THE EFFECT OF SUGAR TEMPERATURE ON THE OPERATING PERFORMANCE OF A CONDITIONING SILO

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Abstract

The intention to cool refined sugar prior to pre-packing at Hulett Refineries prompted an investigation into the influence that cooled sugar at 32°C would have on the performance of the conditioning silo. A number of batch tests were conducted using two pilot conditioning silos arranged in parallel and assembled such that the conditioning air and silo temperature could be changed and accurately maintained. During each test the sugar and conditioning air temperatures and moisture profiles were monitored and caking tests were conducted. The conditioning times for various combinations of sugar and air temperatures were determined. The results showed that for cooled sugar and air of the same temperature, conditioning time is extended by 25%, whilst conditioning cooled sugar at a higher air temperature results in caking taking place within the silo. It is concluded that both sugar and air conditioning temperatures of at least 40°C are required to achieve the optimum conditioning time of 72 hours. Large temperature differences between the sugar and conditioning air should be avoided to prevent caking within the silo.

Introduction

Sugar crystals, after being discharged from the centrifugals are coated with a thin film of supersaturated syrup, which can be dried by crystallizing the sucrose content, thus releasing water which has to be evaporated. This process is normally carried out in granulators, where the evaporation rate is so high that some areas of the syrup film crystallize at an extremely high level of supersaturation, forming an impermeable layer and trapping surface moisture. The moisture removed during this process is termed free moisture and the entrapped moisture is known as bound moisture. The latter should not be confused with inherent moisture (water of crystallization) which is within the crystal.

With time, the bound moisture through a process of diffusion, redissolution and recrystallization will move outwards to the surface of the crystal where it is free to escape. The subsequent drying of this moisture in a static condition leads to inter-crystalline bridging by re-crystallization, and causes caking. It is therefore necessary to remove this moisture as it emerges in order to prevent this condition occurring. The driving off of the bound moisture is described as a process of "conditioning". This process is accomplished by passing a stream of conditioned air through a column of sugar contained in a vessel which is known as a conditioning silo. Conditioned sugar has the characteristic of being non sticky, free flowing, and "lump free".

The conditioning silo at Hulett Refineries can best be described as a thermally insulated cylinder, about 30 metres high and 8 metres in diameter. Conditioning air (at 40°C and about 20% relative humidity) enters at the bottom and flows upwards (at about 50 litres per minute per ton of sugar) counter-current to the flow of sugar. The sugar enters the silo at a temperature of 40°C and is normally subjected to a residence time of 72 hours. The silo has the capacity to hold about 1 000 tons of sugar.

Approximately 25% of the refined sugar production at Hulett Refineries is conditioned to enable bulk transportation and storage without undue caking. The balance of the sugar produced is pre-packed immediately after the granulator station.

The intention to cool sugar to 32°C prior to pre-packing, resulting in the silo supply temperature dropping to a similar level, led to the following line of investigation in order to predict any change in silo performance which might take place:

- The conditioning of cooled sugar (32°C) with a silo operating temperature of 32°C compared to the conditioning of uncooled sugar (40°C) with a silo operating temperature of 40°C
- The conditioning of cooled sugar (32°C) with a silo operating temperature of 40°C compared to the conditioning of uncooled sugar (40°C) with a silo operating temperature of 40°C.

The experimental work was conducted in two pilot sugar conditioning silos (1:30 000 scale to the refinery silo) which were arranged in parallel.

Methods

Equipment design

A systematic arrangement of the equipment is shown in Figure 1.

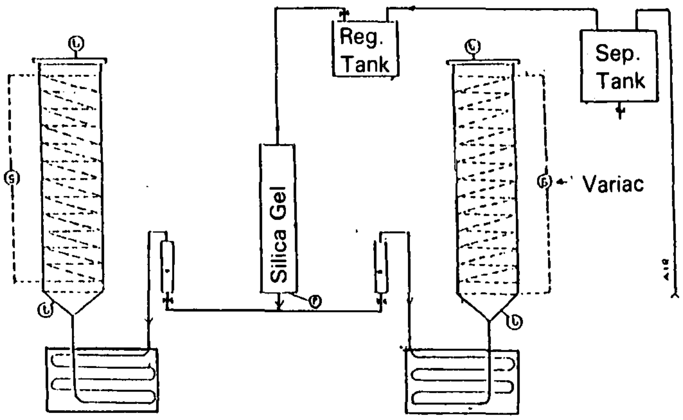

FIGURE 1 Arrangement of Experimental Equipment

Two pilot batch silos belonging to the SMRI were used to conduct the test work. Each silo is 250 mm in diameter, 1 000 mm high and has the capacity to hold 40 kg of sugar on a fine wire mesh screen. Each silo is wrapped externally with silicone rubber heating tape which is connected to two independent variacs. The heating tapes and cones of the silos are covered with asbestos tape to reduce heat losses. The operating temperature within the silo can easily be achieved and maintained by adjusting the variac accordingly.

