A Guide to Understanding Flour Analysis

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Introduction

The quality and consistency of ingredients coming into your bakery should be of primary concern to you, and can have a large impact on the success of your business. Flour millers go to great lengths to ensure that the consistency of their products meet your expectations. The incoming wheat and outgoing flour are subjected to a wide array of testing procedures to ensure that their products meet the quality specifications you use to guide your flour sourcing. For you, the baker, it is critical you be able to understand the results of this analysis, and are able to apply the information you receive to the every day variables affecting your mix and bake.

What follows is a quick “guide to the numbers” that will hopefully prove useful in your bakery as you strive to get a keener understanding of the quality of your flour. I have organized this Guide into two sections. The first section I hope will serve as a quick reference to consult when you are reviewing the flour analysis sheet provided by the mill or your distributor. I cover only the flour quality parameters that you are most likely to come across on a typical COA (certificate of analysis). These parameters include: moisture, ash and protein (MAP), falling number, farinograph values (absorption, arrival time, peak time, stability, and MTI), and alveograph values (P, L, P/L and W).

The second section includes a few “articles” that dig a little deeper into the methods of analysis, and perhaps will allow you to understand more fully what the numbers are indicating.

With all this said I would like to point out that what flour analysis essesntially provides is a set of numbers that we, as flour people and bakers, have chosen to indicate relative flour quality. The only way to really understand what is happening in your bakery and in you finished products is through years of mixing and baking, touching and feeling and correlating those inputs with what numbers show up on the analysis sheet. So don’t end up relying too much on the numbers. Let them guide you relative to what you have experienced in the past and suggest possible actions your bakers may need to take during the mix and bake.

If you ever have any questions or want to discuss the content of this Guide further you can always reach me at 207-774-3358 or via email at tod.bramble@kingarthurflour.com

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Part I

Quick Guide

Moisture, Ash and Protein (MAP)

We are going to look at these parameters together because they tend to be very common indicators of general flour quality but give only a little indication of how the flour is going to perform throughout the bake. They are great numbers to indicate whether you are getting the flour you think you need and can serve as a first point of reference if you think there are quality issues concerning your flour.

Moisture

On an analysis sheet this is a relatively simple number and is fairly meaningless to you as a baker. But it does give an indication of the quality stability of the flour as it was coming off the mill. Most moisture specifications read: “14% Max”. This means that the flour does not contain more than 14% moisture as it comes off the mill. This is important as flour containing moisture in amounts greater than 14% will tend to mold and spoil at a much quicker rate than drier flours. Flour is a hygroscopic material meaning that its moisture content will tend, over time, to equilibrate with the humidity of the surrounding environment. In damp conditions flour will absorb moisture from the environment and in drier conditions will lose moisture to the environment. So it is important to understand the time frame and storage conditions of your flour and realize that this will affect not only its quality but also the quantity of water that can be absorbed by the flour in the mixer bowl.

Moisture
Look for moisture contents of less than 14% as this indicates adequate quality stability at the time of milling

One final note, this moisture value is not indicative of flour absorption as indicated by the farinograph results.

Protein

Bakers are typically only interested in the gluten forming proteins of their flour. This measurement, however, is not a direct measure of gluten forming protein content, rather it is the total protein content of the flour. However, it can be used as a relative measure of the gluten forming protein content (ie the greater the total protein content the greater the gluten forming protein content). There has been much written about protein quality versus quantity. The percentage of protein as indicated on your analysis sheet only concerns quantity and really only serves as a general indication

Flour Grade	Protein Level
Cake	7 - 8.5%
Pastry	8.5 - 9.5%
H&R or All Purpose	10 - 11.7%
Bread Flour	11.7 – 12.9%
Medium Hi-Gluten	13.0 – 13.7%
Premium Hi-Gluten	13.8 – 14.2%
First Clear	14%+
Whole Wheat	14%+

of the flour grade. The chart above indicates the broad categories of flour grades and even this is somewhat imprecise in that there is often a blurring of the lines between grades.

It is very important to note that most protein values in the US are reported on a 14% moisture basis whereas in the France and much of Europe protein (and ash) is reported on a 0% or “dry matter” basis. This is a powerful tool and allows “apples to apples comparisons” between flours that, as we discussed above, may have different moisture contents. It can, however, lead to confusion when you are talking about European flours and want to compare them to US flours. Basically, reporting on a 14% moisture basis gives you a corrected value of protein regardless of the actual moisture content. For those of you who must know here is the formula used for the correction:

$$\text{Protein 14\% m.b.} = \text{Protein \%}_{\text{as is}} \times (100 - 14) / (100 - \text{Moisture Content})$$

This same formula is used to correct ash content to a 14% or “dry matter” moisture basis.

Ash

Ash is another one of those “relative” indicators of flour quality and is best used for ensuring the flour you are getting is the flour you want. The ash value for a particular flour is a measure of the mineral content of the flour. A 100g sample of flour is placed in an oven and incinerated at the temperature that combusts all of the organic mater but leaves the mineral content of the flour. This “ash” is weighed and then reported as the “ash content” of the flour.

Most people use the ash value to determine how much bran has been left in the flour after the milling process. This is an indirect measure of bran content as there is some mineral content in endosperm as well. However, the mineral content of the bran layer is some 20 times greater than that of the endosperm. Therefore the ash value of a flour is a fairly good indicator of bran content in that the higher the ash value the greater the bran content and the darker the flour will appear. Bran in the flour also affects absorption. A higher ash value will indicate more bran in the flour which will result in an increase in absorption over flours with lower ash values.

