THE IMPLEMENTATION OF A DRYER/COOLER CONVERSION AND SHORT RESIDENCE TIME CONDITIONING SYSTEM FOR REFINED SUGAR

By

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Abstract

THE ROTARY sugar dryer/cooler at Central Azucarera Don Pedro (CADP) refinery (Philippines) has been upgraded and a short residence time conditioning system has been installed through 2008–2009 to resolve hard caking issues being experienced in stored 50 kg sugar bags. This paper describes the modifications undertaken and the results achieved in resolving the caking issues. The reconfiguration and automation of the dryer/cooler and the installation of short residence time conditioning (eight hour conditioning period) provided a simple, low capital cost and low operating cost resolution to the caking issues previously encountered at the refinery, compared to alternatives. The reconfiguration and automation of the rotary dryer/cooler has reduced both power and steam consumption and allowed a significant increase in capacity, despite retaining the same rotary shell, fans, scrubber and air heater. The increased performance has eliminated the need for a fluidised bed cooler that was previously under consideration for purchase by the refinery. Since modification, the refinery has completely eliminated hard caking of refined sugar. There has been no need to remelt and recycle bags of sugar due to hard caking.

Introduction

Central Azucarera Don Pedro (CADP) refinery in the Philippines is a relatively new refinery (commissioned February 1994) and was initially rated at 550 tonnes refined sugar/day when built. After expanding twice, it is currently producing 900 tonnes /day (mostly in 50 kg bags).

Over recent years, problems were experienced with hard caking of some of the sugar produced (which is stored in 50 kg bags). This caking was severe around the edges of the bags with a thick, rock-hard crust forming only days after production of the sugar.

The refinery was considering the installation of a fluidised bed cooler for refined sugar, to be located downstream of the existing co-current hot air and counter-current cold air rotary dryer/cooler.

Options of conventional sugar conditioning were also investigated, though the capital involved was substantial and little comfort could be gained that the desired outcome would be achieved (based upon performance of recently installed conventional conditioning systems in the SE Asian region).

Sugar Technology International (STI) offered a solution to CADP which involved the up-rating and upgrading of their rotary dryer/cooler and the installation of short residence time conditioning facilities.

Steps to conditioned sugar

To produce well conditioned sugar, it is believed that four key steps are involved:

1. Pan stage operations need to provide consistent grain size with low CV and few agglomerates,
2. The centrifuging step needs to achieve good purging and have no massecuite balls or wet lumps,
3. The drying step needs to be as slow as practical to minimise the quantity of sucrose in the amorphous state, and deliver sugar of appropriate moisture content and temperature, and finally,
4. The conditioning step needs to crystallise the excess sucrose held in the film around the crystal so the film is at equilibrium with its surroundings.

Of these steps, the first two relate purely to good refinery operating practice and will not be covered further. The CADP sugar refinery was already achieving good pan stage and centrifugal performance so these areas were not the cause of the hard caking that was observed.

This paper deals with the last two steps of achieving well conditioned sugar; drying and conditioning. The drying modifications at CADP are installed and commissioned and results are presented; however, at the time of writing. the conditioning system is under construction and not yet commissioned. It is the intention to discuss the conditioning system results at the ISSCT oral presentation.

Drying

The rotary dryer/cooler is an important part within the broader series of processing steps required to achieve well conditioned sugar that is free of caking problems.

The contribution of the drying step to potential caking issues is well established in the technical literature, but often over-looked within sugar refineries. It should be recognised that the drying step creates the problem of a supersaturated or amorphous sugar film around each crystal that the subsequent conditioning step must resolve.

In the drying step, the obvious goals are to consistently produce sugar of the desired moisture content and temperature. We contend that a more subtle goal is to prolong the drying step within the dryer to allow the greatest opportunity for crystallisation of sucrose within the film around each crystal.

While it is unrealistic to completely crystallise the sucrose within the film (such that the film leaves in a saturated state), to the extent that we can crystallise sucrose during drying, we minimise the quantity of sucrose in the amorphous film around each crystal and hence the task to be undertaken during downstream conditioning operations.

The major mechanism by which we moderate the rate at which drying occurs in the feed end of the dryer is to reduce the air flow rate and temperature. Reduced air flow leads to increased humidity in the exhaust from the dryer and thus a reduction in the driving force for evaporation.

