Sugar Storage in Silos: A Slow Conditioning Approach

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Introduction

For decades bulk sugar conditioning and storage in silos has been one of the most widely discussed issues in the literature. Large variation in types of silos, sugar quality, climatic conditions of sugar plants or storage facilities and other factors has allowed sugar technologists to accumulate significant experience in sugar storage and conditioning. It is well-known that product sugar after dryers and granulators still contains enough bound moisture that will be slowly released in storage. Failure to remove the excess moisture may cause the following problems in storage and handling:

1. Reduced flowability and caking, leading to non-uniform discharge and loading problems. Sometimes useful volume of a silo is reduced significantly.

2. Color formation during storage.

3. Crust formation on silo walls reducing effective volume of a silo.

4. Bacteriological problems.

5. Safety related problems when cleaning is performed

All these problems are interrelated, with excess moisture being the common root. Thus moisture control in storage and transit of sugar remains the main issue of discussion between sugar technologists. Sugar conditioning is generally believed to be the best remedy for improving sugar flowability and quality.

Some facilities have one conditioning silo and several storage silos. Freshly produced sugar is loaded into a conditioning silo and then transferred to one of the available storage silos. This approach certainly improves sugar quality but still has several drawbacks. Conditioning silos are usually designed for certain retention time, therefore fluctuations in product quality significantly affect the rate of water removal. Most conditioning silos are designed for retention time of 24-72 hours. Conditioned sugar reloaded into a storage facility is still subjected to moisture migration and possible hardening.

Simple experiments confirmed that even “matured” sugar has enough moisture to cause hardening problems. Dehumidified air was blown through a bed of sugar which had been previously stored for several months, temperature and RH of exiting air have been recorded. After exiting air reached 0% RH at 20°C the tank was sealed. Following measurement after 24 hours showed RH of 65% at 20°C.
Though sugar conditioning systems work very efficiently in many sugar plants worldwide, installation of new systems or retrofitting of old silos is impaired by high capital investment.

Different sources report significant capital investment of 2-4 million US dollars required to convert existing storage silos into conditioning mode. Therefore, there is a need for an economical solution which will combine benefits of sugar conditioning with the opportunity to retrofit most of the existing storage facilities. Increasing concerns of sugar quality and safety are driving forces in searching for new economical solutions of sugar storage and conditioning.

**What would be considered an ideal conditioning system?**

The requirements for ideal sugar conditioning and storage system may be summarized as follows:

1. All produced sugar is maintained at ideal storage conditions at 20-25°C and RH=55-60%.
2. Excess moisture released by sugar crystals should be continuously removed. At the same time over drying must be avoided.
3. Air should be distributed evenly to avoid moisture migration within the bed of sugar.
4. Periodic sugar movement to prevent intercrystalline bridging.
5. Reduce risk of dust explosion.
6. Reduce or eliminate temperature gradients leading to crust formation on silo walls.
7. Economical feasibility.

Existing conditioning silos usually satisfy most of the criteria. Economical feasibility is still a rather weak point especially for retrofitting existing storage facilities.

**Factors affecting storage and conditioning**

Time of conditioning, air quality and quantity are not independent parameters and should be determined simultaneously based on the type of silo, amount of moisture to be removed and air distribution in the sugar bed. Retention time in conditioning silos is typically limited by production and shipment balance thus imposing certain requirements on a silo design.

Required air parameters are usually calculated as for a mass exchanger based on some assumptions about heat and mass transfer in sugar. Calculations also vary depending on the project goal (new silo or retrofitting an old silo). This may be the reason for large variation in data available.
in the literature for specific air flowrates. Reviews list a number of sugar conditioning silos in Europe with air flowrate varying 0.02 to 86 m³/hr per metric ton of sugar. J. Bruijn et al. indicate that the typical value accepted for many commercial installations fluctuates around 3 m³/hr/ton. Calculations should be carried out on a case-to-case basis.

Understanding of the mechanism of mass transfer is extremely important to correctly calculate the air parameters required for conditioning. It is important to realize that the drying process is driven by the difference between the air partial vapor pressure and equilibrium vapor pressure corresponding to sugar moisture. Therefore the assumption that the difference between RH of air and ERH of sugar is the driving force is valid only if temperatures of sugar and surrounding air are equal.

Kinetics of moisture release may significantly affect the calculation of required air flowrates. The effects of conditioning temperature, grain size and other parameters on the conditioning process have thoroughly studied. Results show that, in fact, very little air is required for conditioning. Reduction of air flowrate does affect the initial rate of water removal but has almost no effect after 48 hours. The authors also indicate that higher than required flowrates are generally applied to maintain even air distribution across the silo. These are very important conclusions which helped justify our approach to sugar conditioning.

A typical drying curve is shown in Figure 1. The first “fast” period reflects the drying when water is readily available for removal. Thus air parameters and flowrate will determine the rate of water removal. Most of the remaining surface moisture may be removed during this period. Various sources indicate that conditioning air humidity and temperature have an effect on sugar moisture only during the first 24-48 hours. These numbers will vary depending on relative flowrates and parameters associated with the sugar and conditioning air.