As with protein, ash in the US is reported on corrected 14% moisture basis and in France on a dry matter (0% moisture) basis. Again this is very important to remember when requesting, say, a “T55” style flour from your US supplier. The “55” refers to the ash content of the French flour but is reported on a 0% moisture basis. So, throwing out all the other performance differences of a European T55 flour, the same flour in the US would actually have an ash content of approximately 0.46%.

Falling Number

Falling Number:
Bread Flour with normal diastatic activity generally possesses falling number values in the range of 220-250 seconds.

The Falling Number for a particular flour is a indication of a flour's α-amylase content and is expressed in seconds. α-amylase is the principle enzyme that reduces the long chains of starch in the endosperm into simple sugar units that are useable by the yeast for fermentation. In order to avoid "sprout damage" wheat is harvested with levels of α-amylase that are generally too low to support the yeast activities necessary for fermentation. As such, α-amylase is often added in various forms to flour to boost the α-amylase content of the flour. Typically you will see "malted barley flour", or "fungal amylase" on the ingredient declaration of your flour. These are two of the more common means in which α-amylase is added to the flour.

Flour not treated with supplemental α-amylase (whole wheat flour is often not treated) typically has a falling number around 400 seconds. While overmalted flours or flours produced from sprout damaged wheat have very low falling numbers in the range of 60 seconds. Depending on your miller's specification you should see falling numbers in the range of 220-260 seconds for flours treated with supplemental α-amylase. As you can see the falling number has inverse relationship to the α-amylase content of the flour: the lower the falling number the greater the amount of α-amylase present in the flour. It is easy to forget this so commit this relationship to memory.

For more in depth information on falling number and how it is measured see the article in Part 2 of this guide.

Farinograph

With the farinograph we move beyond the fairly one dimensional (but important) physical characteristics reported by moisture, protein, ash, and falling number to a tool we can use for looking at how the flour will handle as a dough in the mixer bowl. The farinograph characteristics often reported on flour analysis sheets from the mill include “arrival time”, “peak time”, “stability”, “MTI” and “absorption”. These parameters are drawn from the graphical representation of mixing performance as shown on the farinograph trace which is generated during the actual analysis.

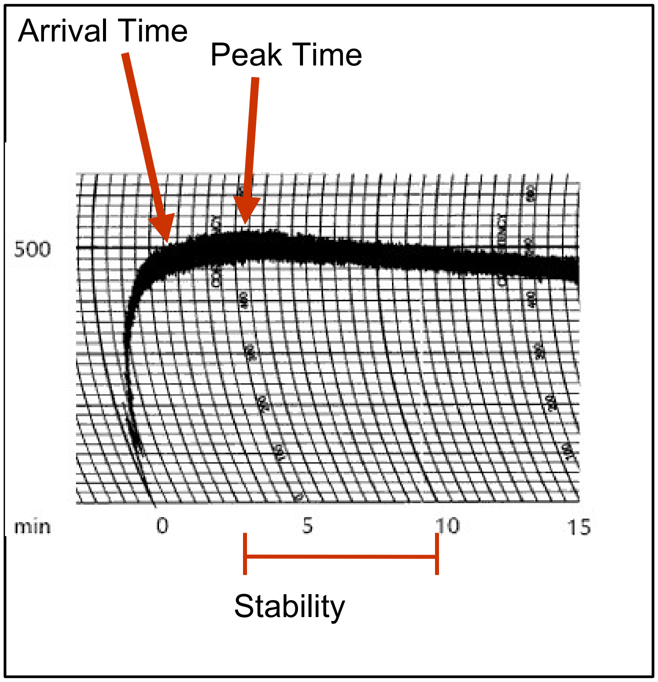

Figure 1: The farinograph trace

Briefly, (there is a more in depth article on the farinograph in Part 2 of this Guide) the farinograph records the torque required to mix a standardized sample of flour and water with the results graphed in BU (Barbender Units – an arbitrary unit that incorporates torque) over time. As everyone knows from mixing in his or her bakery as flour and water (and other ingredients) are mixed the dough develops and gathers strength through the development of the gluten forming proteins in the flour. As the dough strengthens it requires more energy (or torque) to mix it. It is this increase in the torque needed to continue mixing that the farinograph records on the trace.

With flour being a variable material whose performance is directly related to the amount of water it is able to absorb the farinograph requires some level of standardization across all flour samples. This is achieved by mixing the flour sample with enough water to center the trace on the 500BU line. Looking at figure 1 above and you can see a properly centered trace. Once this standardization has taken place it is easy to compare flour samples with varying performance parameters.

The first value of particular interest to the baker is “absorption”. This value is given in terms of % water absorbed for the given flour sample. As with all farinograph parameters this is a relative value and should not be taken as the actual absorption one would find at the mixer bowl. This value is useful in determining whether or not hydration adjustments are needed as you transition from one mill run of flour to the next.

The "arrival time" (reported in minutes) is the time it takes to develop the dough mixture until the trace reaches the 500 BU line (see Fig 1). This value can be used as a relative indicator of the time required for the dough to come together and begin to build strength.

"Peak time" (also reported in minutes) is the time it takes for the dough to reach maximum strength. Again, this is a good indicator of protein quantity (ie the more protein you have the longer it will take to mix to maximum strength) but it also gives you insight into how quickly the proteins bind to form the gluten network and thus provides some insight into protein quality.

