FLOUR MOISTURE CONTROL FOR MAXIMUM WATER ADDITION

by

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ABSTRACT

This thesis examines flour moisture control and how this control can be an effective tool for cost minimization in a flour mill. Specifically, this thesis discusses the economic rationale behind the value of moisture control, the variables associated with moisture control, options for controlling those variables, the current control strategies, the decision process used to examine moisture control options, analysis of the solution, and implementation of optimal control strategies.

In the area of optimal control strategies, two outcomes were generated in the thesis. The first outcome involved collecting data and developing a better understanding of the factors impacting flour moistures. The second outcome was to create a spreadsheet tool for use in the flour mill that would allow operators to determine an optimal water set point that would bring about a desired flour moisture taking into consideration the variables effecting flour moisture and their status at a given time. Both outcomes have been met and are outlined in detail in the thesis.

It is understood that the conclusions of this thesis do not represent an end to the flour moisture control challenge and that more research is needed in order to implement further control measures. Work that remains to be done in order to achieve even better moisture control is also outlined in this thesis.

TABLE OF CONTENTS

LIST OF TABLES

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CHAPTER I: INTRODUCTION

What's the value of a little water? It could be in excess of $15,000 per month in a mid-sized flour mill. This is certainly not an amount of money to be ignored and quite possibly enough money to set one's self apart from the flour milling competition. Flour moisture control offers a flour mill the opportunity to improve efficiency and profitability, both of which lead to a competitive advantage in the flour milling industry.

The objectives of this thesis are to outline the strategy that is currently being pursued, to identify the challenges associated with flour moisture control, and to determine how best to overcome those challenges in order to effectively control flour moisture. This thesis will discuss the economic rationale behind the value of moisture control, the variables associated with moisture control, options for controlling those variables, the current control strategies, the decision process used to examine moisture control options, analysis of the solution, and implementation of optimal control strategies.

1.1. Economic Rationale

Flour moisture control is a real opportunity faced by those in the milling industry every day. It's an opportunity because there is the potential to make a great deal of money and an opportunity to outperform the competition and establish a competitive advantage. Flour mill customers such as bakers, restaurants, frozen dough plants, institutions, and so forth, generally establish analytical specifications for the flour that they purchase. These specifications include several different attributes, one of which is moisture content of the flour measured in percentage terms. In nearly every case the maximum moisture content is 14 percent. This number is significant because it means that flour cannot be shipped from the mill at a moisture content higher than 14 percent. This is also the maximum moisture content that flour can be safely stored at. The opportunity comes into play here because flour can't be shipped in excess of 14 percent moisture meaning that in many cases flour ships at lower moisture levels such as 13.6 to 14.0 percent. It is typical to play it safe when controlling flour moisture so as not to have rejected product for high moisture.

It is important to point out that flour is sold by weight and that water is cheaper than wheat especially when considering recent volatility in commodity prices. Therefore, it makes sense to maximize the moisture content of the flour. The potential profit for a mid-sized flour mill is in excess of $15,000 per month or over $180,000 per year. How was this figure arrived at? In a mid-sized flour mill that grinds 35,000 bushels of wheat per day, increasing the shipping moisture from 13.7 to 13.9 percent would result in a wheat savings of 72 bushels per day. If wheat is valued at $7 per bushel, daily savings are $504 and monthly savings are $15,120. Many would consider this a good reason to get out of bed thinking about flour moisture every morning. However, the less-obvious benefit to this is the potential to establish a competitive advantage in flour production based on the ability to control flour moisture. The problem of precisely controlling flour moisture is occurring all across the industry and if a company can save $180,000 per year on average at each of it's mills then a portion of that savings can be passed onto the customer giving an advantage over the competition or the money saved can be put back into the plants in the form of capital improvements that improve efficiency or used to increase salaries and bonuses in order to attract and retain better people than the competition. Regardless of how the company decides to spend the savings, if used wisely as suggested here it can only give an advantage over the competition, which is why this very basic issue has such huge financial ramifications.

1.2. Variables Associated With Moisture Control

There are many factors that effect flour moisture including the following:

- wheat mix
- age of the wheat
- raw wheat moisture
- temper water addition
- ambient temperature during tempering
- relative humidity during tempering
- ambient temperature during milling
- relative humidity during milling
- time spent in flour storage
- temperature during time spent in flour storage
- relative humidity during time spent in flour storage
- ambient temperature when loading
- relative humidity when loading.

A brief explanation of how each variable impacts flour moisture can be found below.

