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Controlled emptying with whole-area dischargers

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While emptying complex bulk solids apparatuses and silos, the discharger at container bottom can significantly affect the energy demand of the process and the product quality. At practice, a variety of discharge devices has been developed which differ in the closing mechanism and the design of their fixed inserts. Experimental studies with wheat have shown that some whole-area dischargers cause a distinctive flow profile. Due to their design, these systems offer an unexploited potential to locally influence the bulk solids motion and to realize a controlled emptying. Based on a prototype, a new type of discharge device has been developed at the Leibniz Institute for Agricultural Engineering and Bioeconomy e.V. (ATB). First results show that fixed baffles at the walls lead to a decelerated emptying at the sides of the discharge device. On the other hand, a complete renunciation of these installations results in a significant acceleration in the same regions. In future, it is intended to locally control the bulk solids movement by using an optimized design of the fixed inserts of the closing mechanism. Furthermore, it is intended to investigate how the drying process in mixed-flow grain dryers can be influenced and homogenized by using the newly developed discharge device.

Keywords
Discharge of container, bulk material flow, discharge devices, flow problems, discharge system

The discharge of bulk material from silos and devices plays a critical role for maintaining the quality of harvested products. Upon storage, an uneven racking of bulk material may lead to mould formation in the container and hence to spoiling. In treatment processes like drying of agricultural bulk solids, unfavourably designed dischargers may cause distinctive velocity profiles while the bulk material is moving through the dryer column (Weigler et al. 2014). Consequently, the process conditions vary over the device width, and despite optimized device design and whole-area discharge, damage of essential ingredients may occur (Wassermann et al. 1980). Compared to conventional discharge devices below the drain hopper (e.g. rotary feeder, gate valve, slide valve), whole-area dischargers offer a number of options to discharge a container in a controlled manner.

Discharge devices are often discussed in association with their above discharge hoppers. Both systems are in direct relation and need to be adapted to the particular harvested product. A substantial share of the load can be absorbed via the discharge hopper and the shear stresses of the bulk material exerted on the container wall. On discharging of a silo, the terms mass flow and core flow characterize the flow profiles, which may occur due to too low or too high setting of the hopper pitch or an unfavourable dimensioning of the discharge width. Mass flow is characterized by the entire container content getting into motion without building any “dead legs” (Schulze 2014). In some preparation processes, however, it is not sufficient to just achieve mass flow. Here, particular requirements on a potentially even flow profile across the entire device width are made. This includes a potentially

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low variation of the dwell time of the bulk material during the process to ensure e.g. uniform drying times or cooling times for a homogeneous base product. Therefore, discharger hoppers are often foregone in such plants and it is tried to facilitate a whole-area discharge of the bulk material (Teodorov et al. 2011). The whole-area discharge of a container may be effected via rotating or transversal clearing devices or by direct racking using parallel bucket wheels, rotary beams or parallel located discharge hoppers with gate arrangement (Figure 1).

a)

b)

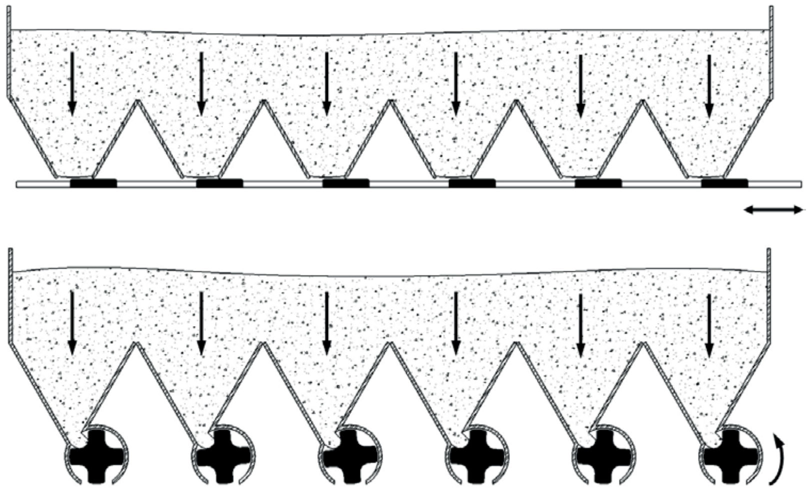

Figure 1: Dischargers for bins with rectangular cross-section and parallel placed hoppers that empty over the entire cross-section with gate arrangement: a) flat-slider b) bucket wheel

