Mapping of causes for variation in quality of sugar in chocolate manufacturing

Maja Modigh

Examinator: Carl-Fredrik Mandenius
Academic supervisor: Robert Gustavsson
Supervisor at Cloetta: Agnieszka Marklund
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The main purpose of the report is to present possible reasons and solutions for variation in quality of sugar used in confectionery manufacturing, with focus on chocolate manufacturing, at Cloetta Sverige AB in Ljungsbro. The project has its purpose to optimize the quality of both the sugar and manufacturing processes in a long-term perspective, since the variation in quality of the sugar affects, more or less, all manufacturing processes and causes yield losses.

Cloetta Ljungsbro uses a pneumatic conveying system to transfer the sugar within the factory and when unloading the sugar from delivery trucks. A various of different analyses were performed in order to study the sugar quality; water content analyses in forms of Karl Fischer titration and particle size distribution analyses with help from sieving. During the sugar sampling time period, an observation of the air pressure used by the road tanker while unloading sugar at Cloetta and the lead time as sugar was delivered was executed. Moreover, data of the dew point in the pneumatic conveying system and, both temperature and humidity in the sugar silos, were collected.

As a result, most of the sugar particles breakage occurred somewhere between the delivery road tanker and while in the storage silos. Most likely it is due to the use of high pressure when unloading the sugar that the particle size distribution of the sugar varies, but also causes the temperature to reach a higher temperature than recommended. Furthermore, the water content of the sugar was higher in the beginning of the autumn. Further investigations of the effect of unloading the sugar and storage of sugar should be done, but also analyse the air velocity used within the pneumatic conveying system.
ABSTRACT

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1 **INTRODUCTION**

1.1. **PURPOSE OF THE PROJECT**

The Cloetta factory in Ljungsbro, Linköping, has been experiencing problems with the variation in quality of the sugar throughout the supply and manufacturing chain. Therefore, the main purpose of this report is mapping out when and where in this process these quality variations of the sugar appears. Since the variation in quality affects the whole manufacturing process in terms of yield losses and poor ability to control quality distribution, the aim of this report was to find possible solution in the issue. The variation of the sugar also influences Cloetta’s ability to control the manufacturing process; poor sugar input may cause problems in terms of producing desired output.

The objective of this project were to map out the variation in quality by performing several studies. Ljungsbro have been facing two types of problems; the first issue is that the sugar absorbs waters or recrystallizes while transported from supplier or somehow throughout the system, which causes formation of sugar lumps. The lumps clog the pipes in the system, and in the worst case scenario causes the pipes to tear open. Secondly, fine sugar is formed due to grinding of the pipes and particle-particle collision, especially while transported in the pneumatic conveying system in the factory.

Although the poor quality of the sugar affects all production lines, including the chocolate manufacturing, Cloetta Ljungsbro have been experiencing most of their production issues within the chocolate production. This is due to the settings that need to be set for many of the equipment and machinery that is crucial for chocolate manufacturing. With large quality variation the control settings poorly fit, which, therefore, leads to complications in forms of e.g. irregular chocolate mass.

Studies of the raw material’s physical and chemical variation was carried out, but also studies of the quality of purchased raw material and the company’s suppliers. Moreover, reviewing current process design and technical solution was included in the project.

In long-term, this project will be a groundwork for improvements for the overall manufacturing process at Cloetta Ljungsbro, but also support for other factories within the Cloetta corporate group. The predominant raw material the company are using for all products is precisely granulated sugar, hence, the project also had its purpose to optimize the quality of the raw material within the factory. By studying the suppliers, quality in the sugar and the process design, further studies in the matter may be done. The results of the report will hopefully be used in Cloetta’s work to generate a modified or new technical solutions for the sugar storage, transportation and processing in the chocolate factory. Therefore, the beneficial aspects of the project were to optimize the company’s chocolate manufacturing processes in terms of costs, efficiency and quality.

1.2. **OBJECTIVES**

The main objective of this project was to evaluate the process system, both take and analyse samples, and thereby find causes for variation in quality of the sugar in the manufacturing process that will led to final suggestions for improvements. The main objective was divided into sub-objectives, which are as following:

- Analyse physical and chemical variation of the sugar
- Evaluate process design and technical solutions
- Review supplier’s quality standards
Determine optimal approach for presentation of analysis data

1.2.1. Analyse physical and chemical variation of the sugar
One of the aims of this project was sampling sugar throughout the manufacturing system and analyse its physical and chemical variation. The physical aspect is the particle size, whereas the chemical aspect is the water content. The physical analyse of the sugar include sieving the sugar to determine particle size distribution. Chemical variation analyses include a study of the water content in the sugar. With these studies, data was assembled and thereby created different sorts of diagrams. Henceforth, make assumptions where the problem appears.

The aim was to get two samples a week, for a total of six weeks, from each sample point. A reference sample was sent from supplier, and four samples were taken at the Ljungsbro factory;

- From road tankers as they arrive to Ljungsbro factory.
- Below the silos (sugar storage container) before transported into the pipelines.
- The nearest production line.
- The production line the farthest away (the raw storage hall, which is the storage facility before sent to chocolate production).

1.2.2. Evaluate process design and technical solutions
A review of existing process design and technical solutions were performed. By assistance of the sugar samples, a circumstantial review of technical solution for the sugar transfer was carried out. It was a substantial task to compare the transfer of the sugar in the factory, which includes silos, pipelines and way of regulating transfer the sugar (Ljungsbro uses pneumatic conveying) with other possible solutions and factories. This included studying how the bends, length and distribution of the pipelines in the factory influences on raw material. By taking two sugar samples in the beginning and at two different productions in the factory, it helped confirm how much the transportation layout affects the quality distribution of the sugar.

This objective also included physical aspects that includes the air pressure of the compressed air used throughout the pipe system and checking the air pressure used during sugar unloading. There is also a chemical prospect, which includes the humidity in the silos (sugar storage container).

Interviews with employees at Cloetta, suppliers and companies in the industry will also help evaluate the process design and resolve final conclusions. By comparing Ljungsbro’s process design with literature, other methods and what other food industries uses, it will altogether may make it possible to suggest improvements.

1.2.3. Review supplier’s quality standards
The product specifications from suppliers implement good quality, but a study visit to supplier’s sugar plant and the sugar analyses assisted to evaluate what quality the supplier actually have. The study visit helped to get a better understanding of their manufacturing process and logistics. This sub-objective also included observation of the lead time of the sugar delivery.

1.2.4. Determine optimal approach for presentation of analysis data
The data from chemical and physical analyses needs to be presented in a proper way to get out as much as possible from the study. A goal was to find approaches to present the data statistically in such a way that it will represent the results to make final conclusions of the quality variations.
1.3. **BOUNDARY CONDITIONS**

The project was applied to Cloetta Sverige AB in Ljungsbro, Linköping, with focus on the raw material crystalline sugar in the manufacturing process of chocolate. A major must were to read theory in forms of literature, but also take into account to collect information from employees at Cloetta, other companies in the industry and suppliers by doing interviews.

The main task was sampling sugar at four different points in the factory, but also use a reference sample from supplier for studies. The four sample point in Ljungsbro factory is (1) from the road tanker as it arrives to Cloetta Ljungsbro, (2) from the silo, (3) from the nearest production line, and (4) from the farthest production line (the raw material storage before entering chocolate production). Analyses in form of sieving and examining water content of the samples were carried out, but also monitor the humidity of the silos, the lead time and the air pressure used. There was a study visit to supplier X with purpose of getting better knowledge of the sugar production process. The results of this report was to suggest possible reasons for the project issues along the manufacturing chain and thereby, suggest technical solutions for the sugar pipes and tanks, suppliers and the raw material.

1.4. **EXPECTED IMPACT OF STUDY**

Cloetta has a vision that read out “To be the most admired satisfier of Munchy Moments” and their mission is “To bring a smile to your Munchy Moments”. Cloetta stands for 67% of the confectionery consumption in Sweden, Italy, Finland, The Netherlands, Norway and Denmark. The company is responsible for big brand like Ahlgrens bilar, Bridge, Center and Juleskum, but recently started a cooperation with the food market Coop in being their main supplier of confectionery and chocolate. (Förvaltningsberättelse [Cloetta AB] 2015)

Due to the fact that Cloetta is one of the main confectionery and chocolate distributor in Europe, the issue with variation in sugar quality effects a big market. Over 50% of the sugar distribution is used in chocolate manufacturing in Cloetta Ljungsbro, which brings this project to an important level. (iReports Cloetta 2015) It has come to their knowledge that it is not only the Ljungsbro factory within the Cloetta concern that has come in contact with this sugar problem, which makes this bigger than just Ljungsbro factory.

