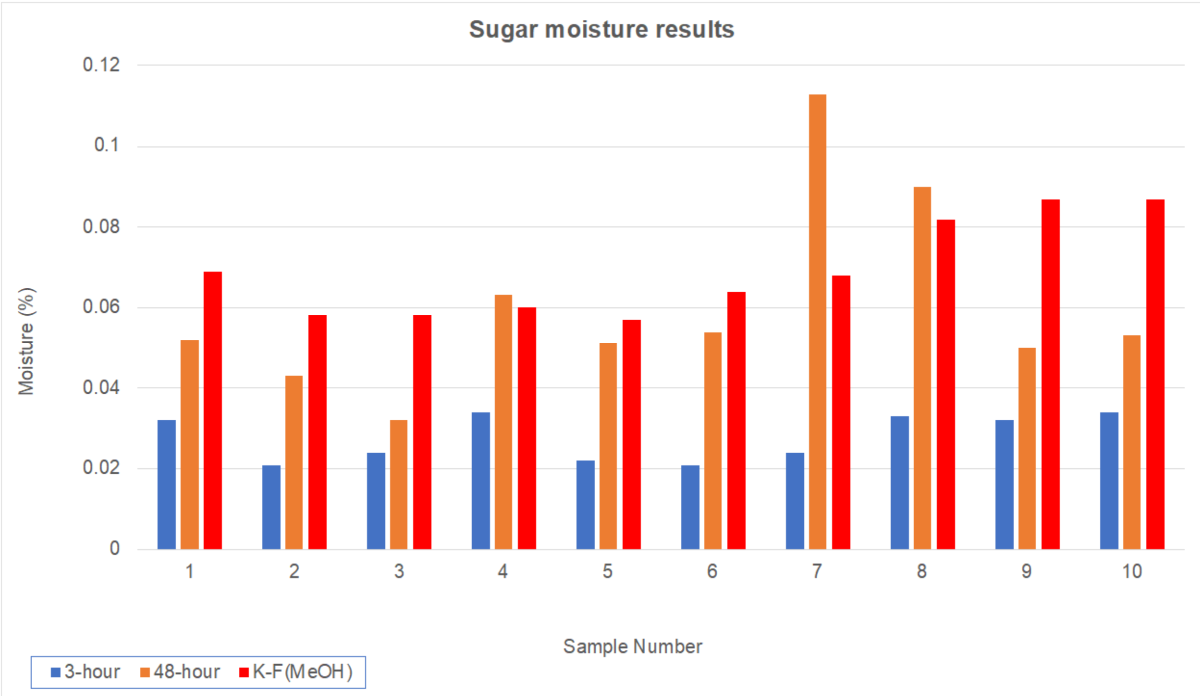

Figure 2. Refined sugar moistures using various methods

Trials with VHP sugar showed similar trends between the three-hour results, compared to the longer drying periods and the Karl-Fischer results (Figure 3).

