DAMAGED STARCH IN THE FLOUR MILL: HOW TO REDUCE THE ELECTRICITY BILL

by

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ABSTRACT

The purpose of the research reported in the thesis, here, is to quantify new value added possible in flour milling with the use of the SDmatic monitor, produced and sold by Chopin Technologies SAS. As an employee of Chopin, part of my responsibility is to market the SDmatic. The SDmatic was designed and is marketed to improve flour quality by providing automatic monitoring of starch damage in flour—damaged starch affects dough characteristics, which affects baking quality and the ideal damaged starch differs by type of bakery product. While the SDmatic is so marketed, Chopin, now, realizes that SDmatic might also benefit a flour miller by increasing operational efficiency of the mill, specifically by reducing the electrical energy used in milling. If that can be done, it would improve mill profitability, reduce energy demand and, thus, reduce the pressure on the climate and environment from energy production. To address that possibility, the thesis research studied the relationship between energy usage and damaged starch in the flour and, then, estimated the cost savings possible by using the SDmatic to mill flour to specifications most efficiently. Finally, those results were used to estimate the return on investment in the SDmatic from improved mill efficiency, alone. The research shows improvement in energy efficiency is definitely possible with better management and targeting of the level of starch damage in flour production. Such improved management is possible, today, because SDmatic dramatically reduces the difficulty and time required to measure damaged starch. Such monitoring has not been done in the past because of the cost and time involved with prior methods. SDmatic makes that possible and cost effective, now.

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CHAPTER I: INTRODUCTION

1.1 Situation

Chopin Technologies SAS manufactures and sells SDmatic, a device to measure damaged starch (DS) content of flour, which can enhance the miller's ability to control the damaged starch content of flour. Chopin has more than 80 years' experience in the quality control of flours and cereals with its range of laboratory devices dedicated to the cereal-based products. The SDmatic device (Figure 1.1) was conceived to answer flour millers' need for a quick method to determine DS. (Chopin measures damaged starch in UCD units.) Millers use SDmatic to deliver flour to customers' specifications for a range of flours with different DS content specifications. SDmatic is acknowledged worldwide for its ability to measure damaged starch, quickly. That recognition is seen through strong sales of SDmatic and by being referenced in a series of international standards and methods (AACC, ICC…).

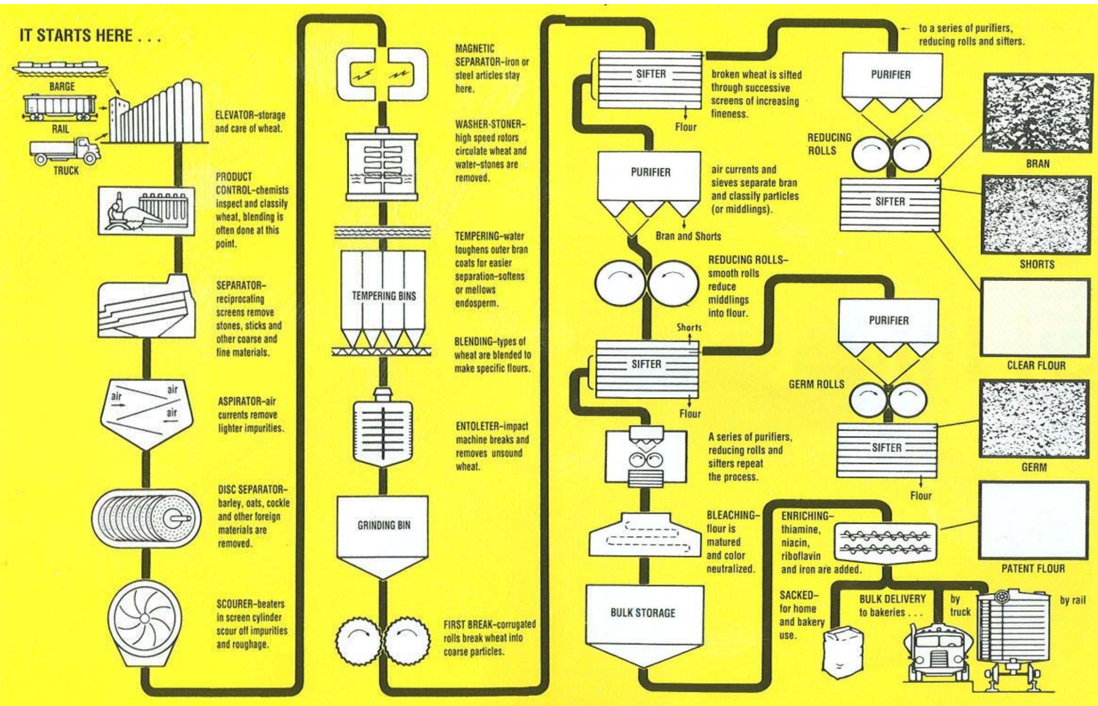
Figure 1.1: Picture of the SDmatic

(Courtesy of Chopin Technologies)

Today, Chopin Technologies SAS visualizes new opportunities related to the use of the SDmatic. Because the core origin of the DS is the milling process based, can it become a process management tool that helps millers to fine-tune final flour produced and to reduce energy consumption? Reduced energy consumption benefits the miller with lowered milling cost, and benefits society with reduced energy demand, which reduces the carbon footprint.

The milling process is not an easy task to visualize, it requires quite special skills. Figure 1.2 is a step-by-step diagram of the process, starting with the wheat storage at the mill site. Steps involved after storage are cleaning, conditioning (also called tempering), milling—a complicated process, flour storage, packaging and delivery. In the milling process, the grain goes though break rolls followed by reduction rolls. The output streams from those rolls are, then, mixed in various highly complex streams going through plansifters, purifiers and bran finishers. In a conventional mill, there may be up to 4 break rolls and 12 reduction rolls. That would result in up to 16 flour streams, including a bran stream, a germ stream and a bran/flour/germ "feed wheat" stream. Such mill streams are illustrated and described on the milling diagram, Figure 1.2.

Figure 1.2: Chart of the simplified milling process



(Courtesy of wheat flour books – US Wheat Associates)

The SDmatic helps millers to fine tune the amount of DS in each stream, but it also provides the possibility of also using it to reduce energy usage, which is the focus of this research.

1.2 What is DS, understanding DS and its impact on the end product

Starch represents 67-68% of whole grain wheat and between 78-82% of the flour produced from milling. The semi crystalline structure of the starch granule in the grain kernel can be damaged by mechanical operations, particularly the milling process. DS is important in bread making: it absorbs 4 times its weight in water as compared to 0.4 for native starch. DS granules are also subject to preferential attack by specific enzymes (α- and β-amylases). Some of these enzymes are incapable of attacking an intact granule because of the protective coating on the granules.

The term “Damaged starch” is somewhat of a misnomer as the word “damaged” has a negative connotation implying something to be avoided. In fact, DS should be optimized as it has both positive and negative effects on bread quality. Increasing damaged starch increases the water retention capacity of the flour; however, too much DS leads to sticky dough, strong proofing, and undesirable browning of crust. The optimum DS value varies with the use of the flour and is greatly dependent upon the flour protein content, the alpha-amylase activity, and the type of bread to be made from the flour. Most baked products around the world have specifications in terms of quality and functionality of flour used, and DS is one of these specifications. Flour with high DS cannot be used for the same purpose as the one with a low DS content. Millers can manipulate the DS content of flours through wheat choice, grain preparation and mill setup and adjustments. The wheat choice is based on the impact of the grain hardness: the more resistant to milling, the greater the DS. This "hardness" can be partly modified when preparing the wheat for milling. At milling particular attention is given to the moisture conditioning and tempering time for the grain to be milled. From a proper conditioning or selection of the wheat, it is possible to increase or decrease the DS at the mill. Furthermore, hardness is higher when the protein content is higher; thus, a direct correlation between the protein content and DS. Nevertheless, the mill set-up and adjustments are the major ways of influencing the end flour DS. This study focuses on those aspects.

1.3 Problem definition and energy savings

As we know now, DS is generated in the milling process as the material passes through the breaking and reduction rolls, as reported in cereal chemistry literature and reported in studies by Chopin, who markets SDmatic to monitor level of damaged starch. Just a few streams generate most of the DS, but produce the smallest extractions of flour. The core topic of this study is to identify the right balance between the amount of DS per stream produced and the amount of flour produced as it relates to milling energy demand. Because we know where the DS is produced, predominantly, we can focus on those streams and rolls to optimize energy consumption. We shall see that the electricity consumption is the third highest input cost for a regular flour mill (excluding the grain for milling) and is of sufficient importance to be managed, carefully. The economic value of this research is to measure and demonstrate the potential cost savings in a flour mill by fine tuning the DS content of flour to fit into customer's specifications for a baked end-product with least energy use. Such mill management can reduce maintenance issues, too. The focus here is to identify for Chopin the added customer value from using SDmatic to reduce energy use and to estimate return on investment from electricity savings, alone.

1.4 Solution development

Starch damage and power usage depend on mill size and type, the wheat used (its hardness and protein content), and the set-up and adjustments of the rolls (roll pressures and gaps). Statistical analysis of the data collected gives a measure of the impact of those variables on starch damage and energy usage. That information allows one to focus on the mill streams where the balance between the amount of DS per stream produced and the amount of flour produced is optimized with regard to the electricity cost. That does not look simple, but can be achieved. Chopin has studies on the impact of those variables, and there is literature on the topic. To obtain empirical results, I set up trials at 3 mills located in three different countries, but not in France.

1.5 Implementation plan

After validation of the model, we can verify whether the flour millers using SDmatic could make substantial savings compared to those not so equipped, and, thus, can find added value by using the SDmatic that goes beyond flour quality and consistency. Using SDmatic for process control, not just laboratory analyses, enhances the value of SDmatic to millers by helping millers reduce electricity bills while also improving flour yield. Beyond that, the program proposed here would reduce maintenance of the rolls, and enhance roller life, all improving the return on investment from having and using the SDmatic in the mill.

CHAPTER II: LITERATURE REVIEW

2.1 Overview

Global energy price increases, once again, are sensitizing the milling business to the issue of power consumption in its value-adding processes. So much so that, monthly electricity bills have become a permanent issue in many companies. Since energy consumption, according to Buhler Group, the flour mill manufacturer, accounts for up to 6% of the total cost of flour milling (DUBENDORFER 2011), both flour and semolina producers are interested in finding new solutions to reduce power requirements. In order to get a broad view of the problem, we need to review the literature to first understand how DS content affects baking, how it is measured, and where the DS is produced into the milling diagram. We shall, then, check the major costs involved in milling to see the significance of energy costs in the total costs. We shall focus on that critical expense not only for savings purpose but also for sustainability of the business and the environment. We, therefore, shall look at the literature, if any, on how DS can help to focus on electricity bill. According to Buhler Group (SCHLAURI 2011), there is the image of the efficiency of the bulb where for energy input equal to 100 %, light is about 10% and loss (heat) about 90%. Correlated to the efficiency of the mill, according to this author, (Example = 400t of wheat per day) for a power used of 1000 kW-h/h (100%), there will be an average 570 kW-h/h in heat (60%) lost and only 430 kW-h/h really used for the transformation (40%). One of the core concerns, nowadays, of mill manufacturers is to try to recover some 2/3 of the heat losses in order to develop and generate other energy sources. This is the flour mill of the future. SDmatic would contribute to total automated milling, but let us try, modestly, to use the SDmatic to reduce the electricity bill.