With sugar being one of the fundamental ingredients for the products manufactured by Cloetta, much good would come of doing a thorough study of its deviations and effect the production. This project will hopefully lead to less waste and variation, and therefore help take better control of the sugar throughout the supply and manufacturing chain. With better knowledge of what and where the issue with sugar appears, the process may improve to be more efficient and economical. With better communication and spreading knowledge internally and externally, continuous development and improvements would be possible.
2 THEORY AND METHODOLOGY

2.1 SCIENTIFIC BACKGROUND

2.1.1 Cloetta and sugar handling in Ljungsbro
Cloetta was founded in 1862 and is now a leading confectionery company in the Nordic region, the Netherlands and Italy. The company manufactures and market sugar confectionery, chocolate products, nuts, pastilles and chewing gum. (Cloetta AB 2015) In 1901, the first Cloetta factory was built, which was placed in Ljungsbro and the company has blossomed ever since. The Ljungsbro factory have twelve production lines and one chocolate hall that together produce approximately 22,000 tons every year of all final products. (Cloetta Sverige AB 2015)

The cost of raw material and packaging material for the Cloetta corporate group represents about 60% of the total production costs. Sugar, glucose syrup, polyols, cacao, milk powder and packaging material are the most valuable and substantial primary products. This project’s main focus is on sugar, and figure 1 shows that sugar represent 16% of the total production cost, which makes it such a valuable primary product to study. Moreover, since this project is delimited to chocolate production it is shown in figure 2 that chocolate make up 17% of the total retail sales per category for Cloetta AB. (Förvaltningsberättelse [Cloetta AB] 2015)

To get a general perspective of the influence by the quality variance of sugar, it is an interesting fact to view how the primary product sugar is distributed amongst the production lines. As seen in figure 3, the sugar distribution for the chocolate manufacturing in the production line “Chocolate hall” (called “Chokladhallen” in iReports) is the substantial consumer.

Sugar is a common name for sucrose, which is fundamentally a disaccharide consisting of glucose and fructose. Sucrose is extracted from sugar cane or sugar beet, and both sources produce identical natural sugar. Sugar has its most important task in food industry to contribute with sweetness and energy, but it also gives volume (bulk), texture and enhances taste. (Nordic Sugar 2010) The purity of crystalline sugar is extremely good, the sucrose content in the sugar industry is generally more than 99.9% and
rarely falls below 99.7%. The quality criteria in Europe for sugar regulates four categories for crystallized sugars according to purity and crystal size; from coarse to icing sugar. The chocolate manufacturing process requires white crystallized sugar to be free flowing and have crystals of uniform particle size for smooth processing. The chocolate industry in European countries is mainly supplied with sugar within size range 0.5-1.5 mm, but may differ depending on desired quality. When fine grains with a particle size below 0.2 mm is used, the particle flow is affected and therefore particles this small must be kept at a low level. The water content must not exceed 0.06 % and generally does not exceed 0.03 % in good quality crystallized sugar when in silo of the sugar factory. Moreover, the proper storage requires a temperature of 20°C and a relative humidity ranging from 20% to 60%. (Becket 2009) According to Becket (2009), all sugar qualities is shown in table 1.

Product specifications from supplier X and supplier Y present values of particle size, moisture content and sucrose content within suggested criteria of Becket (2009), as seen in appendix 1 and appendix 2. The main difference between the two suppliers are the mean particle size and its size deviation. Supplier X (appendix 1) shows smaller range of mean particle size than supplier Y (appendix 2), however supplier X shows a larger deviation range from desired particle size than supplier Y. But take to account that supplier X uses a narrower range of deviation from desired particle size than supplier Y.

Supplier X uses a belt conveying system to transfer sugar, and therefore derived that this is not the reason for sugar attrition and lump formation. The supplier also indicated that the silo condition are optimal and have a promise of the lead time not exceeding three days. No study of supplier Y is executed within this project since Cloetta have no supply contract with them during this time period.

Sugar is delivered by means of road tankers and pneumatically discharged from the vehicles into silos, where it is stored until further processing. (Becket 2009) Andersson describes that the shipments arrives from supplier X or supplier Y depending on which of the suppliers Cloetta have current supply contract with. Cloetta Ljungsbro receive sugar deliveries at least once a day with a load of 30 tons of sugar per shipment. Andersson describes that when a production line is in need of sugar, it sends a signal to the transmitter below the sugar silos to start transporting sugar. If more than one production line requests sugar, the system uses a priority list for transferring sugar. The sugar is sent in different batch sizes with aid of pneumatic conveying.

Crystalline sugar tends to cake in storage silos when stored at high temperatures or if the moisture content is too high. (K-Tron Technologies 2014) Skeppsby confirms that the compressed air used in the conveying system is dehumidified before entering the system, to prohibit the sugar from getting moist. The pneumatic system is regulated to maintain proper

<table>
<thead>
<tr>
<th>Table 1: Sugar qualities</th>
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<tbody>
<tr>
<td><strong>Scientific name</strong></td>
</tr>
<tr>
<td><strong>Purity</strong></td>
</tr>
<tr>
<td><strong>Molecule content</strong></td>
</tr>
</tbody>
</table>
| **Grades of particle size** | **Coarse sugar**: 1.0-2.5 mm  
**Medium fine sugar**: 0.6-1.0 mm  
**Fine sugar**: 0.1-0.6 mm  
**Icing sugar**: 0.005-0.1 mm |
| **Water content** | < 0.06 % |
| **Temperature** | < 20°C |
| **Relative humidity** | 20-60 % |

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1. Sales manager at supplier X, study visit 13 October 2015
2. Johann Andersson, Project manager of Electricity Automation at Cloetta Sverige AB, meeting 3 September 2015
3. Kristian Skeppsby, Maintenance associate at Cloetta Sverige AB, meeting 22 September 2015
humidity throughout the system. A detailed figure of the process design at Cloetta Ljungsbro is found in *appendix 4* and *appendix 5*. As known, supplier X promise a lead time of three days, but it has come to Andersson’s attentions that some trucks have a much longer lead time. The sugar delivery may be affected in ways of temperature and moisture level if held to long in the road tanker without controled conditions. Johansson declares that Cloetta Ljungsbro consume approximately 30 tons sugar (i.e. one shipment) in just one day, and thereby is the substantial storage time at sugar supplier and the distance between sugar factory to Cloetta. Johansson also explains that there is a drying stage within the silos, to ensure low moisture level.

A couple of years ago, supplier X have along with Cloetta done studies by installing sensors for the humidity and temperature inside the silos for almost 2 months, shown in *appendix 3*. The data from supplier X showed that the temperature varied between approximately 7°C and 21°C, which conclusively gave the temperature a mean of 14°C. The relative humidity was in range of 3% to 18%, whereas the mean is 10.5%. Supplier X means that this observation indicates a small probability of sugar lumps.

### 2.1.2. Sugar handling and conveying methods

When bulk material is transported from supplier to costumer, mainly road or rail vehicles are used for transportation in forms of blow tanks. In the case of road tankers, the vehicles usually have its own air supply for off-loading. Rail vehicles generally rely on a site air supply for off-loading with a pressure up to 2 bar, which is the case at Cloetta Ljungsbro. (Mills 2003) In general, truck unloading systems are laid out so that the truck can park as close as possible to the storage silo. When the truck can park next to silo, the pipeline has a vertical run of 20 to 30 meters and may include only one 90 degree bends, or a single 180 degree bends. This minimizes the conveying distance which in turn minimizes the unloading time. For truck silos containing roughly 28 to 30 tons of material, the usual unloading time is 1 to 2 hours, depending mainly on conveying gas density and material characteristics such as particle size and particle density. (Cabrejos & Troxel 2008) Both supplier X and truck drivers confirm that a suitable pressure is 1.5-2.0 bar. Pressure lower or higher than 1 bar is unsatisfactory, and particularly lower pressure indicates lumps. Johansson explains that the air pressure used within the factory is only 0.5 bar, which is significantly lower than used when unloading sugar from the road tanker.