It is interesting to contrast this approach with the earlier operations of this dryer when it used co-current hot air followed by counter-current cooling air flow. In that original configuration, co-current hot air (typically 90–100°C) was used in the sugar feed end of the dryer. Such air has an extraordinarily low relative humidity and sugar can be expected to lose moisture extremely rapidly under such conditions.

Other dryer types commonly used in various parts of the world similarly incorporate heated, extremely low RH air to perform drying (e.g. rotary louver, twin rotary drum and fluidised bed dryers). Of these, the speed with which moisture is removed is probably highest in the fluidised bed dryers.

Details of conversion of rotary dryer/cooler

Modifications to the rotary dryer/cooler involved a re-configuration to purely counter-current air flow, re-flighting of the drum to achieve a significant increase in capacity and the installation of instrumentation and controls to manipulate the dryer operating conditions over the entire sugar flow range (0%–100% capacity). The major modifications are shown in the schematic diagrams in Figure 1 (before conversion) and Figure 2 (post conversion).

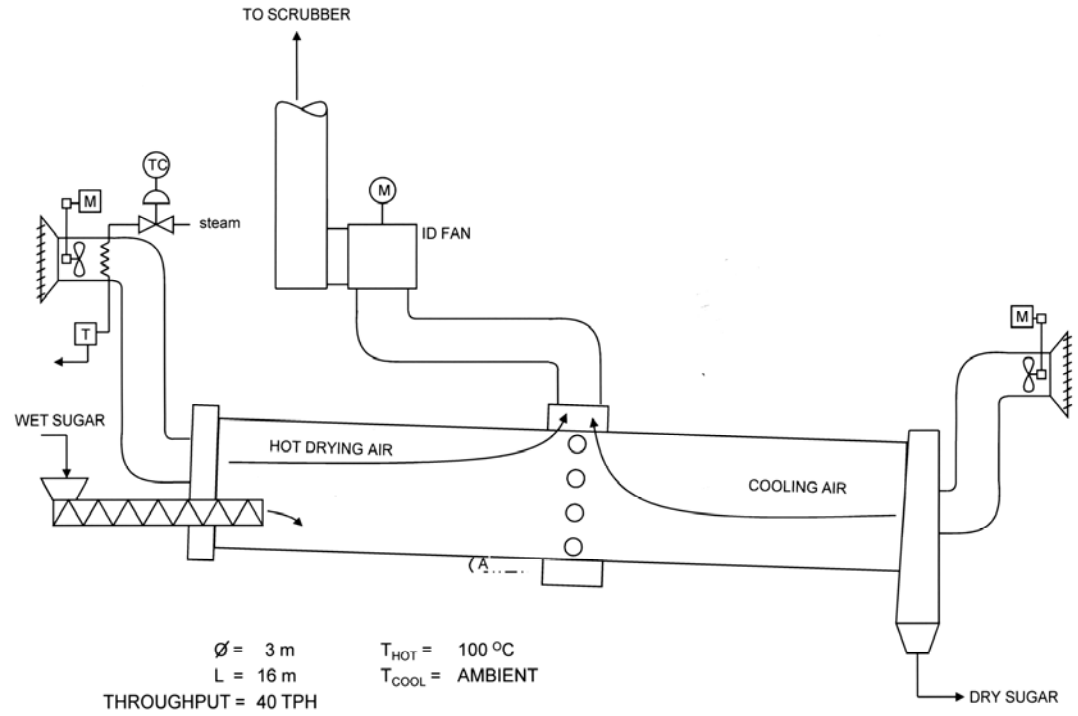

Fig. 1—Sugar dryer before conversion.