2.2 DS and final product

2.2.1 DS in Cereal chemistry

As mentioned, DS has a major impact on the quality of the final product. Starch is the major compound in wheat, and is about 80% of the flour. Starch does not dissolve in water colder than room temperature; it even does not swell or expand. Then, those granules of starch cannot be decomposed by α- and β-amylases (diastases), being somewhat protected against the effect of amylases by the protective layer around the granules. That protective layer can be eliminated with the gelatinization of starch granule either by heat or by pasting. Amylases can also attack granules of starch broken with a physical or mechanical process. Physical or mechanical damaging of starch only occurs during grinding (EVERS et STEVENS, Starch damage 1985), (GIBSON, AL QALLA et McCLEARY 1992). During grinding, the production of starch granules that have undergone physical damage and are now sensitive to amylases is called “damaging of starch.”

2.2.1.2 The importance of the degree of DS

When starch granules are damaged, important changes occur in their properties. Damaged granules are different than intact granules in regard to two important properties.

1- Increased sensitivity to α- amylases
2- Increased water holding capacity (TIPPLES 1969), (EVERS et STEVENS, Starch damage 1985), (BLOKSMA et BUSHUK 1988), (POMERANZ 1988) (Hoseney, Wade et Finley, Soft wheat products 1988).

These two varying properties affect the dough properties and the internal structure of the bread.

Sometimes, the quantity of DS in the flour is specified to be lower and sometimes higher according to the bread production processes and the nature of the final product, impacting the product and its process (TIPPLES 1969). One of the fundamental reasons for the determination of DS in baking flour is the impact of starch damage on water loading capacity (EVERS, BAKER et STEVENS, Production and measurement of starch damage in flour 1984). The usage of more or less water than required, will impact both handling of the dough (stickiness), but also the quality of the bread (EVERS et STEVENS, Starch damage 1985). When starch granules are damaged, their water holding capacities increase. At 30°C, a native granule of starch, undamaged, absorbs approximately 30% of its weight of water, whereas damaged starch can absorb 100% of its weight in water (Mao 2000). Many properties such as the water absorption of flour, its moisture content, the dough power to produce gas, its manual handling properties (stickiness), its loaf volume (and proofing), and the softness of the crumb, that can have a browning color, are associated with the quantity of DS (Greer et Stewart 1959). Excessive damaging of starch leads to the formation of loose dough structure, because damaged granules release water when they react with α- amylases, which lead to a sticky crumb structure. Most of the quality and functionality parameters that are analyzed on the flour at the laboratory are highly impacted. The most important ones are given below.

Table 2.1: Effect of DS on common rheological behaviors

Rheological behaviour of dough	**LOW DS quantity**	**HIGH DS quantity**
MIXOLAB - AACC 54-60.01		
Water Absorption	LOW	HIGH
C3 (Gelatinization)	HIGH	LOW
C4 (stability hot gel starch)	HIGH	LOW
C5 (starch setback)	HIGH	LOW
Fermentation (Rheofermentometer AACC 89-01.01)		
Volume	LOW	HIGH (if gluten network sufficient to hold gas)
Gas production ($C0_2$ release)	LOW	HIGH
Porosity of the dough	LOW (less gas production)	HIGH (if gluten network insufficient)

ALVEOGRAPH - AACC 54-30.02		
W (baking strength)	LOW	HIGH
P (tenacity)	LOW	HIGH
L (extensibility)	HIGH	LOW
P/L (ratio of tenacity/extensibility)	LOW	HIGH
Kneading Tolerance Farrand (1964)	HIGH	LOW
EXTENSOGRAM - AACC 54-10.01		
Resistivity	HIGH	LOW
Flexibility	LOW	HIGH
SEDIMENTATION - AACC 56-61.02	LOW	HIGH

(Courtesy of Dubat, 2011)

Furthermore, flour naturally contains some sugars. The yeast fermentation process, uses those sugars to produce CO_2 that causes bread to rise and creates the bread structure. However, natural sugars the grain may not be sufficient. In some countries that is compensated for by adding sugar to the formula. However, when processes with long fermentation periods are used, or when more yeast is used, sugar is consumed towards the end of fermentation.

The last fermentation step is considered as the “critical period” where bakers are looking for a quality of bread and yeast that works without any problem, such as a sudden collapse of the bread structure that has not been solidified by the baking in the oven. During this critical step of fermentation, yeast is using the sugars that are produced with the decomposing of sugar by diastases (α- and β-amylases) (VIOT 1992).

Finally, the right balancing of the DS is required to optimize the shelf life of the baking product, as the staleness is delayed with a higher DS, as starch cannot recrystallize. This balance is described in Table 2.2. where damaged starch action spots are highlighted in yellow.

Table 2.2: Desirable and undesirable effects of DS on baking

	What we look for	*To be avoided*

Kneading	A High yield (Water absorption capacity) Good tolerance	*Sticky dough* Low hydrating flour
Molding	Good tolerance Good behavior	Sticky dough Dough too tough or soft
Proofing	Good volume Taste development	break down of dough with little volume
Baking	Volume increase A good color	Dough collapsing in oven Breads too "red"
After	A good taste A good conservation	Too fast crumb hardening

(Dubat 2007)

2.2.1.3 Factors affecting the amount of DS

The amount of DS in the flour varies according to the properties of wheat and storage conditions (EVERS et STEVENS, Starch damage 1985). Since the grain hardness affects the starch damaging to a large extent, the tempering and grinding conditions of the mills are adjusted according to the grain hardness (Ziegler et Greer 1971). Conditioning, synonymous with tempering, is a controlled wetting of grain followed by a resting period during which the added water toughens the bran skin and mellows the endosperm in preparation for milling. The bond between protein and starch molecules inside the endosperm cells of wheat is very strong. In addition, proteins cover the surface of starch granules and bind to them tightly. If the cells are forced to break during grinding, then starch granules and proteins detach, and breaking, damaging in the starch granules occurs. As a result of this tight adherence of the protein and starch, in hard wheat, if a force is applied across an endosperm cell, starch granules break. However, protein and starch can be easily separated from each other on soft wheat where very few starch granules are fractured. Therefore, even if grinding is performed under the same conditions, damage is greater on harder wheats (Hoseney, Cereal starch. 1990).

There is a relationship between damaged starch and the gluten amount in the flour. Flours with high gluten amount and of good quality have a tolerance against excessive starch damaging. For the production of bread of good quality, hydrated flour proteins have to produce a gluten film that may coat the starch granules. Swollen or damaged granules require high protein ratio due to their wide surface areas (Farrand 1969). The Table 2.3 summarizes the origins of the DS, considering that the milling process, the grinding, is the major factor influencing its production.

Table 2.3: Milling process variation and impact on DS

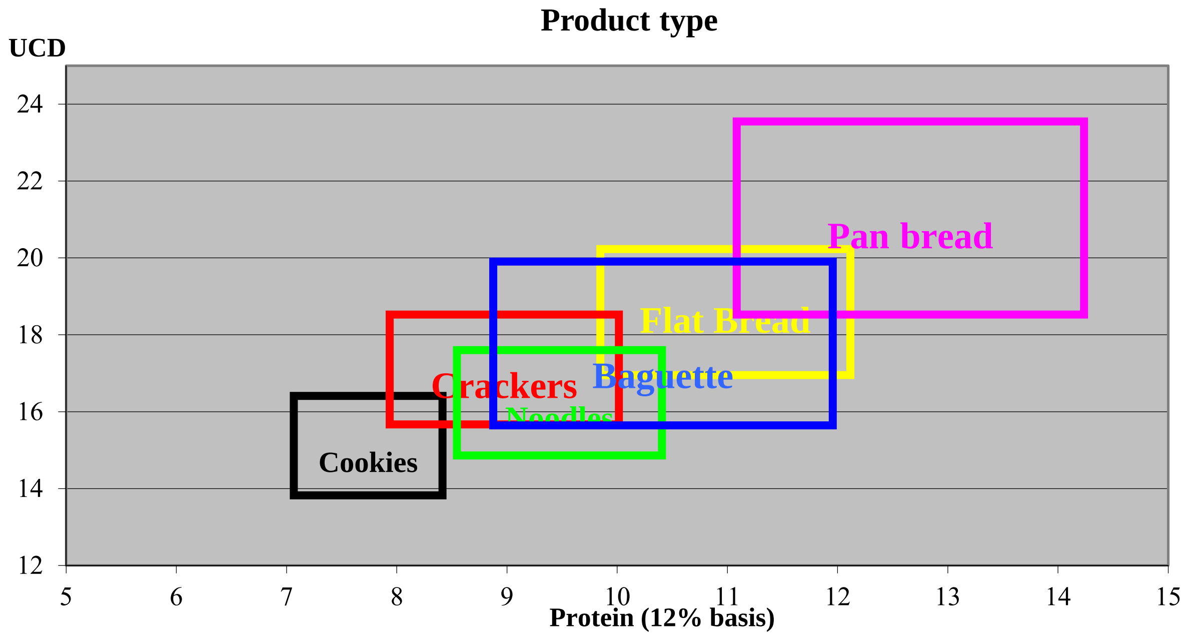
FACTOR	**EFFECT**
Wheat type	Starch damaging is increased with hardening of endosperm structure
Conditonning / tempering	Starch damaging is increased with a kernel insufficiently mellowing the endosperm
Rolls feeding ratio	Starch damaging is increased with decreased feeding ratio.
Rolls speed	Starch damaging is increased with increased speed.
Rolls differential gap	Increased differential increases starch damaging especially in gap material.
Rolls pressure	Increased pressure specially increases the starch damaging in thin feeding material.
Rolls surface	Corrugated surfaces produce more damaged starch than flat surfaces

For good quality breads, there has to be a balance between the amount of water used in the kneading, protein content of the flour, the amount of damaged starch and α-amylase activity. These values also differ in different bread making methods. In fast bread processes, with short resting time, the effect of DS in providing substrate is minimal, but with long fermentation processes the effect is substantial. It has been determined that the level of damaged starch is less important in whole meal bread than in white bread. Except for some biscuit and cake types, wheat with low DS is preferred in cake making (POMERANZ 1988).

2.2.1.4 Common DS content according to end products

There is no specific literature to give a classification of DS and end products, but Chopin Technologies has collected such information over time from SDmatic users, which shown in Figure 2.1.

Figure 2.1: Relationship between DS, protein content and desirable tolerances for the final product



(Courtesy of Chopin Technologies)

End products are classified according to the DS and protein content. Knowing that information, a flour mill laboratory can use the DS according to the purpose of their flours for, as an example:

- Baking target
  - French type (Baguette) : 16 – 20 UCD
  - Pan bread : 19 – 23 UCD
- Biscuit/cookies target
  - 14 – 16 UCD

2.1.2 DS and how it is measured

After the importance of starch damaging was revealed, many methods have been developed to determine the amount of DS in flours. Those methods mainly use the sensitivity of starch with amylolytic enzymes or the extraction of amylose from the starch in cold water. Many methods were developed starting from this point.

