Sugar storage in silos

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Abstract There are large differences in the usual storage of white sugar from beet and cane. Beet white sugar is usually stored in silos. Cane white sugar is commonly filled in bags and stored in warehouses. Sugar quality is much better using silo storage instead of warehouses in terms of fluidity and aspects of hygiene as well as food production. Silo-handled sugar can either be filled in the usual packaging machines or be filled and transported in road tankers – the latter is very economical especially for industrial use. In contrast to the storage in warehouses, sugar storage in silos has to fulfill some important parameters. This paper highlights particular items such as primary screening, temperature and moisture, silo filling procedure, sugar conditioning, dedusting and discharge. The aim of this paper is to provide recommendations for the cane sugar industry to improve their sugar quality by using silos for storing white sugar.

Key words Sugar storage, silos, warehouse, white sugar

INTRODUCTION

Cane sugar factories, beet sugar factories and refineries usually need to store the sugar before sending it to customers. Depending on the packing facilities, the environmental situation and the quality of the produced sugar, different solutions can be applied. Analyzing the local situation is a must in order to find an economical solution. Sugar quality and grain size, temperature and humidity, packaging capacity, customer requests, sugar conditioning and required storage capacity have to be considered.

This paper is to provide recommendations for the cane sugar industry to improve their sugar quality by using silos for storing white sugar.

MAIN REQUIREMENTS FOR SUCCESSFUL SUGAR STORAGE – SUGAR CONDITIONING

To keep white sugar in ‘good flow behaviour’ it is absolutely necessary to condition the sugar before or directly during storage. The intercrystalline bound moisture has to be removed, but the flow behaviour of the sugar also depends on the temperature and humidity of the environment (Tables 1 and 2). This is important for regions with high temperatures and high humidity. It is also recommended to keep the whole route from production to storage and the storage itself in an air-conditioned atmosphere.

Table 1. Flowability of refined sugar at 45% RH.

<table>
<thead>
<tr>
<th>Solidification stress $\sigma$ [Pa]</th>
<th>Flowability ffc without resting time</th>
<th>Flowability ffc after resting time of 24 h at 25°C</th>
<th>Flowability after resting time of 24 h at 40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>8966</td>
<td>'free flowing'</td>
<td>7.3 'easy flowing'</td>
<td>0.2 'not flowing'</td>
</tr>
</tbody>
</table>

Table 2. Flowability of refined sugar at 40°C.

<table>
<thead>
<tr>
<th>Solidification stress $\sigma$ [Pa]</th>
<th>Flowability ffc without resting time</th>
<th>Flowability ffc after resting time of 24 h at 35% RH</th>
<th>Flowability after resting time of 24 h at 45% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>8966</td>
<td>'free flowing'</td>
<td>8.3 'easy flowing'</td>
<td>0.2 'not flowing'</td>
</tr>
</tbody>
</table>
Flowability (ffc) is defined as the ratio of solidification stress $\sigma_1$ to bulk yield strength $\sigma_c$ (Fig. 1). The larger the ffc, the better the bulk sugar flows. The bulk yield strength $\sigma_c$ typically increases with increasing solidification stress $\sigma_1$, as shown by curve A. Figure 1 shows the boundaries of the ranges of the classifications listed as straight lines. The ratio ffc and thus the flowability of a specific bulk solid changes with solidification stress $\sigma_1$.

**Fig. 1.** Flowability profiles for refined sugar (Schwedes and Schulze Schüttguttechnik 2010). ffc<1 not flowing; 1<ffc<2 very cohesive (to non-flowing); 2<ffc<4 cohesive.

The method of measuring $\sigma_c$ and $\sigma_1$ for a defined bulk solid is shown in Figure 2, which shows a hollow cylinder with frictionless walls, filled with a fine-grained, cohesive bulk solid. First the bulk solid is consolidated by the solidification stress $\sigma_1$. Subsequently, the hollow cylinder is removed and the cylindrical bulk solid specimen is loaded with an increasing vertical compressive stress until the specimen breaks (fails). The stress causing failure is called compressive strength or bulk yield strength $\sigma_c$.