Wheat mix refers to the class of wheat and protein content of the wheat. Different wheat and the flour from that wheat will absorb and lose water differently. Age of the wheat refers to how long it has been since the wheat was harvested. As wheat ages the moisture in the kernel migrates from the inner kernel to the outer kernel and the wheat will take on different water absorption characteristics and decrease in overall moisture content. Raw wheat moisture is the moisture content of the wheat when it arrives at the mill from farms or grain elevators. This is the moisture starting point; the drier the wheat is to begin with the more water needs to be added to get the flour moisture to the desired level.

After the raw wheat is run through the cleaning house to remove foreign material such as weed seeds, gravel, husks, other grains, and so forth, water is added to the wheat in a process called tempering. During tempering the wheat is run through a mixing conveyor where the water is added to the wheat. A flour mill controls the water addition rate in gallons per minute and adjusts that rate based on the dry wheat moisture. Once the water has been added the wet wheat will be held in temper bins for 12 hours before it is milled. Ambient temperature during tempering has an impact on how much of the water added to the wheat will evaporate during the tempering process. Increased evaporation is evident during hotter summer months and thus more water is added during these months to compensate for this moisture loss. The relative humidity level during tempering has a similar impact to temperature. When the air is very cool and dry, as is the case in the fall and winter months, more moisture will be lost to the air during the tempering process.

Ambient temperature during milling works the same way as far as the hotter it is when the wheat is being milled the more moisture will be lost to evaporation. Relative humidity during milling affects the amount of water exchanged between the wheat and flour and the atmosphere. The higher the humidity the more moisture the flour has as less is drawn off to the atmosphere.

Time spent in flour storage refers to the length of time that finished flour is held in a storage bin from when it came off the mill until it is loaded into a trailer or packed. The longer the flour is held the more moisture it loses in most cases. Temperature and relative humidity during time spent in flour storage work the same way as they do for the wheat during tempering and the flour during milling.

The ambient temperature when loading or packing the flour affects how much water is lost to evaporation with higher temperatures resulting in greater moisture loss. Relative humidity when loading or packing works just the opposite with higher humidity during loading or packing resulting in lower moisture loss.

Clearly there are many variables to consider when looking at flour moisture control. In the next section of this chapter, the options available to control these variables will be discussed.

1.3. Variable Control Solution Options

When considering how best to control flour moisture, it is important to first define exactly what is being targeted. In this case, a flour mill wants the flour shipping moisture to be as close to 14 percent as possible without going over. The big question is how to do that. Currently, flour shipping moisture is controlled at the tempering stage of the process. A flour mill will adjust the temper water addition rate in gallons per minute to get flour moisture off the mill around 14.3 percent knowing that the flour will lose in the neighborhood of 0.4 percent from the time the flour goes into storage until it goes into the shipping vessel. The moisture off the mill and the shipping moisture fluctuate, but a shipping moisture of 13.7 percent is typical. In order to bring these shipping moistures up to 13.9 to 14.0 percent, it is important to more precisely control the flour moisture because if it is too high during the loading stage the flour cannot be shipped and the load is internally rejected which adds delays and additional cost to the process.

There are three options available to control the moisture variables. One option is to run higher flour moisture off the mill and then dry the flour down to 14 percent just prior to loading it in the shipping vessel by heating the flour. A simple method for achieving this involves the use of heat exchanges on the loading system positive pressure conveying lines. The heat exchanges are operated most of the time with the purpose of removing heat from the conveying lines before they pick up flour and carry it to the vessel. When flour moistures are high the heat exchangers are shut off and the high temperature of the conveying air dries out the flour to a level that is within specification. The flour could also be conveyed through a series of heated pipes much like a radiator.

A second option is to add water to the flour. There is equipment available in the market place that will nearly atomize water and add it to flour as it passes through the machine. Obviously the water has to be a microscopic mist otherwise flour and water make dough. To use this option, a mill would run flour moistures off the mill at lower levels and add the water necessary to bring the moisture content up to 14 percent.

The third option is to devise a methodology for arriving at mill moistures that have been adjusted for the effects of the previously mentioned variables. This would involve establishing a mill moisture target based on the temperature and relative humidity levels and the impact those levels will have on flour moisture content and then adjusting the temper water set point to account for that impact.

1.4. The Best Solution

As noted above, there are three possible options for achieving more precise flour moisture control. In this section, the selection of the option that is the best fit will be discussed. The benefits and costs of each option will be considered in the final determination of the best option.