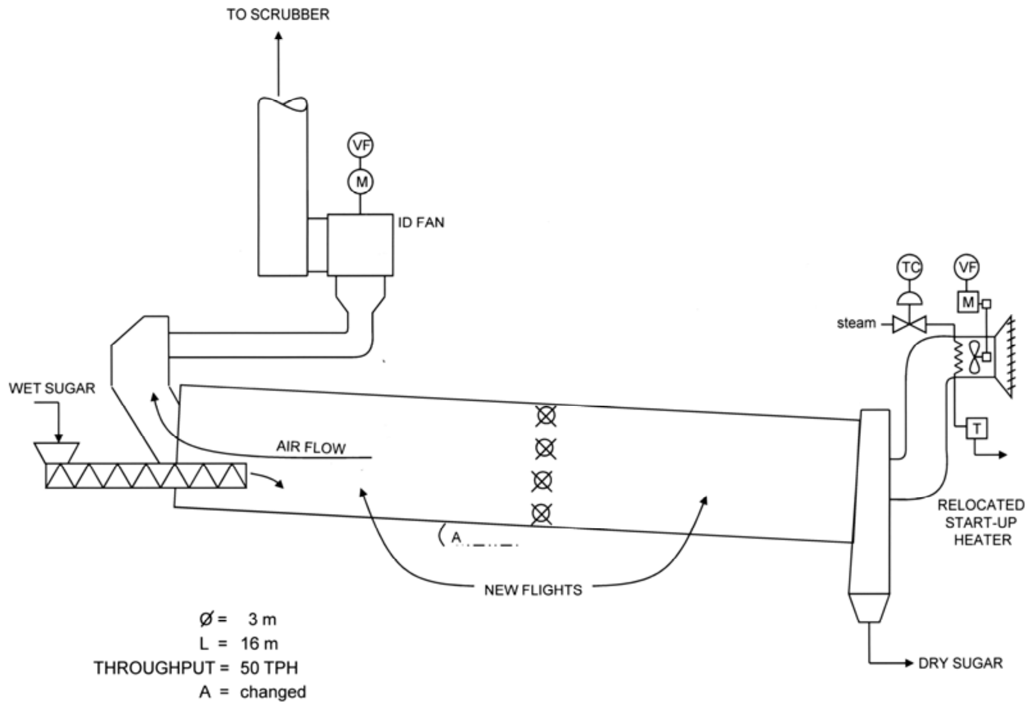

Fig. 2—Sugar dryer after conversion.

The conversion retained the original dryer/cooler drum, though the central air exit holes were blocked when converting to purely counter-current flow. The original ID fan and cool air fan were retained, though variable frequency drives were fitted to reduce the air flows to the desired values. The original steam heated air heat exchanger was relocated, and (part way through the season) 67% of the heat exchange area blocked off, with a smaller steam control valve fitted.

Results of modifications

At the time of writing this paper, the dryer/cooler modifications are complete and have been operating throughout the 2008/2009 season. The conditioning silo modifications discussed in the next section are nearing completion but are not yet operational. The results presented here clearly show the benefit derived from the dryer conversions alone.

The sugar storage facilities at CADP are formidable as is clear from Figure 3. This photograph was taken in June 2009 and shows the CADP warehouse approaching full capacity with 900 000 x 50 kg bags of sugar in storage. Such tall stacks provide significant compressive loads and provide a real test of the caking propensity of the sugar.

Figure 4 shows the hard lumping of sugar in bags prior to the dryer conversion—such lumps were hardest towards the outside of the sugar bags.

Specialised machines to compressively deform the bags (known as ‘lump breakers’) were deployed in an attempt to resolve the issues. It is understood such machines are utilised in countries such as Brazil and Thailand. Since modification, only soft caking is observed even after three months storage in deep stacks (see Figure 5).

The lump breaker machines have not been in use for the entire 2009 season. The soft caking experienced after conversion readily breaks up in the normal handling of bags.

Fig. 3—CADP store with 900 000 bags, June 2009.

Fig. 4—Hard lumps of sugar prior to conversion, March 2008.

Fig. 5—Sugar nature after the dryer conversion and storage for three months, July 2009.

The quantities of sugar remelted due to caking over the past five years at CADP are given in Table 1. The statistics exclude bags remelted due to physical damage to bags in handling.

Table 1—Remelt history at CADP.

Refinery year (July to June)	Re-melted due to caking (50 kg bags)	Total production (50 kg bags)
2004–05	20 000	4 765 000
2005–06	15 000	4 720 000
2006–07	21 000	4 000 000
2007–08	30 000	3 735 000
2008–09	Nil	4 050 000

Figures 6 and 7 provide details of dryer temperatures before and after conversion. The air preheat temperature can be seen to be reduced during the year to the values recommended. This was achieved part-way through the season, when 67% of the air heater area was blocked off and a smaller steam control valve fitted to improve control. Note that, with the low counter-current air flow, hot air in the sugar discharge end of the dryer only has limited ability to heat the sugar, so the sugar outlet temperature after conversion is not increased.