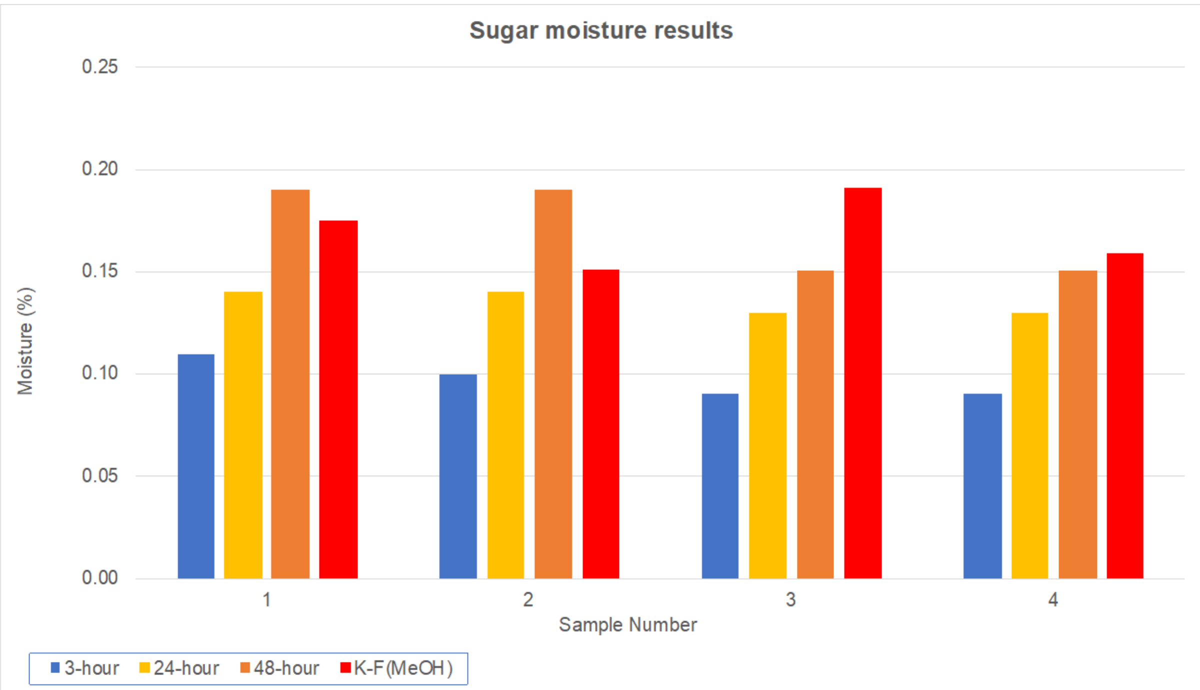

Figure 3. VHP sugar moistures using various methods

It is clear that the three-hour oven test method is not representative of the real moisture content. Unfortunately, there is no obvious replacement for this method at the factory, as the Karl-Fischer apparatus is expensive, and the tests require specialised skills and are expensive and time-consuming. It is recommended that the mill should conduct longer drying period trials periodically, to ascertain what the differences are. This will indicate whether an issue may be arising that could cause caking or wet sugar problems. Trials should be done on sugar produced at different times of the day, as the ambient air conditions may affect the sugar moisture. This will be dealt with later in this report.

It is also important to note that at-line moisture analysers need to be calibrated and this is usually done with the oven moistures. An at-line instrument that can measure the bound moisture would be a valuable control instrument for a factory.

Myth 2: If throughput needs to be increased, increase the air flow and the temperature

This was a solution proposed by an equipment supplier for refined sugar dryers at a mill, and it has been found to be a fairly common recommendation for increasing the dryer capacity. As it came shortly after the literature survey had been completed, the mill agreed to go with the author's recommendations and to decrease both the air temperature and flow in the refined sugar rotary louvre dryers, while increasing the feed sugar temperature. The premise for this was that decreasing the removal rate of water from the surface would reduce the formation of an amorphous layer. Some of the motivation for the mill's agreement was to avoid the costs associated with the replacement or modification of the fan and heater.

Following the change in operations, an improvement was seen in the Karl-Fischer moisture.

With the reduced air flow and temperature, the rate of removal of water from the sugar is reduced and this extends the time before an amorphous layer is formed. It was found that, by extending the constant rate drying period, the critical moisture content can be reduced and this also lowers the final sugar moisture. It should be noted that the effect was not visible by using the oven-drying method for moisture determination. This value actually increased marginally at times, due to the decreased amorphous layer formation, and hence the loss of moisture was faster, when drying for short periods.

Thompson (1998) studied the conditions required for optimum drying and concluded the following:

- the air RH needs to be below the ERH, usually a RH of 60%;
- sugar dried by using hot air gives a higher bound moisture than that which is dried with cooler air;
- wet sugar leaving the centrifugals should contain enough energy to dry itself; and
- it is often possible to reduce the air temperature significantly, without affecting a loss in the drying of the sugar. Energy from the air is not required, as outlined in the previous point.

Schinkel and Tait (1994) and Tait *et al*. (1994) developed a drying model for raw sugar and concluded that air-to-sugar ratios of between 0.2 and 1.0 were sufficient, depending on the quality of the sugar leaving the centrifugals. Observations at the mills showed a much higher ratio, more noticeably in rotary louvre dryers and fluidised bed dryers. They also found that too much air causes cooler, wet sugar, and too little air causes hotter, wet sugar. The feed sugar temperature and moisture were found to have the strongest effect on achieving cool dry sugar.

