SUGAR STORING IN WEIBULL SILOS

Bertil Akermark
Arlov Refinery
Swedish Sugar Co. Ltd., Malmo, Sweden

ABSTRACT

A history of the development of raw sugar and granulated sugar storage in the Swedish sugar industry from the nineteen twenties to the present days is discussed in this paper. Quality demands on sugar for bulk storage and demands on store design to achieve a satisfactory result in long term storage are also explained.

The following factors which have influenced SSA's choice of store system are dealt with: space requirement, mobility, handling costs, temperature and humidity control.

Silo set ups for export and import of cane raw sugar and for storage of granulated sugar are described.

INTRODUCTION

The Swedish beet sugar industry at the beginning of the thirties consisted of about 20 small beet sugar factories which were situated either in the countryside or in the small towns often close to a small harbor town. During the campaign they produced raw sugar which during the rest of the year was shipped to 5 small refineries, all being situated near fairly large harbors and many in the heart of consumer areas.

Bulk handling of beet raw sugar begun during the twenties. Bulk warehouses were often converted and reinforced sack warehouses. The first ground level warehouses for bulk handling were built in 1918 and 1919 for 16,000 and 24,000 tons. Back in 1933, the first steel silo for bulk handling was built. The designer of this was civil engineer Nils Weibull. By 1946, such silos had been built, 3 of which were situated in dispatch harbors and 3 on the site of refineries at receiver harbors.
One silo was situated at a refinery for receiving bulksugar transported by road. The largest was 16,000 tons. We had that time built up a complete transport system so that a proportion of the raw sugar from the beet factories was stored in their own bulk stores and a proportion was carried direct to the silos at the dispatch harbor. For transport to two of the refineries, which were situated in the production areas, the sugar was carried in tank trucks or railway tankers to the receiving warehouse. The sugar was carried in bulk to the other refineries in the company's own ships and off-loaded to the silos on arrival.

In 1957 — after the international break-through of bulk handling of cane raw sugar — we built a 10,000 ton silo for cane raw sugar at Malmo harbor for the Arlov refinery.

The structure of the Swedish sugar industry was rationalized in the middle of the fifties and remained today in mainland Sweden maintaining the same total production as before, from beet sugar factories producing white sugar and one producing raw sugar. Of the five refineries only one remains. Several of what were raw sugar silos have been moved and enlarged and a few have also been converted to white sugar silos.

At the time of the rationalization, the remaining factories, with one exception were converted to the production of white sugar. Some concrete silos were built after those first developed in the USA, Great Western Sugar 1930, but very soon the construction of the raw sugar silos was adapted for granulated sugar. The first of these two 20,000 ton granulated sugar silos was built in 1956 and since then some new granulated sugar silos have been built and some have been converted from raw sugar silos. The largest we have today is a 30,000 ton silo, which was completed in 1961, and which is a conversion of a 10,000 ton raw sugar silo from 1933. Very recently we have equipped the early concrete silos for granulated sugar with the same discharging system as in the modern round steel-plate silos.

This short history shows that Sweden has played a pioneering role in bulk handling not only of raw sugar from beet and cane but also granulated sugar. Assuming up of where we stand today and a description of what we see as the well-developed system that we have at our disposal and which I believe can be of use to companies who are planning new buildings or who only now are beginning to consider complete bulk handling as a result of rising handling costs or for other reasons.

THE DEMANDS FOR SUGAR QUALITY FOR BULK STORAGE

Successful storage of raw sugar puts certain demands on the quality of the sugar. Certain demands are also placed on the design of the storage space and the poorer the quality of the sugar the more important it is that these demands should be fulfilled.

The demands for quality which should be placed on raw sugar have been
summarized as follows (Mead Chen4):

The sugar will not deteriorate in storage if it:

1) Is comparatively free from insoluble matter.
2) Has a hard, uniform and fair-sized grain free from conglomerates.
3) Has a moisture content in relation to polarization which conforms with certain "safety factors."
4) Is an "unwashed" sugar — which is to say that the crystals are surrounded by their original film of molasses.
5) Was manufactured under sanitary conditions keeping contamination by fungi, yeasts and bacteria to a minimum.