The flow mode for a bulk solid material is largely determined by the material properties, in particular, those properties which involve particle-air interaction. These include basic particle properties, such as particle size, size distribution, moisture content, shape and hardness. (Pan 1999) Although crystallized sugar is a medium-hard material, if crushed, an icing sugar is created and then how a tendency to form lumps. This is due to the fact that fresh ground crystallized sugar possesses amorphous surface layers, which are able to take up moisture at higher rates. (Becket 2009) Amorphous sugar is significantly important in chocolate making as it can affect both flavour and the flow properties of liquid chocolate. Its surface is very reactive and can easily absorb any flavours that are nearby. It is also formed from crystalline sucrose at high temperatures, which may occur when sugar is milled. The amorphous state is an unstable one, and in the presence of water it will turn into crystalline material. Once the

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4 Logistics Fulfillment & Packing Development Manager at supplier X, meeting 8 September 2015
5 Per Johansson, Maintenance Manager at Cloetta Sverige AB, meeting 7 September 2015
6 Project manager at supplier X, email dated 2012-05-12
7 Sales manager at supplier X, Study visit 13 October 2015
8 Truck driver at Green Cargo, Sugar delivery 15 October 2015
change has taken place the moisture is expelled. The moisture on the surface makes them stick together resulting build up of sugar. These qualities may not be desired while transferring the sugar in the pneumatic conveying system. (Becket 2000) The effects of particle attrition can be costly in ways of increased dusting, powder caking, decreased product performance and reduced solubility. (Jenike & Johanson 2015)

An alternative to pneumatic conveying, which Cloetta Ljungsbro uses, are mechanical conveying systems. Mechanical conveying is an effective way to transfer large quantities of material for a relatively short distance and in straight lines. However, as distance become greater and the transfer path becomes more complicated, the number of mechanical systems will increase, and pneumatic conveying is preferred. In addition, mechanical conveyors are generally susceptible to food protection issues. Pneumatic conveying moves dry materials through pipelines by using air or other gas as motive force for transportation. Pneumatic conveying has long been a preferred method of sugar handling for its advantages of flexibility and protection of the material. (MAC Equipment Inc. 2015)

When selecting type of conveyor, the most important factor is the form of material to be transferred. Another significant factor when selecting a type of conveyor is the application in means of transfer rate, distance and installation environment. Mechanical conveyors are well suited for heavy, granular material that may be moist, doughy and package. The mechanical convey system is also practical with widely varied particle distribution. Materials commonly transferred by mechanical convey systems include whole grains and crushed rocks. Pneumatic systems are not used to convey short distances, instead long distances with multiple changes of direction and elevation are easily accomplished. Compared to mechanical conveyors, pneumatic systems help simplify the routing of bulk materials transfer paths throughout a plant. Ideal materials for pneumatic convey systems are fine, fluidizable, dry powders such as flour, sugar and food products. (Cyclonair Corp. 2014)

Table 2 illustrates how satisfactory each conveying method is according to Dinnissen (2015).

<table>
<thead>
<tr>
<th>Table 2: Comparing different conveying devices</th>
<th>++ very suitable, + suitable, -/+ satisfactory, - mediocre, – unsatisfactory</th>
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<tbody>
<tr>
<td><strong>Pneumatic conveying</strong></td>
<td><strong>Mechanical conveying</strong></td>
</tr>
<tr>
<td><strong>Screw-conveying</strong></td>
<td><strong>Belt-conveying</strong></td>
</tr>
<tr>
<td><strong>Disc-conveying</strong></td>
<td><strong>Chain-conveying</strong></td>
</tr>
<tr>
<td><strong>Elevator conveying</strong></td>
<td></td>
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<tr>
<td><strong>Contamination</strong></td>
<td>++</td>
</tr>
<tr>
<td><strong>Hygiene</strong></td>
<td>++</td>
</tr>
<tr>
<td><strong>Product breakage</strong></td>
<td>-/+</td>
</tr>
<tr>
<td><strong>Dust-free</strong></td>
<td>++</td>
</tr>
<tr>
<td><strong>Robustness</strong></td>
<td>++</td>
</tr>
<tr>
<td><strong>Energy consumption</strong></td>
<td>--</td>
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</tbody>
</table>

**Mechanical conveying**

The most common form of mechanical conveying is use of screw conveyor or belt conveyor systems. Screw conveying is based on a screw that turns around to convey products through a system of pipes. (Dinnissen 2015) The screw conveyor is suitable for a wide range of material
types, has a relatively simple operating principle and structure. Disadvantages of the screw conveyor design is the required horsepower as a ratio of the capacity and fictional mode of degradation of material. (CDM Systems, Inc. 2015)

Belt conveying systems offer the advantage that they convey products without shaking them. This makes them suitable for conveying ingredients that are fragile, sticky or pose an explosion risk. (Dinnissen 2015) Belt conveyors also have the advantage in distance, carrying material for miles across open terrain. The system often has many wear points and external dust control systems are needed. (CDM Systems, Inc. 2015)

The less common, chain conveying and disc conveying systems, are based on plastic discs attached to a chain or cable. As the chain or cable is pulled through a system of pipes the free-hanging discs push the ingredients through the system. Chain based and disc based conveying systems are especially useful for conveying products that are easily abraded, fragile or fluidizable, and can achieve very high capacity. (Dinnissen 2015)

Vibratory conveyors are common in industry to carry a wide variety of particulate and granular materials. The basic vibratory conveyor consists of a trough which is supported on or suspended by springs or hinged links and caused to oscillate at high frequency, and with small amplitude by an appropriate drive mechanism. (Woodcock & Mason 1987) This type of conveying is particularly suited for fragile powders and granules. (Dinnissen 2015)

Vertical conveying can be realized most effectively using an elevator. Such systems are based on wear-resistant containers mounted on a non-stretch belt or durable chain. Elevator based systems are reliable, energy-efficient, less susceptible to contamination and maintenance friendly. They are suitable for conveying ingredients that are sensitive to wear and tear, abrasion and breakage. (Dinnissen 2015)

**Pneumatic conveying**

When it comes to transporting bulk solids, pneumatic conveying is often the process of choice. This is mainly due to advantages like flexibility in routing, the possible distribution of bulk solids to different areas in the plant and the dust-free transportation of solids. These advantages outweigh disadvantages like high power consumption, wear of equipment and attrition of the conveyed bulk solids’. To date, it has been possible to reduce the impact of bulk solids attrition during pneumatic transport to a tolerable amount by such means as installing additional cyclones and filters. (Frye & Peukert 2002) Pneumatic conveying is suitable for conveying over long distances, with an approximately maximum of 700 meters, and a capacity from 10 kilograms to 50 tons per hour. (Dinnissen 2015)

Although the pneumatic conveying system has several benefits, the system can experience build-ups or plugging, and pipeline wear. The key to solving or preventing pneumatic conveying problems is to determine characteristics of the material or powder. (Jenike & Johanson 2015) Pneumatic conveying may be broadly divided into two broad categories: dilute phase and dense phase conveying, see figure 4. (Fokeer et al. 2004) In dilute phase conveying, particles are fully suspended in the conveying air, transported at low pressure and high velocity in range from 20-30 m/s. (Nol-Tech Systems Inc. 2015) (MAC Equipment Inc. 2015) Dilute phase conveying is frequently the most cost-effective solution for the transport of flour, sugar, granulate, chemicals and palletised products. (Fokeer et al. 2004) In dense phase conveying, particles are not suspended the

![Figure 4](image-url)
conveying air, transported at high pressure and low velocity in range from 2-8 m/s. (Nol-Tech Systems Inc. 2015) (MAC Equipment Inc. 2015) It is particularly suitable for the high rate transfer of food, dairy products and friable materials. (Foekert et al. 2004) Johansson declares that Cloetta Ljungsbro mostly leans towards the dilute phase in their pneumatic conveying system.

Dilute phase conveying works with non-abrasive and non-fragile materials with light density, e.g. flour. (CDM Systems, Inc. 2015) Due to the high velocity, there is significant degradation of conveyed material resulting in the generation of dust. The use of dilute phase for abrasive products causes wear of the conveying line and the pipe elbows. (Pelleton Corp. 2014) Dense phase conveying works with very fragile materials, since the low speed prevents materials to break down and, therefore, generates less dust and eliminate the required for dedusting of the conveyed material. (CDM Systems, Inc. 2015) But friction between the particles, and between particles and the wall caused by high pressure generates a very fine dust. (Pelleton Corp. 2014) Dense phase systems works with slightly hygroscopic materials, such as sugar, without requiring the introduction of air drying equipment because air quantities required for dense phase are significantly lower than of dilute. (CDM Systems, Inc. 2015)

An important factor while constructing a pneumatic conveying system is shaping the length and curves of the system. The major factors of system layout are length of piping, pipe diameter, type of bends, number of bends, product feeding and choice of closed or open loop. Both dilute phase and dense phase conveying generate friction by high velocity respectively high pressure. Friction creates heat and abrasion, which is the main cause for the creation of fines. (Pelleton Corp. 2014)

Pneumatic systems can safeguard the materials being transferred. Sugar left open to the atmosphere will attract all type of attention from insects and micro-organisms. The sugar also will seek moisture from the air. When sufficient moisture is available, it will cause clumping and can make things difficult for downstream equipment to operate well, such as feeders or dispensers. By keeping the sugar enclosed and purging any silos or hoppers with dry air, the material can be protected and kept dry, ensuring its ability to transfer well. Pneumatic conveyors also eliminate many opportunities for spillage that occur with mechanical conveyance systems. (Cyclonair Corp. 2014)

Pursuant to Frye & Peukert (2002), attrition of bulk solids in pneumatic conveying is regarded as a result of a process function and a material function. Therefore, they believe that with knowledge of these two functions, the amount of attrition that develops in a pneumatic conveying system may be predicted. Due to high flexibility in routing, one conveying system hardly resembles another, and therefore it is very difficult to develop attrition tests applicable to more than one conveying system.