The "Stability" parameter is a relatively good indicator of the overall quality of the protein in the flour. Stability (measured in minutes) is the period from the peak to the time at which the trace drops below the 500BU line (again, see fig 1). A number of characteristics unique to each flour sample can show up in the stability portion of the trace. Typical US bread flours will show a relatively long and flat stability. This is because much US wheat has been bred for mechanized dough production. This is not to say that this type of production is looking for long mix times, rather it is looking for a flour that will hold up well under the stresses imposed by this type of production without breaking down. Flours that are formulated for gentler processes tend to show a shorter more rounded stability portion of the trace. These flours require a bit more skill at the mixer bowl as they are easier to over-mix but often allow more of the subtle taste and visual characteristics of the flour to show through in the finished product. My advice is to get used to looking at farinographs and build a visual catalog of the traces in your head (or in a notebook) and how these correlate to your mix and finished products.

Finally, MTI or Mixing Tolerance Index (measured in BU's). This value is the drop in BU's from the peak to 5 minutes after the Peak. It is an interesting value that is often debated as to its usefulness. I like to use it as an indicator of how the dough is going to perform during the critical final stages of the mix. A high MTI means that the dough will tend to breakdown relatively quickly whereas a low MTI might indicate a flour that will require a longer mix time to fully develop.

It is difficult to give guidelines for appropriate values of each of the parameters as flours vary so widely in their applications (ie a pasty flour will yield very different results than a hi-gluten flour). If you look at figure 2 on the next page you will see the variability in flour performance as shown graphically through use of the farinograph.

It is also important to realize that the values reported for each of the parameters have no direct correlation to actual mixer times or absorption. They serve as a guide to how the flour will perform relative to how other flours have performed when the farinograph results have been known. The beauty of the farinograph (like the alveograph) is it gives a graphical representation of flour performance. Over time, with familiarity and

Farinograph values for a flour suitable for making baguettes:

Absorption:	61% +/- 2%
Peak:	7 min
Stability:	12.5 min
MTI:	30 BU

experience, you should be able to look at the trace (or the values) and get a good indication of how this particular flour is going to perform. In the box on the previous page I have given fairly standard values for flour that would generally be viewed as suitable for making baguettes. The best thing for you to do is request an analysis sheet from your distributor or miller. Do not settle for a spec sheet, you want the real values from a particular mill run, and ideally it will be for flour you are using.

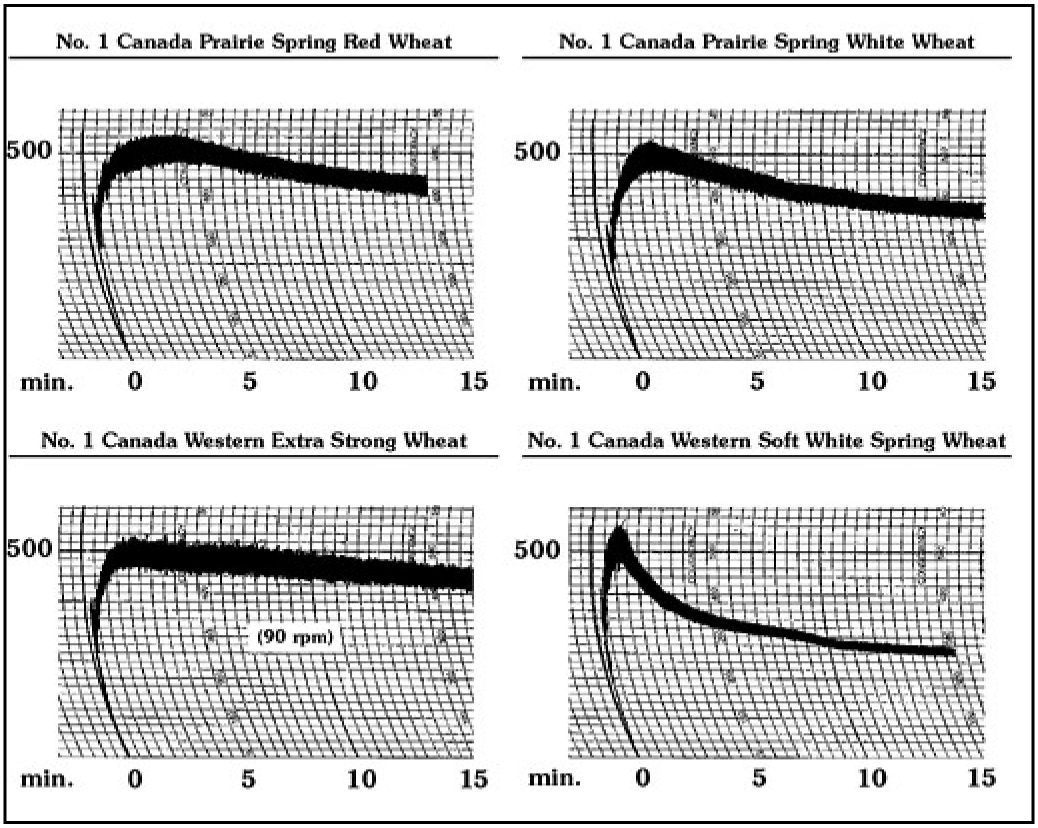

Figure 2: Variability in flour performance as indicated by the farinograph

Alveograph

Like the farinograph, the alveograph was developed to provide an empirical, multi-dimensional look at flour quality. While not as common in the US as it is in Latin America and Europe more US bakers are becoming familiar with the results of alveograph analysis and are using it in conjunction with other analysis methods to provide them with a broad look at their flour and its performance capabilities.

While a more detailed look at the Alveograph appears in Part 2 of this Guide we need a short description of the alveograph's functionality as it may not be familiar to everyone. Basically, a dough is mixed and sheeted into a flat disc and secured. Next, the instrument blows a bubble of dough and measures the pressure during the inflation. Conceptually the physics of blowing the bubble correspond to the expansion of bubbles in fermenting dough and as such the parameters derived from this test should give some indication as to how the dough will act during fermentation. A simplified alveogram is shown in figure 1.