The benefit of the first option of using heat exchangers on the flour loading conveying line or heating the conveying lines is its simplicity. The installation of heat exchangers would be as simple as buying them, installing them, and routing the conveying line through them. There is even the possibility of automatically shutting them down when flour moistures are too high at some point in the future when online analysis of flour has been perfected. Heating conveying lines gets a little more complicated with the need of a heat source such as a steam boiler, but could still be done if the return on investment justified it. The costs associated with this option may prevent it from being the best option. Not only is there an initial capital investment, which at a minimum would be $100,000 for the heat exchangers, there are also continual costs of operating and maintaining them in the form of power consumption, spare parts, and man hours. A boiler gets even more expensive to buy and install and involves mountains of EPA and OSHA controls and reporting not to mention the cost of running the boiler.

The benefit of the second option is again the simplicity of it and the ease of operation. The water addition machinery is relatively inexpensive to purchase and install. However, there are some hidden costs that come with this option. The first is a labeling issue. With this process a mill would basically be taking finished flour and adding water to it as if it were any other ingredient (e.g., iron enrichment or a bleaching agent). Just like with other ingredient additions, a mill would be required to label flour as having water added. In the eyes of the consumer, whether individual or corporate, there is a negative connotation that goes with adding water. The second hidden cost is milling efficiency. If this option is chosen, a mill would be running flour off the mill at lower moistures and bringing them up to ideal for shipping. From a milling efficiency standpoint, a mill may not want to run at lower flour moistures due to problems with bran and endosperm separation, middlings reduction, and ash content control. In addition to these hidden costs, a mill also incurs the costs of operating and maintaining the water addition equipment just as with the first option.

The largest benefit of the third option for moisture control is that there are very few costs associated with it. With this option, a methodology is devised for variable management that controls flour moisture by taking atmospheric condition variables along with wheat mix and raw wheat moistures into consideration at the water addition phase of tempering which allows a mill to bring wheat into the mill that is already set up with a moisture content that will result in flour that will have on-target moisture content regardless of atmospheric conditions. With this option there is no equipment to purchase, operate, or maintain. There are also no labeling issues or milling efficiency issues. The only real cost associated with this option is the time it takes to manage the process allowing the mill to take full advantage of the payback associated with better moisture control. This time is arguably well spent when considering the financial ramifications outlined under the economic rationale for this work and therefore this may be the best solution for more precisely controlling flour moisture.

CHAPTER II: LITERATURE REVIEW

Flour millers have known for a long time that moisture plays a critical role in milling efficiencies such as yield and patent percentage. In the early part of the 20^{th} century Swanson writes "the flour yield, or the pounds of wheat used to make a barrel of flour, is of the utmost importance to the operative miller" (Swanson, 1920). Now that we are well into the 21^{st} century and haven't measured flour production in barrels for quite some time the fact remains that moisture is a critical determinant of milling efficiency.

2.1. Water

Adding water to wheat improves the milling properties of the wheat by making the separation of bran and endosperm easier. An increase in moisture content of the wheat over the range customarily employed in flour mills toughens the bran and increases the mellowness or softness of the endosperm (Kent, 1965). It is also known that flour consumers such as bakers, frozen dough manufacturers, and grocers have set limits or specifications for flour moisture in order to provide for safe storage and consistency of product. In order to safely store flour, which occurs at the bakery, in the warehouse, on the grocery store shelf, and in the homes of individual consumers, it is important to consider the properties of water and how it behaves in a storage situation. Moisture is a component of the solid portion of flour as well as the void spaces around the biological material, which includes protein, fat, fiber, starch, and mineral, as well as moisture (Gwirtz, 2008). Flour will release moisture to the headspace of the container in which it is stored or absorb moisture from the headspace depending on what is needed to achieve moisture equilibrium in the space (Gwirtz, 2008). This leads to mold growth and other biological activity in the storage container. Therefore, it is unreasonable to suggest increasing moisture content specification of flour with a mill's customers.

2.2. Air Stabilization

A great deal of research has been done to determine optimal temperatures and relative humidity levels for flour milling. This research suggests that by controlling temperature and relative humidity levels a mill improves milling efficiency. However, in order to achieve this level of control an air stabilization system is required in the flour mill (Scott et al., 1997). With an air stabilization system the recirculation of plant air and/or outside air is controlled. The optimal air stabilization system includes features that allow the system to supply dehumidified air as well as humidified air (Anderson, 1920). An air stabilization system represents a large capital investment and drives the question of whether or not a mill can bring about a similar level of moisture control without extensive use of capital.