2.1.2.1 Different methods

AACC 76-30.02 Determination of Damaged Starch

This method determines the percentage of starch granules in flour or starch preparations that is susceptible to hydrolysis by fungal α-amylase. Percent DS is defined as g starch subject to enzymatic hydrolysis per 100 g sample on a 14% moisture basis (Donelson et Yamazaki 1962).

AACC 76-31.01 Determination of Damaged Starch—Spectrophotometric Method

In this method, DS granules are hydrated; this is followed by hydrolysis to maltosaccharides and limit dextrins by fungal α-amylase. Amyloglucosidase is then used to convert dextrins to glucose, which is specifically determined spectrophotometrically after glucose oxidase/peroxidase treatment. DS is calculated as a percentage of flour weight on “as is” basis. This method is applicable to wheat flour and starch. (GIBSON, AL QALLA et McCLEARY 1992). An assay kit was developed to get a faster use of this technique.

AACC 76-33.01 Determination of Damaged Starch—Amperometric Method

The Iodometric (amperometric) method is using the SDmatic from Chopin Technologies. It uses a different technique described below. Results are reported in absorbed iodine (AI%) calculated and expressed in UCD unit (Unité Chopin Dubois).

The AACC - American Association of Cereal Chemists states that:

“Damaged starch is a very important flour quality parameter because it affects water absorption. To determine the extent of damaged starch, this method measures the kinetics of iodine absorption in a liquid suspension, using an amperometric probe. Results are given in an iodine absorption index percentage (AI%). An indication of the speed of iodine absorption in seconds is also reported as “*V*abs”.
The method is specific to white flour obtained from *Triticum aestivum* coming from either laboratory or industrial milling, but it can also be used on wholemeal flour.”

Time for the test is between 7 to 10 minutes. There are some correspondences between all the different units used (Farrand, UCD, AACC%) to measure the DS.

2.1.2.2 Iodometric (amperometric) method

The SDmatic uses Medcalf and Gilles principle elaborated in 1965 to calculate the DS in the flour. This empirical scale method consists of measuring the iodine amount absorbed by starch granules in a solution at 35ºC. The device provides the required amount of iodine proportional to the weight of the tested flour and then measures the residual iodine amount absorbed by the flour to determine the DS.

USED MATERIAL:

- Chopin SDmatic device
- 1 g flour sample (± 0.1 g)
- 3 g Boric Acid
- 3 g Potassium Iodine
- 120 ml purified water
- 1 drop of Sodium Thiosulphate (0.1mol)

The test takes 7 to 10 minutes, with no particular skills of the operator.

2.1.3 DS per mill stream

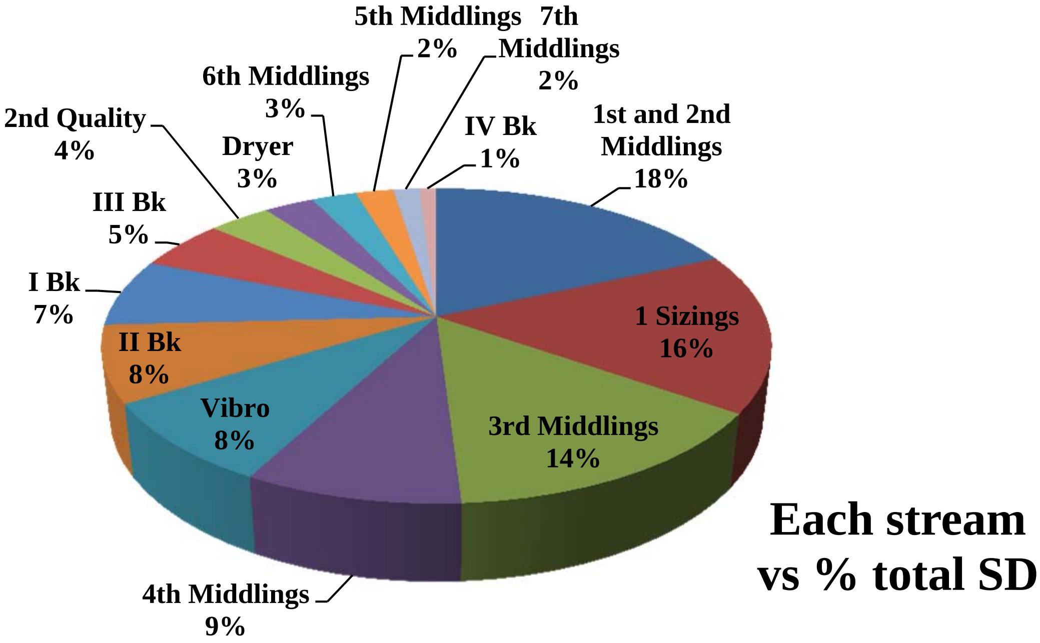
Knowing the nature of the DS, where it comes from in cereal chemistry terms, how it impacts the baked products and how it is measured, we can come back now to our topic which is to link the DS production with the milling process and therefore enlighten critical electricity power use points. We cannot get into details of the milling diagram and the codification, but let us take a 150t/d mill with 4 breaking streams (BK), 1 Sizings (SIZ) and 7 Middling and second quality streams (converting/reduction) (MID) and ancillary equipments for an all-purpose flour (US Grade, French type 55). See Table 2.4.

Table 2.4: Milling streams and flour produced and respective DS % generated.

Stream in the processing order	% of flour produced	DS generated - UCD unit	
I Bk	6.8	16.5	21% of the total
II Bk	7.9	17.1	
III Bk	5.3	16.9	
IV Bk	1	17.1	
1st Sizings	15.7	18.0	**65% of the total**
1st and 2nd Middlings	18	17.5	
2nd Quality	2.8	22.3	
3rd Middlings	17.7	13.9	
4th Middlings	10.8	14.1	
5th Middlings	1.8	20.6	14% of the total
6th Middlings	1.9	23.1	
7th Middlings	1	25.0	
Vibro	5.4	26.8	
Dryer	3.9	12.6	
Type 55	**100%**	**17.2**	

(Ben Amara 2009)

Figure 2.2: Total flour DS produced Vs. Milling streams. 150t/d mill.



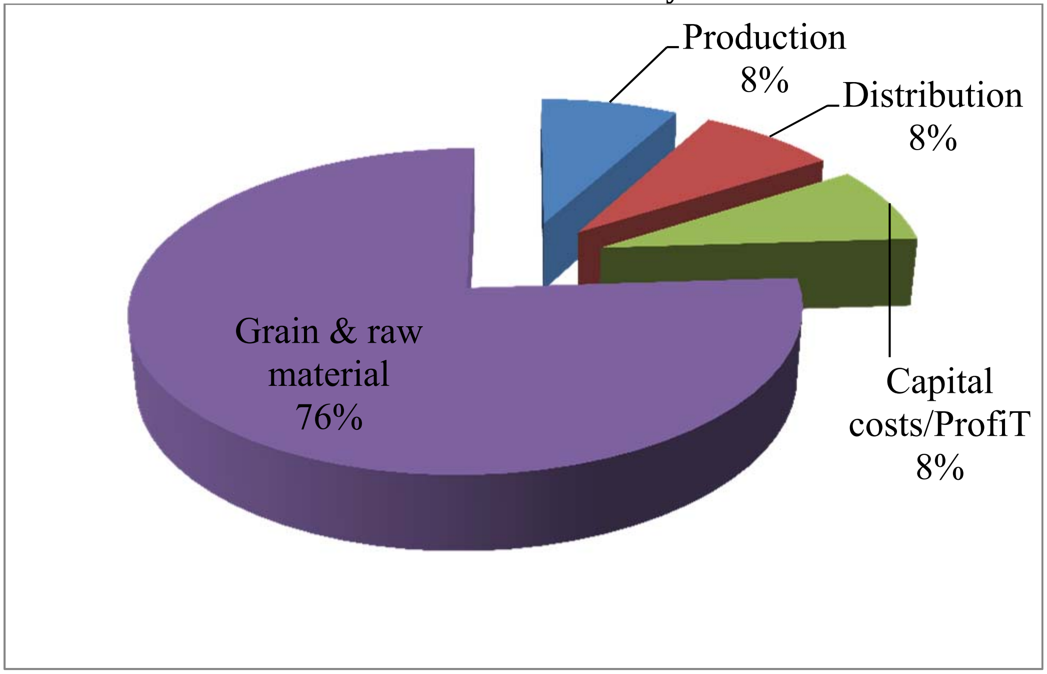
51%, about half of the DS produced into this milling diagram is on 1st and 2nd Middlings (1M and 2M), 1rst Sizing (S1) and 3rd Middlings. They are the main streams where we should focus our attention.

2.3 Costs structure in flour milling, energy costs

2.3.1 Structure of the general costs

A flour mill today, in the USA, may be spending $45 in manufacturing costs and close to $400 in wheat, freight and taxes to produce one ton of flour. (Fowler, Managing the milling process Learning to manage people, processes and profits will help milling companies maximize performance 2010). Let us have look with table2.3 at the total operation and production costs of a flour mill in percentages from the experience of a major manufacturer like Buhler Group.

Figure 2.3: Total cost structure in a flour mill annually. 350t/d mill.



(SCHLAURI 2011)

Table 2.5: Dispatch of the production, distribution, capital and raw material costs (SCHLAURI 2011)

	% ranging from - to	
Production	7%	8%
Energy	1%	2%
Personnel	4%	6%
Maintenance	1%	
Distribution	7%	8%
Packing	2%	
Transport	2%	
Personnel	2%	
Marketing	1%	
Capital costs/Profit	7%	8%
variable profit	X? %	
Transport	2%	
Depreciation	4%	
Grain and raw material	76%	82%

2.3.2 Costs analysis without raw material

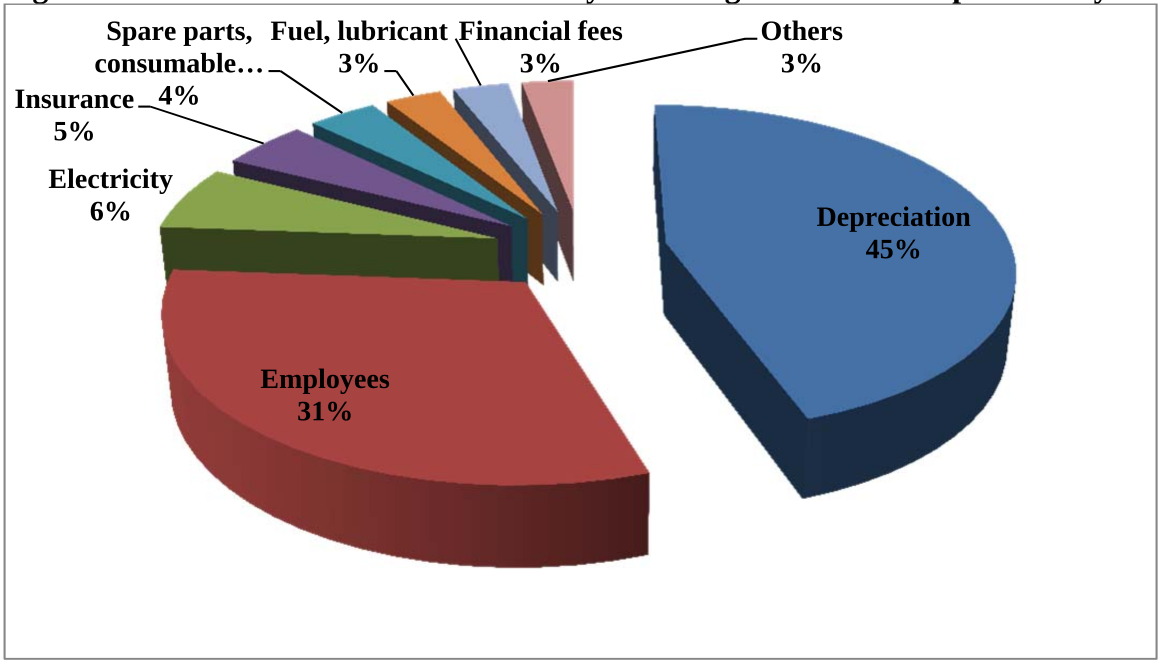
This analysis can be extremely volatile and variable. That is the reason why we will try to correlate DS and energy based on various examples and flour mills types considered as variables to determine a model. For the good sake of the understanding of that study, we shall take one example here on how the structure of the cost are dispatch when it comes to exclude the raw material costs to go into much narrower analysis. Let us take a 150t/day flour mill -Neofar- , Algeria -based, where energy costs are quite low. This is what Tables 2.6 and 2.7show.