The bulk material shall thus be moved in direction of the discharge opening in a plug flow. Augers arranged in rows have particularly proved effective for discharge of cohesive bulk materials (Eberle 2013). The arrangement of several discharge hoppers across the entire container width is particularly suitable for lose material with good flow properties like wheat, rapeseed or corn in rectangular devices. Therefore, such discharge devices can often be found in mass flow dryers for grain. Research has demonstrated that a controlled discharge can be realized by arranging several smaller discharge hoppers. Moreover, it could be determined that both, the design of the hoppers as well as the operation of the gate has a substantial impact on the flow profile of the bulk material in the container above (Franke et al. 2015). Praxis shows, however, that whole-area dischargers still have potential for optimization, and that apparently extreme flow profiles, which neither relate to the classic core flow nor to the ideal mass flow, may occur in unfavourable constructive designs.

The challenge of whole-area discharge

Compared to the conventional silo hopper, outlets of whole-area dischargers are arranged in a number of rectangular opening slots across the container width. In order to avoid bridging and clogging, the slot widths are dimensioned considering the bridge accumulation tension (Stiess 1995). The tilt of all discharge hoppers can be adjusted for the wedged hopper respective to the limits for mass and core flow according to Jenicke (Bohnet 2004). Mass flow is prerequisite for setting an even flow profile in the container. Although such dischargers are sufficiently accurately designed to the flow properties of a bulk material, and all wear mechanisms realize an even release of the opening slots, an ideal plug flow of the bulk material motion cannot be established (Figure 2).

a)

b)

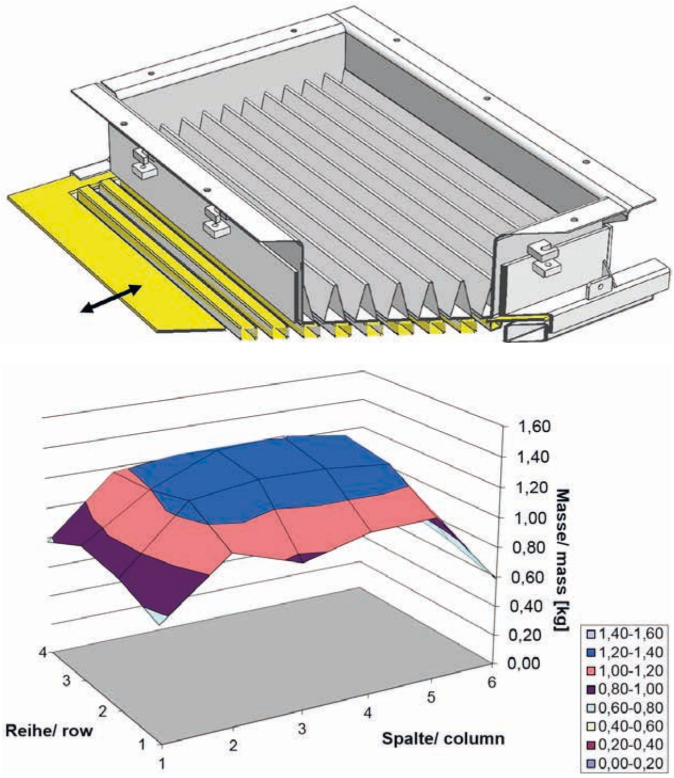

Figure 2: a) 3D - sectional view of a discharger (600x400 mm) with flat-slider
b) distribution of discharge mass over the cross-section, discharge time of 2 s

Manufacturers and plant operators are aware that a bulk material device or silo is normally not designed for different products. Any product has different requirements on container and discharger design and has specific flow properties. These may, moreover, change in the course of processing. Water is retrieved from a bulk material like e.g. wheat or corn in the course of the drying process. Thus, it tends to flow better towards the end of a drying process. In addition to that, bulk material near the container walls is exposed to other conditions than in the centre of the device. Due to friction effects, shear forces are transferred to the wall in such high ratio that the flow velocity is measurably slower there despite simultaneous release of all discharge hoppers. In rectangular containers this can particularly be noticed in the corners. This effect can be amplified additionally by mountings on the walls. These associations are currently investigated in more detail in experimental trials and numeric simulations and various solution approaches are followed up on, with which the mode of action of the discharge device can be adjusted locally to the flow velocity in the container.

