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The Mathematical Modelling of Caking in Bulk Sucrose

This thesis is presented as partial fulfillment of the requirements for the degree of Master of Engineering in Bio Process Engineering at Massey University

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Abstract

Ever since the need for bulk transportation of sugar, there have been problems with the product caking during storage and transportation. This project was carried out in order to try and understand the mechanisms behind caking, and by mathematically modelling the system, to find the conditions needed to avoid caking, and to compare these to the observations and experiences made by those working in the industry.

A thermal analysis monitor was used to determine if significant quantities of amorphous sucrose existed on the dried sugar, to support the amorphous recrystallisation caking mechanism. The level of amorphous sucrose was found to be less than 0.1%, so it was reasoned that any moisture contribution from such a small fraction, even given its tremendously hygroscopic nature would be negligible in contrast to that from the humidity caking mechanism.

The water activity at which capillary condensation begins to occur significantly was then investigated and found to be 0.8. At this critical water activity, significant capillary condensation between particles occurs, forming liquid bridges between the particles and causing the bed to lump. If the lumped bed is then subjected to an environment with a lower water activity, over time the liquid bridges will begin to crystallise, creating solid bridges between the particles. These solid bridges have several times the mechanical strength of the liquid bridges and it is at this point that the bed is considered to be caked. The data from this experiment was then further used to build a relationship between the water activity of a bed, the radius of the liquid bridges formed by capillary condensation (Kelvin radius), and the resulting lumped strength of the bed.

A model based on the caking of lactose was then adapted for sucrose and validated by testing conditions of heat and moisture migration through a packed bed, and the resulting effect on the strength of caking. Various model parameters were then adjusted between experimentally known values in order to obtain the best-fit possible for the experimental data. The data from the experiment and the model agreed well, however the temperature data did exhibit some scatter, possibly caused by insufficient grounding of the measuring device, making it susceptible to noise.

The model was then used to build up a graph of the effect of initial water activity, cold and hot temperatures on the maximum water activity that a bed would reach at the cold surface. Using the critical water activity, this graph can be used to represent the limits at which sucrose of a certain condition can be stored and transported without the sucrose caking. This also opens paths for future research, as this will allow conditions created by the changing of process conditions such as temperatures and residence times within the driers, to be measured in terms of whether the end product will have a tendency to cake.

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CHAPTER 1

INTRODUCTION

1.1 Problem Description

The caking of sucrose has been a serious problem in the sugar industry since the introduction of bulk handling and transport as early as the 1900's.

Through many years of observation, experience and experimentation, many factors contributing to the caking phenomenon have been described. These include:

- Caking is caused by the migration of moisture caused by temperature gradients across the storage vessel.
- The hygroscopic nature and the physical chemistry of the sugar crystals surface are responsible for moisture absorption.
- Packing at temperatures above ambient can cause sugar to set.
- Products with large crystals and a high coefficient of size variance are more prone to caking.
- Literature suggests rapid drying causes an amorphous layer to form around the crystal, trapping a film of saturated sugar on the crystal surface.
- The amorphous surface allows increased moisture uptake from its surroundings.

From these observations, mechanisms have been conceptualised in order to explain the occurrence of these events. It is the aim of this project to investigate these and attempt to put a solid theoretical base to the caking phenomenon.

1.2 Project aims

There are several specific aims for the project:

- Searching the available literature for existing caking work and determine the parameters to be used in these models.
- To experimentally confirm undocumented parameters to be used by any models.
- Make amorphous sucrose in the lab and use it to find an accurate as possible value for the amorphous content of sucrose at different stages in the production process.
- Determine whether the physical properties of sucrose are similar enough to lactose to be able to be use the model formulated by Bronlund (1997), for modelling the caking of bulk lactose.
- If suitable take the lactose model and adapt, apply and then validate the model for sucrose, using it to generate data suitable for process control within the plant.