Pneumatic conveying design

According to Mills (2014), the influence of material properties is so marked that different modes of flow of the material in the pipeline are possible. This then leads to wide variations in the velocity of the air necessary to convey the material. Mills (2014) also implicates that it is the velocity at the start of the pipeline that is the critical parameter in the design of a pneumatic conveying system, and is, therefore, an obvious area for errors and hence faulty operation. Moreover, the feeding of material into a pipeline a controlled rate is a particular requirement with pneumatic conveying.
Conveying material vertically up or down is no more of a problem than conveying horizontally. Pipe bends in the conveying line provide flexibility, but they will add to the overall resistance of the pipeline. Bends can also add problems with particle degradation if the conveying material is friable, and suffer from erosive wear if the material is abrasive. (Mills 2003)

Huber et al. (1998) concluded that an increasing in pipe diameter will decrease particle-wall collision frequency while turbulent length scales increases. It was observed that particles were better dispersed in larger pipes. Kalman (1999) investigated the effect of bend radius on particle attrition and concluded that increasing bend radius would increase the angle of collision and thus reduce particle attrition. It was also concluded that lower attrition is achieved by operating at high loading ratio as this keeps particle velocity low. Frye & Peukert (2002) concluded from an analysis of particle-wall impact in various pipe bends that most of the impacts take place under impact angles 10 to 50°.

The results of the research work of Akilli et al. (2001) provided an outline of the particle segregation process in pipe elbows due to the action of centripetal forces, whereby solid particles impinging on the outer wall of the elbow form a relatively dense phase structure that is termed as a rope. Just after an elbow, transport of particles is mainly due to this roping effect. The region of the rope has a much higher solid concentration than the remainder of the pipe and, therefore, due to particle-particle collisions, the particles are decelerated. Yilmaz et al. (2001) found that particle ropes be strongly dependent on the pipe bend radius and to a lesser extent on the conveying air velocity and solids loading. Marcus (1984) concluded that the pressure drop experienced along a section of pipes can be reduced by implying an outer steel pipe that supplies bleed air into an inner porous pipe to create an air envelope to the flow of materials.

Fluidization can be a highly effective method for handling fine bulk material in an aerated or liquid-like condition. The process withholds a granular material that is converted from a static solid-like state to a dynamic fluid-like state. The advantages for handling powders and bulk solids via fluidization instead of traditional gravity flow include reduction of arching or rat holing problems, increased discharge rate from a silo and increasing gas-solid interaction from drying, agglomeration or reactions. Typical bulk solids suitable for fluidization have a fine particle size, a low permeability, a tight particle size distribution and low cohesive strength. (Jenike & Johanson 2015)

With materials that are hygroscopic, such as sugar, air drying is normally recommended. For the majority of materials this is not necessary. With compressor, however, large quantities of moisture can be generated if the supply air is warm and humid, and this moisture can be carried over into the air supply lines. Owning to the intermittent nature of the conveying process it is also possible for water to collect in the air supply lines and this can be blown into the blow tanks on the start up. This often resulted in partial blockage of the blow tank discharge line in pneumatic conveying system. (Mills 2003)

**Pneumatic system types**

The majority of pneumatic conveying systems are generally conventional, continuously operating, open systems in a fixed location. The suit the material being conveyed, the application, or the process, however, inventory, batch operating and closed systems are commonly used. To add complexity to the selection, system can either be positive or negative pressure in the process, or a combination of both. (Mills 2003)
Open systems are continuous operating and are used where strict environmental control is not necessary. Positive pressure systems, which discharges to a reception point at atmospheric pressure, are probably the most common of all pneumatic conveying systems. In many processes, it may be convenient to convey one batch at a time. There are two main types of batch type conveying systems to be considered. In one, the batch size is relatively large, and the material is fed into the pipeline gradually over a time of period, and can be considered as a semi-continuous system. In the other, the entire batch of material is fed into the pipeline as a single plug. Closed systems uses air drawn from the atmosphere and return back to it, after being filtered, which gives a more controlled environment. (Mills 2003)

Semi-continuous systems are when material can be conveyed in dilute or dense phase, depending upon the capability of the material, the pressure available and the conveying distance. Since batch conveying is discontinuous, steady state of material flow rate have to be higher than those for continuously operating systems in order to achieve the same time averaged mean value of material flow rate. (Mills 2003)

2.1.3. Chocolate production
When sugar finally has been transported to the chocolate production, the sugar is mixed with milk solids, cacao and fats. Up to this state the milk solids and sugar particles are more or less in scale of millimetres, and therefore the next step is to crush them so that the particles are small enough not to be detected by the human tongue. The most common method to achieve this is by the use of roll refiners in order to get he chocolate ingredients into a paste form, this is called grinding. (Becket 2009) Marklund account for that the manufacturing equipment is adjusted depending of the quality of the incoming powders, and therefore do variation in particle size of the sugar matter.

2.2. Methodology

2.2.1. Water content
The amount of water present in sugar is fundamental for stability and sustainability in sugar and chocolate confectionery. (Edwards 2000) If the water content is high it increases the possibility of micro-organisms to breed, but it also affects the texture of sugar confectionery and chocolate. (Andersson 2006) Thereby, measuring the water content is an important task for this project. Some methods of oven drying are still used, but is difficult since the moisture levels are often low. A common method is Karl Fischer titration which is suited for low-moisture foods such as chocolate and sugar (Edwards 2000), illustrated in figure 5.

Karl Fischer titration is a rapid and accurate method with a wide measurement range. (Jin et al. 2014) On the downside is requires hazardous chemicals and needs all of the samples to be resolved. (Andersson 2006) The Karl Fischer method is especially useful for low moisture levels (less than 1 %), and for samples that may decompose if using for example gravimetric methods. Moreover, the method can either be coulometric or volumetric. The volumetric

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9 Agnieszka Marklund, Value Engineer at Cloetta Sverige AB, meeting 3 September 2015
titration is based on the volume of the standard solution that is to react with water, whereas the coulometric method measures the number of electrons transferred during titration. (Clippard et al. 2015) Eurofins® explains that coulemetric titration is used for samples with water contents lower than 0.01 %, whereas volumetric is used for higher water levels.

At the end point of this method measures the amount of iodine present, after adding an iodine containing reagent. (Jin et al. 2014) A reagent prepared by reacting sulphur dioxide with iodine dissolved in pyridine and methanol is used. The water content is derived by the reagent, where iodine and water react in the presence of a solvent including methanol and pyridine. (Edwards 2000) The standard Karl Fischer reaction conducts of: \( H_2O + I_2 + [RNH]SO_4CH_3 + 2RN \rightarrow [RNH]SO_4CH_3 + 2[RNH]I \), where \( R = CH_3(CH_2)_n \). (Jin et al. 2014) More specifically, when RN is in contact with a reactive product within the reaction of methanol and sulphur dioxide in the basic surroundings of RN, the water content in the sample reacts with the iodine. This causes the electrical potential to drop and is therefore measured by an electrode. As the potential reaches zero it indicates that all water has bound. The amount of iodine is proportional to the amount of water in the sample. (Andersson 2006)

The sample size when using Karl Fischer is so small that good representativeness of the sampling technique is required. (Jin et al. 2014) Although it is possible to perform Karl Fischer titration by hand in a fume cupboard, special titration apparatus is normally used. These titration apparatus work in such a way that the sample is titrated with Karl Fischer reagent until the end point is reached, which is when free iodine appears causing an increase in conductivity. (Edwards 2000)

2.2.2 Particle size

It is common to analyse the particle size of different powders when in the food industry. (Ljungberg & Carlsson 1986) An understanding of particle properties is just as important as knowing bulk material flow properties. This may be performed by advanced instruments, such as laser diffraction technique, or more simple segregation methods as sieving. (Jenike & Johanson 2015) Since the particle size for the advanced apparatus are as low as 4 µm (Ljungberg & Carlsson 1986) and sugar dust are particles below 0.1 mm (Becket 2009), it is more suitable to use the simpler method for this project. An illustration of sieving is seen in figure 6. Sieving segregation is a side-to-side mechanism where the fine particles concentrate under the point of impact in a pile, while the coarse particles stay put at current sift. (Jenike & Johanson 2015)

There are numerous reasons for the selection of testing sieves as first choice in particle size analysis work. Standard sieve analysis is probably the fastest and most frequently used quality control procedure in powder process control industry. The outcome of the analysis is easily calculated, and the technique is known for its quick procedure for rapid particle size distribution data. With variation of opening sizes, the time interval of the sieve analysis becomes extremely important. Another factor to consider is reaction of the material to ambient conditions, low relative humidity is optimal. But extremely dry conditions can cause fine powder to adhere to the sieve components. (Advantech Mfg 2001)

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10 Customer service Eurofins, telephone meeting 28 January 2016
To obtain meaningful sieve analysis data, six steps are recommended by Advantech Mfg (2001); (1) obtain a representative sample of the material to be evaluated, (2) prepare the sample for evaluation, (3) reduce the sample to a size suitable for the sieve analysis procedure, (4) perform the actual sieve analysis procedure and (5) compute the data and convert the data into a usable format, (6) organize the data and assemble the information for presentation.