2.3. Relative Humidity

A key factor in establishing the previously mentioned control is understanding the impact of relative humidity on the process. When relative humidity is very low it is possible to lose from one-half to one percent moisture from tempered wheat between the temper bins and the first break rolls. This undoes the work of tempering and suggests the need for increased water addition (Pence, 1920). On the other hand, if the relative humidity is very high the wheat may actually absorb water in its travel from bin to roll. The same process applies to flour in the mill. The milling moisture loss will be greater in times of low relative humidity and in times of high relative humidity there may be no loss at all and there may actually be a gain in moisture content over and above the moisture content of the wheat to roll. It is known that as temperature changes relative humidity changes. Relative humidity is the measure of how much water the air is holding expressed as a percentage of the air's total water-holding capacity. Temperature comes into play here because as temperature changes the water-holding capacity changes (Anderson, 1920).

2.4. Milling Efficiency

To fully understand the importance of atmospheric control, it is important to understand its impact on milling efficiency. A key measure of milling efficiency is yield, which is the amount of wheat required to produce flour measured in bushels per hundredweight. The ideal situation from a yield perspective is to have incoming wheat with very low moisture content, add a lot of water to it during the tempering process, and ship flour with the highest possible moisture content. This allows a mill to produce a maximum amount of flour from a minimum amount of wheat (Shollenberger, 1921).

CHAPTER III: METHODS

If there were no scarcity, producers would not care as much about production costs. But because scarcity is an economic reality, producers are interested in cost minimization - that is producing output at the lowest possible cost (Baye, 2006). When a company looks at opportunities for increasing profit they must evaluate ways of increasing their profit margin on their good or service. To increase the profit margin, firms can increase the sale price to generate more revenue over the cost of providing the good or service, decrease cost further below sale price, or both. For the purpose of this thesis, the focus is cost minimization of goods produced. When working in a commodity market where price of the product, in this case flour, is determined in large part by the price of the principle raw material, wheat, it is far more realistic to increase profits through cost minimization rather than through sale price increases.

Here is an example of how cost minimization adds profit to the bottom line:

Table 3.1 Initial Example

Cost of goods sold	$100
Price of goods	$125
Profit on goods	$25

If we minimize cost we can achieve higher profit:

Table 3.2 Impact of Cost Minimization Example

Cost of goods sold	$95
Price of goods	$125
Profit on goods	$30

The law of demand also tells us that as we reduce the price the quantity demanded will increase. Therefore another example of how cost minimization can add to profit may look like this:

Table 3.3 Initial Example

Cost of goods sold	$100
Required margin	$25
Price of goods	$125
Profit on goods	$25
Quantity sold	1,000
Total Profit	$25,000

If we minimize cost we can achieve higher profit:

Table 3.4 Impact of Cost Minimization Example

Cost of goods sold	$95
Required margin	$25
Price of goods	$120
Profit on goods	$25
Quantity sold	1,100
Total Profit	$27,500

The primary objective of this thesis is to provide a methodology for consistently shipping flour to customers with an increased moisture content which has the potential to lead to $15,000 per month in cost savings. This money that is saved in the form of wheat purchased adds profit to the bottom line. Cost minimization techniques are significant in the flour milling industry because flour price is very competitive between companies and our ability to set higher sale prices is limited.

Flour mill customers such as bakers, restaurants, frozen dough plants, institutions, and so forth, generally establish analytical specifications for the flour that they purchase. These specifications include several different attributes one of which is moisture content of the flour measured in percentage terms. In nearly every case the maximum moisture content is 14 percent. This number is significant because it means that flour cannot be shipped from the mill at a moisture content higher than 14 percent. This is also the maximum moisture content that flour can be safely stored at. The opportunity comes into play here because a mill can't ship flour in excess of 14 percent moisture. Typically mills will play it safe by producing flour so as not to have it rejected for high moisture. It is important to point out that flour is sold by weight and that water is cheaper than wheat especially when considering recent volatility in commodity prices. Therefore it makes sense to maximize the moisture content of the flour.

This thesis examines the reduction in cost resulting from an increased finished flour moisture. The idea is that we can increase finished flour moisture by better understanding the variables at work in determining flour moisture and then deliver a tool that allows the operator in the flour mill to simply key in information and get a water set point result that can be used to more effectively control flour moisture. Therefore, there are two targeted outcomes. Outcome number one is to examine the relationship between flour moisture and the several determinants of flour moisture. Outcome number two is to develop the tool for the operators to use in setting up optimal water addition.

3.1. Outcome 1: Regression Analysis

In order to examine the relationship between flour moisture and the determinants of flour moisture, data needs to be collected. Rather than attempting to control all of the variables listed in Chapter I, the focus is on the following five variables: wet wheat moisture, ambient temperature during milling, relative humidity during milling, age of the wheat crop, and time of day. These five variables have the largest impact on flour moisture based on experience and the options available for moisture control.