One issue with the fluidised bed dryers is that the minimum fluidisation velocity of sugar (the air velocity at which the sugar will start to fluidise) is highly dependent on the sugar moisture. A general rule of thumb is that the minimum fluidisation velocity of wet sugar is 10x that of dry sugar. This makes it very difficult to set up the air velocity in a fluidised bed dryer.

Myth 3: After drying, cool with ambient air

It is fairly common in factories to cool the sugar with ambient air. Unfortunately, many of the mills are situated in humid environments, particularly at the start and end of the crushing seasons. Air intakes inside the factories are also often situated near the dryers and centrifuges, where the 'ambient' air is hot and wet, due to all the steam in the vicinity. Even if it is drawn from outside the building, the relative humidity can be above 50% for most of the time, resulting in a high equilibrium moisture content. If the air is introduced into the second stage of drying, after the drying air has caused the amorphous layer to form, this dry, crystalline layer absorbs moisture from the air and this moisture forms free moisture, which is very mobile once the sugar is packaged. Often, the result is wet and sticky sugar.

A trial was conducted by the author to get the moisture profile along a refined sugar rotary louvre dryer using ambient air for cooling (Figure 4). The dryer was stopped and samples were taken at 0.5 m intervals. These were then tested by using the Karl-Fischer method (formamide). It could be seen that the constant drying zone lasted only 1.5 m along the dryer, after which the drying slowed rapidly and then it stopped. After the introduction of the ambient cooling air, the moisture in the sugar actually increased slightly. This moisture is all free moisture and will affect caking.

Simply warming the secondary air slightly, or dehumidifying the air to reduce the relative humidity, will improve the final moisture content of the sugar, and it will result in an improvement of the final packed sugar quality. Together with the air and sugar changes mentioned above, when a dehumidification unit was added to the cooling air on this dryer, the cases of caked sugar decreased by over 90%.

If the sugar is conditioned after drying, it is not as large a problem, as this free moisture will be removed rapidly in the process.

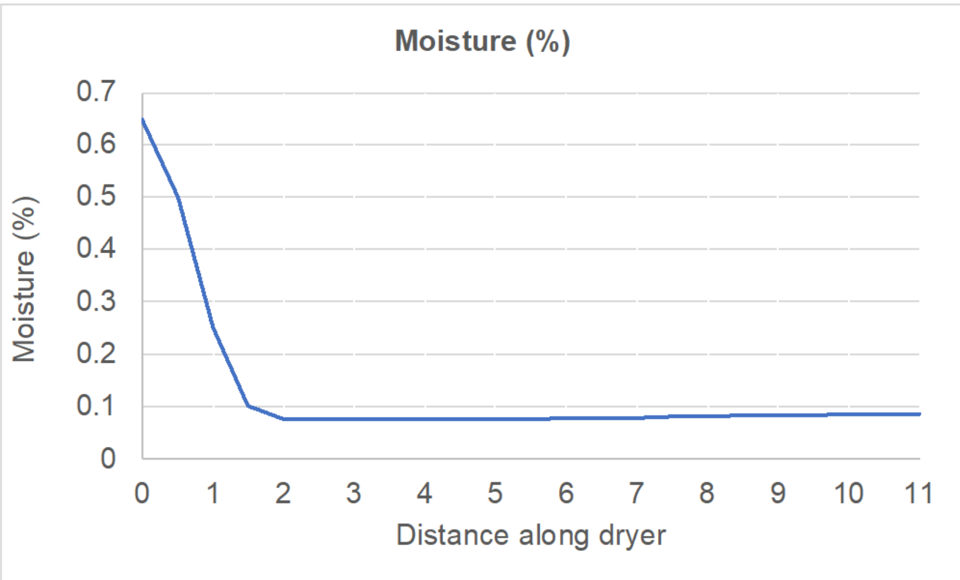

Figure 4. Moisture profile along refined sugar rotary louvre dryer (Karl-Fischer using formamide)

Myth 4: The final sugar temperature can be controlled by using the hot air temperature

Some dryers use this control strategy with contradictory results. This is used mainly where a higher temperature is desired before a conditioning silo. The major mechanism involved in determining the sugar temperature leaving the dryer is the vaporisation of the water to the air. This uses energy from the sugar, thereby decreasing the temperature. It should also be noted that air has a heat capacity of about 700 J/kg/K, while crystal sugar has a specific heat capacity of 1 369 J/kg/K at 50°C. For this reason, the airflow has to be high, in order to affect the sugar temperature, and this, together with the higher air temperature, increases the likelihood of an amorphous layer forming.