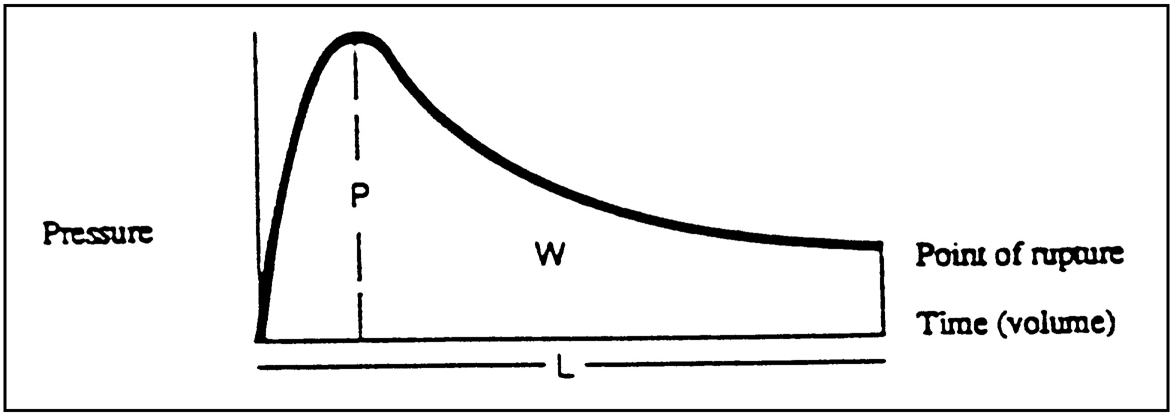

Figure 1: a simplified alveogram

The variables of interest to most bakers include "P" (Peak height), "L" (Length), the ratio of "P/L" and "W" (area under the curve). The P-value (measured in mm) expresses the resistance of the dough to deformation (ie how difficult it is to blow the bubble). The P-value is representative of the dough's elastic properties. The L-value (measured in mm) is the length of the curve from the origin to the point where the bubble ruptures. This is taken to represent the dough's extensible properties. Therefore, the P/L ratio gives a general indication of the viscoelastatic properties of the dough. A P/L of 1 would indicate a general balance of elasticity to extensibility. Greater than 1 and the balance shifts towards increased elasticity and less than 1 and the balance shifts towards greater extensibility.

The W-value is the area under the curve and is viewed as being proportional to the energy required for deformation (ie the total energy needed to blow the bubble). For the baker this is an indication of baking strength of the dough. W-values range from a low of 45 for doughs mixed from soft wheat flours to over 400 for extremely strong dough.

W-value	**Flour type**
45 – 120	very weak, not suitable for bread production.
120 – 160	weak flour, suitable for cookie production.
160 – 250	flour of average strength. Suitable for producing breads that do not require much dough strength (ie. Ciabatta, focaccia, etc).
250 – 310	flour with good strength suitable for making a wide range of hearth breads.
310 – 320	strong flour suitable for making products requiring above average dough strength.

Much of what was said for the farinograph holds true for alveograph analysis. Namely, use these results to build up a body of understanding regarding the correlation between the numbers on the page and the graphical representation of the trace to what you find when you mix and bake products made from these flours. Over time your experience will allow you to draw conclusions based on the analysis sheets you receive and will indicate what steps at the mixer bowl may be necessary to produce the bread you and your customers demand.

Part II

Articles

Falling Number

Tod Bramble – King Arthur Flour Co., Inc.

In this article we will look at the method used to determine enzymatic activity as determined by the Falling Number Apparatus.

The Falling Number method was first described by Hagberg and Perten in the early 1960's for the purpose of providing a rapid means of determining the extent of sprout damage in wheat or rye (Doty, 1980). It has found widespread acceptance because of its rapid analysis time, simple operation, and high degree of reproducibility (Pyler, 1986). Sprout damage in wheat is of critical concern if the end-use for the flour being milled is bread production. As little as 5% heavily sprouted wheat in a mill mix of otherwise sound grain can make the mixture unacceptable for bread production (Perten, 1985). Sprouting in wheat results in a higher than normal level of α-amylase in the flour. Wheat that has been harvested before sprouting has occurred contains low levels of α –amylase (Posner, 1997).

α-amylase is of greater concern in bread production than β-amylase for four reasons: (1) it is able to hydrolyze damaged raw starch; (2) it has a higher thermal stability allowing it to act on gelatinizing starch for 3-4 minutes when the interior of the bread load is 140-150ºF, (3) it is stable at the common pH of bread dough: 5.0 – 5.6, and (4) it is activated by calcium ions that inactivate β-amylase (Pyler, 1986). In addition to this, β-amylase is only able to act upon the non-reducing ends of starch chains from which it splits off maltose, and it is unable to act upon intact raw starch (Doty, 1980). The activity of β-amylase also is dependent upon the level of starch damage in the flour as damaged starch has more sites at which β-amylase can act. Starch is damaged in the milling process and typically accounts for around 8% of the total starch in hard wheat flours (Pyler, 1986).