Table 2.6: Amount of the costs of a flour mill excluding raw material costs

millers's costs/month	
Depreciation	25,000.00 €
Employees	17,455.00 €
Electricity	3,542.00 €
Insurance	2,628.00 €
Spare parts, consumable…	2,094.00 €
Fuel, lubricant	1,712.00 €
Financial fees	1,703.00 €
Others	1,600.00 €
Excluding wheat, additives, bags, labels…	

(Ben Amara 2009)

Figure 2.4: Total cost structure in a 150t/day mill – Algeria – with cheap electricity



(Ben Amara 2009)

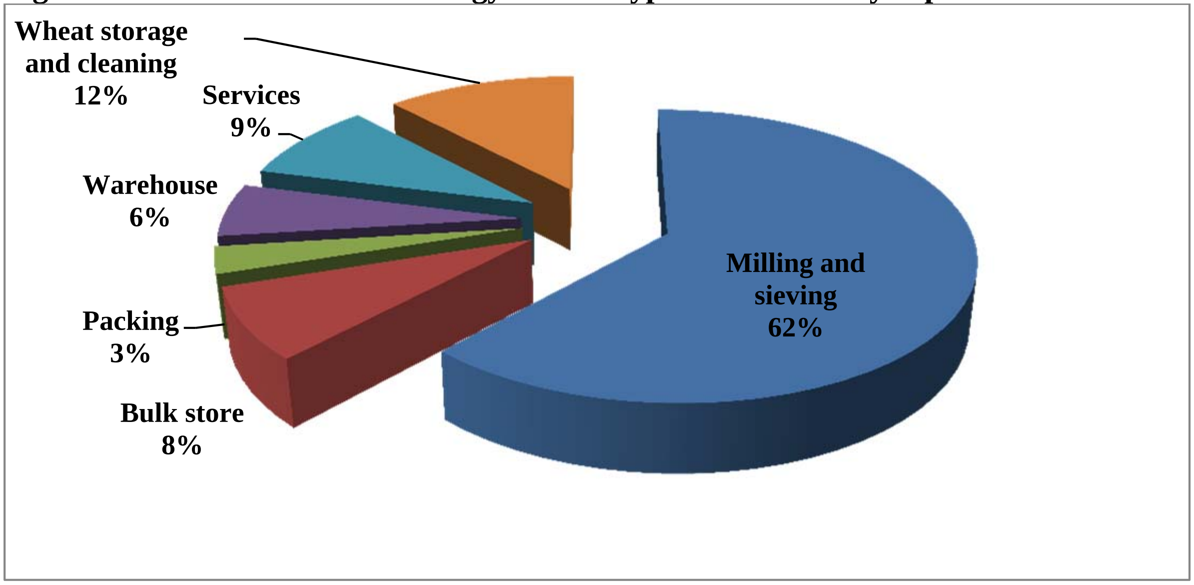
2.3.3 The electricity bill

Approximately 62% of the energy is used for milling flour from wheat. In flour milling, electricity accounts for almost 75% of total energy use and over 90% of energy costs (Walshe 1991).

If we focus on the breakdown of energy use, as per Table 2.5, the main processes in flour milling are

- Wheat reception and storage;
- Cleaning and conditioning;
- Milling and sieving;
- Blending, flour storage and packaging.

Figure 2.5: The breakdown of energy use at a typical flour mill by department.



(SCHLAURI 2011)

2.4 Energy savings in a flour mill

In a competitive business environment, much attention is paid to the operating costs of the entire production chain. Indeed, most commercial flour producers have already streamlined their processes in terms of manpower requirements. This means that the potential for further cost reductions in the manpower area is low. The focus must therefore be on energy costs, which are a substantial production cost factor. As a result of utility price increases already experienced or expected in the future, monthly electricity bills have become a permanent issue in many companies (DUBENDORFER 2011). According to a report prepared by the United Nations Food and Agriculture Organization and the European Bank for Reconstruction and Development in October 1999, energy costs for the French milling industry were the third largest expense at 7.5%, behind labor-related charges and management/administration/office charges at 40.2% and 33.1%, respectively (Gwirtz 2008). According to a report on the manufacturing industry prepared by the U.S. Census Bureau in 2005, energy use in the United States was approximately 4 to 7 kilowatt hours

(KW-h) per cwt. of flour produced. Using the average cost of 6 ¢ per KW-h, the total energy cost is 24 ¢ to 42 ¢ per cwt., or approximately $4 to $7 per ton of wheat milled. Looking at these figures, it's easy to see why energy consumption is a major part of mill conversion costs (Gwirtz 2008). The monitoring/fine-tuning of power consumption through the process controled computerized systems is now possible. In order to fine-tune power consumption in industrial processes, one needs a clear idea of the current situation. For this purpose, a plant will ideally be divided into plant sections or sub-processes that are detailed as accurately as possible. The energy requirements of these sub-processes can then be accurately determined by global power measurements. Another possibility is to analyze plant sections that operate simultaneously. As power rates often depend on peak power consumption, this may allow fine-tuning of power usage according to the peaks costs of electricity (DUBENDORFER 2011). Power measurements are also a suitable instrument for pinpointing process operations with high power consumption. The flour mill manufacturer, Buhler Group, one of the major experts in milling, auditing a mill, would first recommend modifying the machinery to improve the energy consumption through different ways:

- Auditing the power supply system and the related electrical equipment used. Whenever possible, transformers should be installed as near as possible to the equipment that uses the power. The longer the cable routes, the higher the power losses.
- Another important factor is the selection of the electric motors. In the recent past, most manufacturers of induction (asynchronous) motors have substantially improved the efficiency of their products.

Buhler would therefore first check the characteristics of all motors, then the plant design and plant engineering aspects for a plant layout for minimizing material conveying distances, pneumatic lifts…

- The energy consumption peaks during starting and stopping of motors is often underestimated. This means that more attention must be paid to continuous operation of equipment.
- There are modern ways to use the heat recovery. Since we also use energy in our latitudes to heat buildings or recycled air, we must also briefly point to the possibility of energy recovery. In the grain processing industry, instead of exhausting the thermal energy generated in various sub-processes, it may be worthwhile to consider recovering it.

As an understandable example, an energy audit was recently proposed by Steven Winter and Assoc. (SWA) to The Bay State Mill in Clifton, NJ. It processes 26,000 bushels of raw wheat into packaged sacks of whole wheat and white flour each year. (STEVEN Winter & Ass. Inc s.d.) :

> “One of the simplest energy conservation measures that SWA suggested was to upgrade the lighting system and its controls. As a factory, not all areas of the mill are constantly occupied by employees. SWA found that many areas were overlit when compared to their relatively low occupancy rates. Thus, the firm recommended upgrading to long-life, energy efficient fixtures, and installing occupancy sensors and timers on certain lights, while still assuring appropriate baseline levels of lighting throughout the factory. However, the largest portion of the facility's energy use actually comes from the 350 motors used in the milling and packaging process. These 75 to 125 horsepower continuous operation motors consume 80% of the total energy used at the mill. SWA recommended implementing a wide-scale motor upgrade to premium efficiency motors; the firm estimated that an efficiency improvement of only 2% to 4% would amount to savings of $131,000 annually, while the complete capital upgrade itself was estimated at $269,000. The equipment upgrade offers both a lifetime 870% return on investment and the opportunity to increase productivity at the mill.

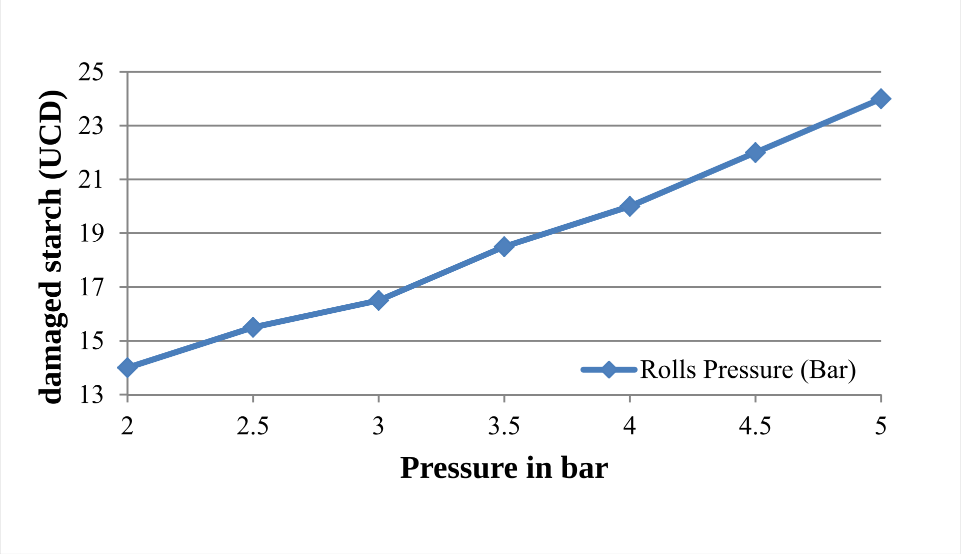
> SWA also identified great potential for the installation of photovoltaic panels on the facility's rooftop. The mill’s location in New Jersey makes it eligible to sell Solar Renewable Energy Credits at an average rate of $600/MWh through NJ Clean Energy’s superb energy credit trading program.”

The SWA study gives evidences, if needed, that the milling industry still has many opportunities for power savings, no mention is made of monitoring of the damaged starch in the milling process.

2.5 Relationship between DS and energy consumption

Indeed, our scope is to correlate the DS, controlled in the major streams of the flour mill to the electricity consumption. In order to understand how electrical power consumption is related to DS, refer to figures 2.6 and 2.7 from Chopin Technologies.