For sieving analysis, it is recommended to use a sample of 25 to 100 grams. Analyse various sample sizes adjacent to recommended sample range for a period of five minutes by using a mechanical sieve shaker. If the test with 100 grams sample shows approximately the same percentage passing the finest sieve as the 50 grams sample, whereas the 200 grams sample shows a lower percentage, this would indicate that the 200 gram sample is too large and the 100 gram sample would be satisfactory. (Advantech Mfg 2001)

The duration of the sieving interval is commonly 10, 15 or 20 minutes. To determine the best interval for a new material following procedures can be used according to Advantech Mfg (2001); (1) Weigh up a sample of the material to be tested and introduce it to the completed sieve stack, (2) shake the sieve stack for a period of 5 minutes, (3) Weigh the residue and calculate the percentage in the relation to the starting weight, (4) resemble the stack and shake for one additional minute and (5) repeat the weigh-up procedure and calculate the percentage.

2.2.3 Humidity and air pressure
Humidity is defined as the presence of water vapour in air. In normal room air there is typically about 1 % water vapour, but it is widely present in greater or lesser amounts. Humidity is measured by using a hygrometer. Humidity affects many properties of air, and of materials in contact of air. A huge variety of manufacturing, storage and testing process are humidity-critical. Humidity measurements are used wherever there is a need to prevent condensation, corrosion, mould, warping or other spoilage of products. This is highly relevant for foods, chemicals and many other products. Humidity measurements contribute both to achieving correct environmental conditions and to minimising the energy cost of it. (Bell 2011)

Dew point is a type of temperature often measure in Celsius [°C]. When the temperature decreases to dew point, saturation is reached the relative humidity of 100 %. Dew point occur when the air temperature no longer is able hold the water vapour and, therefore, transcend to condense. Condense appear when the temperature decreases and the energy which holds the water in the vapour decreases. Dew point is measured with a dew point hygrometer. This instrument work in a way that a polarized surface is cooled until condense appears, and the dew point is, thereby, the temperature on that particular surface. (Wern 2013)

Some processes sensitive to moisture may have some specification for the air pressure in means of dryness. Absorption dryers absorb water vapour from the air stream and produce a dew point of -40°C or lower. Within the food processing industry it is better to have a dew point lower than -26°C to prevent growth of microorganisms, but normally it may be up to +5°C depending on industry. (Vaisala 2013)
3 Materials and Methods

3.1. Materials
The samples taken in terms of this project are the sugar conveyed throughout the manufacturing process. The sugar was contained in plastic jars when taken from sampling point and enclosed with a lit. To ensure that minimum amount of moisture would come in contact with the sample, the box and lit were enclosed with Scotch tape. The plastic jar was filled up to approximately 1-2 kilograms to certify a representative sample. After the particle size analysis had been performed, the sugar samples from the road tanker were sent to an external testing facility for volumetric Karl Fischer titration.

The sugar samples were segregated to measure the particle size distribution, though no chemical or biological materials were used for this experiment either. For this an apparatus with vibrating motion was used in addition to sifts with different mesh openings. To use the fair sample size for sieving analysis, various sample sizes was tested for the same out time as suggested by Advantech Mfg (2001). The sieve machinery includes a sift with the widest mesh openings is one top, and every sift below decreases in size. While analysing, 5 sieving trays with different mesh openings was used, which were following: (1) particles larger than 850 µm, (2) 600 to 850 µm, (3) 425 to 600 µm, (4) 212 to 425 µm and (5) particles smaller than 212 µm at the bottom.

Residual analysis includes following observations; (1) the lead time between supplier and Cloetta Ljungsbro, (2) air pressure used by the road tanker when unloading the sugar into the silos, (3) the dew point and air pressure in the pneumatic conveying system at Cloetta Ljungsbro and (4) the temperature and humidity in silos.

3.2. Methods
The samples of sugar were taken at four different points in the Ljungsbro factory and one reference sample is sent from supplier X. The sampling period was six weeks, starting October 15th, and each week 2 samples were taken. The four samples carried out in the factory were;

1. From delivery road tankers as they arrive to Ljungsbro factory, before unloading the sugar into the silos.
2. Below the silos, before transported into the pneumatic conveying system which leads to the production lines.
3. Nearest production line, which is either Mumsen, Klubban or Biskvin depending on the production schedule.
4. Farthest production line, the raw material storage facility coupled with the chocolate production.

A schematic illustration of all the sugar sampling and analysis of the conveying system is illustrated in figure 7 below.
Leif Ingmarsson at Cloetta in Ljungsbro is responsible for sugar unloading reception from supplier’s road tankers. Every time a sugar truck arrived to Cloetta, Leif was in contact with purpose of taking a sample from its tanks (see sample 2 in figure 7). As sugar delivery arrives, the lead time from supplier was observed and reference sample from supplier X was received (see sample 1 in figure 7). By making a copy of the delivery note, it is possible to observe when sugar was loaded on the vehicle and when it arrives to Cloetta Ljungsbro. This is to assure that the deliveries are according to specified agreement, which is not exceeding three days.

While the truck driver unloads the sugar from the road tanker to the silos, the air pressure used was noted. Whereas the range of 1.5 to 2 bar was set to satisfactory due to recommendations from supplier and senior truck driver, and an air pressure below 1 bar indicates sugar lumps and an unsatisfactory sugar delivery. The air pressure was observed on an air pressure measuring instrument in the road tanker.

The silos are not completely empty when refilled, and therefore it is crucial to monitor how much is in the silo before refill to determine when to sample sugar from below the silo (see sample 3 in figure 7). Thenceforth, an observation of sugar utilization must be done to be able to pursue the sugar batch in question to the closest production line, Mumsen, Biskvin or Klubban (see sample 4 in figure 7), and the production line further away, raw material storage facility, which is a storage room of powders and fats before sent to the chocolate production (see sample 5 in figure 7).

To define particle size distribution, a segregation method was performed by sieving in assistance with a vibrating aperture. Cloetta Ljungsbro uses a sieve shaker from Retsch and a sieve series by the brand Endecotts LTD, which is to used in this project, seen in figure 8. First step is to decide sample size and the duration of the sieving intervals pursuant to Advantech Mfg (2001), and all samples are to have the same weight, be sieved for the same amount of time and at the same rate. The collected sample is poured into the set of sieve trays, starting from the highest size on top. The sugar from each sieving tray is then manually poured onto a scale with help from a
brush and weight up. Particle breakage is characterized through changes of particle size distribution and reported as coarse fraction percentage.

The first attempt was to determine sample size for the particle size sieving analysis, whereas sample sizes of 25, 50, 100 and 200 grams was tested for 5 minutes each with a speed of 30 rpm as suggested by Advantech Mfg (2001). The distribution between 50 grams and 100 grams differed little while 25 grams and 200 grams gave a bit different distribution than adjacent sample sizes. This indicated that 100 grams is satisfactory as sample size. The second sieving setting to determine was the time duration. The test started with 5 minutes, and thereafter 10 minutes was tried, but the distribution difference is obscure. Therefore, it was gratifying to set the sieving setting on 5 minutes on further sieving analysis. When these sieving settings were completed, they were to be applied to the “real” sugar samples from the manufacturing chain (sample 1 to 5 in figure 7).

In addition, a chemical study is to be performed in terms of analysing the water content of the sugar samples. The water content levels were analysed by implementing the Karl Fischer method, which an external laboratory had to perform these experiments. Due to limited budget, only the samples from the road tanker were analysed. The samples were chosen since the water content specified in the supplier’s product specification may be compared. The sugar samples from the road tankers was sent within two days of sampling time to the external laboratory.

During the time period of sampling sugar, a sensor measuring temperature and humidity is installed in the silos with help from Per Johansson at Cloetta Ljungbro. This is to assure that the humidity levels do not exceed intended satisfactory conditions for sugar storage and, therefore, determine if this may be a cause for the sugar issue. Moreover, monitor data of the dew point in the regulated compressed air used in the conveying system is to be evaluated.