The moisture content of the product sugar (by gravimetric determination) is seen to rise from the before modification period to after (though still within specification), yet the product sugar exhibits dramatically reduced caking propensity. This underlines the fact that moisture content in isolation is not a measure of the degree of conditioning or caking propensity (as discussed further in the conditioning section).

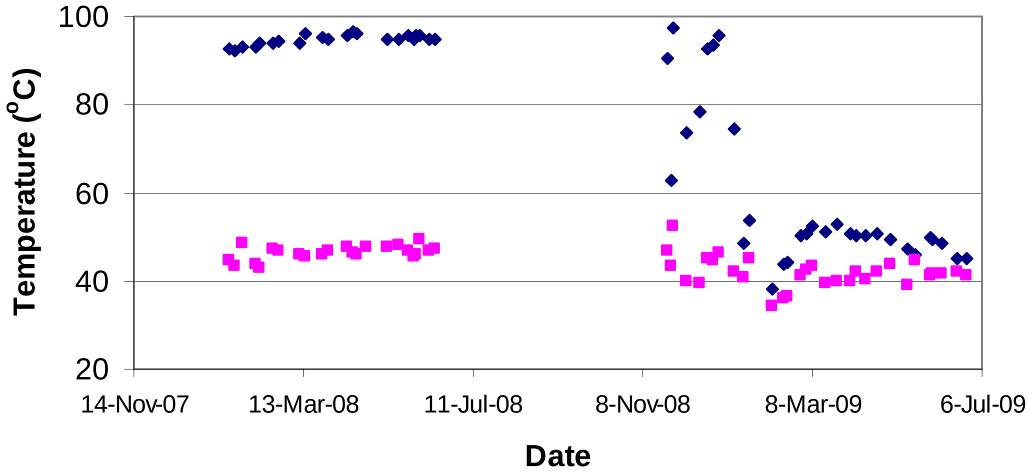

Fig. 6—Inlet air and product sugar temperatures.

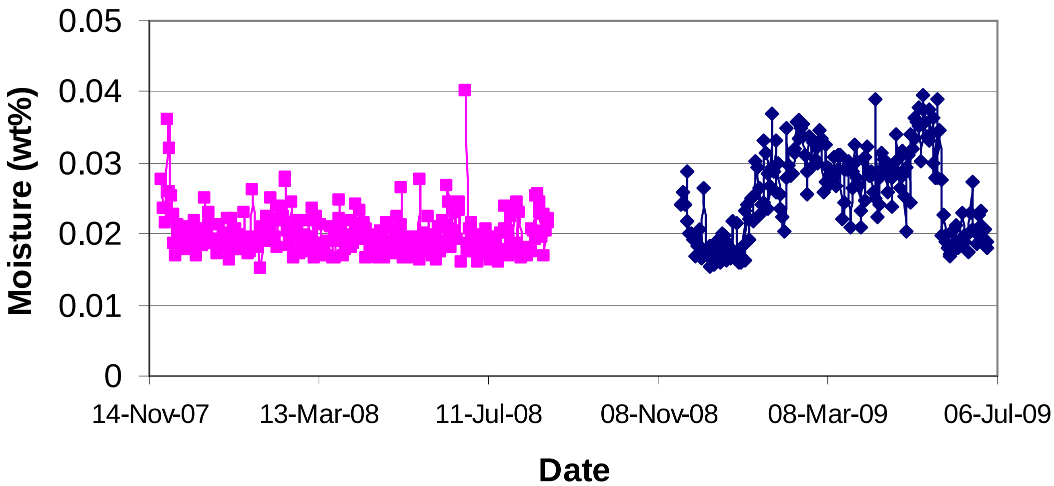

Fig. 7—Moisture content of sugar product.

The elimination of hard caking of sugar through dryer modifications alone has been demonstrated. The sugar does still exhibit soft caking that breaks up readily in normal bag handling operations. This soft caking tendency will be addressed with the commissioning of the SRTC system.

The test through the 2008–09 season has been particularly good as many bags have been stored over several months in tall stockpiles without caking.

Conditioning of refined sugar

The means of assessing the 'condition' of sugar has been the subject of much debate over many years. Some refinery staff maintain that the moisture content of sugar can be used as a measurement of the degree of conditioning and that moisture removal is the primary aim of conditioning (Rein, 2007). While conditioning is often associated with a small reduction in moisture content, moisture content does not imply the state of conditioning, irrespective of how the moisture content has been measured.