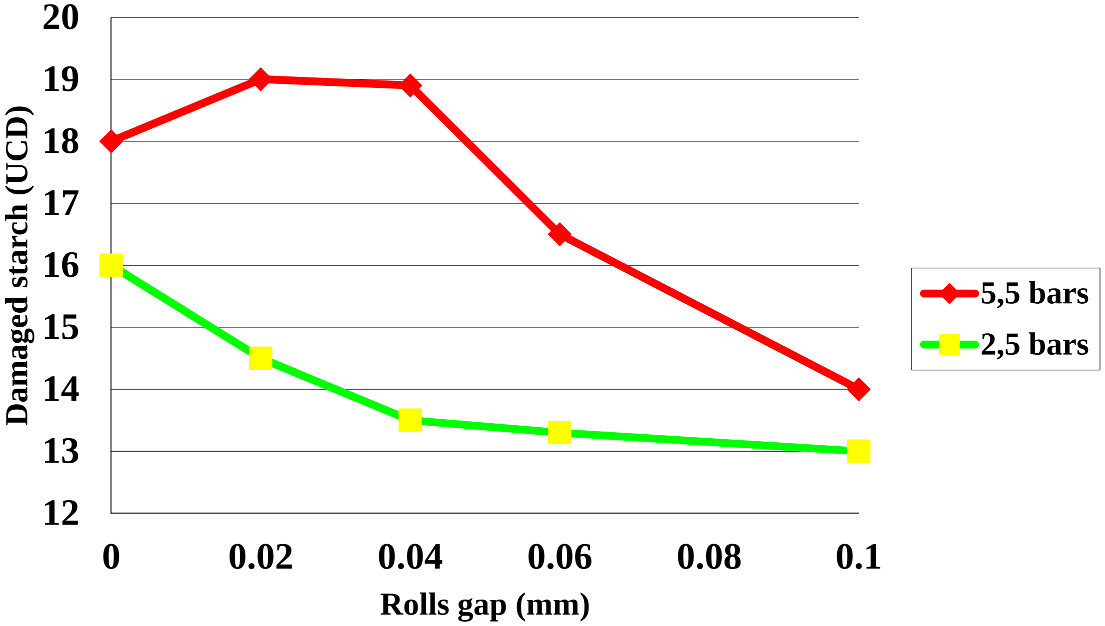
Figure 2.6: Relationship between the pressure on the rolls and the DS production



(Courtesy Chopin Technologies)

In Figure 2.6 we correlate the increase of the rolls pressure on the milled grain which linearly increases the DS content.

Figure 2.7: Relationship between the DS production and the rolls gaps



(Courtesy Chopin Technologies)

Also, on Figure 2.7, we see the correspondence between the rolls gaps that affects DS content. Increasing the extraction of flour—mill yield—can be done, by increasing roll pressure and/or by reducing roll gaps, both of which increases energy demand, And in the end, the resulting flour may be out of specification for the customer. Balancing the flow of ground product through the mill and obtaining the optimal distribution of quality products is the key component of getting the best extraction of quality products in any milling process. Achieving this balance also improves profitability. In the flour milling process, the break system and the purification system are two points in the process that constantly change depending on wheat condition, temperature and relative humidity in the mill, equipment wear and a number of other variables that are difficult to control. However, you can monitor these variables and make adjustments to compensate for changes in them. Therefore, the primary areas of focus for this discussion are the practices necessary to optimize mill product — the break system and the purification system. We identified above that 50% of the DS produced in flour was on 1st and 2nd Middlings (1M and 2M), 1st Sizing (S1) and 3rd Middlings. This is shown in Figure 2.8 with a different angle.

Figure 2.8: Diagram of DS study per stream

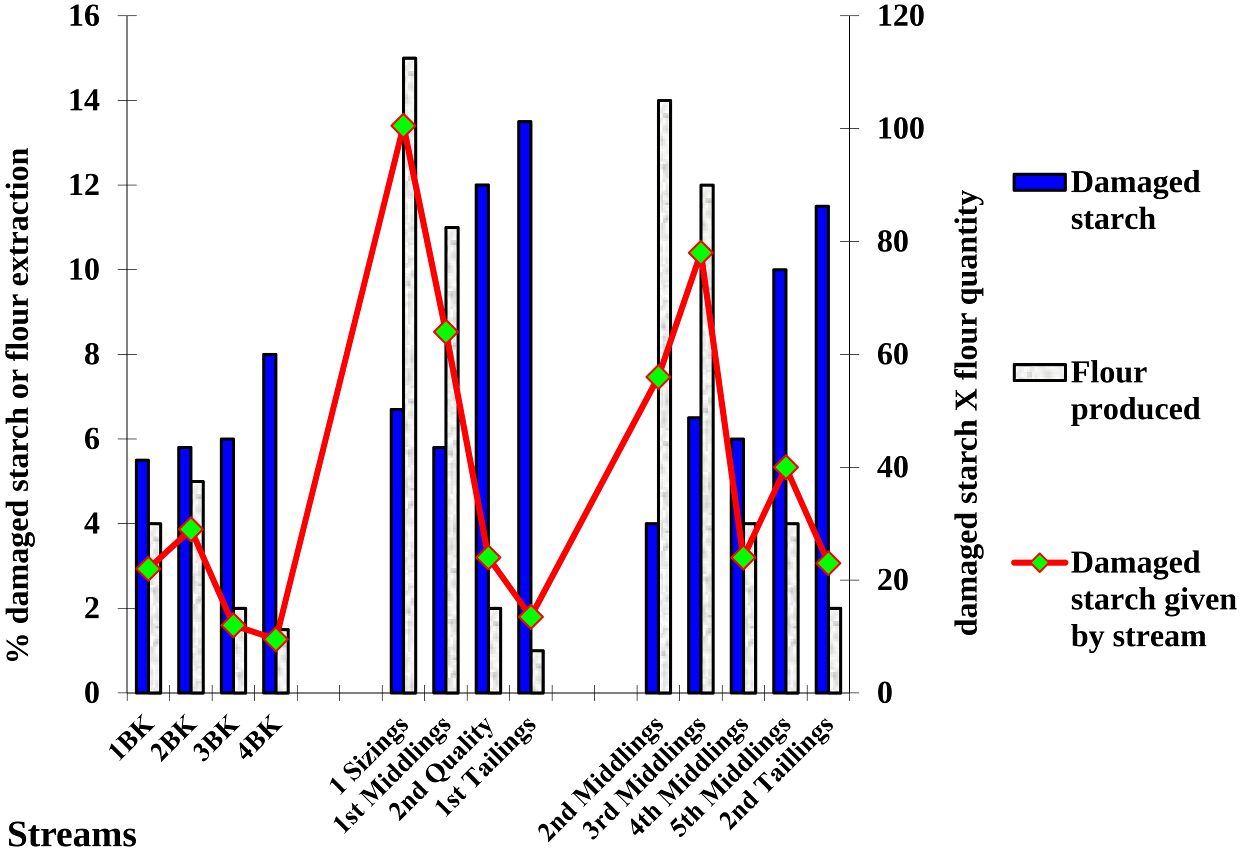
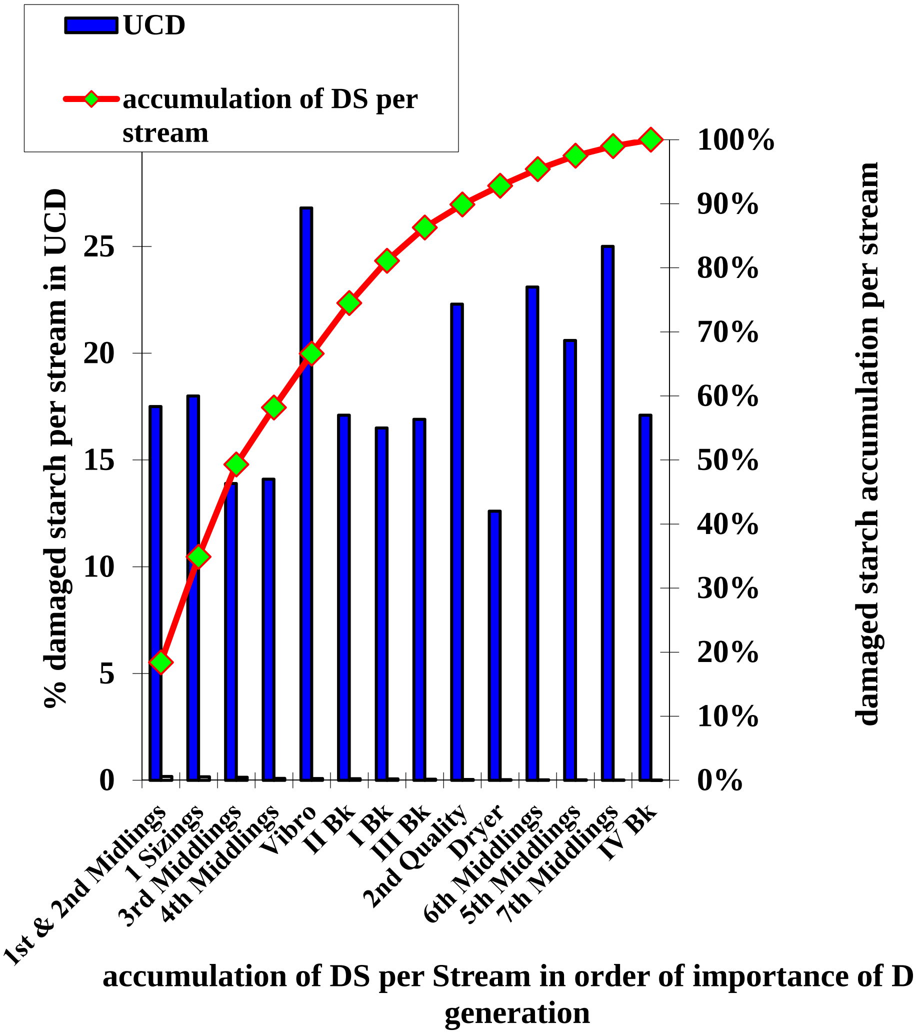


Figure 2.9: Cumulative curve of DS generation per stream in percentage



The Table 2.9 is showing the accumulation of 100% DS produced for 100% flour per stream, in order of generation volume.

> “The mill roll floor is like the gas pedal in the car analogy. You can often get more wheat through the mill by pushing a little harder, but your gas mileage or yield may suffer. Understanding the balance between choice of wheat, mill throughput, DS and the yield potential is important. For example, the value of 1% increase in milling yield from 75% to 76% would be worth just over $4 per ton of flour sold today. This would be about $3 per ton of wheat purchased. So to turn this “gauge data” into usable information, you might say that if a particular type of wheat allowed you to increase your extraction by 1%, you could pay up to $3 per ton more and still break even on the purchase.” (Fowler, Managing the milling process Learning to manage people, processes and profits will help milling companies maximize performance 2010).

2.5.1: DS after the break rolls

The secondary breaks (4Bk and 5Bk) or tail end breaks function to clean up the bran and remove any remaining flour. Flour from the tail end breaks is much darker with higher ash content and DS in comparison to flour from the head end breaks. For this reason, maximizing the quantity of high quality semolina from the primary break streams is extremely important to balance the mill and optimize the production of high quality flour.

