COMPUTER-AIDED SILO DESIGN

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1. INTRODUCTION

In the ceramic manufacturing process, most of the raw materials used are found as particulate solids (bulk powder consumption in the Spanish ceramic tile sector is assessed at 40,000 t/year). The behaviour of such materials is so complex and poorly understood that problems very often occur in handling. These include segregation, breaks in material discharge from the silos owing to arching, dead zones in the silos, uncontrolled solids discharges, silo failure, etc., which can adversely affect the manufacturing process. These problems can be minimised when bulk powder discharge is appropriate, the discharge opening is suitably sized, and pressure distribution of the stored material on the silo wall is known [1].

The discharge flow of a particulate solid can be of two types: funnel or mass flow (Figure 1). Funnel flow consists of the formation of a flow channel aligned with the silo discharge opening, surrounded by a region in which the material initially remains static (Figure 1a). In contrast, in mass flow (Figure 1b) all the material moves simultaneously during discharge; in particular, the material next to the walls slides down the walls and is evacuated with the rest. Table 1 compares the two types of flow. For a given material and silo, the kind of flow that occurs will depend on the angle formed by the silo wall with the vertical [θ] in the discharge zone.

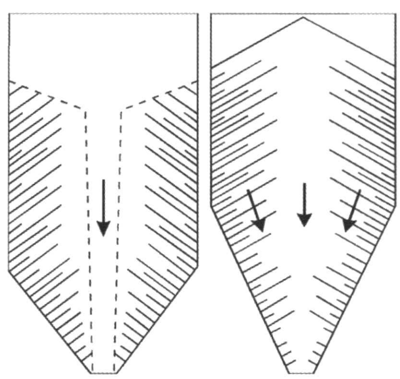

Figure 1. Funnel (a) and mass (b) discharge flows

FUNNEL FLOW	MASS FLOW
- Lower height is required for the same capacity. - Walls need to withstand lower pressures. - Less wall abrasion.	- Suppresses possible obstructions to flow. - Minimises effects relating to size segregation. - Renewal of material (there are no dead zones). - Flow is uniform and readily controllable. - Discharged powder bed density is practically constant. - The entire storage capacity is used (there are no dead zones).

Table 1. Comparison of funnel and mass flow. Respective advantages.

Silo discharge opening size (D) needs to be sufficiently large in order not to become blocked during discharge. This phenomenon can be caused by arching, if the powder is cohesive, or pluggage as a result of the formation of structures, if particles are sufficiently large.

The material stored in a silo exerts normal pressure on the silo wall, which differs depending on the height of the material in the silo, and whose value peaks during discharge. Knowing pressure distribution on the silo wall when pressures peak enables calculating the minimum required wall thickness to avoid failure, optimising the quantity of material needed to build the silo and reducing silo cost. Owing to the variation of bulk powder density with pressure, to correctly estimate peak pressure distribution on the silo wall it is necessary to know the compaction diagram of the particulate solid. Moreover, this behaviour needs to be taken into account in calculating actual silo capacity.

2. METHODOLOGY

We have used the Jenike theory to calculate the maximum angle of mass flow (θ) and minimum silo discharge opening diameter (D) to avoid arching during discharge, also taking into account the possibility of obstruction of the discharge opening owing to the accumulation of particulate solids in this region and the compaction that the material undergoes on impact during silo filling [1], [2], [3], [4].

The pressure distribution on the silo wall during evacuation has been calculated in accordance with Spanish Experimental Standard UNE-ENV 1991-4 of March 1998, which has also enabled estimating the real maximum capacity of the silo.

3. RESULTS

Figure 2 shows a block diagram of the software developed. The software enables calculating the above design parameters for silos of five different geometries (cylindrical, square, rectangular, chisel and transition). To use the software it is necessary to know the angle of internal friction of the particulate solid (δ), the angle of friction of the material with the silo wall (ϕ), the flow function of the particulate material (MFF) and its compaction diagram (ρ= f (P)). The rheological parameters of the particulate material and of the system silo-particulate material (δ, MFF and ϕ) are experimentally determined in the laboratory by shear cells [5], [6], [7].

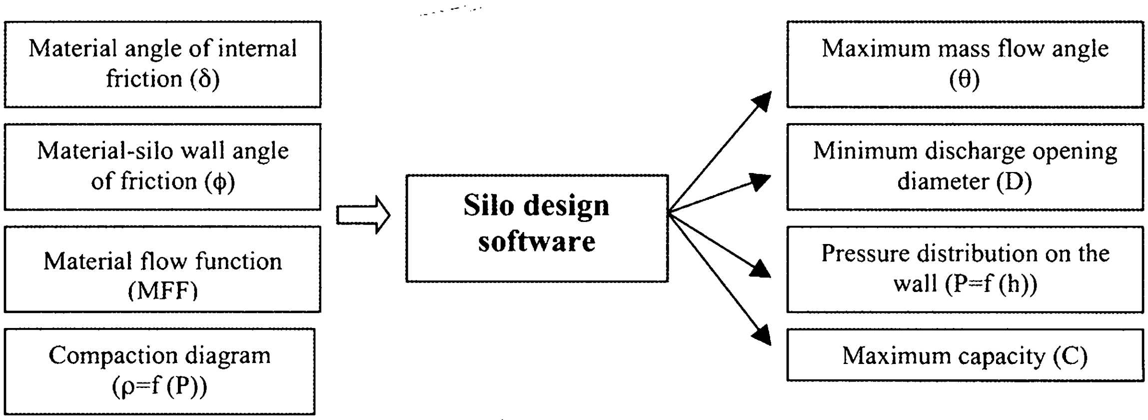

Figure 2. Flow diagram of the software developed

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