Experimental investigations

Whole-area discharge devices use the most different closing mechanisms below their parallel arranged discharge hoppers. Besides the simple slider gate with elongated slots, roller and rotary gate valves as well as flaps, pendulums and tipping troughs are used to prevent uncontrolled discharge from the container (Franke et al. 2015). Each of these discharge principles has its benefits and drawbacks. Due to the multitude of options to adjust the discharge dimension, the tilts, the number of hoppers, and the selection of closing mechanism to the bulk material the different systems cannot be compared with each other directly without difficulties. The present investigation demonstrates the characteristic interaction between discharge and bulk material motion on the example of three different discharge systems. For this purpose, experimental investigations on discharge properties were carried out.

Simple slider gate discharge device

In simple slider gate or slot bottom discharge systems, the closing mechanism is operated via a pneumatic or hydraulic driven cylinder in horizontal direction. This principle allows for continuous as well as interval discharge by simultaneous release of all discharge widths. In a trial with wheat of 14 % w. b. (wet basis), the discharge mass was determined with a row and slot arrangement of sample containers below the discharge system (Figure 2, b). The gate speed was set on 2 seconds, since this way a constant mass flow could be established for a short moment (Teodorov et al. 2011). Conclusions on the velocity profiles within the container could be drawn from the mass distribution below the discharge device. The results of this trial showed that the flow velocity within the core zone of the container was substantially stronger expressed than at the margins. In the marginal areas, clearly less wheat was discharged at the same gate speed. All discharge hoppers are designed with respect to mass flow and use uniform tilts. Since the closing mechanism also ensures a simultaneous release of all opening slots, the extreme flow profile can only be contributed the impact of the container walls. Due to friction, the shear stress of the bulk material is transferred to the walls. This effect slows down the motion of the bulk material. A wall coating could minimize the friction. This, however, cannot be translated into practice with respect to economical efficiency of grain drying. Therefore, solution approaches were followed, which allow an adjustment of operation and design of the discharge device to the flow properties.

Double slider gate discharger

By varying the tilt of parallel arranged discharge hoppers, the discharge velocities at the margins and in the centre of the container can be impacted in a targeted manner. In order to prevent higher flow velocities in the centre of the container, special implements similar to the cone in a silo hopper can be utilized. In addition to that, the local control of closing mechanisms may facilitate a preferred discharge from the margin or the centre of the containers (Wehry et al. 2005). The work group drying technology of the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) followed up on these approaches to build a prototype of a “double slider gate discharge system” (Figure 3). This system features two separately mounted closing mechanisms (slider bottoms), with which the margin (green) and core (red) zone of the discharge tub could be released independently. This way, the gate speed for each zone can be set individually. The discharge tub features a total of 56 uniformly dimensioned discharge hoppers (30 in the core zone, 26 in the margin zone), which technically allow for the separation of both zones. The hopper flanks were tilted longitudinal to the discharge tub at $\theta_1 = 25°$ and transversely at $\theta_2 = 15°$. Each discharge hopper thus features an opening surface of 0.0013 m^2.