2.5.2: Setting the break release

Changes in the break release may be the result of many different variables including the type of wheat, the tempering time or final moisture of the wheat, feed rate to the grinding stream, distribution of product across the grinding roll, roll wear and even the method used to collect the sample from beneath the roll being checked (Fowler, Optimizing mill performance : Carefully monitoring variables that affect the break and purification systems is of the utmost importance 2011). Checking the break release is a simple procedure. Each step of the procedure is important to obtain accurate and repeatable results. The sampling method used must be the same for each miller checking the break release. Differences in collecting the sample will result in different samples being collected. Before taking the sample, check that the mill is operating under the proper load. The stock must be uniform across the roll. To collect a representative sample, the sample should be taken equally from the left side and right side of the roll, near the front to back center of the rolls. This sample, processed on the SDmatic for DS, shall be with the DS content a clear monitoring of all milling conditions, but also of energy consumption, through the settings of the rolls (pressure and gaps). Improper testing of the break release may result in the miller making incorrect adjustments to the rolls. These adjustments will cause increased mill system and product quality variability. A reporting log should be maintained to report excessive changes in break release, and the cause for these changes should be investigated and eliminated.

2.5.3: FLOUR: dashboard - performance

> “The mill’s quality assurance laboratory is to the mill what the tune-up technicians are to the modern engine. A consistent performing car needs regular tune-ups, and a mill’s flour consistency performance is just as important to measure. For the bakery customer, consistency of product quality might be of even greater value than the relative level of quality itself. As bakers push to improve their products and streamline their processes, they must receive flour that performs consistently day after day. This consistency comes in the form of water absorption (flour moisture), rheological properties such as dough tolerance and extensibility, loaf volume, as well as color and appearance.” (Fowler, Optimizing mill performance : Carefully monitoring variables that affect the break and purification systems is of the utmost importance 2011)

Setting a standard of identity for each type of flour based on market demand becomes the critical first step. The role of the quality assurance team becomes consultative in their ability to help mill operations deliver that same product daily. Specific flour performance specifications can be met through an infinite combination of wheat blends. We got now all the parameters understood. The objective of the next chapter of this study will be to combine them as variables, in order to get a statistical model that can explain and predict the variations of electricity consumption in those core streams according to the DS.

CHAPTER III: MATERIALS AND METHODS

This chapter deals with the process of validation of a model for correlating the DS content with the electricity bill. The method was a survey of 3 flour millers who agreed to cooperate by running mill tests for Chopin. The tests were performed according to a required protocol to control the Amperage and UCD content of their flour with different milling settings (Normal, +1 gap on the rolls, +1 Pressure on the rolls, and so on…) on sampled flours in certain streams in their industrial flour mill. The data collected that way was statistically analyzed, in order to correlate DS and power.

How? The millers were asked to sample test it using SDmatic flour at specified critical streams with different roll settings that resulted in different electrical power usages. We collected data at 3 flour mills, whose identity are confidential. The Results were, used to find the statistical relationship between amperage and damaged starch content.

3.1 Sources of data: definitions

The objective in the milling of white flour is to extract the maximum amount of flour of the required quality characteristics from a given mass of wheat, with minimum bran contamination. DS, as seen, is one of these core characteristics for baking. DS creation and particle size reduction are accomplished by increasing the grinding pressure in the reduction streams as the product moves through the mill stream as shown in the milling diagram. The modern flours mills are all taking advantage of features such as computerized grinding gap adjustment, and, as seen, this can be particularly efficient in terms of DS creation when applied to the head reduction streams (1st and 2nd Middlings (1M and 2M), 1st Sizing (S1) and 3rd Middlings (3M), representing 50% of the DS produced. Those streams must be considered as central to the final quality of the flour and their variation may have the greater impact in the way of predicting the DS. Having the relative energies correlated to these streams, involving the entire possible variables may be also significant. We therefore need, as variables:

- The type of mill: we received data from 3 mills: a 350tons/day Buhler, a 250tons/day Alapala, a 150tons/day GBS Group S.p.A.- GOLFETTO SANGATI SPA. The input/output, energy consumption is different from mill to mill. The mills are located in South Africa, Turkey and Algeria respectively.
- The type of wheat milled: the physico-chemical and rheological properties of the wheats differ widely. Variations are critical from one local wheat in Turkey from another coming from elsewhere, imported or locally harvested. In terms of DS impact, the hardness of the kernel is critical. We selected 3 wheats, regardless any varietal identification, for each mill, which they used randomly: for the purpose of our study, they milled 3 types of wheat with 9%, 11% and 13% protein content (dry base).
- We kindly asked them, also, to make their measurements in the 3 major streams 1M/2M, S1, 3M.
- We then asked them to set their rolls into those streams with 3 different gaps (gaps): 0.15, 0.3, 0.4 millimeters
- Finally we asked them to impact those gaps with 2 different pressures on the rolls: 4.5 and 2.5 bar.
- And report the results for each combination in terms of UCD content for DS & Amperage for power consumed.

- Table 3.1 is showing all the independent variables and units used of this study, Table 3.2 the dependent variables and their unit and finally Table 3.1 shows the combinations of dependent variables

Table 3.1: Independent variables used in the experimental design

n°	Independent Variable	Unit			
1	Mill	type of mill	A	B	C
2	protein content	% Dry Base	9%	11%	13%
3	Stream	steam number	S1	1M/2M	3M
4	Roller Gap (RG1,2,3)	Mm	0.15	0.3	0.4
5	Pressure on rolls (P1,2,3)	Bar	4.5	2.5	
6	Type of flour produced	Quality & extraction		Straight Grade 0.55-0.75 ash	

Table 3.2: Dependent variables used in the experimental design

n°	Independent Variable	Unit
1	Damaged starch	UCD
2	Power consumption	Amperes

Table 3.3: Acronym & combinations between gaps and pressure

Gaps		Pressure	
RG1	0.15	P1	4.5
RG2	0.3	P2	2.5
RG3	0.4		
Combinations :			
	RG1P1	RG2P1	RG3P1
	RG1P2	RG2P2	RG3P2

3.2 Sources of data: sampling

A questionnaire was conducted with 3 SDmatic users though a form displayed on BooRoo (www.booroo.com) asking the following question: please proceed into your flour mill to the 6 combinations of rolls gaps & pressures, based on your mill, 3 qualities of wheat (9,11,13% protein content) and give us the measurement of the DS in UCD & power consumed in Amperes into 3 majors streams of your mill (1M/2M, S1, 3M) for a type of flour produced straight grade (0.55-0.75 ash). The results were obtained for 162 observations, 54 on each mill with both UCD & Amperes measures collected along with the measure for the six independent variables.

3.3 Analytical methods

The SDmatic was used by those 3 flour mills. They conducted their tests according to the AACC 76-33.01 method for damaged starch determination. An Ampere meter was used for each measurement, from the monitoring software that operates automatically the mill.

3.4 Statistical development

All the analytical data on the 162 runs were imported into STATA for statistical analysis. A linear regression was performed. Unfortunately, the data were not obtained in duplicate to enable the repeatability of each of the methods. This is missing in our study to assess the reproducibility of each prediction model, including the SDmatic results.

CHAPTER IV: ANALYSIS

This chapter discusses the data collected, the regression and its analysis, validates the model and discusses the results.

4.1 Trial results

Table 4.1 provides the results obtained from the tests. The three mills are the reference on energy consumption and damaged starch.

Table 4.1: Influence of energy consumption on damaged starch: gaps between rolls, pressure on the rolls with 3 types of wheats type 9%, 11% and 13% protein content.

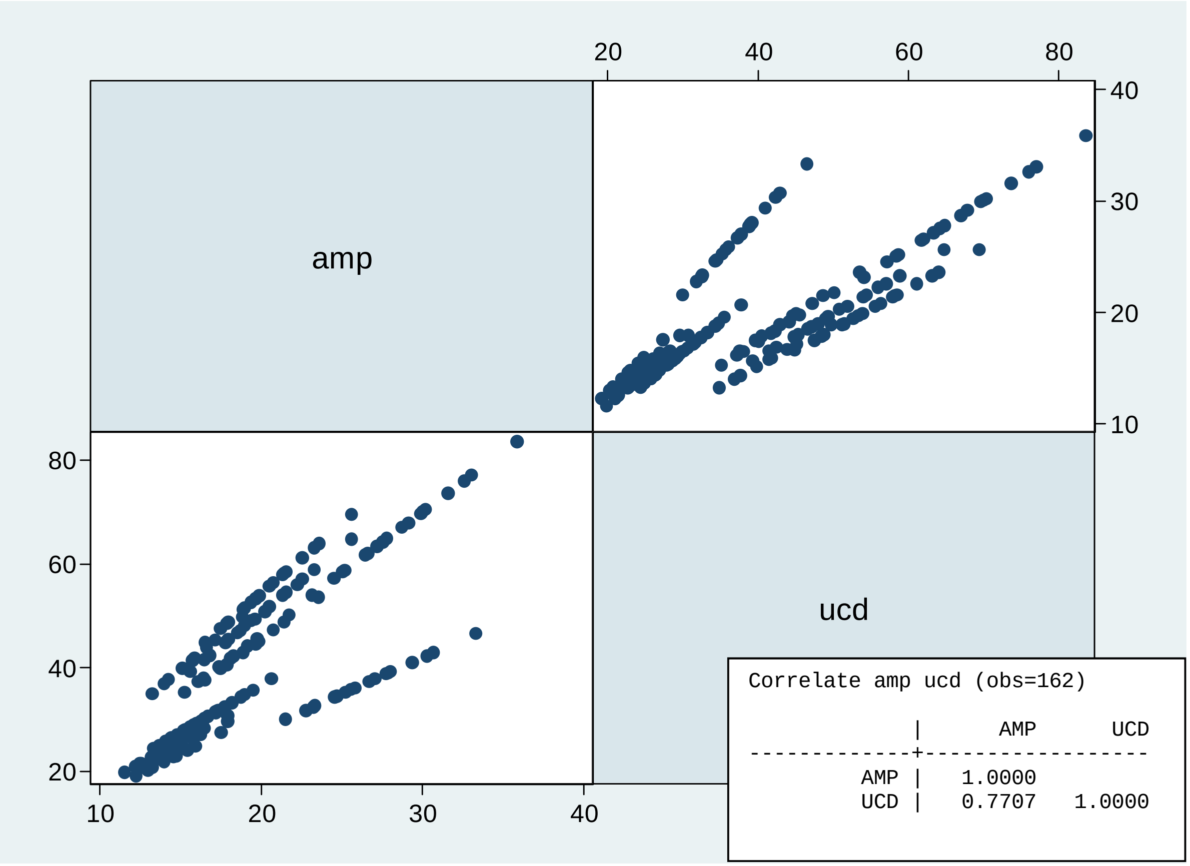
	Gaps (Roller Gap - RG) & pressure (P) combinations and effect on Power (Amp.) and DS (UCD)											
CODE: mill/protein/ stream	RG1/P1		RG1/P2		RG2/P1		RG2/P2		RG3/P1		RG3/P2	
	UCD	Amp.	UCD	Amp.	UCD	Amp.	UCD	Amp.	UCD	Amp.	UCD	Amp.
	Mill A: Buhler 350t/d => Straight Grade 0.55-0.75 ash											
A9S1	29.9	69.7	27.8	38.8	21.4	57.9	17.2	31.5	19.7	44.6	14.9	24.7
A91M2M	21.4	53.9	16.3	29.7	18.5	46.6	14.9	25.6	15.7	41.5	14.6	22.8
A93M	27.5	64.2	25.6	35.7	19.7	53.3	15.8	29	18.1	41.8	13.8	23.6
A11S1	31.6	73.7	29.3	41	22.6	61.2	18.2	33.3	20.8	47.2	15.8	26.1
A111M2M	22.6	57	17.2	31.4	19.6	49.3	15.8	27.1	16.6	43.8	15.4	24.1
A113M	29.1	67.9	27	37.8	20.8	56.4	16.7	30.7	19.2	44.2	14.6	24.9
A13S1	35.9	83.6	33.3	46.5	25.6	69.4	20.6	37.8	23.6	53.5	17.9	29.7
A131M2M	25.6	64.7	19.6	35.6	22.3	56	17.9	30.7	18.9	49.8	17.5	27.4
A133M	33.1	77	30.7	42.9	23.6	64	19	34.8	21.7	50.2	16.5	28.3
	Mill B: Alapala 250t/d => Straight Grade 0.55-0.75 ash											
B9S1	27.2	63.3	25.2	35.2	19.4	52.6	15.6	28.6	17.9	40.6	13.6	22.5
B91M2M	19.4	49	14.8	27	16.9	42.4	13.6	23.3	14.3	37.7	13.3	20.7
B93M	25	58.4	23.3	32.5	17.9	48.5	14.4	26.4	16.5	38	12.5	21.5
B11S1	28.7	67	26.7	37.3	20.5	55.6	16.5	30.2	18.9	42.9	14.4	23.8
B111M2M	20.5	51.8	15.7	28.5	17.8	44.8	14.4	24.6	15.1	39.9	14	21.9
B113M	26.5	61.7	24.6	34.3	18.9	51.2	15.2	27.9	17.4	40.2	13.2	22.7
B13S1	32.6	76	30.3	42.3	23.3	63.1	18.8	34.3	21.5	48.7	16.3	27
B131M2M	23.3	58.8	17.8	32.4	20.2	50.9	16.3	28	17.2	45.2	15.9	24.9
B133M	30	70	27.9	39	21.5	58.2	17.3	31.6	19.8	45.6	15	25.7
	Mill C: GBS 150t/d => Straight Grade 0.55-0.75 ash											
C9S1	25.2	58.6	23.4	32.6	18	48.7	14.5	26.5	16.6	37.6	12.6	20.8
C91M2M	18	45.4	13.7	25	15.6	39.3	12.6	21.6	13.2	34.9	12.3	19.2
C93M	23.2	54	21.5	30.1	16.6	44.9	13.3	24.4	15.3	35.2	11.6	19.9
C11S1	26.6	62	24.7	34.5	19	51.5	15.3	28	17.5	39.7	13.3	22
C111M2M	19	48	14.5	26.4	16.5	41.5	13.3	22.8	14	36.9	13	20.3
C113M	24.5	57.1	22.8	31.8	17.5	47.5	14.1	25.8	16.1	37.2	12.3	21
C13S1	30.2	70.4	28	39.2	21.6	58.5	17.4	31.8	19.9	45.1	15.1	25
C131M2M	21.6	54.5	16.5	30	18.7	47.1	15.1	25.9	15.9	41.9	14.8	23