Since October 2008, data on wheat mix, wet wheat moisture, wheat to roll moisture, temperature during milling, relative humidity during milling, time of day, and the corresponding flour moisture has been collected. Wheat to roll moisture is the moisture content of the wheat as it begins the milling process and is the total moisture that a mill has to work with. The amount of moisture loss will be determined by temperature and relative humidity as well as wheat mix. The goal is to capture, at a minimum, a year's worth of data to account for changes in the impact of the variables during different times of the year. Using the data collected, regression analysis will be used to examine the relationship between the five variables noted above and flour moisture.

3.2. Outcome 2: Developing the Tool

Based on the results of the regression analysis, an equation and temper water set point spreadsheet will be developed for each wheat mix. In these spreadsheets the operator enters data for: wheat rate to the water addition stage of tempering in bushels per hour, dry wheat moisture, temperature, relative humidity, date, and time of day. Based on this entered information and the results of the regression analysis, the spreadsheet calculates a target wheat to roll moisture and then based off the dry wheat moisture and wheat rate through tempering gives a water addition set point in gallons per minute. It is also important to point out that a target flour moisture has to be established for this spreadsheet to function.

CHAPTER IV: DATA SUMMARY

4.1. Source of the Data

Data on wheat milled and flour produced was collected from Horizon Milling's Chattanooga, Tennessee facility. Three different wheat classes were used. The tables below highlight the data from each class. The soft wheat sample size was 220 observations collected from October 8, 2008 through January 13, 2009. The hard red spring wheat sample size was 153 observations collected from November 2, 2008 through January 13, 2009. Finally, for hard red winter wheat a sample of 75 observations collected between October 8, 2008 and January 13, 2009 were used. Each observation represents 2,200 bushels of wheat that was milled over a time interval of 3.25 hours. A sample of the wheat for each observation was collected and analyzed on a Foss 5000 near infrared analyzer for moisture content. Temperature and humidity measurements were taken at the time of the wheat sample collection on the mill roll floor using an analog Robert E. White Instruments, Inc. thermometer and hygrometer. The flour produced from the wheat sampled was analyzed on the Foss 5000 as well for moisture content.

4.2. Explanation of the Data

In the case of all three wheat classes, data collected included wet wheat moisture, temperature, relative humidity, age of wheat, time of day, and patent flour moisture. Wet wheat moisture is reported as a contents percentage of the wheat. Temperature and humidity are ambient measurements taken at the time the wheat sampled was being milled. Patent flour moisture is reported as a contents percentage of the flour produced from the wheat sampled. Tables 4.1 through 4.3 contain summary statistics for each wheat class.

Table 4.1 Soft Wheat Statistical Analysis

Statistical Analysis	Wet Wheat Moisture	Temperature	Humidity	Patent Flour Moisture
Mean	14.39	82.95	48.46	13.33
Median	14.3	84	48	13.3
Mode	14.4	86	46	13.4
Std. Dev.	0.4304	5.8877	3.8289	0.3178

Table 4.2 Hard Red Spring Wheat Statistical Analysis

Statistical Analysis	Wet Wheat Moisture	Temperature	Humidity	Patent Flour Moisture
Mean	15.20	83.93	49.95	14.36
Median	15.2	84	49	14.4
Mode	15.2	86	50	14.5
Std. Dev.	0.2708	5.5579	4.4467	0.2708

Table 4.3 Hard Red Winter Wheat Statistical Analysis

Statistical Analysis	Wet Wheat Moisture	Temperature	Humidity	Patent Flour Moisture
Mean	15.37	83.59	50.49	14.19
Median	15.4	85	49	14.2
Mode	15.3	86	46	14.3
Std. Dev.	0.4688	7.3523	6.8780	0.3227

Temperature and relative humidity conditions are not impacted by the class of wheat being milled and would have been reported as the same for two different wheat classes being milled at the same time. Therefore, the differences in the temperature and relative humidity for the three wheat classes are a result of the time during which the observations were made and the number of observations made.

The age of the wheat has been determined from the date of the observation. For each wheat class there is a start date in the spreadsheet that indicates when the Chattanooga facility started milling the 2008 wheat crop of each class of wheat. The age of the wheat is calculated by determining the difference between the start date and the date of the observation.

Wet wheat moisture is a measurement of the moisture content of wheat after it has been tempered and is being fed into the first roller mill of the mill flow. There are differences of about one percent moisture between the soft wheat and the hard wheat averages. This is due in part to the desired patent flour moisture for each wheat class. The desired flour moisture for soft wheat off the mill is 13.5 percent while it is 14.3 percent for the hard wheat, so more water is added during the hard wheat tempering process.