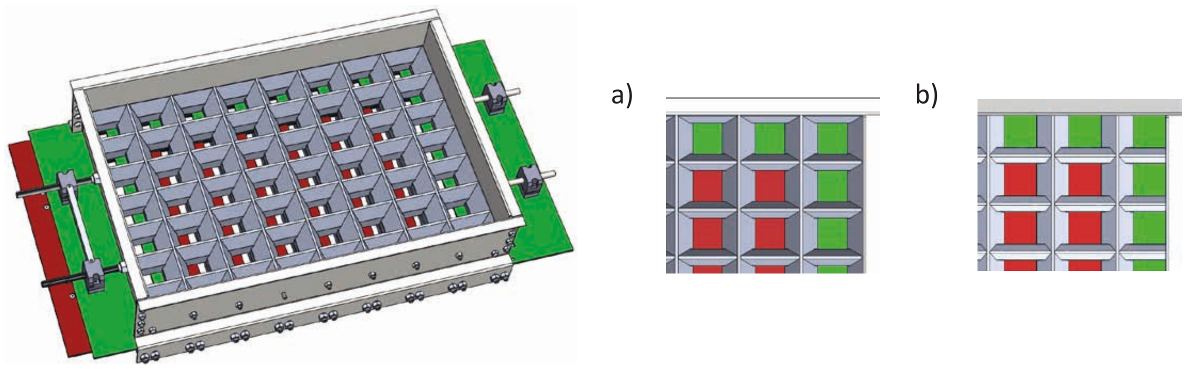

Figure 3: Prototype of a double flat-slider discharge device
a) with baffles on the walls b) vertical side walls (without baffles)

Before the local impact of different gate speeds on the flow profile was investigated, the relation between arrangement of the hoppers and the bulk material motion had to be understood. Therefore, two variants of the prototype were investigated to just understand the impact of the constructive design. Variant 1 matches the above mentioned uniform distribution of all discharge hoppers with the respective tilt of the hopper flanks (Figure 3, a). In variant 2, the guide vanes at the margin of the discharge tub were left away (Figure 3, b). This means, the discharge hoppers of the margin zones feature vertical outer flanks. These variants were chosen to accelerate the flow motion in near-wall areas of the bulk material device. Due to the constructive change, the opening area of all discharge hoppers increased to 0.0016 m^2 each. In a first trial with wheat, only the discharge tub (600 × 400 × 150 mm) was filled evenly with material. Both discharge slider gates were moved synchronously. Due to uniform gate speeds (1.5 seconds, 1 stroke) of all discharge hoppers, a representative flow profile for both variants was established, which clearly characterizes the impact of the guide vanes at the margin. Similar to the discharge properties of the already discussed single slider gate discharge device, a bigger mass discharge in the core zone of the discharge tub was observed for variant 1 (Figure 4, b). In the margin zone, however, the discharge hoppers were still filled with wheat by the end of the trial. Compared to that, variant 2 of the double slider gate system showed a completely different flow profile. With an expressed bulk material cone, the core zone differed clearly from the marginal zone (Figure 4, b), which contained only small stock in the discharge hopper towards the end of the discharge trial. The result of this experiment demonstrated that the braking effect of the friction forces in connection with the guide vanes at the side walls cause a slowing of the bulk material motion in the margin zone. Foregoing these guide vanes causes an uncontrollable fast emptying of the margin zones. This makes clear that such implements are an indispensable part of the discharge design. Therefore, it is the goal of further investigation to impact the bulk material motion in margin and core zone by variations of the respective gate speeds.

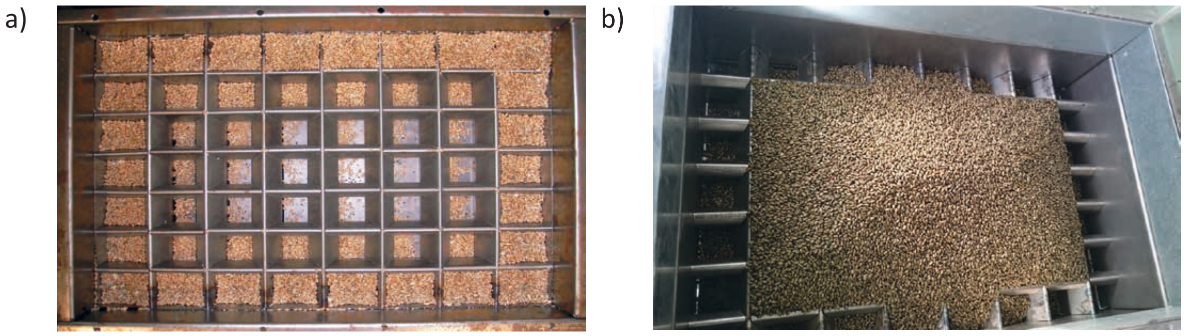

Figure 4: Investigation of a double flat-slider discharge device
a) with baffles at the walls, b) without baffles at the walls