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11 Per Johansson, Maintenance Manager at Cloetta Sverige AB
4 Results

4.1. Particle Size

Figure 9 to 13 shows the particle size distribution and its variation throughout the manufacturing process maintained during the sampling time period (each dot indicates one sample, and therefore its quota of the indicated particle size range). The sampling points in these figures are as following: (1) reference, (2) road tanker, (3) silo, (4) the nearest production line, and (5) the storage facility before entering chocolate manufacturing hall.

The result in figure 9 shows that the variation of smaller particles' percentage is more widely spread in the silo compared to the other sampling points. The silo differs almost 20% between lowest and highest point, whereas the rest of the sampling point only differ in a range of approximately 7-8%. The silo is also the point in which the quota of particles smaller than 212 µm significantly increases with approximately 10%. The quota of fine particles only increase 1% between the silo and the nearest production when observing the mean value curve, thenceforth fines increase about 2% when transferred further to the storage facility before entering the chocolate production.
Figure 9 also shows a red line which indicates the maximum percentage, 7.5%, of particles smaller than 224 µm according to supplier X, which is relevant for the reference sample (1) and the sample from road tanker (2). The figure shows only one sample that appears over the red line, which may be insignificant, and therefore, the conclusion is that no sample contained more of smaller fines than promised by supplier X, seen in appendix 1.

Observations of figure 10 to 13 result in less drastic variation in the mean value compared to figure 9. The mean percentage of particles in smaller than 212 µm (figure 9) differ 12% between highest and lowest value throughout all sampling points, whereas particles in range of 212 to 425 µm (figure 10) differ 4%, particles in range of 425 to 600 µm (figure 11) differ 5%, particles in range of 600 to 850 µm (figure 12) differ 8% and the particles larger than 850 µm (figure 13) differ only 1% between highest and lowest mean percentage value for all sampling points.

Figure 10 shows most variation of the particles in range of 212 to 425 µm within sampling points reference (1), road tanker (2) and silo (3). But the percentage range is far wider within this particle size range compared to the particles smaller than 212 µm (figure 9). Notice how, for instance, the sample from the road tanker (2) differs more than 20% between the sample that gave highest and lowest quota. The figure also shows a significant change in the mean percentage value between reference sample and sample from road tanker.

In figure 11, a more narrow variation in the particles in the size range of 425 to 600 µm is shown. The mean quota is about the same in the reference (1) and road tanker (2) samples, but slopes downwards a few percent when entering the silo and keeps it at a steady level at further sampling points.

Definite variation in the mean quota, somewhat alike figure 9, is seen in figure 12. The particles in the size range of 425 to 600 µm are at its highest when in reference (1) and road tanker (2) samples, thereafter the amount decreases in the silos (3) and stays at quite the sample percentage level in the nearest and farthest production line. Here the reference (1), road tanker (2) and silos (3) samples seems to have most of the variety in percentage quota.

Figure 13 have the lowest variation in quota. The figure has the widest variation span within the road tank (2) samples and the samples from chocolate raw material storage facility (5). The supplier has a specification for larger particles, and appendix 1 demonstrates maximum 10% of particles larger than 800 µm, which is also indicated by the red line in figure 13. Although the particle size analysed in this project has its particle size limit at 850 µm (which is 50 µm higher than supplier’s product specification), only one or two is above the line. This line should probably be lowered to about 9% to correspond to 850 µm, and no significant deviation from the specification is shown in figure 13.
Figure 11, 12 and 13 shows a significant decrease in the mean quota when entering the silo, whereas figure 9 and 10 present an increase of their mean quota in the silos.

4.2. **Water content**

According to Becket (2009) it is recommended not to let the water content exceed 0.06 % (green line in figure 14), and supplier X promises not to exceed 0.05 % (red line in figure 14) in their product specification shown in appendix 1. Figure 14 illustrates the water content of the sugar sent to the external laboratory for Karl Fischer titration. The figure shows that samples 1 to 7 and 12 resulted in a water content of 0.05 g/100 g or higher, which can also be written as 0.05 %. This is equal to, or higher, than what the supplier promises in their product specifications. This means that a total of 66 % of all the samples have 0.05 % or higher water content. Moreover, 50 % of the samples (sample 1-6) also indicates higher water content than literature recommended and may therefore be a critical parameter for effecting the sugar rheological properties and is classified as unsatisfactory delivery.

4.3. **Lead time**

As known, supplier X have an estimated delivery time of three days at the most. Therefore, a lead time of three days or fewer is thereby satisfactory (below the red line in figure 15), which means that a delivery time longer than three days is unsatisfactory (above the red line in figure 15). Figure 15 demonstrates the lead time for the sugar transportation in association with taking sugar samples from the road tanker. The lead time is defined by the time difference between the road tanker was loaded with sugar at the supplier and when arriving to Cloetta Ljungsbro. Figure 15 shows that 33.3 % of the delivery made while taken samples is unsatisfactory, while the majority 66.6 % is defined as a satisfactory delivery time.
4.4. **AIR PRESSURE IN ROAD TANKER**

An air pressure of 1 bar and lower is suggested to be unsatisfactory for optimal pneumatic conveying when transferring sugar from road tanker to silo. According to literature and supplier, the air pressure should be within the range of 1 to 2 bar. Thereby figure 16 classifies the air pressure used by the truck driver as unsatisfactory if the air pressure was 1 bar or lower (above the red line figure 16), whereas an air pressure higher than one is defined as satisfactory (below the red line in figure 16).

Figure 16 shows that 25% of the sampling occasions gave unsatisfactory air pressure used, whereas the majority 75% is to a satisfaction.

4.5. **DEW POINT AND AIR PRESSURE IN THE CONVEYING SYSTEM**

Although no humidity level could be studied in the conveying system, the dew point of the compressed air is constantly observed at Cloetta Ljungsbro. Skeppsby collected data from the regulated system by observing the dew point of the compressed air for the time period of sugar sampling. The data showed the highest value of -8.05°C and the lowest value of -44.93°C. This seems to be within approximate range recommended by Viasala (2013). Complete figure of the data may be seen in appendix 6, and shows a significant variation in high and low air pressure that is used.

4.6. **TEMPERATURE AND RELATIVE HUMIDITY IN SILOS**

![Figure 17](image)

Figure 17 Temperature and relative humidity in silo 1 during the time period 2015-09-22 to 2015-12-01. The thicker curve indicates the temperature and the thinner line is thereby the relative humidity.

Results from study from year 2012 of temperature and humidity levels in the silo may be seen in appendix 3. Figure 17 presents the results of temperature and humidity levels in the silo 1 within this project. Silo 1, was measured approximately 11 weeks, whereas silo 2 was observed for only one week. Silo 1 was the sampling point used for this project, and is therefore more

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Kristian Skeppsby, Maintenance associate at Cloetta Sverige AB, email 6-23 October 2015
relevant for this study. Know that the measurements in the beginning and after 2015-11-23 are when the measuring device is not in the silos. The measurements gave the highest temperature of 24.8°C and lowest temperature was 13.1°C, which approximately gave a mean value of 16.3°C throughout the whole measurement time period. The highest relative humidity was measured to 48.5% and its lowest value were 1.7%. The calculated mean value of the relative humidity was 10.0%. Becket (2009) recommended that the storage temperature would not exceed 20°C, which is seems happen on many occasions and is thought to be associated with the sugar unloading from the road tanker. The proper relative humidity suggested by Becket (2009) was a range between 20 and 60%. Mostly levels of lower moist value are registered, hence no levels of high moisture seem to be an issue. But it is noticed that the moisture level rises as the temperature level increases.
5 DISCUSSION

In the beginning of this project, many had various speculations about what was the cause of the issue with sugar lumping and attrition. Many had the assumption that the suppliers were the cause of sugar lumps origination, while others thought it was due to the long distance of the pneumatic conveying system in the Cloetta factory. Previous attempts to implement studies of the issue with sugar were executed a couple of years ago, but it seems like the final conclusions were a bit vague and the study suggested that the sugar build-up and the degradation was due to the long distance of the pneumatic conveying system used at Cloetta Ljungsbro. But this study shows different results since it seems like most significant change in particle size distribution appeared when entering the silos, in observation of figure 9 through 13.

Wypych (1999) suggests that applications of feeder with distances within 100-200 meters is considered a relatively short distance when discussing pneumatic conveying. For greater distances often results in problems like flow instabilities or pipeline blockage, which may be avoided by method of air injection, fluidising-discharge-cone or cone-dosing valve. The pneumatic conveying system at Cloetta Ljungsbro is approximately estimated to 200 meters from the silo to the chocolate production, which in this case will clarify this distance as relatively short when discussing pneumatic conveying.