**Fig. 2.** Measurement of bulk yield strength $\sigma_c$ and solidification stress $\sigma_1$ (Schulze 2009).

Another prerequisite for a good conditioning result is the grain size distribution of the sugar to be stored. When crystals $>2$ mm and $<0.15$ mm are removed by sieving before storage, positive results will be achieved. Additionally, the moisture of the sugar should not be higher than 0.04 % after drying. These boundary conditions are solid ground for successful conditioning and, hence, undisturbed discharge of sugar (trouble-free emptying of the silo). Our own experiences regarding crystal sizes and moisture contents are confirmed by Rogè and Mathlouthi (2008) and by Chitprasert *et al.* (2006).

**DEDUSTING IS EXPLOSION PROTECTION**

The worst case accident in a silo is a sugar dust explosion. An important duty for a silo designer and a silo operator is to avoid situations where dust explosions can arise. Dust explosions may occur when the following conditions are met:

- Inflammable dust of sufficient fineness;
- Sufficient oxygen in the air;
• Concentration of dust in the air within the explosion limits;
• Effective ignition source with a minimum ignition energy of 30 mJ.

Only if all of these requirements are present, will an explosion happen.

By avoiding dust formation one can avoid the risk of an explosion. There are two main dust prone areas in a silo:

1. The dust in maintenance areas around the conveyors and elevators.
2. The dedusting systems, including the conveyors and the conditioning system with separate piping system and filters (see Fig. 3).

Item 1 can be solved with a consistent cleaning schedule.

Item 2 can be solved with a well-designed dedusting system combined with a consistent automation system that stops the conveying when the dedusting systems are not working. The dimensioning of the piping system is crucial. The speed of the dust-laden air should be around 18 m/s to avoid dust deposits in the pipes. The dedusting of the conveyors can only work if sufficient air is drawn in at the hoods placed around conveyor heads and transition chutes.

The danger source ‘dust concentration’ depends on several items. The fine dust proportion is very important for the danger classification. In experiments some samples containing particles of 20 µm size exploded with a concentration of 60 g/m³. If the dust is laying on horizontal surfaces like cable trays or beams, the risk is reduced. However, if it falls down because of vibrations, the situation will become dangerous. The accepted limit in the sugar industry for the lower explosion limit is 30 g/m³. A further influencing factor for the classification is the temperature of the ignition source. With rising temperature the risk rises.

OVERVIEW OF STORAGE SYSTEMS

Warehouse storage

Warehouse storage usually has the lowest investment costs for storing sugar. A well-working packaging station is necessary with a capacity always higher than the production line.
Normally there are no air-conditioning systems inside the warehouse and often the storage is not airtight so the air conditions are the same outside and inside the warehouse. The result is often caking of the sugar inside the bags. The best way to prevent caking is first sieving to remove large and small crystals, then conditioning of the sugar for example in smaller conditioning silos. In the end, the temperature has to be kept at a maximum 30°C and the humidity at 65% RH (maximum).

Silos – storage silo – conditioning silo

The aim for storage silos is to stay flexible with regard to the sugar market. Normally it is not necessary to have a mass-flow silo (first-in first-out) as a storage silo. The discharge system can be kept very simple, for example mainly by gravity flow and just for final emptying with a discharge screw. Storage silos can be built for very high capacity with low investment regarding the cost per tonne. It is more economical to build a big storage silo than a small one as the costs per tonne for smaller silos increase in a non-linear fashion. A conditioning system can be installed. However, as the system does not work on a first-in first-out principle, sugar which stays less than 3 days in the silo does not get the full conditioning time. Storage silos are the preferred solutions for beet sugar factories to stay independent of the crop season. Storage silos are also the preferred solution for factories and refineries working with more than one silo or with additional conditioning silos.

Figure 4 shows a typical bottom floor of a storage silo with a conditioning possibility. The underground channel with the discharge funnels is shown in the East-West axis. The air-conditioning aeration channels are shown in North-South direction. The residual discharge screw is shown at a 45° angle.