Discharge device with dosing chambers

An alternative to the conventional slot bottom discharge is the slider gate system with dosing chambers (Figure 5). Here, the discharge mass flow is determined by the chamber volume and the number of strokes in both directions. With each stroke, the chambers filled with bulk material empty below the roof-like implements. At the same time, the chambers that are still empty during the first step are filled. In comparison to the conventional slot bottom discharge with discharge control via gate speed of the slider gate, an even bulk material racking from all discharge hoppers is enabled utilizing this volumetric dosing system. Besides other methods, the use of tracer particles is helpful for the quantitative investigation of the bulk material flow in a silo or container. For this, wheat was tinted with red food colour and applied as an even horizontal layer on the non-tinted goods. With each discharge stroke of the pneumatic cylinder, the tinted layer moved further towards the discharge hopper. After a few strokes only, a flow profile determined by the wall friction in margin and core zone began to arise.

Options for controlling the bulk material motion locally in this arrangement can only be realized by varying the tilt and the dimension of single chambers. Should single discharge hoppers be released, separately controlled pendulums and flaps or rotary gate valves and rotating drum systems are suitable alternatives with regard to technical feasibility.

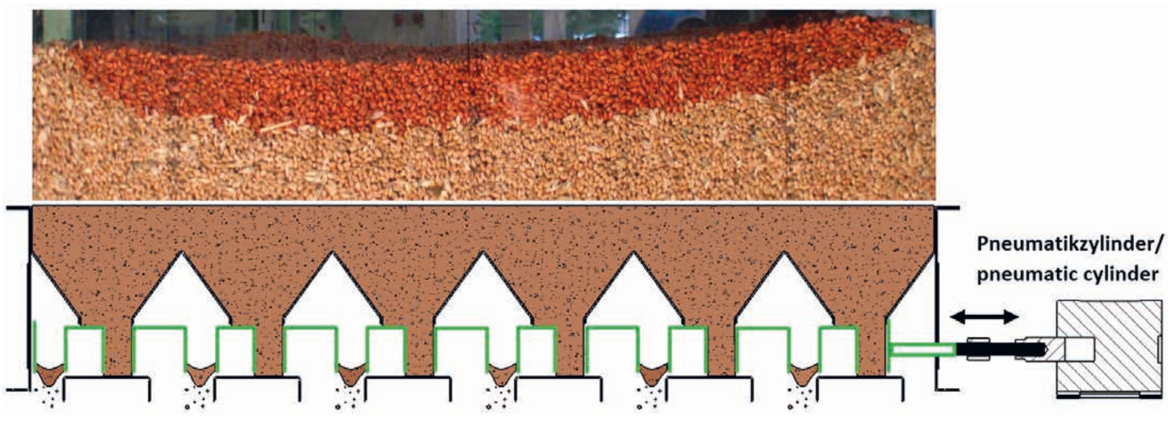

Figure 5: Flow-profile of a red pigmented wheat layer after some discharges (Photo: G. Franke) above a discharge device with metering chambers (Type NDT, co. Neuero)

Conclusions

Harvested products are stored in different silos and containers and are potentially processed in very complex devices. In order to empty simple storage containers it is often sufficient, to get the entire container content into motion to completely empty it. In some processes such as drying of agricultural bulk material, however, potentially even motion of bulk material is particularly required to generate uniform dwell times and identical drying conditions across the entire device width. Besides the device design, the operated discharge device at the bottom of the containment has a significant impact on the bulk material motion. Using experimental investigations about bulk material motion associations between operation mode and design of whole-area discharge devices and the discharge properties were investigated. Whole-area discharge devices with single slider gates control the mass flow during the gate speed at simultaneous release of all discharge hoppers. The interaction between bulk material motion and wall friction causes a slowing of the flow velocity in the near-wall areas. A decrease of tilts at the margin might compensate this effect. Completely foregoing the here used guide vanes, however, caused uncontrollable emptying of the margin zone when testing a prototype with a double slider gate system, which makes these implements indispensable. Rotating drums, rotary gate valves, or slider gates with dosing chambers are used as closing mechanisms for better control of the discharge volume. Although the volumetric dosing enables a uniform bulk material racking here as well, the simultaneous discharge cannot prevent from forming of flow profiles in the upper device. A new type of discharge devices for storage containers and mass flow dryers is currently tested at the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB). Future investigations will identify to which extent an uneven drying process in the upper dryer column can be compensated with locally adapted discharge. In this way, production quality as well as energy efficiency of the process shall be improved.

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