flow silo, cone in cone

Literature

Literature references can be called up under LT 05303 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm. .

When concentrates are stored in silos it is important to ensure that the first-in - first-out principle is observed strictly, i.e. in the mass flow, in order to avoid the formation of moulds and yeasts as well as toxins. The dwelling times in the individual product zones of the silo must therefore be approximately equal. Toxins are food poisons and not only endanger animal health, but also substantially influence the quality of milk and meat.

Mass flow silos generally require very slight angles of inclination between the hopper and the perpendicular. That is why mass flow silo structures are always expensive. For this reason many efforts have been and still are being made to produce mass flow in funnel flow silos with the aid of inserts. Investigations in a large-scale silo installation revealed that by optimally installing rigid coaxial inserts, i.e. cones with the tip pointing upwards, mass flow is achieved in funnel flow silos [1]. However, the relative sensitivity is a disadvantage for asymmetrical flows, for instance when the cones with the tip pointing upwards are not installed absolutely centrally, or when due to demixing the flow properties of the product are not distributed symmetrically about the silo axis during filling of the goods. The „cone in cone" concept also offers the possibility of producing mass flow in silos originally designed as funnel flow silos [2]. The geometry and arrangement of „cone in cone" installations in silo outlets can be optimised by applying the Finite Element Method (FEM). This is described below.

Theoretical examinations

Thanks to its simple structure of an ideal plastic material model with few material parameters, the basic version of the FEM program „Silo-Flow-Program-System" from Karlsson [3] and Klisinski [4] used for the calculations guarantees numerically stable simulations for the process of unloading a silo.

Silo Flow Programme System

The movement equations for the analyses are defined in the EULERís coordinates:

$$\rho \dot{u}_i + \rho u_j u_{i,j} = \sigma_{ji,j} + f_i \qquad (1)$$

with the velocity field u_i, the constant density ρ, the Cauchy tension tensor σ_{ij} and the load vector f_i. The material model of Mohr-Coulomb produces the ideal plastic flow condition in the main tension area:

$$F(\sigma_{ij}) = mp + g(\theta)q - C = 0 \qquad (2)$$

with the hydrostatic tension p , the norm q of the tension deviator, the constants for the inner friction m and the cohesion C. The angle θ defines the intersection level for the meridian function $g(\theta)$ in the p-q level. Minimising the material parameters meant that only linear p-q- functions existed.

Expansion of the material law

In order to take the compressible properties of the concentrate into account the original

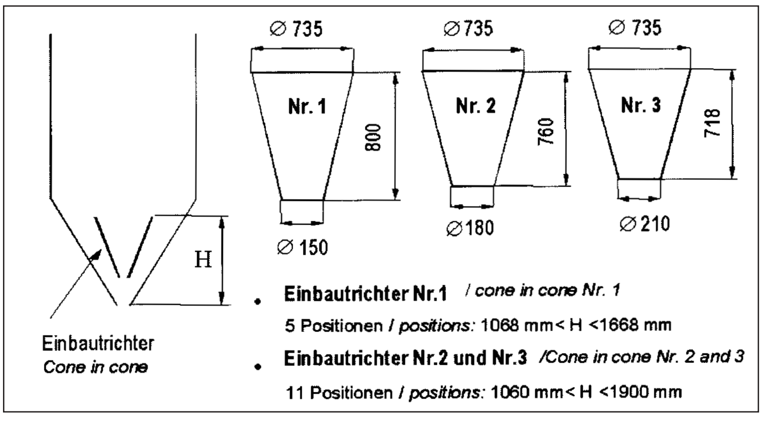

Fig. 1: Geometry of the examined cone in cone and position in the silo

material law is to be extended. Plastic material parameters were therefore calibrated on the basis of hydrostatic and conventional triaxial compression experiments for a material law with closed yield surface. This closed yield surface is made up of the flow condition in accordance with Drucker-Prager and a flow cap [5].

Comparison of the results obtained from numerical calculations and from experiments

The experimental examinations were conducted at the large silo installation [6] of the Institute of Agricultural Engineering Bornim (ATB). The experimental silo is 8 m high and has a diameter of 2.4 m. The hopper height is 1.86 m and the outlet diameter 250 mm. Owing to the hopper angle to the perpendicular of 30° and the corresponding wall friction angles for concentrates, without inserts the product flows out as funnel flow. In order to achieve mass flow, various „cone in cone“ with different geometries in accordance with the cone-in-cone concept were examined (*Fig. 1*).

Rotational symmetrical modelling was used for the idealised tension and expansion condition for the numerical simulation.

By analogy with the chronology of an experiment on the large silo installation, the work steps of an FEM simulation were also sub-divided into filling and subsequent emptying. The elastic parameters used for the FEM calculations are set out in detail in [5]. They were obtained in the material investigations.

Funnel flow silo without „cone in cone“

The calculations and the experiments conducted for the silo examined without the „cone in cone“ clearly show a funnel flow [5, 6].

Funnel flow silo with „cone in cone“

The vertical and horizontal velocities of the product over the silo cross section at emptying time 20 sec and 80 sec are shown in the upper part of *Figure 2*. The lower part shows the movement of particle tracers during the outflow.