In the conditioning of sugar, we maintain that the key goal is to crystallise sucrose that is held in a supersaturated state within the amorphous layer. By doing so, the later uncontrolled crystallisation of this sucrose is avoided. It is the crystallisation of sucrose at the contact points of sugar crystals leading to intercrystalline bridging that is caking.

Sugar moisture measurement is complicated by the known influence of supersaturated films on the moisture content as determined by conventional laboratory drying tests (Rein, 2007). Karl Fischer analysis of moisture is recognised as being a more accurate moisture determination than gravimetric techniques, but such equipment is not commonly available in refinery laboratories.

With highly supersaturated films, a significant proportion of the water is 'bound' and will not be detected during gravimetric analysis. With crystallisation of sucrose in the supersaturated film, bound water is converted to free water.

This is exemplified by the observation that the gravimetric moisture content of sugar can as much as double simply by storing the freshly dried sugar in a sealed container (Schmalz and Stroebel, 2004).

The observed 'creation' of moisture adds to the mystique of sugar conditioning but is quite easily explained in terms of the reduced activity of water in supersaturated films of unconditioned sugar.

In modelling of sugar dryers and sugar conditioning systems, the scientific means by which the 'availability' of water is expressed is by calculating the activity of water. The activity of water is simply the vapour pressure expressed by the water in a film divided by the vapour pressure that would be exerted by pure water at the same temperature.

If a supersaturated film has a water activity of 0.2, then it will be in equilibrium with air at the same temperature if the air RH is 20%. Water activity is useful because it can mathematically describe the varying 'availability' of water without resorting to a 'bound water' versus 'free water' classification.

The quantity of sucrose that is contained in a supersaturated film can be used to rank the caking potential of sugar as shown in Table 1.

The table below demonstrates that while the goal of a conditioned sugar is to achieve a nearly saturated film with low moisture content, knowing just the moisture content (however measured) is not sufficient to judge if conditioning has been completed.

In practice, no matter how well conditioned, it is always possible to induce caking by subjecting sugar to extreme treatment (e.g. gross wetting and partial dissolution followed by drying). In normal operations, however, having only thin films around crystals that are nearly saturated provides the least quantity of sucrose in solution that can form bridges.

Table 1—Caking potential

CAKING POTENTIAL				
		Moisture Content of Dry Sugar		
		Low 0.02% (grav)	Medium 0.04% (grav)	High 0.06% (grav)
Water Activity of Film	0.1 Highly S'Satd	High	Extreme	Extreme
	0.5 Moderately S'Satd	Low	Moderate	Moderate
	0.7 Mildly S'Satd	Very Low	Low	Moderate

Through the simulation of evaporation, heat transfer and crystallisation processes with a sugar dryer (Tait *et al*., 1994), it is possible to predict the partial pressure of water vapour exerted by the sugar as it progresses through the dryer. Figure 8 shows the predicted partial pressure of water exerted by the sugar in 30 equal increments as it moves through the rotary dryer (highest vapour pressure and temperature at the sugar feed end). Also presented in Figure 8 is the vapour pressure exerted by water of varying activities.