The source of air supply for the silos was taken from the factory compressed air system. The air, at a temperature of 30°C and a pressure of 400 kPa, was passed firstly through a moisture separator and then into a receiving tank. The air pressure was reduced to 200 kPa on the exit line from the receiving tank by means of a regulating valve. The purpose of the receiving tank was to assist in smoothing out any fluctuations in air pressure.

The air, after being predried (to less than 20% RH) by passing it through a silica gel column, was split into two streams, one for each silo. The air in each stream was controlled to a flow of 2 litres per minute by means of a rotameter, and heated to the required temperature by passing it through a 4 m × 8 mm I.D. copper tube coil immersed in a thermostatically controlled water bath, before being introduced into the bottom of each silo. This arrangement provided easy adjustment and accurate control of the air temperature by adjusting the water bath temperature accordingly.

A minor problem experienced with the system was the exhaustion of the silica gel in the air drying column after a period of 60 hours' use. However, a two minute interruption in air supply to the silos in order to replace the desiccant did not prove detrimental to the test runs.

Thermometers were placed in the water baths, in the cones of the silos and at the top of the silos in order to monitor the temperatures of the water, air and sugar respectively.

In summary, the arrangement of the silos and auxiliary equipment provided easy adjustment and accurate control of the silos to any desired operating temperature.

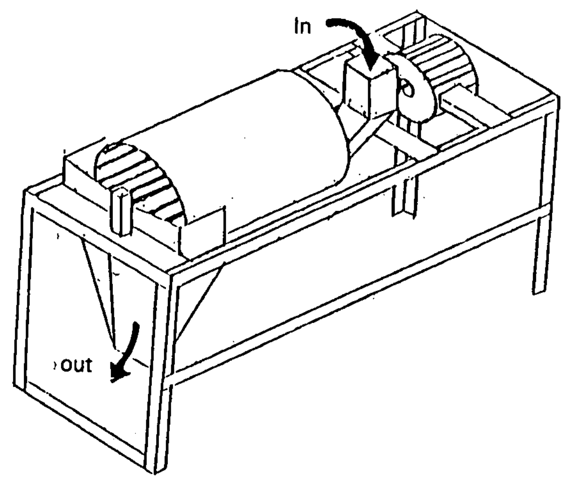

FIGURE 2 Sugar cooling equipment

The laboratory drier (Figure 2) which consists of a motor driven rotary drum (speed 15 rpm) was used for the sugar cooling. Sugar was passed twice through this drum in order to reduce the temperature from 40°C to 32°C.

Procedure

Prior to commencing each test run, the silos and the conditioning air were first heated to the required temperature. Work commenced only after the required temperature had been stable for a period of two hours.

Sufficient granulated sugar at 40°C for both silos was simultaneously collected in buckets from the factory silo feed belt. This procedure was implemented to ensure that both silos had the same quality sugar. The fresh sugar was filled directly into the silo to be operated at 40°C and cooled to 32°C before filling the other silo. The cooling of the sugar resulted in a slight increase in moisture content which is evident in Tables 1 and 3.

During each test run, temperatures were frequently monitored to ensure that the silos were operating at required conditions. Sugar was sampled about 10 cm below the top of the silo with a sample thief. The frequency of sampling was every 12 hours initially, and increased to every 4 hours when approaching the expected conditioning time. The sugar sample was immediately poured into two test tubes (one of 28 mm ID and 200 mm long, and the other 22 mm ID and 80 mm long) which were closed with rubber stoppers and sealed with adhesive tape. Caking tests were conducted on all the samples collected in the 200 mm long test tubes. This test consists of immersing the lower 20 mm of the sealed test tube into a thermostatically controlled water bath. This part of the tube was exposed firstly to a water temperature of 10°C for a period of 1 to 2 hours followed by a water temperature of 40°C for an equal period of time. The seal was then broken and the sugar slowly emptied from the test tube at an angle of 45°C to the plane of the work bench. The test indicates that the sugar is conditioned only if it flows freely and "lump free" from the test tube.