The standard deviation results indicate that the most opportunity to improve the consistency of the patent flour moisture lies with the hard red winter wheat closely followed by the soft wheat. Hard red spring has the lowest standard deviation. A standard deviation in the neighborhood of 0.3 percent is evidence of the need to make improvement in order to increase the mill's control of flour moisture so that the shipping moisture can be brought up to increase profits. The standard deviation results for temperature and relative humidity also show that there are some significant swings in both conditions. This thesis will demonstrate how these swings impact flour moisture and provide a methodology for compensating for the temperature and humidity swings.

CHAPTER V: CORRELATION AND REGRESSION ANALYSIS

5.1. Soft Wheat Correlation and Regression Results

Table 5.1 shows the simple correlation coefficients between each of the variables being considered in this thesis in addition to the correlation of those variables with patent flour moisture, which is the outcome of interest. The purpose of this correlation matrix is to check for the presence of multicollinearity in the regression equation. It is clear from the correlation coefficients that this is not a concern due to the low values shown below. The most highly correlated variables are temperature and humidity at 0.5284 and this is to be expected. Temperature and relative humidity are related as outlined in Chapter II, section 2.3.

Table 5.2 illustrates the results of the soft wheat regression analysis on the chosen variables. The t-statistics suggest that the wheat age, wet wheat moisture, and relative humidity variables are significant with t-statistics greater that 2.0. The time and temperature variables have been included because of their fundamental role in the theory behind what impacts flour moistures.

Table 5.1 Soft Wheat Correlation Matrix

	Time	Wet Wht. Moist	Temp	Humidity	Wht. Age	Pat. Flour Moist
Time		-0.0695	0.1522	0.0599	-0.0446	-0.0409
Wet Wht. moist	-0.0695		-0.2463	-0.1712	0.4456	0.5482
Temp	0.1522	-0.2463		0.5284	-0.2191	-0.0318
Humidity	0.0599	-0.1712	0.5284		0.0756	0.1103
Wheat Age	-0.0446	0.4456	-0.2191	0.0756		0.1432
Pat. Flour Moist	-0.0409	0.5482	-0.0318	0.1103	0.1432	

Table 5.2 Soft Wheat Regression Results

Regression Statistics				
Multiple R	0.60647			
R Square	0.36781			
Adjusted R Square	0.35304			
Standard Error	0.25564			
Observations	220.00000			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	5.73126	0.73990	7.746	0.000
WHEAT AGE	-0.00207	0.00072	-2.861	0.005
TIME CONVERSION	-0.01335	0.00104	-0.214	0.830
WET WHEAT MOIST	0.48912	0.04616	10.597	0.000
TEMPERATURE	-0.00244	0.00367	-0.666	0.506
HUMIDITY	0.02175	0.00554	3.927	0.000

5.2. Hard Red Spring Wheat Correlation and Regression Results

The simple correlation coefficients for hard red spring wheat shown in Table 5.3 while different in value than those of the soft wheat show much of the same information in so far as demonstrating the absence of multicollinearity in this wheat class as well. The most highly correlated variables are relative humidity and wheat age at 0.3457, which is not a high enough correlation to be concerned about.

The results of the spring wheat regression analysis shown in Table 5.4 also resemble those of soft wheat in that wheat age, wet wheat moisture, and relative humidity are clearly significant variables and time and temperature have lower t-statistics, but are included for the same reasons as outlined in section 5.1.

Table 5.3 Hard Red Spring Wheat Correlation Matrix

	Time	Wet Wht. Moist	Temp	Humidity	Wht. Age	Pat. Flour Moist
Time		-0.0042	-0.0355	0.0123	-0.0197	-0.0335
Wet Wht. moist	-0.0042		-0.0928	-0.2924	-0.0606	0.3980
Temp	-0.0355	-0.0928		-0.1402	0.1850	-0.0658
Humidity	0.0123	-0.2924	-0.1402		0.3457	-0.0429
Wheat Age	-0.0197	-0.0606	0.1850	0.3457		-0.1836
Pat. Flour Moist	-0.0335	0.3980	-0.0658	-0.0429	-0.1836	

Table 5.4 Hard Red Spring Wheat Regression Results

Regression Statistics	
Multiple R	0.45428
R Square	0.20637
Adjusted R Square	0.17938
Standard Error	0.16640
Observations	153.00000

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9.47377	0.93682	10.113	0.000
WHEAT AGE	-0.00192	0.00070	-2.745	0.007
TIME CONVERSION	-0.02398	0.00080	-0.500	0.618
WET WHEAT MOIST	0.29638	0.05283	5.610	0.000
TEMPERATURE	0.00126	0.00257	0.492	0.623
HUMIDITY	0.00693	0.00350	1.981	0.049

5.3. Hard Red Winter Wheat Correlation and Regression Results

The trend of no multicollinearity continues in this section with hard red winter wheat. Table 5.5 shows that the variables with the highest correlation are temperature and relative humidity at 0.4900. Just as with soft wheat this simple correlation coefficient is low enough to not be of concern and can be understood based on the relationship between the variables outlined in Chapter II, section 2.3.