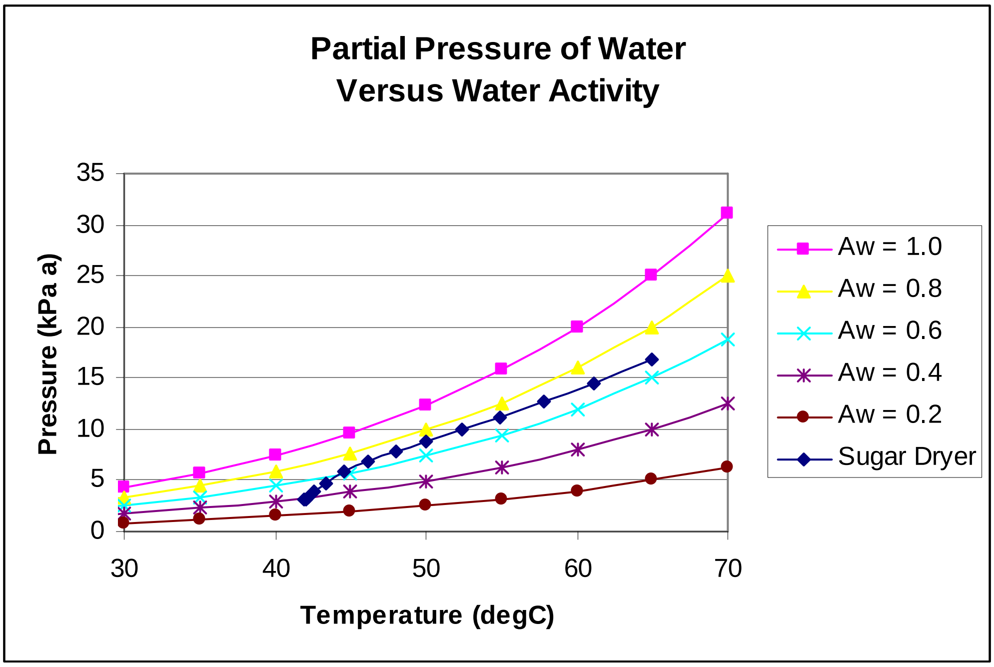

Fig. 8—Calculated water activity profile through dryer.

It can be seen that the calculated water activity at the sugar feed end is significantly less than that for pure sucrose at saturation (which is about 0.82–0.84). This is due to the rapid evaporation and concurrent crystallisation occurring near the feed end of the dryer. For about the first 6 elements (i.e. about 20% of the flighted length), the crystallisation rate is able to keep pace with the onset of supersaturation due to both the removal of water and the reduction in temperature. For the balance of the dryer, however, the activity of water rapidly reduces as the kinetics of crystallisation fall away. For this simulation of a refined sugar dryer, a water activity just under 0.4 is predicted. This prediction seems consistent with published measurements (Schmalz and Stroebel, 2004) who quote water activities of 0.45–0.55 for sugar of <0.05% moisture content. The results of these simulations and plant measurements confirm that air of 10%–20% RH (as used in conventional conditioning) would remove further water from this sugar in the already supersaturated state it leaves the dryer. For a macro-scale comparison, to understand the nature of the films being dealt with, the water activity of 'Hard Candy' is 0.20 to 0.35.

Details of short residence time conditioning installation

The STI SRTC system at CADP is achieved by fitting radial internal divider partitions in two existing silos as shown diagrammatically in Figure 9. The silos are capable of receiving sugar of different grades from the refinery. The three compartments within each silo will consecutively fill, condition and empty on a cycle. The fill time is nominally six hours, conditioning time of eight hours and a further 5–8 hours in which to empty the compartment before the next charge is due.