α-amylase is far more able to reduce the long starch molecules into smaller pieces upon which the β-amylase can act. α-amylase is able to act upon interior portions of the starch molecules. The result of this is that the β-amylase now has more open sites upon which is can act and produce more maltose molecules: a source of energy for yeast involved in fermentation. It is the combined action of these two molecules that can convert nearly the entire starch molecule into fermentable sugar (Doty, 1980)

This amylolytic action in dough occurs once the dough ingredients are combined and mixed. The conversion of starch to maltose and other yeast fermentable sugars is critical to the bread baking process. This conversion results in several changes in dough properties including: a decrease in absorption capacity, a slackening of dough consistency, and the development of a stickier dough. The rate at which these changes occur is directly proportional to the amount of starch damage and α-amylase level of the flour. As we noted above, flour milled from sound, un-sprouted wheat has a very low α-amylase content and requires supplemental α-amylase to have the required functional properties for bread production. Hard wheat flours typically have a total sugar content of 1.5%. This level is initially boosted to 2.0 to 2.5% during mixing by the rapid action of β-amylase upon the damaged starch (Pyler, 1986).

Typically, wheat is harvested once the grain has dried to an appropriate moisture level that takes into consideration both optimality for harvest and suitability for prolonged storage. In a dry, normal growing season this is done before the grain has had a chance to germinate and sprout. The direct implication of this is that α-amylase levels are typically quite low and supplementation of the milled flour must occur. The Falling Number Method is used to measure the level of α-amylase activity in newly harvested wheat as a means of detecting sprout damage and as a method for determining the proper supplementation rates of barley malt, or other α-amylase enrichment (Doty, 1980).

Bread flours with normal diastatic activity (milled from sound, unsprouted wheat and supplemented with α-amylase through the addition of barley malt, or fungal amylase) typically having falling number values in the range of 220 to 250 seconds. Flours deficient in diastatic activity will typically have values in excess of 400 seconds and over supplemented flours or flour milled from sprout damaged wheat can have the minimum value of 60 seconds.

The Falling Number Method is based on the starch liquefying action of α-amylase and expresses this as the time in seconds required to stir and allow the stirrer to fall a measured distance through a heated aqueous flour gel that is undergoing liquefaction (Pyler, 1980). The instrument consists of a boiling water bath, a stirring head, and a timer. Also needed are, a test tube and a stirring rod. The stirring head consists of motors and gears which allows for precise and uniform stirring insuring reproducibility of the results (Doty, 1980).

The procedure for flour involves mixing 7 g of flour with 25 mL of distilled water in a test tube. The tube is shaken and the stirring rod is inserted and then the whole assembly is placed in the boiling water bath. The timer is automatically started and a stirring process is activated and continues for 55 seconds and a rate of 2 strokes per second. At the end of 60 seconds the stirring rod is released from the up position and allowed to fall through the heated flour-water slurry. Upon completion of the vertical fall the timer stops and displays the elapsed time in seconds (Pyler, 1986). The descent of the stirring rod through the slurry is related to the α-amylase activity of the sample. Upon completion of the stirring action the α-amylase present in the flour starts to break down the gelatinized starch reducing the viscosity of the slurry (Doty, 1980).

If analysis of a wheat sample is required then a 300 g sample is ground in a hammer mill to obtain a flour sample. From here the procedure is the same as above for the flour sample (Doty, 1980).

There are several factors that have the potential to affect the results of the Falling Number Method. These include the sampling method, the preparation of the samples, moisture content of the samples, boiling temperature (affected by altitude), heat treatment of the grain, and the stirring procedure (Perten, 1967). This last issue is not of particular importance today as the Falling Number Instruments most commonly found are fully automated and require little operator input aside from the initial shaking of the sample.

The falling number method as described is an absolutely essential analysis technique in both the milling and baking industries. As α-amylase plays such a critical role in baking, the development of this rapid, simple, and highly reproducible technique has proven to be invaluable.

Farinograph

Tod Bramble – King Arthur Flour Co., Inc.

Mixing is arguably the most critical process in bread production. As a result, much research has been conducted to investigate the parameters that lead to an optimally developed dough that will result in a high quality bread product that satisfies not only processing requirements but satisfies customer expectations. The study of dough development and formation includes investigation of a dough's rheological properties. Rheology is the study of how materials deform, flow, or fail when force is applied (Hoseney, 1994). While this definition applies to many mechanical processes it is applicable on many levels to dough mixing. Two common instruments used in the measurement the rheological properties of doughs are the mixograph and the farinograph.

Dough mixing involves the combining and blending of ingredients with the application of sufficient physical energy (work) that will transform the mixture into a cohesive mass with the required viscoelastic properties (Pyler, 1986). Specifically for bread dough formation mixing is the process of converting flour and water into a dough by both blending and distributing the dough ingredients and developing the gluten protein into a continuous phase possessing viscoelastic properties (Hoseney, 1974). What makes bread dough a viscoeleastic material is the derivation of it physical properties primarily from two states of mater: liquid and solid. A dough exhibits *plasticity* that combines the attributes of both fluids and solids, *elasticity* which is a property generally exhibited by solids, and *viscosity*, a characteristic of liquids (Pyler, 1986).

The two principle components of bread dough are flour and water. As water is added to flour the particles are wetted and slowly hydrated. With mixing comes the application of physical energy and several physical and chemical changes occur. The flour-water mass gradually becomes coherent mixture, loses its wet, sticky appearance and becomes a smooth and homogeneous dough. This transformation of a mixture from a wet sticky mass which exhibits a high degree of extensibility to a dry and increasingly elastic material involves the presence of free water in the dough (Hoseney, 1974). The presence of free water allows for the lubrication of the constituent particles of a mixture or dough and allows for some degree of flow. Upon mixing the protein and other constituents of the mixture become hydrated, decreasing the level of free water present and leading to the development of a drier feeling dough. As a result resistance to extension increases and dough mobility or extensibility decreases.