An interesting mail conversation between different quality managers of different Cloetta factories suggested that the Ljungsbro factory is not the only factory with bulk solid issues. Another factory within Europe had a resemble problem and decided to switch silo, which seems to have solved their problems. But this conveying system is of 20-30 meters, which is in significant difference to Ljungbro’s set up.

Some executions of the analysis may have been trickier then others, which may have caused some source of error within this project. While taking sugar samples, it was difficult to assure that the “same” sugar was traced all the way from the supplier to the production. Since the sampling was taken at arbitrary occasions, however, when thought of being transferred to the next sampling point, it may be tricky to guarantee that the exact same sugar delivered from the supplier is the same sugar sampled at further sampling points. On account of different production schedules, it was not possible to sample from the same production line nearest to silo. This may show in the results in a way that the size distribution varies depending on which production line that was used for sampling. Moreover, due to limited access to the road tanker, only a smaller opening was the alternative to taking samples of the sugar. This opening did not allow bigger particles or lumps to appear in the sample, which may have misled the results when analysing the particle size distribution.

Fitzpatrick (2007) argued that particle size is the most important property and has a major influence on many operations. Furthermore, particle size is a major product quality parameter. As seen in figure 9, the quota of fine particles varies more or less for every sampling point. But it is difficult to conclude how much the change in size distribution affects the confectionery and the chocolate production, since the size range is significantly wide for the sugar. It would be interesting to observe how much of a difference in size distribution that is needed in order to affect the conditions in chocolate production. It may be a time consuming task to study how large quota of fine particles is required to effect the chocolate production in a negative aspect, and therefore model what is a significant deviation. Frye & Peukert (2005) actually suggests that particle breakage may be predicted through making a model with process functions and materials function.
Fitzpatrick (2007) suggests that particle breakage in pneumatic conveying is important because a reduction in particle size can affect the subsequent operation and powder quality. With the evolution of coated particles, this becomes even more important because pneumatic conveying can potentially erode the coating which could nullify an expensive coating process. With this argument, it may be particle size and particle breakage are important parameters to observe in further investigations. Albion et al. (2006) suggests that parameters that influence particle breakage and attrition in pneumatic conveying include particle strength (particle material, size and shape), operation parameters (particle velocity, concentration, loading ratio) and bend structure of transport line.

Observations of figure 9 to 13 indicates a relatively steady amount of each particle size range for the reference and road tanker samples. It is noticeable that the most significant change in quota is somewhere in between the road tanker and the silo. The percentage increases for the smaller particles, figure 9 and 10, whereas the portion of larger particles decreases when entered the silo. Alboin et al. (2006) suggests that stresses contribute to particle breakage, which include impact and friction. Particles experience impact stresses at bends, due to the change in flow direction. They also suggest that velocity and feed rate greatly increases the breakage rate. However, at nearest and furthest production line, little degradation is registered. Fitzpatrick (2007) implies that particle strength is another important property in determining particle size as this will determine the particle resistance to size reduction by breakage. This may be another analyse in question if the interest is in what is required for the sugar to be degraded.

According to Kalman (2000), the effects of attrition can be a loss of product by removal of undersized particles from the process streams, the requirement of additional filtration, loss of flowability and environmental pollution caused by large quantities of dust. Kalman (2000) showed that to quantify breakage for process design and optimisation, three pieces of information is needed – the stress distribution, the rate at which breakage occurs, and the number and sizes of the “daughter” particles resulting from breakage of a parent particle. He also suggests that attrition is lowest in a long radius elbow, and indifference to Alboin et al. (2006) he concluded that small particles can follow the air stream easily through the bend. It context with literature with Akilli et al. (2001) it would be more reasonable if the sugar breakage appeared in association with bends in the conveying system, but it seems not to be the only reason for degradation in this project.

Fitzpatrick (2007) implies that most food powders contain components in the amorphous glassy state, such as amorphous sugars. Amorphous components are thermodynamically unstable and there exists a driving force for them to crystallize, however, this requires that the molecules must be able to move. This raises speculations how much of the sugar is amorphous when arriving to Cloetta, and in which amount the degradation effects to enter the amorphous state. It is with the possibility that this may be the reason for the sugar lumps origination within the pneumatic conveying system, but maybe also in the silo. Fitzpatrick (2007) also suggests that problems can occur due to the powder particles sticking together during handling and storage or due to particles sticking on to the chamber walls during drying and mixing. Furthermore, the glass transition temperature is a very strong of powder water content. Therefore, particle attrition in association with high water content, is probably a big issue in means of sugar build-up.

According to Dynamic Air (2011), optimum pressure balance in a pneumatic conveying system must be accomplished. If excessive compressed air is used to convey given material, it may result in material breakdown and excessive wear on the system. Furthermore, the system...
will use excessive energy and maintenance becomes higher and reliability is reduced. When not enough compressed air is used, the convey rate may be too low and it is even possible that conveying line plugging can occur. It seems that little has been investigated when it comes the air used in Cloetta’s pneumatic conveying system, including the pressure, rate and temperature. With an air pressure of approximately 0.5 bar used within the factory pneumatic system, it is surprising to use such a significant higher pressure when unloading the sugar from the road tanker into the silos.

After discussing the strategy of the air pressure in different production line, mostly dilute phase pressure systems are used at the Ljungsbro factory. At greater distances, for instance to the raw storage facility connected to the chocolate manufacturing, dilute phase is used – in other words, the sugar is mixed with air and blown at a high rate. Dynamic Air (2011) suggests that tubing bends are a major cause of friction in pneumatic conveying, and is easily responsible for more than 50% of the total resistance. Due to that high speed and sugar mixed with air is used for longer distances, this causes the sugar particles to hit the pipe walls more frequently. Since sugar mixed with air also let the particles collide with each other, this may not be an optimal way to transfer sugar when degradation is a concern.

According to Dynamic Air (2011), continuous dilute phase pressure systems (sends sugar in a mixture with air) uses a speed of at least 10 to 20 m/s and is recommended for non-abrasive bulk solids where degradation is not a concern. Recommendations for materials that are heat sensitive and semi-abrasive, such as sugar, are to implement continuous dense phase pressure systems (sends sugar batch wise) for their pneumatic conveying system. Gericke (2008) states that low speed dense phase conveying systems has its purpose for base powders or granules not to be destroyed during transport, since the breakdown of particle size can reduce the performance of the plant and generate explosion risk or change process parameters. Dense phase pressure systems send bulk solids in the speed of 0.5 to 10 m/s, which advocates for any particle size range for long distances. When the sugar is blown batch wise, it makes the particles more compact and it decreases the risk of collision between particle-particle and particle-wall, which thereby decreases the generation for particle attrition and system wear. Therefore, Cloetta is suggested to try to implement a continuous dense phase pressure system throughout their whole conveying system. Gericke (2008) confirms that gentle conveying is typically required in the food industry. Jenike & Johanson (2015) suggests that fluidization lines parallel to the piping system may be added to help push the bulk solids forward, when using dense phase pressure systems.

Cabreros & Troxel (2008) suggest that conveying velocity is one of the most important parameters in the design and operation of pneumatic transport systems. Keeping the mean gas velocity above a minimum value in all horizontal sections of a pipeline ensures no deposition or accumulation of solids in the system. Moreover, if the velocity is set at the beginning of the piping system, the velocity will increase along the pipeline due to compressibility effects (density decrease) so the rest of the pipeline should be well above the lower velocity bound. This is also a concern for Cloetta when administrating the air pressure velocity for their conveying system in means of being sure of decreasing the attrition.

Hann & Stražišar (2007) concluded that the solution of problems relating to the discharge of solids from a silo can be found in narrowing the particle size distribution, even if average particle size has to be lower. Observation of figure 9 shows quite a big range of size distribution in the silo since the quota of fine particles largely varies. On several accounts when taking samples from the silo at the Cloetta factory, it seemed like the sugar had become compact, and did not freely poor into the sampling box from the silo opening. Therefore, an arbitrary tool
had to be used to separate the sugar particles from each other in order to get a sample. It has also come to my attention that a stack up of sugar lumps period wise appeared at the bottom of the transmitter below the silos which need to be cleaned out. Fitzpatrick (2007) explains that during handling, storage, processing and distribution to the final consumer, the powders may experience a variety of temperatures and atmospheric humidity which may alter the handling behaviour and appearance of the powders. He also suggests that the consumer of the bulk solid usually is very sensitive to any lumping, caking or difficulty in discharging the powder from its container.

Since particle size distribution analysis has shown that the transportation within the pneumatic conveying system at Cloetta Ljungsbro only increases the fine particles with a mean of 5% between silo and production line furthers away from silo, it is one of the reasons for the variation in particle size. Although the results of this project suggest that fine particles increase in longer distances and with bends, it came as quite the surprise when the fine particles had its definite peak when entering the silo. Hence, the piping distance is only about 10-20 meters between the road tanker and the silo, it is less likely that it is the transportation distance that is the cause of a mean increase of 10%. According to Chapelle et al. (2004), negligible degradation of the particles was assumed to take place within the silo during filling and discharging.