C133M	27.8	64.8	25.8	36.1	19.9	53.9	16	29.3	18.3	42.2	13.9	23.8
Min	18	45.4	13.7	25	15.6	39.3	12.6	21.6	13.2	34.9	11.6	19.2
max	35.9	83.6	33.3	46.5	25.6	69.4	20.6	37.8	23.6	53.5	17.9	29.7
average	26.1	62.3	23.1	34.6	19.8	52.4	15.9	28.6	17.8	42.4	14.4	23.6

4.2 Summary of trial results

The first thing we had to make sure was to obtain a statistically significant correlation between UCD measurement & Amperage. We knew that by experience that we had to make a quite comprehensive variables selection. The range of samples tested was also large enough to predict the amperage. This was done in purpose to get a stronger correlation. The correlation achieved between DS (UCD) & Power consumption (Amp.) has a 0.77, as per Table 4.2. This is good.

Table 4.2: Scattered plotting of UCD & Amperage



```
Correlate amp ucd (obs=162)

             |      AMP       UCD
-------------+------------------
         AMP |   1.0000
         UCD |   0.7707    1.0000
```

We constrained the constant term of the linear regression to zero, as per Table 4.3.

Table 4.3: Detailed results of the linear regression without and with constant

```
regress ucd amp

      Source |       SS       df       MS              Number of obs =     162
-------------+------------------------------           F(  1,   160) =  234.04
       Model |   20721.747     1   20721.747           Prob > F      =  0.0000
    Residual |   14166.153   160  88.5384565           R-squared     =  0.5940
-------------+------------------------------           Adj R-squared =  0.5914
       Total |     34887.9   161  216.695031           Root MSE      =  9.4095

------------------------------------------------------------------------------
         ucd |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         amp |   2.134763   .1395412    15.30   0.000     1.859183    2.410343
       _cons |  -1.009787   2.821519    -0.36   0.721    -6.582008    4.562435
------------------------------------------------------------------------------

. regress ucd amp, noconstant

      Source |       SS       df       MS              Number of obs =     162
-------------+------------------------------           F(  1,   161) = 3274.67
       Model |  288363.881     1  288363.881           Prob > F      =  0.0000
    Residual |  14177.4934   161  88.0589649           R-squared     =  0.9531
-------------+------------------------------           Adj R-squared =  0.9528
       Total |  302541.375   162  1867.53935           Root MSE      =   9.384

------------------------------------------------------------------------------
         ucd |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         amp |   2.086567   .0364627    57.22   0.000     2.014561    2.158574
------------------------------------------------------------------------------
```

With no constant term, the Pearson correlation increases to $0.95R^2$, the prediction equation from the UCD results to get amperage is:

$$A=2.086UCD$$

The correlation between UCD measurement and Amperage is based on a calibration with a range large enough that makes the prediction model of a statistical significance, with a very significant T statistic. Basically, the amperage increases of .456amp when increasing one point UCD.

4.3 Theoretical DS vs. energy consumption at the flour mill optimization

Possible changes in electricity cost can have a major impact on mill viability. In the case under study, variations in energy can be predicted according to DS content at some key points of the milling process. We statistically explained that an increase of DS content impacts directly the power absorbed in Amperes. In order to relate this to a costing of the electricity mostly expressed in Kilowatt-hour, we have to translate our intensity in Amperes into Watts. The formula is:

P = U.I ; P : power in Watt, U is tension in Volt, I is intensity in Ampere.

There is a regular tension for electric motors in flour mills (380V).

The prediction equation from the UCD results to get amperage becomes:

$$A=2.086UCD$$

$$2.086x380=792.7$$

W=792.7UCD with the same statistical performances.

The industrial cost of electricity in the United States in 2011 averaged 7 USD cents per Kilowatt/hour (International Energy Agency IEA 2011), in the EU it was 13 USD cents per Kilowatt/hour (Eurostat 2012).

4.4 Example of costing validation with rolls pressure and with rolls gaps

Let us take the example of one gap turn in our model from mill n°3 in Sizing 1 stream with 9% protein based wheat, having the 2 combination pressures with Table 4.4.

Table 4.4: Example with roll gaps/pressure

						7c/kW-h	13c/kW-h
Stream	Gap/press	Combination	UCD	Amp.	Watts	US cost	EU cost
S1	RG1/P1	0.15/4.5	25.2	58.6	22,286	$ 1.56	$ 2.90
S1	RG2/P1	0.3/4.5	18.0	48.7	18,512	$ 1.30	$ 2.41
S1	RG3/P1	0.4/4.5	16.6	37.6	14,271	$ 1.00	$ 1.86
S1	RG1/P2	0.15/2.5	23.4	32.6	12,401	$ 0.87	$ 1.61
S1	RG2/P2	0.3/2.5	14.5	26.5	10,065	$ 0.70	$ 1.31
S1	RG3/P2	0.4/2.5	12.6	20.8	7,908	$ 0.55	$ 1.03

In this example, 0.1mm gap at 4.5bar is increasing of about 0.3 cent the cost per kW-h. The reduced pressure of 2.5bar is decreasing the cost about the half (0.15cent) with the same combinations.

Let us take an even more detailed example. We are focusing on 1 turn gap at 4.5bar, from 0.3 to 0.4mm:

- 37.6A → 48.7 A
- Changing in Watts
- This is 14,271Watts → 18,512 Watts
- ΔP ≈ 4.242 Watts (+23 %) for 0.1mm gap
- if we assume the mill is working 24h/day during about 300 days per year
- we multiply these 23% difference by number of working days, hours, and transform in kW-h
- Upon 300 days/24h = 30,539KW-h per year
- This is an OVERCHARGE = 30,539 KW-h

This is in the USA for 1 kW h = $0.07

→ Overcharge = $2,137

This is in the EU for 1 kW h = $0.13

→ Overcharge = $3,970

And this is only for one stream, among more than 20 streams that has a flour mill, for just 0.1mm gap.

We could do the same calculation for the pressure increase on the rolls, in the same way. Similar calculations can be obtained, as far as we focus on the 3 streams (1st/2nd Middlings, 1st Sizing and 3rd Middlings) observed in this study that represent 50% of the total DS produced.

This cost difference could have been predicted by using the equation:

$$kW\text{-}h = 792.7 UCD.$$

4.5 Validation of the model DS vs. energy consumption at the flour mill optimization

As previously mentioned, we had no duplicates in the tests therefore making neither repeatability nor reproducibility data available, but based on the equations obtained, we can value any increase/decrease of the DS content. Any gap on the rolls from 0.4 to 0.3 to 0.15 mm with a pressure alternatively with 2.5 or 4.5 bars, increases the DS and the Amperage (i.e. kW-h). We therefore correlated the Amperage with the rolls settings, 6 alternative gaps and pressures, we also did the same with the UCD.

In order to compare, we assumed as reference the lowest consumption would be flour mill C (GBS 150t/d) milling the 9% protein wheat with 0.4mm and 2.5 bars. Having this as a reference we dropped it, correlated all the other possible settings and got the results as per Table 4.5.