Obviously this transformation in the mixture is not only the result of the decreasing presence of free water. Other physical and chemical changes occur as a result of mixing. Upon hydration of the flour particles the protein structure becomes altered. This protein structure begins (just after the start of mixing and the hydration of the flour) as a tangled mass. As mixing proceeds a gradual orientation of the long linear protein molecules occurs with a simultaneous decrease in chain entanglements (Pyler, 1986). If mixing is halted before the development of this ordered protein structure then the dough will be less able to retain the gases of fermentation and result in reduced loaf volume (Hoseney, 1974).

As mixing continues beyond the optimum development point of the protein network dough breakdown will occur. During breakdown the dough begins to lose the elastic component of its viscoelastic characteristics and become more extensible, and progressively softer (Pyler, 1986). Experimental evidence suggests that with continued mixing beyond optimum development the protein network becomes even less entangled allowing for increased laminar flow and thus the increase in extensibility. Hoseney argues that this orientation of protein molecules would greatly increase the probability of protein-protein interactions that could result in the release of bound water. This increase in free water would result in a decrease in elasticity (decreased viscosity) and account for the wet and sticky appearance of the dough (Hoseney, 1987).

It is the complex nature of the dough development process and the needs of the baking industry for a reliable set of tests that are able to determining the mixing and baking qualities of flour that the mixograph and the farinograph were developed.

The farinograph as developed by Hankoczy, a Hungarian in 1928 (MacRitchie, 2000a) and later refined by Brabender has gained wide acceptance and is used more often in cereal analysis than any other piece of experimental dough testing instrument (Pyler, 1986). The farinograph was initially designed to test the rheological properties of the lower protein European wheats but today it has been modified and found to be an accurate instrument for assessing the qualities of North American wheats as well.

The farinograph is used to assess the rheological properties of wheat flours as they are mixed and developed into a dough. As we have seen above this is a complex process which can be broken down into the following three processes: absorption of water, dough development, and dough break down (Preston, 1984). The farinograph measures the energy required to mix a dough as it progresses through these three stages of development. From this information the dough's relative quality characteristics can be assessed.

The Brabender Farinograph consists of a high speed mixer with two 'z' shaped paddles which rotate in opposite directions at a differential of 1.5:1 (MacRitchie, 2000a). Flour and water are mixed together at a constant temperature to form a dough. This mixing apparatus is designed in a manner such that the resistance of the dough against the constant mechanical shear is accurately transferred to a dynamometer and recorded by a computer which translates this information into a trace producing a visual chart of the quality characteristics of the flour. It is this very setup, however, that makes the farinograph a poor instrument for studying the "basic" properties of dough rheology. The 'z' shaped paddles contribute a complicated mixing action that does not impart homogeneous stress and strain forces over time making mathematical analysis impossible. The farinograph trace, as a result, can not be broken down into its fundamental rheological components; rather, the trace is a composite of these forces (Preston, 1984).

That said the farinograph is useful in the study of a dough's rheological properties. Typically, the most commonly gathered information from the farinograph trace consists of flour absorption, and the mixing characteristics of the dough (Tanaka, 1969). As the flour and water are mixed into a dough, development progresses through the three stages mentioned above. Obviously in such a complex system as dough development it is not a case of seamlessly moving from one stage to the next. Rather, each stage goes through a period of dominance as mixing progresses.

The farinograph is used extensively for determination of a flour's water absorption characteristics. Several studies have indicated that flour absorption is a function of protein content, starch (damaged starch in particular), pentosans, and gluten strength (Preston, 1984). Flour absorption, as determined by the farinograph is the amount of water required to develop a dough that centers the trace on the 500 BU line. Use of the farinograph as a method for determining flour absorption is not accepted by all cereal scientists. Hoseney indicates that there is little evidence that the farinograph absorption value is related to that as determined during baking. He also notes that in choosing an arbitrary dough consistency of 500 BU and adjusting the water to meet that consistency assumes that water is the only factor affecting optimum dough consistency, and he feels that that is an incorrect assumption (Hosney, 1974). Even with such criticism the absorption values determined by the farinograph are widely used and are useful in determining relative water absorption characteristics between flour samples.

In addition to identifying a flour's absorption for baking purposes it is also necessary to have a standardized absorption for the evaluation of a flour's mixing qualities at a particular consistency so that results can be compared across a range of flours. As we will see relative quality characteristics of a wide range of doughs require that the consistency be such that the "peak" of the farinograph trace is centered on the 500 BU line. From this peak consistency several quality characteristics are determined. Over absorption of the flour will cause the trace not to reach the 500 BU line (too high a level of extensibility or too low of a resistance to mechanical sheer) and under absorption will cause the trace to be centered above the 500 BU line (too high a level of elasticity or too great of a resistance of mechanical sheer) (Pyler, 1986).

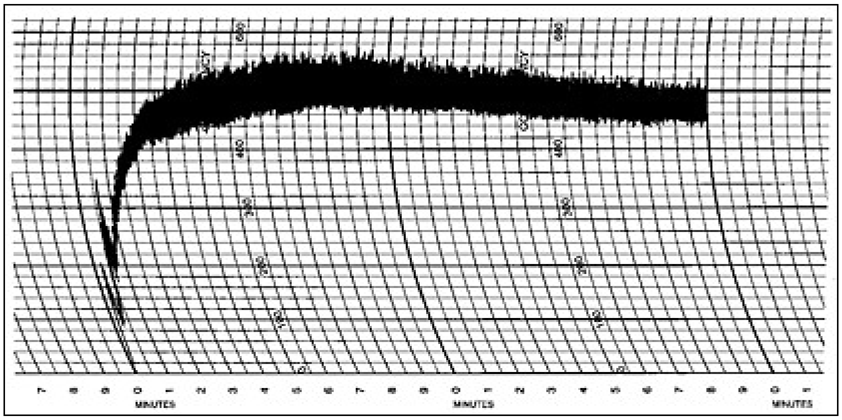

Figure 1: A farinograph trace

The other area of use for the farinograph is in relative flour quality characteristics. An example of a farinograph trace is given in figure 1. The mixing action of the farinograph develops the dough through the stages outlined above. The resistance of the dough to mechanical development is recorded by the dynamometer and recorded on a chart measured in arbitrary "Brabender Units" (BU). From the farinograph trace a number of flour quality characteristics have been derived. The most common use of the trace is in the characterization of the inherent mixing properties of the flour. These parameters are outlined as follows:

- Arrival time – the time required for the top of the curve to reach the 500 BU line. This is a generalized measurement of the rate of water take up by the flour. It has been shown that as protein content increases arrival time increases as well.

- Dough Development Time – This is the time between the first addition of water and the dough's development to minimum extensibility.

- Stability – This is the difference in time between the point at which the peak first crosses the 500 BU line and the point at which the top of the curve leaves the 500 BU line. This is taken to be an indication of the flour's mixing tolerance level.

- Departure time – The time from the first addition of water until the top of the curve leaves the 500 BU line. As this values increases it indicates increasing dough strength.

- Twenty minute drop – Difference between the height of the curve at peak development and the height of the center of the curve after twenty minutes. This is an indication of the rate of breakdown and the strength of the flour.

- Mixing tolerance index – This is the difference in BU's between the height of the curve at the peak and the top of the curve measured five minutes after the peak. This is a composite value which indicates mixing tolerance and flour strength (Shuey, 1984)

These values can be used as a relative composite description of a flour's overall quality characteristics. Flours can be generally placed into one of the following descriptive categories as outlined by Preston:

- Weak – Flours with short (< 2.5 min) development times, high MTI values (> 100) and low water absorption (< 55%).

- Medium – Flours having a dough development time ranging from 2.5 to 4.0 min, MTI values in the range of 60 – 100, and absorptions of 54% - 60%.

- Strong – Flours having long development times (4.0 – 8.0 min), low MTI values (15 – 50) and absorptions generally above 58%

- Very strong – Flours having very long development times (> 10 min) and very low MTI scores (< 10)(Preston, 1984)

Alveograph

Tod Bramble – King Arthur Flour Company

As we know wheat flour contains gluten proteins which, when mixed with water, develop to form a gluten matrix resulting in a dough with viscoelastic properties (Walker, 1996). In that wheat flour is used to manufacture a wide range of products, characterizing protein quality and dough strength is important in determining a flour's suitability for a particular end use. Cookie and biscuit manufactures want a flour which will not develop into a strong elastic dough before the ingredients are properly incorporated into a dough or batter. The bread baking industry, on the other hand, wants a dough that will develop quickly and form a strong elastic dough that can not only resist damage from the mechanics of bread production but will trap carbon dioxide and develop into a well risen loaf of bread. The importance of the viscoelastic properties of wheat flour doughs to many production processes has resulted in several instruments capable of measuring and characterizing wheat flours and the doughs that result from them. Two instruments widely used in the milling and baking industry are the Brabender extensigraph and the Chopin Alveograph. Both are considered "stress-strain" instruments, however, their use and application are markedly different. In this article we will examine in detail the Alveograph.

Chopin Alveograph

The Chopin Alveograph is a dough-testing instrument that inflates a thin sheet of dough into a bubble by means of air pressure. The theoretical justification for this method of analysis is its simulation of the inflation of bubbles in a dough with carbon dioxide produced by yeast during fermentation (Hlynka, 1955).

Marcel Chopin originally developed the Alveograph in France in 1920 as an empirical instrument to measure flour quality (Hoseney, 1986). He was interested in developing a dough testing instrument to use in place of baking tests to characterize the baking qualities of French wheat (Faridi, 1987). In 1927 Chopin wrote:

> …it appears that the sole mechanical test on dough which corresponds exactly to the deformation which it undergoes in forming a loaf is one which consists in stretching a test sample from a compact state into a thin membrane until it finally becomes weakened to the point of rupture. This test must be made upon the dough itself and not upon the gluten contained in the dough. Furthermore, it is possible to measure the tensile strength of the membrane which is being stretched (Chopin, 1927)."

This formed the motivation for the development of the alveograph. Chopin's model (which he called a "extensimeter") was designed to measure the plasticity of wheat flour doughs. This was accomplished through the measurement of (1) the "tenacity" of the dough (its resistance to extension) which was estimated by the pressure required to force a uniform cylinder of dough to a take a definite form (a bubble) in a fixed period of time, and (2) the ability of the dough to be stretched into a thin membrane (Faridi, 1987).

The original design has been modified several times over the years to its current form. The instrument consists of three main components: (1) a mixer, (2) the bubble blowing apparatus (the alveograph), and (3) the recording manometer (Pyler, 1986). The most current versions include a computer component for analyzing the various measurements taken from the alveogram. Even with the several modifications that have taken place over the last 80 years the principles of operation remain the same: a dough is mixed for a set period of time to a standardized moisture content, sheeted into a flat disk and allowed to rest. After the resting period the dough is secured into the instrument and air pressure is used to inflate a bubble with the instrument measuring the pressure required to inflate the bubble (Hoseney, 1986).