The safety factor has, as we know, been expressed in many different ways and defines the measure of the relationship between non-sugar and water. A moist pure sugar is more difficult to store than a moist impure sugar.

DEMANDS ON STORE DESIGN FOR BULK STORAGE

The demands for good initial storage should be as follows:

The storage set-up should be designed in such a way that the sugar when stored will take on the temperature of its environment. This is best achieved by insuring that the flow of sugar into the store is fine and well spread rather than dense.

Moisture migration must be avoided. This is achieved by spreading the sugar thoroughly and by insulating the walls of the store. An uninsulated roof can also give increased condensation and dropping moisture, so the insulation and ventilation must be thoroughly done.

The relative humidity of the air in the store as well as the air temperature should be kept under control.

Many studies of the atmospheric conditions best for storage have been made and the consensus is that relative humidities (HR) of 60 to 70% are critical.

Cooling of raw sugar before storage and temperature and relative humidity controls of the air of the store are therefore desirable for the storage of raw sugar but in many climates difficult to carry out for practical and economic reasons. In many cases the problems arising with more simplified storage systems are not so
great that it would be economically viable to adopt other more precise methods which more or less exactly follow the theoretical recommendations.

Crumbling is not uncommon in bulk stored raw sugar. In contrast to the plain scrolls used in the case of white sugar silos, the scrolls in a raw sugar silo are therefore larger and have the edges serrated in order to break up any light crust which might form on the sugar from time to time.

The measures which are desirable but not necessary in a raw sugar store are an absolute must in a granulated sugar store where a rise in moisture of a few hundredths of a per cent makes the sugar sticky and damp and where drying out of the sugar can result in enormous lumps as hard as concrete.

SPECIAL REQUIREMENTS FOR STORAGE OF GRANULATED SUGAR IN SILOS

For the sugar to remain in good condition during long storage periods it must be well dried and cooled and be kept at a constant temperature. The air in the silo must be controlled. This applies both to raw sugar and white sugar. It is a deciding factor in the storage of white sugar.

For this reason and also to avoid discoloration white sugar must be cooled down to the maximum of 30°C before storing. The white sugar must be dried to an apparent (free) moisture of about 0.03%.

Sugar which has been stored under these conditions does not change even during long periods of storage, provided that its temperature and moisture are kept constant. As long as the vapor pressure of the moisture in the sugar is at equilibrium with that of the surrounding air, the moisture content of the sugar will remain constant. Refined sugar with a moisture content of 0.03% attains this equilibrium when the surrounding air has a relative humidity of about 70% (2).

The exact degree of relative humidity depends upon the purity of the sugar, the temperature and the grain size, but at normal values, for this parameters, the relationship follows the well known curve shown in Fig. 1 (McGinnes 9). If the humidity of the surrounding air is above or below that corresponding to the moisture content of the sugar, water will be either absorbed or removed. If absorbed, then the syrup film on the grains will be increased and the sugar will become sticky. If moisture is removed then the syrup, film will be dried causing caking.

It is necessary if large quantities of sugar are to be stored in a free-running condition for long periods, for the development of temperature gradients within the sugar to be avoided (Rodgers 5). This can be achieved in the silo by controlling the temperature of the silo.
Moisture content shown in grams moisture per 100 grams of dry sugar. Humidity surrounding sugar shown as "effective humidity" (actual rel. humidity must be adjusted if any temperature differences exist).