It is true that this philosophy appears to work, as the hot air conditions lead to the formation of an amorphous layer and the loss of heat by vaporisation is reduced. However, this strategy is not recommended, as the sugar temperature control can then only be by the air/sugar temperature difference, which requires a high flow of air.

Myth 5: Sugar conditioning is complete within 48 hours (or 72 hours)

While being involved in the design of conditioning silos, from the client's side, the author experienced the principle of setting a conditioning time when designing a silo. This was based on his previous experience in conditioning. It should be clear from the above discussions that the conditioning time is dependent on the characteristics of the amorphous layer which, in turn, are determined by the operation of the sugar dryer.

Meadows (1993) concluded that the conditionability of the sugar depends on the initial bound moisture entering the conditioning process, and thus, drying is the main determinant of the sugar's conditioning behaviour. He concluded that the main aim of drying is, therefore, to dry the sugar *thoroughly but slowly*, in order to get a thin amorphous layer. He suggested that high-temperature drying is not necessarily advantageous, and he also concluded that the rate-limiting step is, in fact, the diffusion of the molecules across the amorphous layer.

A new dryer installation at a mill included the control of the air-to-sugar ratio, using one tonne of air to one tonne of sugar, as well as the air temperatures, in the drying section of the rotary louvre dryer. Following the commissioning of the dryer, the conditioning time of the dried sugar decreased to 48 hours, from the previous 72 hours.

It is recommended that if conditioning is practised, or is to be considered, at a mill, the drying operation should be optimised first. Once this is done, using various oven-drying periods to test the sugar moisture will give a good indication of the time required for conditioning, as it can be assumed that the moisture will be removed at a similar rate in both processes. It is important to ensure that the dried sugar is placed in the ovens as quickly as possible, as standing time in the laboratory also allows for the moisture to move through the amorphous layer.

Conclusion

It is clear from the literature survey, as well as the trials conducted at mills, that the drying of sugar is more complicated than the drying of other substances, due to the molasses layer surrounding the sugar crystal and the formation of an amorphous sugar layer, if the moisture is removed too rapidly.

There are a number of references that state what the rate limiting step is. Some claim that it is the movement of water across the molasses layer, others claim that it is the rate of vaporisation of the water, and still others claim that it is the rate of crystallisation or dissolution of the sucrose. It is the view of the author that all of these are correct at different times of the drying process, but that it is the drying conditions that control this. It is also the view of the author that the desired rate limiting step is the rate of vaporisation of the water, and that the dryer should be controlled to ensure that this can be maintained as the rate limiting step for as long as possible. This will ensure the minimum Critical Moisture Content and reduce the propensity for the sugar to cake or get moist later.

In order to optimise the removal of moisture in the dryer, the following conditions are recommended. Some optimisation around these settings is advised:

- the sugar temperature into the dryer should be as warm as possible; 60-65°C has been found to work well;
- the heating air temperature should be the same as the sugar temperature in the dryer;
- the cooling air should be heated, or dehumidified, to ensure that the relative humidity is less than 50%. If the cooling air is used to reduce the sugar temperature, it should be dehumidified first, rather than heated;
- the heating airflow-to-sugarflow should be set at a 1:1 ratio in tonnes. This is not possible in a fluidised bed dryer, due to the high airflow required for fluidisation; and
- the cooling airflow is not as important and can be set the same as the heating air.

In a cascade dryer, which has only one air supply, it is recommended that this be counter-flow to the sugar flow. This ensures that dry air is in contact with the dry sugar and more moist air is in contact with the moist sugar. This will optimise the removal of moisture from the sugar across the dryer.

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