Evaluation of the rheological behavior of a dough sample by blowing it into a bubble until it ruptures allows for a unique analysis approach. During the inflation of the bubble the dough piece is being extended in two directions: along a parallel and along a meridian of the bubble. This type of deformation is called bi-axial extension and in dough rheological testing is unique to the alveograph (Launay, 1987). Bi-axial extension has distinct advantages over uni-axial stretching. Physically, bi-axial extension simulates the type of deformation that takes place during fermentation and oven rise. The other difference is the rate of extension. The rate at which a bubble expands in an alveograph test changes with the volume of the bubble (Faridi, 1986).

Perhaps owing to its European origin the alveograph was originally used principally for the evaluation of European wheats which were generally weaker (lower protein content) than were varieties found in the United States (Walker, 1996). Today the alveograph is used on all types of wheat flour including very strong bread flours, however, it is still principally used in Continental Europe, French speaking Africa, Latin America and some parts of Asia (Sugden, 1998).

The alveograph testing procedure begins with mixing a dough from the wheat sample. 250g of flour are placed in the mixer and the mixer started. The appropriate amount (based on the initial moisture content of the flour sample) of 2.5% sodium chloride solution is added to the flour over a 20-second time period. After 1 minute of mixing the mixer is stopped and the side scrapped for 1 minute. The mixer is restarted and allowed to mix for six additional minutes. After mixing for 8 minutes in total the mixer is reversed and the dough is extruded out the front gate. Pieces are cut off and sheeted on the

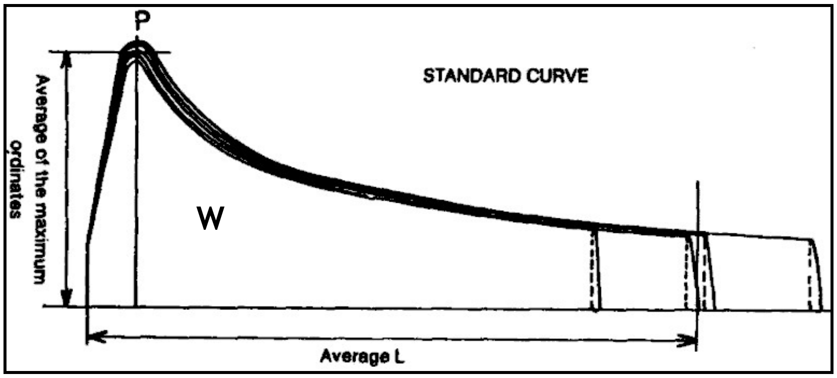

Figure 1: Alveogram

sheeter assembly and cut into round discs and placed in the resting cabinet for 20 minutes. After the rest a disc is placed in the alveograph and the inflation process is activated by switching on the airflow. The bubble is allowed to inflate and burst. The recording/analyzing computer performs the analysis automatically (MacRitchie, 2000).

The procedure used above results in an alveogram. A typical example is shown in figure 1. The common parameters obtained from an alveogram are the maximum over pressure (P), the swelling index (G), the average abscissa at rupture (L), the configuration ratio (P/L) and the deformation energy (W).

The interpretation of the alveogram has been researched and debated almost from the time the alveograph was developed. The following "standard" interpretation has been adapted from "Interpretation of the Alveogram" (in Faridi, 1986).

The overpressure (designated as "P" in figure 1) is measured as the maximum height of the alveogram multiplied by a factor of 1.1. The P value has received much research attention and its use as an indicator of flour quality has been debated widely. Typically, P is regarded as a measure of dough tenacity as related to the maximum pressure attained in the inflation process.

The "L" value (see bottom of figure 1) is the average length, in millimeters, of the curves from the point where the dough bubble starts to inflate to the point where the bubble bursts. Very little debate has occurred over the L value, and is widely regarded as a measure of dough extensibility.

The configuration ratio, P/L, is an approximate indication of the shape of the alveogram combining the dough tenacity measurement (P) and the dough extensibility (L).

G, the swelling index, is the square root of the volume of air needed to rupture the dough bubble. Several studies have related the G value to various dough characteristics, however, it is primarily taken as a measure of dough extensibility.

And finally, the W value represents the work or energy needed to inflate the dough until it ruptures and is derived from the area under the curve. The W value is widely used as a measure of flour strength, and is often used as the principle indicator of the processing behavior of the flour.

From these five indexes the processing characteristics of a flour can be determined and its suitability for a specific end use can be evaluated. As was stated above the alveograph was initially developed for use in the evaluation of European wheats that tended to be lower in protein and thus “weaker” than the hard wheats grown in the United States. The strongest of the US wheats are typically hard spring wheats grown in the northern growing regions of the US. Initial research indicated that the alveograph was not suitable for evaluation of this wheat class (Khattak, 1974). A study was conducted by Chen and D’Appolonia (1985) to examine the influence of increased water absorption resulting from increasing levels of starch damage on alveograph values. Their research resulted in a modified method for use in evaluating hard spring wheats with the alveograph thus extending its use to a wider range of wheat flours.

On the other side of the flour strength spectrum is the application of alveography in the evaluation of soft wheat flours. In the introduction to their research Rasper, et. al. (1986) indicated that concern had been expressed about performing a stretchability test on doughs of constant water content without allowing for hydration capacity of the tested flours. This was the same question raised above by Chen and D’Appolonia for hard spring wheats. The objective of the Rasper study was to evaluate the suitability of the alveograph in quality assessment of soft white wheat flours. Their research also resulted in a modified method and determined that the Chopin Alveograph could be used successfully in the evaluation of soft wheat flours and was more sensitive to variations in quality than the widely used cookie spread test procedure.

With these two research projects and the established research prior to these studies the alveograph has been shown to be an effective and valuable tool in wheat flour quality evaluation and a good indicator of end use potential for the entire range of wheat flours.