Gericke (2008) discusses whereas pneumatic conveying systems within process plants can be easily designed for gentle conveying often less focus is given to unloading bulk tankers where due to the higher rates of discharge significant degradation of product can occur. This would explain the drastic increase in fine particles somewhere in between the road tanker and when at the bottom of the silo. Gericke (2008) suggests a mobile conveying unit, which can be coupled between tanker and silo, which allows the truck to be discharged with minimal attrition of powders or granules, thereby preserving the quality of the raw material. To exclude possible lumps from the road tanker, a sieving filter installed somewhere before the sugar enters the silo may be the solution. This may ensure that only satisfactory particles would enter the conveying system. But no conclusion is made if it is the unloading of the road tanker or the silos that causes the degradation of the sugar. Cloetta should study further on this issue by taking more samples between the road tanker and the silo. One method would be to take samples on top of the silo and thereby compare the degradation to the samples taken at the bottom of the silo. It is possible that new silos need to be installed.

A study in the detergent industry of their raw material while discharged from bulk tankers was made by Gericke (2008). The raw material natriumperborat tetrahydrat was used with a low conveying velocity of 5-8 m/s with help from a new discharge unit connected between the road tanker and the silo, to control the air flow used when unloading the bulk solid. As a result, the new discharge unit reduced the amount of fine particles by more than 15% compared with the old system. The gentle pneumatic discharge and conveying from bulk vehicles applies to sugar. This may be another solution for the particle degradation issue. By investigating the velocity used when unloading the sugar, this may decrease the particle attrition.

Observation of the quality of the supplier includes water content, lead time and particle distribution of the reference sample and samples from road tanker. The study the water content of the sugar showed that many of the samples had significantly higher content than recommended by literature and promised by the supplier. The study resulted in 50% of unsatisfactory samples due to the high water content, which may be a reason for sugar build-up. Sugar is bulk solid that readily take up moisture present, and interaction with particle
attrition Becket (2009) explains how the amorphous surface created causes an accelerated rate of moisture take up and lumping formation. Observations of figure 14 show that higher water content in the beginning of the study, which may be associated with the moist harvest at the beginning of the autumn. Eurofins implicates that they may have an error margin of 25% in terms of their volumetric Karl Fischer titration, which should be considered. Thereby, more water samples should be taken to achieve a more representative water content result. Analyses of the dew point shows that the dehumidification of the sugar within the silos is much alike the temperature measurements, and have many high and low points depending on the pneumatic usage. But it seems to keep in recommended range in the pneumatic conveying system in the Ljungsbro factory.

Hann & Stražišar (2007) concluded that the moisture content in the bulk solids is one of the most important parameters that determine the properties of the bulk-solid flow. Even small changes in the moisture content can significantly affect bulk-solid flow. Furthermore, the capacity of bulk solids to absorb and retain moisture depends, to a great extent on the amount of fine particles. For an equal mass of bulk solids, the total surface area of the particles is larger if the particles are small. Hence, an increase in the surface moisture is inversely proportional to the diameter of the particles. For this reason, the cohesive and adhesive force with fine particles are greater than with coarse particles. This issue with smaller particles leads to a larger amount of surface to cover has also been known to cause problems while producing the chocolate at Cloetta. The variation in the particle size distribution aggravates the possibility of regulating the settings of the system.

Observations of figure 17 shows that temperature increases in association with sugar unloading from road tanker. Since the temperature outside have effected the sugar while delivered, which is below 15 °C during the time period of the project, it is probably due to the friction the sugar is transferred between the road tanker and silo that causes the temperature to increase.

Particle size distribution analyses show that particle degradation in sampling occasion 1, 7 and 9 were highest. In figure 16 it is seen that the air pressure used by the road tanker is below the satisfactory line during sampling occasion 1, 6 and 7, whereas the water content of the sugar in figure 14 is unsatisfactory in sampling 1 to 6. Furthermore, the lead time is unsatisfactory for sampling occasion 3, 9, 10 and 12. The particle degradation, road tanker air pressure and the water content seem to have most in common, whereas the lead time seems to have less effect on the other parameters. This may be something to think about, since this may indicate that there are many factors in jeopardy when observing the particle attrition issue.

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13 Costumer service Eurofins, telephone meeting 28 January 2016
6 CONCLUSIONS

Particle properties can have a major influence on the design and optimisation of particle production, handling and processing operations. It can be argued that particle size and its distribution are possibly the most important particle property as it is an important product quality parameter and it affects the design and performance of so many particle operations. Particle breakage can have a major influence on particle size through transportation, separation and subsequent processing. Consequently, particle breakage is an important design consideration along with the development of design strategies that can reduce it.

In the design of processing plants, flow of silos and the influence of particle properties on flow often does not receive the careful design attention that it deserves. To ensure an efficient discharge of material per conveying cycle, the method of blow tank air injection should be matched to the material and its behavioural properties. However, if problems do occur later on they can reduce throughput and add to cost. This research on the influence of quality variation of the bulk solid shows that the particle size degradation seems to occur somewhere between the discharging the sugar from road tanker and while stored in the silos. But on the basis of the measured data, some particle breakage is also occurring while transferring in the conveying system between the silos and the production.

Further work of the bulk solids handling between the road tanker and the silos would help improve to decrease the degradation of particles. The question is if the particle attrition is caused by the road tanker as the sugar is unloaded or if it is caused while stored within the silos, but also how much of particle size distribution variation is needed to affect the chocolate production. This work also includes observation of the air pressure system used while unloading the sugar from road tanker, to ensure quality of the bulk solid.

Since some particle degradation also occurs within the pneumatic conveying system, further investigations of the air pressure design system should be done. These developments will hopefully support the design and optimisation of the existing conveying system, where material quality is a major requirement. According to the literature, continuous dense phase pressure systems, where the bulk solids are transferred batch wise at lower velocities, are recommended for bulk solids like sugar when particle degradation is of concern.

The glass transition versus water content relationship for many food powders is important in the design and optimisation of many powder handling and processing operations. Glass transition can constrain dryer design due to the problem of particles sticking onto dryer walls. It can also constrain powder handling and packaging in order to prevent potential caking problems. Previous studies show that the moisture content in bulk solids is one of the most important parameters that determine the properties of bulk-solid flow. Measured data show a significant amount of water content in the sugar in the beginning of autumn, whereas the lead time has little effect on particle size distribution. Further studies of the water content influence the handling and processing of sugar should be executed, especially in the manufacturing of chocolate. This would also include having an open dialogue with supplier about the moisture issue of the bulk solids arriving to the factory.

With these considerations, we can reduce unwanted effects that will result in increased value of the shear parameters of bulk solids, and consequently, lead to problems in discharging from road tanker or silos, thus causing hold ups in the production processes, or incurring unwanted investment costs of having to build new silos with larger dimensions. Further work on the pneumatic transport between the road tanker and silo, and within the piping system of the
factory will hopefully help decrease the quality variation of the sugar particles. Thereby, there
is a smaller chance that sugar build-up and sugar dust will be generated.
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APPENDIX

APPENDIX 1: PRODUCT SPECIFICATION SUPPLIER X
Table of product specifications from supplier X.

<table>
<thead>
<tr>
<th>Chemical and physical specifications for supplier X</th>
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<td>Moisture content (max %)</td>
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<tr>
<td>Mean particle size (µm)</td>
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<td>Fraction &gt;800 µm (max %)</td>
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APPENDIX 2: PRODUCT SPECIFICATION SUPPLIER Y
Table of product specifications from supplier Y.

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<td>Fraction &gt;200 µm (max %)</td>
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APPENDIX 3: SILO MEASUREMENTS
Measurements of silos humidity and temperature 2012-02-24 to 2012-04-04 by supplier X and Cloetta.
APPENDIX 4: PROCESS DESIGN SILOS
Process design for Cloetta’s sugar storage system. Figure by Johann Andersson (2014), Project manager of Electricity Automation at Cloetta Sverige AB.
APPENDIX 5: PROCESS DESIGN PRODUCTIONS
Process design for Cloetta’s pipelines and production lines. Figure by Johann Andersson (2014), Project manager of Electricity Automation at Cloetta Sverige AB.

APPENDIX 6: DEW POINT IN PNEUMATIC CONVEYING SYSTEM
Data of the dew point of the compressed air used in Cloetta’s pneumatic conveying system.

Dew point of the compressed air in Cloetta Ljungsbro between 2015-09-29 to 2015-11-23. The curve shows highest value of -8.05 and the lowest value of -44.93.