FIGURE 1
TYPICAL DRYING CURVE
In the second period, drying kinetics will be determined by crystallization and internal diffusion through the amorphous layer of sucrose (an excellent review of the conditioning mechanism is given by D. M. Meadows). At this time air ventilation may be helpful to stabilize sugar but excess air will lead to over drying. Air temperature, humidity or flowrate will have very little or no effect on moisture removal.

Today excellent commercial conditioning systems are available from different manufacturers. High cost is usually a payment for high quality. One should realize that significant number of silos in the USA and other countries are not designed for conditioning. Retrofitting is sometimes difficult or impossible to justify economically. Addition of double walls for heat compensation reduces useful volume of a silo and creates structural problems. Changing distributors, adding air circulation systems and redirecting the flow of sugar are complicated and expensive procedures.

It is worthwhile to discuss how insulation or heat compensation of a conditioning silo affects the operation parameters. Heat compensation (or heating of silo walls) creates a uniform temperature profile across the silo. On the other hand because of the high cost this option, it may be only feasible for the installations. Our evaluations show that just the insulation of a relatively small 40 ft. diameter silo may cost several hundred thousand dollars. It is worth mentioning that the presence of insulation will only change the temperature gradient across the silo wall but cannot be considered as an ultimate solution. Specialists from BC Sugar have indicated that in the absence of insulation, moisture migration to the walls cannot be eliminated but it will no longer cause problems provided the air parameters are correct6. This raises the question whether insulation of the silos is a necessary measure in retrofitting applications.

It is well-known from the literature that beet sugar quality can be achieved at temperatures about 20-25°C and relative humidity of the surrounding air at 55-60%13. These conditions correspond to dry mature sugar with an average moisture of 0.025%. It would be extremely difficult to maintain these conditions in the conditioning silos because of the fluctuations in product moisture and rates of water elimination. Maintaining the RH of air in the head space of a silo between 55-60% has a positive effect on agglomeration of dust particles and accumulation of static charge. Overdrying of the head space which may occur when moisture is not readily released by sugar leads to increased dust and a potential risk of explosion. Some silos are equipped with misters for moisture control in the head space.

The ‘slow’ conditioning approach

The concept of “slow” sugar conditioning was introduced and analyzed by a group of specialists from Amalgamated Research Inc. and Amalgamated Sugar Company for retrofitting an existing cluster of concrete silos. The main idea was to initially condition all produced sugar and then maintain good storage conditions with continuous ventilation. Thus conditioning in the traditional meaning of the term will be applied to all stored sugar. The principle flow diagram of a system with one silo is shown in Figure 2. Air conditioning is achieved by using a simple refrigeration unit. No desiccants are required. Air temperature may be varied to maintain constant RH in the head space of the silos. The system can be easily modified for a cluster of silos by adding the booster blower under each silo. One head space ventilation fan may be used for several silos.
Part of conditioned air is introduced to the head space of all silos maintaining constant relative humidity around 55%, thus minimizing the risk of explosion. Several conditions should be satisfied simultaneously for explosion to occur: minimum ignition energy, dust concentration within explosive range and ignition source. By stabilizing air RH in the head space of a silo at the safe level dust agglomeration and lower static charge can be achieved. The above author also reported that dust moisture content has significant effect on strength of explosion.

The proposed system uses relatively low air flowrate (through sugar) of about 0.5 m³/hr per metric ton of sugar. This quantity of air will be sufficient to remove available moisture without overdrying the sugar. Low air flowrates will not adversely affect air distribution across the silo since a fractal distribution principle will be applied for positioning of the air outlets (fractal distributors have been successfully applied for industrial chromatography columns in molasses desugarization). The main features of fractals - invariance to scaling and hydraulic equivalence of all outlets - can be effectively applied for air distribution. The construction of the distributors provides for equal pressure drop in each channel. Good distribution can be accomplished without high pressure drop within a distributor. Therefore the booster blowers should only provide enough head pressure to overcome friction within the bed of sugar.
Benefits of the new system

- All produced sugar is conditioned, conditioning time is equal to storage time.
- Economically feasible to convert existing storage facilities into conditioning units.
- Stable operation of conditioning system practically independent of fluctuations in product moisture, sugar grain size and CV.
- RH control in the head space reduces risk of explosion.
- Even air distribution across the silos is accomplished using fractal principle.
- Crust formation on the walls is minimized improving safety in operation and cleaning.
- Optimal storage conditions guarantee high sugar quality and flowability.
- Final product moisture is no longer limited by the retention time in a conditioning silo.

Additional comments

The first phase of the project was implemented in the Nampa factory (The Amalgamated Sugar Company). Air was circulated through the head space of all silos. The sugar warehouse reported improved sugar flowability. Absolute humidity in the head space of the silos was significantly reduced to the optimal level. The fractal air distributors will be installed as silos become available for cleaning.

Lack of heat compensation in silo walls should be considered a disadvantage of the proposed approach. It is certainly beneficial to complement the 'slow' conditioning approach with wall heating. Testing will show if moisture elimination will be sufficient to minimize buildup of sugar on silo walls.

Periodic sugar movement may be recommended to prevent sugar crystals from bridging. Frequency and quantities of sugar to move should be determined experimentally.

References


