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The right approach how to design the conditioning system of a sugar silo*

Gestaltung der Konditionierung eines Zuckersilos

In the light of the constantly growing requirements regarding efficiency, work safety and increasing capacities the design of silos and its conditioning systems demands for customer-specific and experience-based approach. After production fresh sugar has a residual water content which can lead to agglomerations during storage. This affects the product quality, discharge and transport from the silo and endangers staff who has to remove cakings manually. Therefore it is necessary to prepare and distribute the air constantly at optimal conditions.

Time of conditioning, air quantity and humidity are the parameters to be determined simultaneously based on the type of silo, residual water content of stored sugar, size of sugar crystals, product feed-in rate and environmental conditions [1]. In the design the amount of water to be removed, air distribution in the sugar bed and temperature are considered. Depending on weather conditions the supplied air is mixed with fresh, dried, cooled or heated air to meet the needed conditions and to enable an energy-efficient operation of the plant.

Key words: sugar, water content, conditioning system, silo

1 Introduction

The ideal design of a conditioning system of a sugar silo can avoid far-reaching consequences like increased crust formation on silo walls, color formation of sugar, microbiological activities, decreased appearance and flowability of the sugar [2]. In these days sugar silos are designed for up to 80,000 t and the roadmap how to design the conditioning system is always a customised approach.

The main target is to ensure the product quality of the sugar for the ongoing process, a smooth transport and work safety. Ensuring the product quality includes the warranty of long shelf life. The sugar shall be conditioned for 48 to 72 h in order to make it storable [3]. At a good and clever design of silo conditioning system, an evenly distribution of feed-in sugar and conditioned air inside the silo must be ensured and the sugar must be kept moving, continuously flowing and discharged from the silo (Fig. 1).


Schlagwörter: Zucker, Wassergehalt, Konditionierung, Silo

1). In the conditioning process the right treatment of the air, low air velocities, the air distribution within the silo are important to
achieve a free-flow ability and the specified residual humidity of the sugar. In order to protect the silo against damages it is necessary to control the pressure and to equip the silo with a mechanic vacuum breaker system additionally. For the operators the focus is also be on low installation times and operating costs. A general misbelief is that conditioning is simply water removal but sugar conditioning is usually associated with a case-by-case/situation-related reduction in water content. Therefore it is explained which points need to be considered and which assumptions are the basics for the right design of the conditioning system because it is nothing that you one purchase off-the-shelf.

2 Initial situation

The residual water content of sugar can cause blockages and cakings which affects the product quality, discharge and transport from the silo. Another important reason for conditioning is to avoid the necessity of entering a non-emptied silo and herewith dangers for the staff. The silo should be completely emptied without external assistance [4]. The pictures in Figure 2 show, how staff enters a silo and is subjected to dangers through self-loosened blockings.

In the preheating phase the silo is heated up to approx. 30 °C for 2 to 3 days by conditioned air. The supplied air should already be conditioned. Thus the target values of relative humidity, for example, which are used in the conditioning process, are to be achieved. During filling phase the silo air has a temperature of approx. 25–30 °C and a relative humidity of approx. 30%. The regulation of the circulating air volume takes place by adjusting the fan speed. At increasing filling height the fan speed must be increased depending on the pressure loss of the sugar layer until the required quantity of supply air is achieved. During filling phase and up to 72 h after filling process, the air is conditioned appropriately. Hereby the risk of the so-called moisture spots in the sugar is reduced. The dew point is not exceeded and the conditioning process is advanced to the required residual water content of the sugar. After the conditioning process, the water content of the sugar crystals should remain stable [4]. The length of conditioning depends on the following aspects:

- Size of sugar crystals
- Water content of sugar crystals
- The relative humidity, temperature and air flow [2]
- Filling quantity
- Filling time

The phase of post-conditioning starts, when the sugar has already dried and no additional sugar is filled into the silo. After filling and conditioning, the silo should be regularly ventilated. When ventilating, attention should be paid to the relative humidity in the silo. In order to minimize the risk of static discharges, the relative humidity should not be too low. The air quantity can be reduced by up to 50–60%. To maintain the flavor of sugar at least 10% of circulated air is replaced by fresh air independent of any weather condition. At appropriate weather conditions up to 100% of fresh air can be supplied to operate energy-efficiently. Beside the air conditioning (Fig. 3), the air distribution is an important aspect of good conditioning. Low air velocities and large outlet surfaces improve the air distribution in the sugar and avoid moisture spots, in which the sugar is not conditioned adequately [4].

Fig. 2: Principle sketch for entering a silo (left) and equipment with silo retraction pants (right) [5]

Fig. 3: Air treatment and distribution [4]
4 Design criteria and parameters

The basic design criteria and parameters are the sugar quality, sugar crystal size, feed-in rate, type of silo as well as environmental conditions like temperature. Based on calculation, experience and worst case assumptions the target values of product quality, relative humidity, temperature and air distribution have to be determined. Figure 4 shows the main parameters which have to be considered.

4.1 Product quality

When calculating the necessary air volume for the conditioning system, the individual particle size and residual water content of sugar must be taken into account. Larger crystals need more time of conditioning than smaller sizes. If the cooling and drying process do not work properly, it is useful to make worst case assumptions. Stored sugar shall usually have a residual water content of approx. 0.030 to 0.035%, but the system will be designed for a higher value based on experience in order to ensure a reliable functionality of conditioning system in any case.