The discharge of a storage silo is done mostly by gravity from the central discharge funnel. As soon as the sugar flow from the central funnel has finished, the auxiliary funnels left and right are opened until the whole area over the discharge channel is sugar free. The remaining sugar (around 15%) is discharged by using the revolving residual discharge screw, which pulls the sugar to the center.

The aim for conditioning silos is to keep the sugar for 3 days under the conditioning mode in order to remove the bound moisture of the sugar. This can be done by using several silos in rotation (merry go round), but this is a very expensive solution. It can also be done by mass-flow silo with a first-in first-out principle. For mass-flow silos, the configuration of the discharge is important (see Fig. 5).
For secure mass flow, the discharge hopper needs a very steep angle. Therefore, more height is essential. Otherwise, several hoppers are required. With several hoppers, the aim of mass flow can only be reached when all hoppers have the same discharge rate. For each hopper, dosing elements with low discharge rate are required. If one element does not work, the mass flow changes into funnel flow. This means the conditioning times cannot be reached.

On first view, a mass-flow silo seems to be the best solution. However, the system is susceptible to disturbances.

In general, it is possible to build a mass-flow silo also for storage, but there are several disadvantages that also hold true for bigger conditioning silos. Sugar is a difficult mass with regard to its flow behavior. Not only caking, but also hardening due to compaction, has effects on the flow behavior. Experiments with refined sugar show a relation between environment temperature and humidity and the flow behavior of the sugar. The span moves from free flowing (23°C, 28% RH) to not flowing (40°C, 45% RH, time = 24 h) (see Tables 1 and 2). Different conditions inside of the silo, for example due to different humidity of sugar, can change the mass flow into funnel flow (Fig. 5). This risk increases with the diameter of the silo (Meadows 1993).

**Fig. 5.** Mass flow and funnel flow in silos.

**Fig. 6.** Conditioning silos during erection in 2010 (4000 t, supplier ACMB) with multi-cone bottom for mass flow at a Nigerian refinery.
The investment and operation costs for a multiple hopper system are higher than the costs for a storage silo. Conditioning silos need a full cellar under the multiple hoppers as well as a large amount of belt conveyors and discharge screws (Fig. 6). Storage silos can be operated with a single point gravity discharge for 85% of the content. The discharge principle is described previously. Figure 7 shows the single residual discharge screw that revolves around the central funnel.

![Residual discharge screw for a 80,000 t storage silo](image)

**Fig. 7.** Residual discharge screw for a 80,000 t storage silo (Silo design by IPRO 2013) with a central discharge channel.

An alternative method to prevent hardening and caking in conditioning silos is to keep the sugar in flow. This method can be recommended in environments with high temperature and humidity.

### Shape of silo and material

Concrete or steel? Investors always ask this question. In quality and operation, both materials are of equal functionality.

For steel silos, the prevention of corrosion is important. In cold climates silos should be provided with wall insulation and wall heating. The heating can be either electrical or hot water or hot air based. If the minimum outside temperatures are higher than 20°C, wall heating can be dispensed with. The aim is always to avoid condensation resulting out of temperature differences causing steel corrosion or sugar adhesion on the inside wall. The insulation designer has to consider the sugar temperature during filling with around 35°C. In warm and humid climates the main danger of corrosion is by the moisture in the air.

Steel silos have the advantage to have a very smooth surface of the inside wall which is favorable for sugar moving inside the silo. In the case of ground settlements the steel shell, however, is susceptible to movements and piling is often recommended.

Concrete silos (Fig. 8) have better wall insulation and are more robust against ground settlement. The wall surface is rougher and crack size has to be limited to maintain the internal coating. The price difference depends very much on the prices for steel and on the availability of the materials and of companies competent to build silos. The building time for concrete silos is normally shorter than for steel silos. During recent years, concrete silos have been less expensive.
Dome silo or cylindrical silo?