Moisture levels were determined in the sugar samples collected in the smaller test tubes (about 20 g), using Karl Fisher automatic titration equipment. This measures the total moisture in the sugar sample and includes inherent, bound and free moisture if present.

Each test run was considered complete when the sugar in both silos was conditioned. Differences in data were tested statistically by means of the 't' test at a 0,01 level of significance.

Results

Test 1

To compare

Silo 1: Conditioning of cooled sugar at 32°C with a silo operating temperature of 32°C.

with

Silo 2: Conditioning of uncooled sugar at 40°C with a silo operating temperature of 40°C.

The average results of six tests are shown in Table 1.

Table 1

	Silo 1 Sugar Temp. 32°C Operating Temp. 32°C	Silo 2 Sugar Temp. 40°C Operating Temp. 40°C
Conditioning Time (Hours)	92	74
Initial Moisture % Sugar	0,057	0,054
Conditioned Moisture % Sugar	0,039	0,037

The increase of 18 hours in conditioning time was found to be significant. The average periodic moisture contents of the last 3 runs are shown in Table 2 and the moisture profiles are shown in Figure 3.

Table 2

	Silo 1 Sugar Temp. 32°C Operating Temp. 32°C	Silo 2 Sugar Temp. 40°C Operating Temp. 40°C
Time (Hours)	Moist. %	Moist. %
0	0,056	0,054
24	0,046	0,041
48	0,043	0,039
72	0,041	0,035
96	0,038	0,032

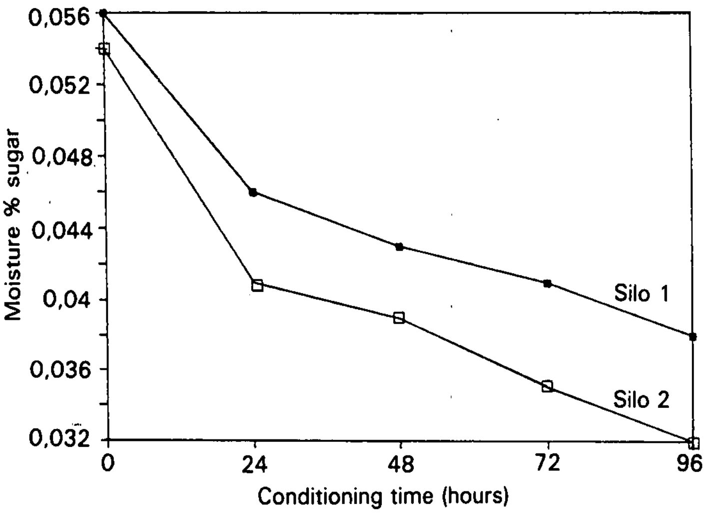

FIGURE 3 Moisture profiles in Silo 1 and Silo 2, during Test 1

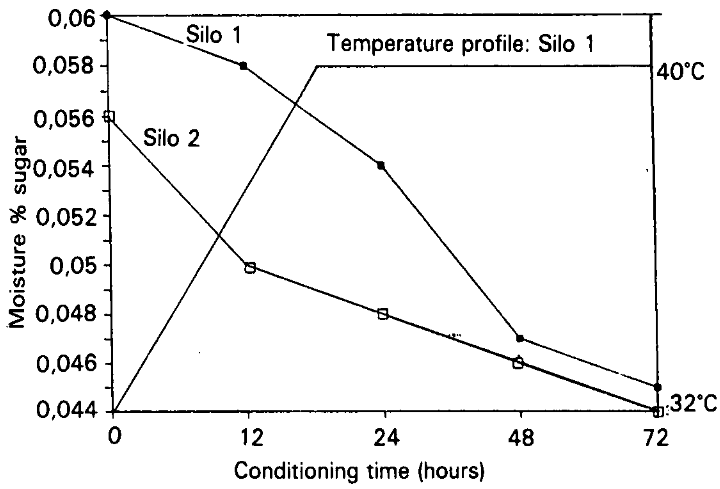

FIGURE 4 Moisture profiles of Silo 1 and Silo 2 with a Temperature profile for Silo 1, during Test 2

From Figure 3 it will be noticed that the moisture profile in Silo 1 was always higher than in Silo 2 at any given time. This shows that the conditioning rate in Silo 2 was greater than that in Silo 1. Both profiles show a sharp drop after 24 hours and a more gentle drop thereafter.