By comparison with the silo without a „cone in cone“, the left and middle diagrams of the velocity profiles show suspension of the strong gradients in the vertical components due to the effects of the built-in hopper 2 in elevation positions H=1060 and 1380 mm. This indicates mass flow. The experimental dwelling times for H=1060 mm also show a slight funnel flow and for H=1380 mm mass flow. At an installation height of H=1900 mm funnel flow was observed again.

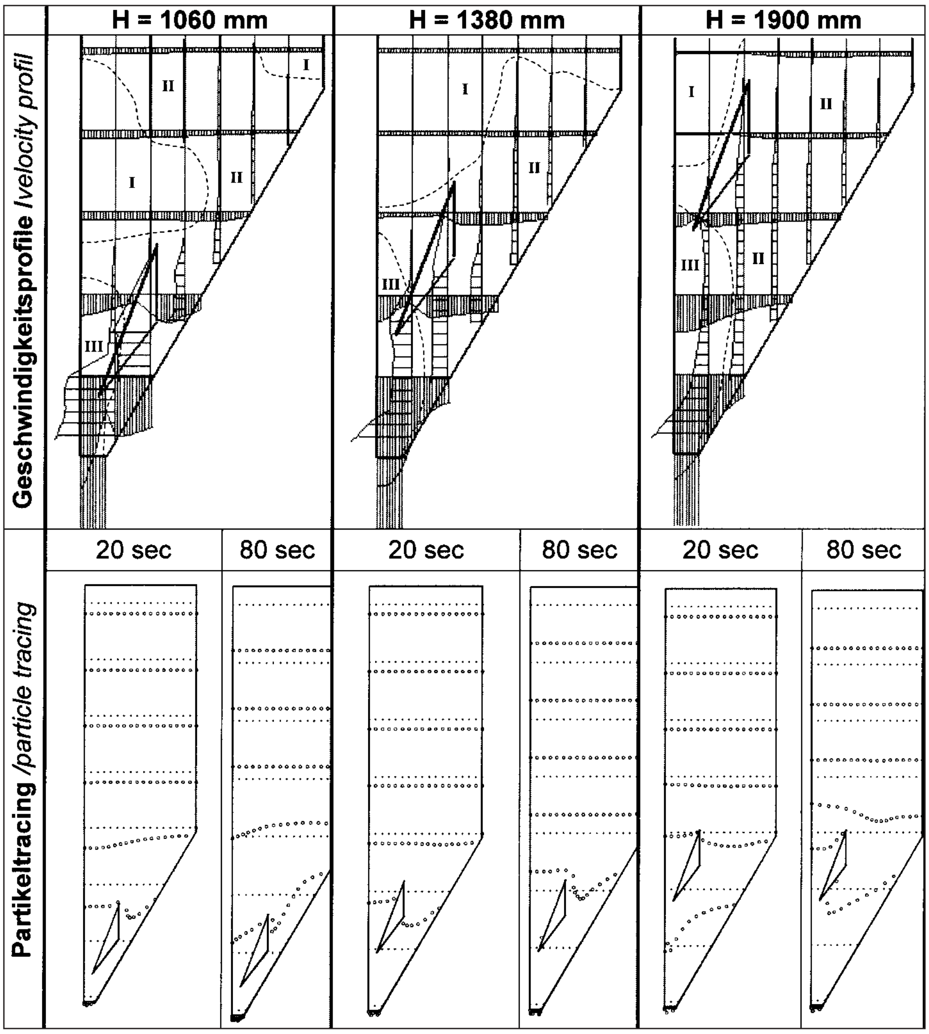

Fig. 2: Calculated velocity profiles and movement of particle tracer

With post-processing good quality advance calculations are possible showing that the reduced velocity gradients allow a statement on mass flow with substantially lower de-mixing tendencies. At elevation position H=1060 mm the slightly elevated vertical velocity components in the area of the lower installed hopper are also reflected in the FEM tracer movements. The particle tracers show a uniform lowering over the entire silo radius for the shaft area. With the transition to the silo hopper, the particles accelerate considerably more strongly in the area of the axis of symmetry and show a delay in the movement behaviour along the hopper wall (*Fig. 2, bottom part*). The FEM dwelling times calculated for H=1380 mm show the lowest gradients in the velocity field and in the dwelling times for the particle movements. The calculated dwelling times illustrate uniform movement behaviour of the particle tracers for the central and outer areas. The topmost elevation position H=1900 mm indicates that the arrangement of the „cone in cone“ is not optimal.

The experiments show mass flow for the elevation positions H=1110 mm to H=1550 mm of the silo. In the bottom elevation position H=1060 mm and for H=1630 mm to H=1900 mm the experiments reveal funnel flow.

Summary

A program was used for the calculations that in its initial version contains the constitutive equations of an ideal plastic material law. The compressible properties of this bulk product are taken into account with the implemented expansion of a new material law. The complete emptying of the silo is calculated in a fluid definition.

On the basis of hydrostatic and conventional triaxial compression experiments, plastic material parameters were calibrated for a material law with a closed flow surface. The results were checked in large silo experiments using dwelling time measurements from which it was possible to conclude at what hopper geometries and installation positions mass flow is achieved from the original funnel flow.

The comparison between experiment and numerical simulation shows good qualitative approximation of the FEM results in the assessment of the velocity distribution in the silo.