The decision on the shape of the silo (Fig. 9) depends on the space available, the capacity required, and on the silo type and on the company's philosophy about the discharge system. Dome silos are fully reinforced concrete silos with a dome-shaped roof. Some have a short cylindrical wall to increase the volume. Normally, the wall is not pre-stressed. Cracks in the wall are typical, just as a very rough surface. Compared with the cylindrical silo, there are no facilities provided to inspect and maintain the wall surface. This work can only be done in dome silos by lifting platforms, which have to be brought in from outside. The dome silo type can be a good solution for silos on large areas with low total heights, if crackless surface coating is not an important aim. The number and size of discharge elements depends on the diameter. The main advantage of dome silos is a large space for sugar storage, where the sugar can be stored also against the wall until the angle of repose of the sugar (35°-38°) is reached.

Fig. 9. Different shapes of storage silos.
Cylindrical silos are based on the opposite idea: small base and a higher cylindrical wall. The wall shell is made of pre-stressed concrete, built with slip forms. Typically, the roof has a cone shape parallel to the angle of repose. Due to the pre-stressing, the cracks can be limited to a size not affecting the coating. Discharge type also depends on the diameter.

For wall inspection and maintenance in cylindrical silos a travelling platform can be employed - this hangs on a peripheral rail placed below the silo roof (see Fig. 10).

**Fig. 10.** Cylindrical silo inspection platform.

**SUMMARY**

An improvement of the sugar quality brings economic advantages for sugar sales. By preserving the free flow of sugar, bulk sugar can be transported at lower cost by silo trucks and clients’ smaller storage silos can be filled pneumatically from the truck. Hence, advantages for sugar handling are obvious.

In contrast to sugar handling in bags, a notable improvement in hygiene and foodstuff safety can be achieved.

The storage of conditioned sugar allows the sugar factory to serve even the most fastidious client on the basis of safety and high quality.

**REFERENCES**


Stockage du sucre dans des silos

Résumé. De grandes différences existent entre le stockage habituel de sucre blanc de betterave et celui de canne. Le sucre blanc de betterave est habituellement stocké dans des silos ; le sucre blanc de canne est généralement empaqueté dans des sacs et stocké dans des entrepôts. La qualité du sucre est meilleure quand il est stocké dans un silo plutôt que dans un entrepôt, en termes de fluidité et d’hygiène, ainsi que pour la production alimentaire. Le sucre en silo peut soit être empaqueté par les machines habituelles ou être chargé et transporté dans des véhicules-citernes – ce dernier système est très économique surtout pour les usages industriels. Par contraste avec le stockage dans des entrepôts, le stockage du sucre dans les silos doit satisfaire certains paramètres importants. Cet article met en évidence des éléments particuliers tels que le tamisage primaire, la température et l’humidité, le processus pour le remplissage du silo, le conditionnement du sucre, le dépoussiérage et la décharge. Le but du document est de fournir des recommandations pour l’industrie du sucre de canne afin d’améliorer la qualité du sucre à l’aide de silos pour le stockage de sucre blanc.

Mots-clés: Sucre blanc, entrepôts, silos, stockage du sucre

Almacenamiento de azúcar en silos

Resumen. Hay muchas diferencias entre el almacenamiento normal de azúcar refinada de remolacha y el de caña. El azúcar refinada de remolacha es almacenada normalmente en silos. El azúcar refinada de caña es comunmente empacada en sacos y guardada en bodegas. La calidad del azúcar es mucho mejor si se usa almacenamiento en silos en vez de bodegas en términos de fluididad y aspectos de higiene así como en produccion de alimentos. El manejo del azúcar en silos puede tanto usarse para llenar las maquinas empacadoras usuales o puede llenarse y transportarse en trailers por carretera – esto ultimo resulta muy economico especialmente para uso industrial. Al contrario del almacenamiento en bodegas, el almacenamiento del azúcar en silos debe de cumplir con algunos parametors importantes. Este trabajo enfatiza temas particulares como el cribado primario, temperatura y humedad, procedimiento de llenado del silo, acondicionamiento del azúcar, desempolvado y descarga. El objetivo de este trabajo es proveer recomendaciones para la industria cañera para mejorar la calidad de su azúcar usando silos para el almacenamiento de azúcar refinada.

Palabras clave: Almacenamiento de azúcar, silos, bodega, azúcar refinado