FIGURE 1. Approximate moisture content of granulated sugar at various humidities.
ARGUMENTS IN FAVOR FOR BULK STORAGE IN ROUND STEEL SILOS

Space requirements

The main consideration for the Swedish factories was often to choose a storage system which gave the greatest possible tonnage stored in the smallest possible storage area. Table 1 shows how a silo of the right dimensions fulfills these demands. A cylindrical 40,000 ton silo takes up only 1/3 of the area which is needed for a store house of primatic or parabolic form, and when you get up to 60,000 tons the cylindrical type takes 1/4 of the area needed than the other types. These days this is a major consideration for many sugar factories.

TABLE 1. Storage space for 40,000 tons of bulk raw sugar

<table>
<thead>
<tr>
<th></th>
<th>Prismoid</th>
<th>Parabolic</th>
<th>Cylindrical diam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length x breadth or diam.</td>
<td>155 x 37</td>
<td>174 x 31</td>
<td>49</td>
</tr>
<tr>
<td>Max sugar depth m</td>
<td>20</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>Arenas m2 sugar floor</td>
<td>5735</td>
<td>5394</td>
<td>1885</td>
</tr>
<tr>
<td>Plan of building</td>
<td>6038</td>
<td>5977</td>
<td>2067</td>
</tr>
</tbody>
</table>

Storage space for 60,000 tons of bulk raw sugar

<table>
<thead>
<tr>
<th></th>
<th>Prismoid</th>
<th>Parabolic</th>
<th>Cylindrical diam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length x breadth or diam.</td>
<td>232 x 37</td>
<td>260 x 31</td>
<td>52</td>
</tr>
<tr>
<td>Plan of building</td>
<td>8863</td>
<td>8677</td>
<td>2110</td>
</tr>
</tbody>
</table>

Construction weight

Comparative cost studies are always difficult to do but the capital cost of a store is often expressed as the price per unit capacity, that is, that a store should be large enough to work out cheaply.

But fragility also increase with size. So an ordinary warehouse is costly because it does not have the advantages of the cylindrical shell. An indication of the cost can be obtained from the total weight of steelwork. For example 25,000 tons of raw sugar requires about one million cu. ft. of stored space, thus, could be stored in one silo with a weight of about 400 tons. “A” frame installations of about the same size demand an iron frame work which is 8-18% heavier.

Moving, converting and enlarging

A sugar industry in a period of development and change as was the case with
the Swedish sugar industry during the forties and fifties has derived great benefit from the fact that these steel can be dismantled and rebuilt in a different place. The costs of these are considerably lower than from building from scratch. Moreover, these silos have been able to be enlarged by a relatively simple method of extension. A third advantage that we have derived from this construction is that it has been rather easy to convert from raw sugar storage to granulated sugar storage. In other words, we made an extremely successful move at the end of the thirties when we went over to building steel silos of this type instead of large ground level warehouses which are rather difficult to change and practically impossible to move.

**Labor requirements**

Swedish industrial wages these days are among the highest in the world. It is therefore vital for us that our handling of such cheap raw material as sugar should involve as little labor as possible. The raw sugar at the raw sugar factory is carried to the silo by steel belt conveyors and the silo is self-filling. From the time the raw sugar has been removed from the centrifugals and passed the raw sugar scales in the factory the entire operation is unmanned. All that is necessary is that one looks at the silo once or twice per shift. When discharging, the silo is operated so that the sugar is transferred to a discharge hopper and the truck driver empties the hopper himself in his truck. The only manpower that is required here is to check that the automatic system is working. A corresponding installation for granulated sugar requires equally little power.

Our silo for receiving cane raw sugar from boats is manned by two workers per shift. It is situated a long way from the refinery and so it requires a man to be stationed for supervision of scales, sampling, etc. According to safety regulations this man may not be left alone at an isolated working station. He has radio contact with the other man who is responsible for discharging into trucks and so on. So in theory, even this silo does not need to be permanently manned.

So this silo construction makes very small demands on labor. This applies even to complete emptying of the silo, which is something we try to do once a year at the beet sugar factories for inventory purposes. The whole job is done in less than one day with one man and one mechanical shovel. (At the Malmo raw sugar silo the job takes from 2.5-3 man-hours.)