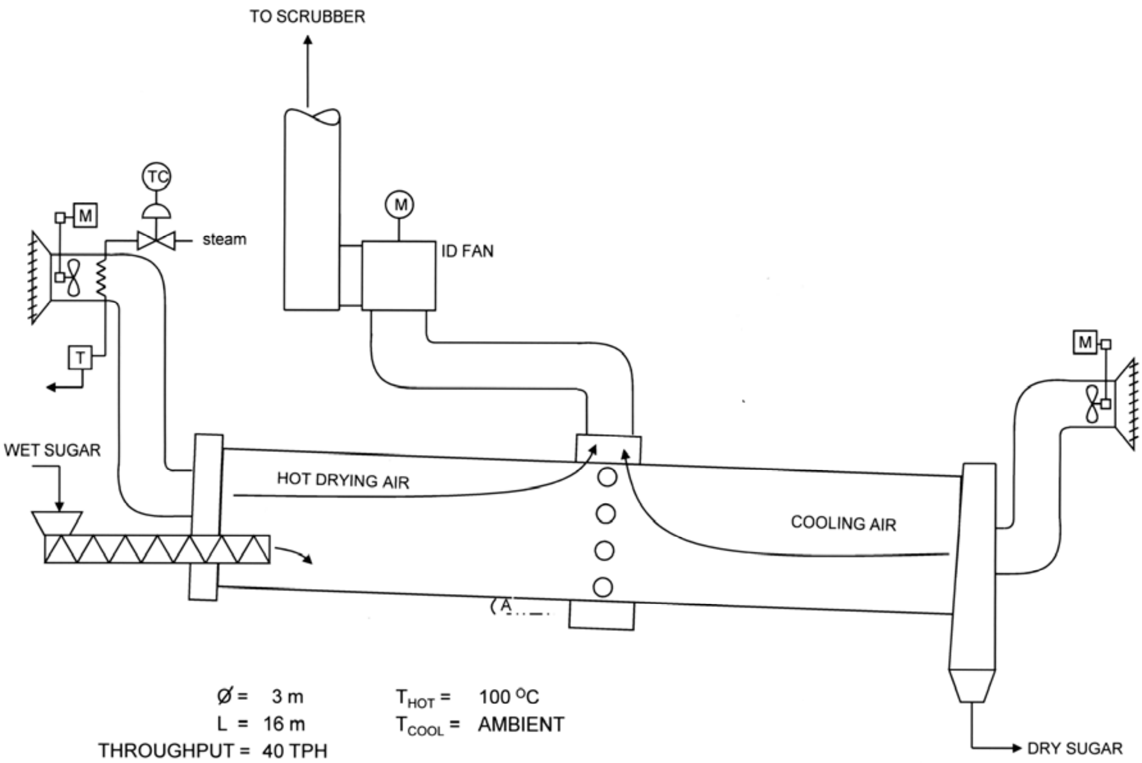

Fig. 9—Short residence time conditioning system

By this means, an essentially continuous flow of sugar to downstream packaging equipment is maintained despite the conditioning operation being conducted as a batch. A specialised refrigeration and control package is used to supply air at the required conditions to each silo. Air is only directed to one compartment per silo simultaneously.

Comparison of SRTC and conventional conditioning

It is informative to reflect upon the combination of factors that lead to conventional conditioning systems requiring the long residence times they do.

In a tall silo, there will be an appreciable pressure drop as air is blown through it. Compressing refrigerated air raises the partial pressure of water vapour within that air. To avoid problems with moisture pick-up in sugar against the inlet or against the walls/floor of the silo, it is necessary to prepare quite low RH air. As this air expands (pressure reduces), the RH falls further. Thus, if you build a tall silo, there is not much choice other than to pass low RH air through it.

If sugar continually enters and leaves the conditioning silo (and perhaps is recirculated on occasion), this further complicates the issue because unconditioned sugar is more 'moisture hungry' than conditioned sugar of the same true moisture content. When comparing sugars of the same moisture content, the water in conditioned sugar has a higher water activity because its vapour pressure is not so suppressed by the supersaturated conditions in the film.

In conventional conditioning (Rein, 2007), air of typically 10% to 20% RH is supplied to silos of 24 to 48 hours residence time at a specific air rate of 3 m^3/h.t of sugar. For a refinery producing 50 t/h refined sugar, this translates to storage of 1200 to 2400 tonnes and air flows of 3600 to 7200 m^3/h. Such air flows have the capacity to aggressively strip moisture from the film surrounding each crystal resulting in a low water activity.

The rate of sucrose crystallisation in a supersaturated film is extremely slow under conditions of low water activity (Broadfoot, 1980) because, while the supersaturation driving force for crystallisation has been enhanced by removing moisture, the mobility of molecules within the film is severely reduced and therefore the kinetics of crystallisation are reduced.

If a silo operates under conditions of low RH, then the sugar within it is destined to undergo slow, conventional conditioning. Under these conditions, long residence times are required (e.g. 48 to 72 hours).

The STI short residence time conditioning system conducts conditioning in a batch of sugar over a much shorter residence time (hours) compared to conventional sugar conditioning (days). The obvious advantage of this is that the physical size of silos and associated equipment is dramatically reduced.

The underlying principle of short residence time conditioning is that conditioning can be performed relatively quickly if:

- the highly supersaturated sugar film is first given moisture to *lessen* the degree of supersaturation;
- crystallisation is allowed to proceed rapidly under the resulting higher mobility/ lower viscosity/ lower supersaturation film environment; and
- then, as the water activity rises in the film, moisture is removed (generally slightly more moisture is removed than was ‘loaned’ in the first place).

Central to the concept of short residence time conditioning is the establishment and propagation of a moisture wave through a batch of sugar. While supersaturated conditions are retained throughout the passage of the moisture wave, at the peak of the wave, the degree of supersaturation in the film is significantly reduced compared to the highly supersaturated film on sugar that enters the silo from the dryer.

In Table 2, the contrasting paths of conventional conditioning and short residence time conditioning are highlighted.

Table 2—Caking potential highlighting alternate conditioning paths.