Test 2

To compare

Silo 1: Conditioning of cooled sugar of 32°C with a silo operating temperature of 40°C

with

Silo 2: Conditioning of uncooled sugar of 40°C with a silo operating temperature of 40°C.

The average result of three tests is shown in Table 3.

Table 3

	Silo 1 Sugar Temp. 32°C Silo Temp. 40°C	Silo 2 Sugar Temp. 40°C Silo Temp. 40°C
Conditioning Time (Hrs)	72	72
Initial Moisture %	0,060	0,056
Final Moisture %	0,045	0,044

The conditioning time for both silos was 72 hours. The average results of the periodic moisture determinations and sugar temperatures of Silo No. 1 and Silo No. 2 are shown in Table 4. The corresponding moisture profiles are shown in Figure 4.

Table 4

Silo 1 Time (Hrs)	Silo 1 Temp (°C)	Silo 1 Sugar Temp. 32°C Silo Temp. 40°C	Silo 2 Sugar Temp. 40°C Silo Temp. 40°C
0	32	0,060	0,056
12	36	0,058	0,050
18	40	—	—
24	40	0,054	0,048
48	40	0,047	0,046
72	40	0,045	0,044

From Figure 4 it will be noted that there is an appreciable difference between the average moisture content of the sugar in both silos after 12 hours of conditioning time. This indicates that there is very little drying in Silo 1 during the first 12 hours of conditioning. The temperature rise in the sugar from 32°C to 40°C in Silo 1 took about 18 hours.

On emptying Silo 1 after a period of 72 hours, soft fragile lumps about the size of a closed fist were found in localised areas within the silo.

This was observed over all three tests and indicated that some degree of caking occurred.

Test 3

To compare

Silo 1: Conditioning of cooled sugar of 32°C with a silo temperature of 40°C

with

Silo 2: Conditioning of cooled sugar of 32°C with a silo temperature of 32°C.

Only one test was conducted and the results are shown in Table 5.

Table 5

	Silo 1 Sugar Temp. 32°C Silo Temp. 40°C	Silo 2 Sugar Temp. 32°C Silo Temp. 32°C
Conditioning Time Hrs	72	96
Initial Moisture %	0,055	0,055
Final Moisture %	0,046	0,047

The results from Silo 1 were similar to that of Silo 1 in Test 2. The conditioning time was 72 hours and on emptying lumps were noticed. The results from Silo 2 were similar to those of Silo 1 in Test 1. The conditioning time was 96 hours.

The increase in sugar temperature from 32°C to 40°C within Silo 1 again took 18 hours.

Discussion

The rate of conditioning is governed by the crystallization velocity of sucrose within the supersaturated film around the sugar crystal. Since lower temperatures decrease this velocity, it can be expected that lower conditioning temperatures will increase the period of conditioning. Hence the increase of 25% in conditioning time experienced from the tests, when cooled sugar of 32°C is conditioned with silo operating temperatures of 32°C, is supported.

The phenomenon of localised caking which occurred when cooled sugar of 32°C was conditioned with silo operating temperatures of 40°C can be attributed to the existence of a thermal gradient within the silo. This gradient probably prevails during the period when the sugar temperature is increasing from 32°C to 40°C in the silo, and causes moisture to migrate from areas of high temperature to areas of low temperature, resulting in localised areas of moist sticky sugar. When these areas are subjected to air of 40°C, the water molecules in the syrup film on the crystal surface are driven off, resulting in supersaturation. In order to re-establish equilibrium, crystallization occurs which then binds crystals together and results in caking. Bagster[1] indicates that cake formed by this mechanism is fragile and will reset immediately if broken. This was confirmed by the tests.

The results of these tests provide evidence that conditioning rate is dependent on silo operating temperature and within the limits of this experimental work, not dependent on the sugar temperature. However, caking is dependent on both input sugar and silo operating temperatures.

Conclusions

A minimum retention time of 72 hours is required when both the sugar and conditioning temperatures are at 40°C. This period is extended by 25% when the sugar and conditioning air temperature are at 32°C.

Large temperature differences between the sugar and the conditioning air temperature must be avoided to prevent sugar caking within the silo.

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REFERENCES

1 Bagster, DF (1970). Cause, prevention and measurement of the caking of refined sugar - a review. *Int Sugar Journal* 71: 263-267, 298-302.