So, where handling of the sugar is concerned we do not believe that one can go much further with labor saving than we have up to now. Naturally, the larger the installation and the higher the hourly capacity the lower are the labor requirements in terms of working minutes per handled ton.

In other words, the larger installations do not require any more supervision than the smaller ones. A large installation is always more economical than a small one both as far as running costs and capital investment are concerned.
SILOS FOR EXPORT AND IMPORT OF RAW SUGAR

In the case of an export silo (Fig. 2), the raw sugar arrives at the port in trucks. It is discharged into a receiving hopper and is transported via a bucket elevator to the top of the silo. Here it falls down onto a rotating feeder table, where it is ploughed down into chutes to the sprinklers. These are located on the slowly rotating bridge. The sprinklers spray out the sugar and it falls down on the stored sugar. At the sugar surface the scroll conveyor suspended from the rotating bridge, moves it out towards the silo shell. The conveyor follows the movement of the rotating bridge the whole time.
FIGURE 3. Import silo
When emptying the silo, the scroll conveyor is reversed and thus moves the sugar toward the central tower. Here, gates are opened at the base of the central tower and the sugar falls down into a hopper and from there on to a belt conveyor which transports the sugar to the ship.

In the case of the silo in an import receiving port (Fig. 3), the sugar is discharged from the ship by means of port cranes, fitted with grabs to either of the two cylindrical towers, which contain a hopper through which the sugar falls into an automatic scales, which weighs and records accurately the net weight of the sugar passing through. The sugar is sampled in an automatic sampler.

From the scales, the sugar passes through a lump crusher on to a steel belt conveyor at the boot of the elevator in the central tower. From the elevator the sugar is discharged through a hopper which is attached to the rotating bridge. The hopper has four outlets linked with four "trimmers" or "throwers", which are designed to throw the sugar towards the silo shell. The sugar can be levelled by means of the retractable scroll conveyor which is suspended from the rotating bridge. When reclaiming operation is in progress the sugar flows through a number of gates located at the base of the central tower onto a feed table.

After the angle of repose has been reached, the remaining sugar can be pushed towards the outlets by means of the scroll conveyor. From the feed table the sugar is ploughed on to the steel belt conveyor which is now reversed, and ploughed off the boot of a bucket elevator and lifted to a day hopper from which sugar is drawn off to trucks travelling between the port silo and the refinery.

CONTROL OF AIR HUMIDITY AND TEMPERATURE IN THE SILO

The relative humidity (RH) inside the silo is controlled by an air conditioning unit, Fig. 4, which takes air from inside the silo, checks the RH, automatically switches in a drying or humidifying function to obtain the preset RH and blows it back into the silo. The RH is set at a value corresponding to the sugar moisture, i.e. value where the vapor pressure of the air is equal to the vapor pressure of the sugar (equilibrium).

The silo is insulated with a dynamic insulation system. This means that the storage space is completely surrounded by heating or cooling air in the space between the silo shell and the ordinary insulation. The air is circulated by a fan (F) and heated or cooled by a radiator R, (Fig. 4).

SILO FOR GRANULATED SUGAR

Our silos for granulated sugar are a development of the silos for raw sugar. The central tower, which is always made of steel, houses the machinery for air conditioning, dust collecting and sugar transport in accessible positions. Insulation is
FIGURE 4. Heating and Air Conditioning

more highly developed than what is normally required for a raw sugar silo. The sugar from the disc sprinklers falls through the air like snow flakes thereby exposing the individual sugar crystals to a very intimate contact with the air, which has been conditioned to a suitable temperature and humidity by thermostat and hydrostat controlled radiators and air dryers.