Conditioning Pathways					
Caking Potential			Moisture Content of Dry Sugar		
			Low 0.02% (grav)	Medium 0.04% (grav)	High 0.06% (grav)
Water Activity of Film	0.1	Highly S'Satd	High	Extreme (Conventional)	Extreme
	0.5	Moderately S'Satd	Low	Moderate	Moderate
	0.7	Mildly S'Satd	Very Low	Low (SRTC)	Moderate

Conventional conditioning initially reduces moisture content flowed by slow crystallisation, while SRTC initially adds moisture before crystallising and drying under faster though moderate conditions. While the same net result is obtained, the kinetics of crystallisation along the SRTC path is dramatically faster.

It is fair to say that short residence time conditioning is considered somewhat controversial as it represents a radical departure from conventional conditioning operations. It is through the careful manipulation of moisture that the greatest gains in conditioning kinetics can be achieved. Ironically in sugar conditioning, it appears that when well handled, moisture can be your best friend, yet when poorly handled, it is your worst enemy.

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L’INTRODUCTION D’UN SECHEUR/REFROIDISSEUR ET D’UN SYSTEME DE CONDITIONNEMENT A COURT TEMPS DE SEJOUR POUR LE SUCRE RAFFINE

Par

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**MOTS-CLEFS: Sécheur,
Refroidisseur, Conditionnement.**

Résume

LE SECHEUR/REFROIDISSEUR pour le sucre à la raffinerie de CADP (Centrale Azucarera Don Pedro, Philippines) a été revalorise et un système de conditionnement a court temps de séjour a été installé en 2008–2009 pour résoudre les problèmes de prise de masse rencontrées dans des sacs (50 kg) de sucre stocké. On décrit les modifications effectuées et les résultats obtenus pour résoudre le problème de prise de mass. La reconfiguration et l'automatisation du sécheur/refroidisseur et l'installation de conditionnement a court temps de séjour (période de conditionnement de huit heures) a été une solution simple et de coût faible pour résoudre les problèmes de prise de masse à la raffinerie, par rapport aux alternatives. La reconfiguration et l'automatisation du sécheur/refroidisseur ont réduit la consommation d'énergie et de vapeur et ont permis une augmentation en capacité, tout en conservant le même tambour rotatif, les ventilateurs, l’équipement pour le lavage des gaz et le réchauffeur d’air. L'amélioration des performances a éliminé le besoin d'un refroidisseur a lit fluidisé, qui avait été considère précédemment par la raffinerie. Depuis la modification, la raffinerie a complètement éliminé la prise de masse du sucre raffiné et il n'a pas été nécessaire de refondre et de recycler les sacs de sucre.

IMPLEMENTACION DE LAS MODIFICACIONES EN LA SECADORA/ENFRIADORA Y DE UN SISTEMA DE ACONDICIONAMIENTO DE CORTO TIEMPO DE RESIDENCIA

Por

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PALABRAS CLAVES: Azúcar, Enfriadora, Secadora, Acondicionamiento.

Resumen

EN EL CENTRAL Azucarero Don Pedro (CADP) una refinería ubicada en Filipinas, se realizaron modificaciones a la secadora/enfriadora rotatoria y se implementó un sistema de acondicionamiento de corto tiempo de residencia durante la zafra 2008–2009. Estas modificaciones fueron hechas con el fin de resolver los problemas de aterronamiento observados en azúcar refinada empacada en bolsas de 50 Kg. Este artículo describe las modificaciones realizadas y los resultados alcanzados en la solución del aterronamiento. La reconfiguración y automatización de la secadora/enfriadora y la instalación de un sistema de acondicionamiento con un tiempo de residencia de 8 h fue una solución simple, de bajo costo de capital y operación, para resolver los problemas de aterronamiento comparada con otras alternativas. La reconfiguración/automatización de la secadora/enfriadora redujo la potencia y el consumo de vapor y permitió significativos incrementos en capacidad a pesar de que la secadora conservó tanto la misma carcaza, como los ventiladores, el srubber y el calentador de aire. El incremento en el desempeño de la secadora eliminó la necesidad de un enfriamiento en lecho fluidizado alternativa que había sido considerada en la refinería. A partir de la modificación, la refinería eliminó completamente el aterronamiento del azúcar refinado. No ha sido necesario derretir o reciclar azúcar debido a aterronamiento.