The hard red winter regression analysis results shown in Table 5.6 show the least promising results of the three wheat classes. Wet wheat moisture was the only variable that was significantly related to patent flour moisture. However, it is important to note that this wheat class had the smallest number of observations at 75 and includes observations from both Chattanooga milling units versus the soft wheat ground only on the A-Mill unit and the hard red spring ground only on the C-Mill unit. For the purpose of this thesis these results will be used, however, going forward it may be advantageous to collect data on the hard red winter wheat based on the milling unit and analyze it separately.

Table 5.5 Hard Red Winter Wheat Correlation Matrix

	Time	Wet Wht Moist	Temp	Humidity	Wht. Age	Pat. Flour Moist
Time		-0.1465	0.0622	0.0004	-0.0239	-0.1958
Wet Wht moist	-0.1465		-0.0635	-0.0210	-0.2510	0.3196
Temp	0.0622	-0.0635		-0.4900	-0.0879	-0.0496
Humidity	0.0004	-0.0210	-0.4900		0.3018	0.1187
Wheat Age	-0.0239	-0.2510	-0.0879	0.3018		0.0900
Pat. Flour Moist	-0.1958	0.3196	-0.0496	0.1187	0.0900	

Table 5.6 Hard Red Winter Regression Results

Regression Statistics	
Multiple R	0.40016
R Square	0.16013
Adjusted R Square	0.09927
Standard Error	0.30628
Observations	75.00000

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	10.07113	1.45666	6.914	0.000
WHEAT AGE	0.00164	0.00137	1.200	0.234
TIME CONVERSION	-0.14921	0.00191	-1.299	0.198
WET WHEAT MOIST	0.23371	0.07973	2.931	0.005
TEMPERATURE	0.00196	0.00559	0.351	0.727
HUMIDITY	0.00489	0.00623	0.786	0.435

CHAPTER VI: SPREADSHEET TOOL

6.1. The Developed Tool

The second outcome for this thesis, as outlined in Chapter III, section 3.2, was the development of spreadsheet tool that can be used by mill operators to determine what the optimal water set point should be for each wheat class based on the variables at the time in order to bring about the desired flour moisture. This outcome has been achieved and is shown in Table 6.1. In order to use this tool the operator simply enters the information in the highlighted cells for dry wheat moisture, ambient temperature, ambient humidity, time, and date. Once this information has been entered the Solver tool is run to calculate the temper water set point in gallons per minute. Solver takes into consideration the desired patent flour moisture and adjusts the wet wheat moisture to achieve the desired flour moisture. The spreadsheet has a built-in equation that then calculates what temper water set point will result in the required wet wheat moisture based on the dry wheat moisture and the cleaning house flow rate. The cleaning house flow rate is fixed and the dry wheat moisture is entered by the operator. Once the operator has the water set point they are finished with the spreadsheet tool until the next time a wheat sample is analyzed.

As mentioned in Chapter I, section 1.2 tempered wheat is held in temper for 12 hours before it is milled. Therefore, the spreadsheet tool has a milling time that is calculated by adding 12 hours to the time entered by the operator. The milling time is converted to decimal form in the time conversion and this number is used in the calculation where it is multiplied by the time conversion coefficient. By doing this we are taking the time when the flour is made into consideration which is advantageous because the time of milling are the time that were captured in the sample observations.

6.2. Maintaining the Tool

In order to maintain the functionality of the tool a couple of things have to happen continuously. First, data must continue to be collected on the variables that are being used to determine the water set point as well as the resulting flour moistures. As time goes on and weather conditions change with the seasons, the wheat ages, and after a year's time a new wheat crop is available to work with. This means that there will be an ongoing collection of data in order to supply observations for regression analysis. Second, regressions must be run on a regular basis in order to take advantage of the data from the latest observations and then make updates to the spreadsheet tool so that the resulting water set points match current conditions with weather and wheat. Based on what is understood at this point in time, regressions will probably be ran weekly on each wheat class in order to keep the tool as current as possible.