The sugar is evenly distributed in a thin layer over the entire horizontal area of the silo by running the scroll conveyor in such a way that the circular sugar ridge formed below the disc sprinklers is moved towards the periphery. Thus, the sugar is exposed to the conditioning air for a longer period of time. This final treatment improves the storage quality of the sugar. The silo serves not only as a sugar store but also as a sugar conditioner. Using this method of handling, the sugar also becomes thoroughly mixed and so the silo also serves as a blender for the sugar stored in it. The quality of the sugar leaving the silo is more homogeneous than the sugar entering the silo.
Many sugar factories carry out conditioning by blowing air through the sugar. If the air has not been correctly treated this introduces new contamination, risks. 48 hours blowing is often quoted as the time required to reach equilibrium (McGimpsey3).

In our silos the sugar is exposed to correctly treated air in the silo upon storing. The sugar is spread into the silo and undergoes mixing by the conveyor in layers never more than a half meter thick for at least 24 hours. In this way the sugar is conditioned without the need for air to be blown in. Emptying the silo is carried out in the same way as for the raw sugar silo. The energy required for the treatment of the air varies considerably according to the climate. A 40,000 tons silo is given as an example in Fig. 5. A few words should also be said on the subject of the risk of injuries and accidents inherent in the silos themselves and in their operation.

First of all, it should be pointed out, that anyone who has had experience of emptying concrete silos before they were equipped with discharging system, is very glad that this type of handling no longer occurs. These concrete silos were subject to moisture migration since the discharging system was such, that peaks of sugar were formed inside the silos. Emptying silos had not been done for a very long time before it became necessary to send men into the silos in breeches buoys to brake the sugar loose and this was both unhygienic and extremely dangerous for the man doing the work since great avalanches of sugar were often the result. The risk was even greater when one gets down to the bottom of the silo while there is still great mountains of sugar left, which had to be broken down in some way. Occurrences such as this have never been observed with the discharging system now described. The silos are emptied practically to the bottom without human intervention. The machinery, in form of sprinkler, bridge and conveyor inside the sugar store, has been shown to cause very little inconvenience provided selection and assembly have been properly carried out and by keeping sensitive electrical parts under conditions of high air pressure.

SUMMARY OF THE CHARACTERISTICS OF THE DESCRIBED SILOS

The only disadvantages we know of is that it is not possible in a round raw sugar silo to keep sugar from different factories apart plus the slight disadvantage of having machinery inside a white sugar silo. Otherwise, the advantages are many:

- the contamination risk can be virtually eliminated by strict control.
- the sugar is maintained at a constant temperature, within close limits, by the complete envelopment of the walls, roof and the floor in a jacket of circulating air which maintains the temperature of the silo accurately. The air in the space above the sugar is maintained at a controlled humidity. These two
factors enable the sugar to be stored for very long periods at the highest desirable quality.

- the silo is fitted with machinery for automatic filling and complete emptying.

- the above factors also enable the reclaiming gear to empty the silo completely without the use of manual labor.
no cellars are required making for a cheaper foundation.

- increase in storage capacity is simple and can be done as and when required.

- the heating or cooling air is completely isolated from the stored sugar, thereby reducing the risk of explosions.

- the silo can be equipped with any available source of heating such as electricity, steam, hot water or separate oil heating.

- hygiene is maximal as human hands never touch the sugar.

- excellent insulation of walls, floor and roof, mean that heating or cooling costs are kept at a minimum.

- there is an ideal relationship between the diameter and the height of the walls giving the maximum storage volume for the minimum surface area and thus keeping the cost of building and building materials at a minimum.

REFERENCES


El trabajo se inicia con la historia del desarrollo en las industrias azucareras de Suecia, en almacenar azúcar granulada desde el siglo 19, hasta nuestros días.

Se explica que para conseguir resultados satisfactorios en almacenar azúcar por periodos largos, depende del diseño.

Los siguientes factores que han influido en la elección de los silos redondos de Weibull se conjugaron: Requerimientos de espacio, costos de manejo, temperaturas, control de humedad.

Se describe como el arreglo de silos sirve para exportación e importación de azúcar cruda y almacenaje de azúcar granulada.