4.2 Feed-in rate

The feed-in rate is highly dependent on the production capacities and can vary greatly. The feed-in rate as well as the water content of sugar are relevant for determining the required air quantity in order to achieve an average water content of usually 0.02%. Figure 5 shows how the air quantity to be determined is related to the existing feed-in rate.

4.3 Type of silo

There are different types of silos used which are shown in Figure 6. Each type of silo has its particular characteristics regarding storage conditions of sugar which have to be considered case-by-case. A circular floor area avoids product deposits and poorly ventilated areas due to non-existent corners or edges. The circle corresponds to the natural foot shape of freely applied bulk goods and enables clear static conditions for feeding and storage. The cylindrical or spherical shell construction provides best requirements to apply the pressure, resulting from filling material, uniformly to the building structure [4]. Another aspect includes the type of insulation, heating system as well as the discharge options which have a great influence on the resulting air conditions and design of floor duct system. The type of silo determines its lengths and numbers to be installed as well as the needed amount of air. For example, the “dome” construction with its larger floor area requires more meters of floor ducts and a correspondingly designed filtration system due to large air volumes.
4.4 Relative humidity

With decreasing relative humidity (e.g. by increasing storage temperature), the product is “post-drying” involving a blocking risk. An increasing relative humidity (e.g. by cooling during transport to the customer) can lead to water penetration. Therefore it is necessary to prepare and distribute the air constantly at optimal conditions from drying to discharge to keep the stored sugar free-flowing [4].

Figure 7 shows a typical drying curve. It has been found that the first 24 to 48 h of storage are decisive because the water in sugar crystals and residual surface water content are readily available for removal. The exact period depends on parameters relating to sugar crystal size, air conditions and flow rates [1].

![Typical drying curve](image)

Modern silos are ventilated with conditioned air of 20–30 °C and have a low relative humidity. In the case of continuous ventilation and avoided condensation, the sugar is in equilibrium with a water content of up to 0.05%, so that no caking occurs [2].

Figure 8 shows how the relative humidity affects the product quality. The optimal percentage ranges from 30% to 40% at the silo head. A relative humidity of more than 50% will lead to reduced flowability, caking and ultimately to discharge and loading problems. Cooler fresh air is supplied into the silo. The excess water released by sugar crystals should be continuously removed while overdrying must be avoided at the same time.

![Relative humidity/product quality ratio](image)

For dehumidification absorption dryers or conditioning units are used. Absorption dryers are equipped with a rotor with drying agents/desiccants which absorb the water from process air. They are only energetically worthwhile when a cooling medium already exists. Otherwise conditioning units are useful because they operate with only one process and with lower wear costs compared to absorption dryers. Though the cooling process cause higher energy costs.

If the air humidity drops to less than 20%, humidifiers like steam humidifiers or distribution systems for existing pressurised steam are applied. Steam humidifiers evacuate water by heating that requires large amounts of energy. In contrast, the distribution systems for existing pressurised steam are much more easy to install, require low maintenance and energy costs.

4.5 Temperature

Undesired condensation in the wall area is created through temperature falling below dew point. Thereby the wall construction and arrangement of floor ducts play an essential role and must be designed according to environmental conditions. The silo wall separates the product from the environment and protects against contamination and water. Under temperature gradients between inside and outside caking of the sugar crystals and adhesion at the silo wall can occur. In Central Europe, there is a significant temperature difference between the product with >35 °C and the environment of the silo with <35 °C. The silo wall ensures a temperature exchange, so that the water, contained in the product, moves towards the wall and condenses. To prevent this procedure the silo wall is heated and provided with insulating elements to meet the temperature requirements [4].

Alternatively or in addition, these temperature gradients between inside and outside can be avoided through a special arrangement of floor ducts. At greater temperature differential additional floor ducts will blow more conditioned air into the outer silo area in order to avoid condensation and enable an evenly distribution of the warm or cool air inside the silo. Depending on the ambient temperature the silo conditioning system has to supply the corresponding amount of fresh air. At cold ambient temperature more fresh air is needed, at warm ambient temperature less fresh air is supplied.

4.6 Air distribution and velocity

The most important elements for an even air distribution are the floor ducts. Riedel Filtertechnik has developed unique floor ducts that consist of an extruded aluminium profile, covered by a construction of two perforated plates with a filter membrane inbetween. They withstand high loads and are quick and easy to install.

The question of how to arrange the floor ducts in the respective silo arises in each project because all influencing factors need to be taken into account. Different arrangement like the Christmas tree, parallel path or circle system have to be carefully considered regarding ways of discharge, silo construc-
tion, installation and operating costs. Figure 9 shows three different ways of arranging the floor ducts in the silo bottom. For planning of floor duct system it is reasonable to consider the existing and potential behaviour of airflow. By means of numerical calculation on the air distribution in the entire silo, Riedel is able to analyze, evaluate and visualize this behavior. During duct design the following numerical flow simulation was carried out using a silo with a diameter of 50 m, a height of 45 m, a volume flow of 12,000 m³ and a process temperature of 30 °C. As shown in Figure 10 the arrangement was a circular duct system at the outer wall of silo and with straight ducts in the center. Figure 10 visualize the results of the investigation by means of velocity. In addition, vector arrows represent the flow direction. Figure 10 shows the air velocities at a scale of 0.003 to 0.005 m/s. A homogeneous air distribution is achieved after 6 m in the outer area and after 3 m in the center. Depending on its know-how and the results of numerical flow simulation Riedel is able to design the floor duct system optimally for each customer.

References

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