6.3. Implementation

Once this thesis has been properly vetted by the committee and reviewed by Horizon Milling management and employees the process outline herein will be implemented at the Chattanooga facility. While data for the analysis reported in this thesis stopped being collected in January 2009, the data collection process has continued and will be analyzed going forward along with updates being made to the spreadsheet tools for each wheat class. The Chattanooga facility will implement one wheat class at a time starting with soft wheat. As each class is implemented thorough monitoring of desired patent flour moistures versus actual flour moistures will occur as well as desired wet wheat moistures versus actual wet wheat moistures to develop a strong understanding of how well the process is working in bringing about increased moisture control. Operators will be trained on not only how to use the spreadsheet tool, but the theory and analysis behind the tool. The operators will also be given an opportunity to make recommendations on any necessary improvements based on practical experience with the tool during implementation.

Table 6.1 Soft Wheat Set Point Equation Spreadsheet

Dry Wheat Moist (%)	Temperature	Humidity	Time	Date
12.0	80	45	8:00 AM	03/09/09

	24hr Time	Start Date
Water Setting (gal/min)	8:00	07/01/08
3.35	0.333	
	Milling Time	Wheat Age
	20:00	251
Wheat to Roll Moisture Target (%)		
15.4	Time Conversion	
	0.83	

Patent Flour Target Moisture (%)
13.5

Regression Data	
Intercept	5.731255656
WHEAT AGE	-0.002069641
TIME CONVERSION	-0.013356496
WET WHEAT MOIST	0.489122843
TEMPERATURE	-0.002443681
HUMIDITY	0.021752069

Cleaning House Rate (Bu/hr)
830

CHAPTER VII: CONCLUSIONS AND FUTURE PHASES

7.1. Summary and Conclusions

The objectives of this thesis were to outline the strategy that is currently being pursued in moisture control, to identify the challenges associated with flour moisture control, and to determine how best to overcome those challenges in order to effectively control flour moisture. Chapter I outlined the challenges that exist with flour moisture control and some of the possible solutions that could bring about better control. Chapter II showed the importance of understanding ambient conditions in the flour mill and how those conditions can impact flour moisture. Chapter III dove into the theory and the foundation of this thesis in regard to maximizing water addition from a cost minimization standpoint. This is also where the outcomes for the thesis were established and included examining the determinants of flour moisture control and developing a tool that could be used by mill operators on a daily basis to generate the temper water set point that would bring about the desired patent flour moisture.

Chapter IV presented summary statistics for patent wheat moisture, wet wheat moisture, temperature, and relative humidity collected as part of this thesis. Chapter V illustrates the results of the correlation between variables and results of the regression analysis on the samples collected and demonstrates the impact that each variable has on flour moisture. Chapter VI discussed the spreadsheet tool that has been developed for the mill operators to use in determining the necessary temper water set point. An outline of work that remains to be done in Phases II and III of this project in order to bring about even better moisture control is discussed below.

What's the value of a little water? Not only has this thesis demonstrated the importance of good flour moisture control techniques, but it has provided a new methodology of control that is ready to be implemented. This methodology of data collection, regression analysis, and water set point optimization has the potential to bring about the level of flour moisture control necessary to increase flour shipping moistures and reduce wheat costs resulting in excess of $15,000 per month in wheat cost savings at a mid-sized flour mill. Regardless of what readers might understand about flour milling or flour moisture control, they, without a doubt, have a strong understanding of the significance of these kinds of savings in a highly competitive market place.

7.2. Phase II: Ambient Milling Conditions Prediction

It is understood that there are more variables that impact flour moistures that will not be controlled by the process described in this thesis. Two of these variables are ambient temperature and ambient relative humidity during milling. The process that has been outlined is based on taking real time data on temperature and relative humidity when the water set point is being determined 12 hours in advance of milling. By the time the wheat is milled the ambient conditions are subject to change and thereby the ability to control flour moisture is impacted. Phase II of this flour moisture control project will be to develop a methodology for taking into account the ambient conditions at the time of milling. Potential sources for predicting these conditions include internet-based weather forecasting services such as TheWeatherChannel.com where an operator could access a website and ascertain the temperature and relative humidity prediction for the time of milling and enter that data into the spreadsheet tool.

7.3. Phase III: Flour Moisture Loss in Transfer, Storage, and Loading

The third phase of this project will entail developing a better understanding of the variables impacting flour moisture loss during flour transfer from the mill to the storage bin, during storage time in the bin, and during the loading process where flour is transferred from the storage bin to the shipping vessel. It is known that moisture loss occurs during all of these processes, the questions are how much moisture loss and how to build those losses into the spreadsheet tool's calculation of required wet wheat moisture. The approach in the short term will be to set the target patent flour moisture set points higher than the maximum shipping moisture with the expectation that moisture loss will occur to such an extent that the flour is below the maximum level of 14 percent by the time of shipping.

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