Table 4.5: Example of the impact of the variables (Roll Gaps/pressure) on amperage and UCD

	dependent Variable = AMP	dependent Variable = UCD
	Coefficient (std. dev.)	Coefficient (std. dev.)
Buhler 350t/j	3.367 (0.183)	7.014 (0.486)
Alapala 250t/j	1.433 (0.183)	2.985 (0.486)
11% Protein Wheat	1.027 (0.183)	2.139 (0.486)
13 % Protein Wheat	3.594 (0.183)	7.487 (0.486)
1st Sizings Gap @ 0.15mm	12.250 (0.275)	19.778 (0.729)
1st Sizings Gap @ 0.3mm	2.740 (0.275)	10.269 (0.729)
1st Sizings Pressure @ 4.5bar	4.176 (0.237)	25.827 (0.627)
1/2 Middlings Gap @ 0.15mm	2.978 (0.275)	9.695 (0.729)
1/2 Middlings Gap @ 0.3mm	0.908 (0.275)	4.045 (0.729)
1/2 Middlings Pressure @ 4.5bar	2.805 (0.237)	21.268 (0.627)
3rd Middlings Gap @ 0.15 mm	10.441 (0.275)	16.796 (0.729)
3rd Middlings Gap @ 0.30 mm	1.679 (0.275)	8.034 (0.729)
3rd Middlings Pressure @ 4.5bar	3.284 (0.237)	23.308 (0.627)
Constant Term	11.217 (0.212)	14.745 (0.561)

This table, with reference of the minimal consumption model, is showing for each situation the additional Amperage consumption and UCD related. For example, the Buhler 350t/d mill has a coefficient of 3.3 of amperage consumption compared to the GBS 150t/d. Also, another example, on the 3rd Middlings decreasing the gap from 0.4mm to 0.3mm is impacting of coefficient of 1.67 on the amperage and a coefficient 8 on the UCD.

4.6 Country impact

As mentioned, every situation is different. We therefore attempted to run models individually for each mill. This might help for understanding country unique factors. The

Equation with UCD and Amperage as dependent variable was run for each mill. Results are shown in Table 4.6.

Table 4.6: Country impact on the variables (Roll Gaps/pressure) on amperage and UCD

	dependent Variable = AMP				dependent Variable = UCD			
	Mill A	Mill B	Mill C	combined mills	Mill A	Mill B	Mill C	combined mills
	Coef. (std. dev.)				Coef. (std. dev.)			
Mill A Buhler 350t/j	-	-	-	3.36 (0.16)	-	-	-	7.01 (0.48)
Mill B Alapala 250t/j	-	-	-	1.43 (0.16)	-	-	-	2.98 (0.48)
Mill C GBS 150t/j	-	-	-	-	-	-	-	-
9% Protein Wheat	-	-	-	-3.59 (0.16)	-	-	-	-7.48 (0.48)
11% Protein Wheat	1.12 (0.31)	1.01 (0.28)	0.94 (0.26)	-2.56 (0.16)	2.33 (0.92)	2.12 (0.83)	1.96 (0.77)	-5.34 (0.48)
13 % Protein Wheat	3.92 (0.31)	3.56 (0.28)	3.29 (0.26)	-	8.16 (0.92)	7.42 (0.83)	6.87 (0.77)	-
1st Sizings Gap @ 0.15mm	12.50 (0.54)	11.36 (0.49)	10.52 (0.45)	-	21.22 (1.59)	19.29 (1.45)	17.87 (1.34)	-
1st Sizings Gap @ 0.3mm	2.13 (0.54)	1.94 (0.49)	1.79 (0.45)	-9.50 (0.28)	10.85 (1.59)	9.87 (1.45)	9.14 (1.34)	-9.50 (0.84)
1st Sizings Gap @ 0.4mm	-	-	-	-11.46 (0.28)	-	-	-	-19.46 (0.84)
1st Sizings Pressure @ 2.5bar	-3.98 (0.441)	-3.62 (0.40)	-3.35 (0.37)	10.87 (0.33)	-27.94 (1.30)	-25.40 (1.18)	-23.51 (1.09)	11.97 (0.97)
1st Sizings Pressure @ 4.5bar	-	-	-	14.52 (0.33)	-	-	-	37.59 (0.97)
1/2 Middlings Gap @ 0.15mm	-	-	-	-	-	-	-	-
1/2 Middlings Gap @ 0.3mm	-2.25 (0.54)	-2.05 (0.49)	-1.9 (0.45)	-2.06 (0.28)	-6.16 (1.59)	-5.60 (1.45)	-5.18 (1.34)	-5.64 (0.84)
1/2 Middlings Gap @ 0.4mm	-3.96 (0.54)	-3.60 (0.49)	-3.33 (0.45)	-3.63 (0.28)	-10.49 (1.59)	-9.53 (1.45)	-8.83 (1.34)	-9.62 (0.84)
1/2 Middlings Pressure @ 2.5bar	-2.11 (0.62)	-1.92 (0.56)	-1.78 (0.52)	1.12 (0.33)	-17.79 (1.84)	-16.17 (1.67)	-14.97 (1.55)	1.81 (0.97)
1/2 Middlings Pressure @ 4.5bar	1.42 (0.62)	1.29 (0.56)	1.19 (0.52)	4.36 (0.33)	5.34 (1.84)	4.86 (1.67)	4.50 (1.55)	23.03 (0.97)
3rd Middlings Gap @ 0.15 mm	9.55 (0.54)	8.68 (0.49)	8.04 (0.45)	8.76 (0.28)	9.55 (1.59)	8.68 (1.45)	8.04 (1.34)	8.76 (0.84)
3rd Middlings Gap @ 0.30 mm	-	-	-	-	-	-	-	-
3rd Middlings Gap @ 0.40 mm	-1.96 (0.54)	-1.78 (0.49)	-1.65 (0.45)	-1.80 (0.28)	-9.18 (1.59)	-8.34 (1.45)	-7.73 (1.34)	-8.42 (0.84)
3rd Middlings Pressure @ 2.5bar	-3.33 (0.62)	-3.03 (0.56)	-2.8 (0.52)	-	-19.77 (1.84)	-17.97 (1.67)	-16.64 (1.55)	-

3rd Middlings Pressure @ 4.5bar	0.33 (0.62)	0.30 (0.56)	0.28 (0.52)	3.36 (0.23)	5.92 (1.84)	5.38 (1.67)	4.99 (1.55)	23.56 (0.69)
Constant Term	19.10 (0.47)	17.36 (0.43)	16.07 (0.4)	16.44 (0.27)	48.11 (1.40)	43.73 (1.28)	40.49 (1.18)	30.13 (0.79)
F. stat	143	143	143	393	130	130	130	351
n° observations	(1-54) 54	(55-108) 54	(109-162) 54	162	(1-54) 54	(55-108) 54	(109-162) 54	162
R²	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97

When omitted: Stata has removed the results because of a collinearity.

This is very much showing the impact of all the settings on amperage and UCD.

4.7 Value to the flour miller

By fine tuning the DS content into the streams of the flour mill process, energy savings can be achieved. The flour miller shall determine per stream, *a priori,* a target DS content value, named: the optimum operating point. We can assess how close or far away our target is on the basis of this operating point. He will keep in mind his flour yield, the extraction rate from his milling process. Increasing the gap is reducing the yield. This is, as seen before, relative to the flour's use. For example, for "French baguette", the flour miller produces flour with DS content between 17 and 20 UCD (Dubat 2007). This content can increase to 19-23 UCD for flour intended for loaf bread flours produced from hard wheat varieties, and fall to 14-16 UCD for biscuit flours. In terms of testing frequency, the flour miller shall vary between 1 and 3 daily tests in normal operation: systematic measurements shall be done when changing wheat varieties and following any human intervention on the mill. Moreover, traceability system is based on batch numbers that are automatically incremented following any intervention. This system keeps each mill plant manager informed in real time of everything that is happening on the mill. We shall consider the optimum operating point (our target value). In our example in Table 4.4, it is set at 18 UCD and corresponding to a gap of 0.3 mm for 4.5 bars. From this point, if the rolls are tightened, we initially observe a significant increase in damaged starch. However, after a certain point, gaps do not appear to increase damage further. Another added value, that could be the topic for another thesis, is the rolls wear. Roll wear depends on many factors. The quality of the rolls, shelf life and hardness, wheat cleaning quality, the amount of wheat being milled (input feeding), wheat hardness and conditioning and finally roll gaps and pressure. This wear has various consequences on the milling process, including lower extraction, higher electricity consumption, flour heating and also flour sifting problems and impaired flour quality. It has been shown with this study that the DS monitoring of the milling lines detects 2 weeks earlier than the other methods conventionally used in the milling industry, incorrect roll setting or tramming.

This measurement gives a faster responsiveness, resulting in savings that are easy to calculate. Any further research would be great to conduct for finding an optimization model, despite a great complexity in the variables. This could be achieved by achieving a minimizing model of the amperage, according to the UCD content.

4.8 Value to Chopin Technologies

We have a good indication of what the return on investment (ROI) when using a SDmatic. The device is about $16,000, operating the device would be about $400 per year in terms of chemicals, labor, power used by the device. This is a $16,500, let us say. Just monitoring one stream, S1, as seen in our example above can let us save $2,137 in the U.S. The device is therefore paid for in about 8 years based on only one stream. But, if we control the 3 major streams representing about 50% of the total DS produced, payoff is in less than 3 years.

CHAPTER V: SUMMARY AND CONCLUSIONS

Power and energy requirements for milling of wheat are affected by the physical characteristics of wheat and the operational parameters of roller mills. Among the physical properties of wheat, single kernel weight and hardness affects the grinding process significantly. In the tests done here, the power and energy requirements for harder (13% protein) wheat were higher than softer wheat (9%). As feed rate increases, fast roll power, slow roll power, and net power increases. Roll gap has a significant effect on power and energy requirements, and was included in all prediction models. DS is highly correlated, at least in the most significant streams where about 50% for the DS of the final flour is produced, with a R^2 of 0.77. The prediction model, if enriched with all variables used for this test scheme, is reaching an outstanding R^2 of 0.98. We also see this study as an opportunity to develop an optimization (actually minimizing) model to the amperage according to the UCD content. The prediction model unfortunately could not get properly validated with a set of verification tests, or duplicates. This is the weakness of the suggested prediction model that has a potential for predicting power and energy requirements for wheat milling.

For this study, we shall acknowledge and thanks the 3 flour millers that accepted to survey according to our required settings in our flour mill, which are sometimes out of their realities, therefore exploring setting situation unfamiliar to them.

The challenges for the milling industry are meeting our project here. The challenges guidelines (SCHLAURI 2011) are: To make the best out of the raw material, to get a high yield, get an efficient plant operation, get low production costs, get the top technology and equipment, produce high quality products having a high sanitation based on the plant engineering and the food safety regulation. The SDmatic is a tool useful for 5 of these challenges.

The DS is a logical and inevitable consequence of all wheat milling processes. The lack of an accurate, reproducible, user-friendly test has caused this very important parameter to be under-utilized. Laboratories of the cereal industries are fully equipped with efficient means to control the quantity and quality of proteins. Rare are those who are concerned with damaged starch. To emphasize its importance, just realize that starch represents 80% of flour produced or used. The lack of a simple, rapid analysis method can explain this situation partially. Very few millers in the world would measure the protein content in their flour if it was still necessary to use the Kjeldahl reference method. The complexity, requirement of high-qualified staff, and safety issues limited its use considerably. The creation of automatic devices for protein determination or NIR gave all cereal laboratories access to protein measurement. In a similar manner, the SDmatic now allows the measurement of DS to become a routinely analyzed parameter. DS measurement enables all laboratories of the cereal industry to measure this parameter that influences so many aspects of dough including: dough hydration, handling (stickiness), fermentation and the final product characteristics (volume, color, stability). We also tried to show how significant the DS can be into the milling process, with the targets of the end product's DS content. This study also enlightens the interest in fine tuning the flour mill by controlling the DS properly. This parameter is so important I foresee SDmatic evolving into an online monitor of the milling process.

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