24.4 Optimization of Flour Moisture in Milling and Baking: Theoretical Principles and Technical Realization

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24.4.1 Introduction

The water content of flours (absolute moisture) is extremely important for storage and processing in both milling and baking, so both industries have a need for uniform, consistent flour moisture. In principle it is true to say that whether it is possible, or makes sense, to optimize the moisture content of flour depends on the way in which the water is bound to the constituents of the flour. Whereas millers are attracted by the possibility of producing flours with a defined and high percentage of water for economic reasons, this also enables subsequent processors to handle their recipes more easily at the dough-making stage, especially when changing from one consignment of flour to the next.

On the other hand, bakers also have a financial interest in making the fullest possible use of the water content of their doughs (dough yield), although in this case the technological consequences are much more complex.

- Better flavour development during fermentation and proving;
- Better properties of the crumb;
- Moister crumb structure;
- More pleasant texture;
- Enhanced chewing properties;
- Larger volume of the baked goods;
- Longer shelf life;
- Higher yield.

1 - 2% more water can make all the difference to the overall operating result (Freund, 1995). That applies to baking as well as milling. Large companies with automatic plant, especially, insist on a uniform moisture content of the flours supplied over long periods. Only if the flours always contain the same amount of water is it unnecessary to adjust the recipe after each delivery of flour.

24.4.2 Theoretical Principles of Flour Wetting

From the rheological point of view, numerous dry substances used in the food industry may be regarded as simple dispersed systems, more specifically as aerosols of solid matter. Gas (air) is finely distributed in the solid matter as a dispersing agent. If finely distributed water is introduced into this system as a second dispersing agent, we speak of a complex dispersed system. These three phases, also known as volume phases, are in contact with each other at interfaces between which an equilibrium of forces exists.

Since dispersed systems always show a tendency to minimize free interfacial energy, internal and/or external interactions cause changes in the adjacent interfaces where the individual volume phases meet if, for example, water wets the dry substance. In practice this phenomenon can always be observed when the moisture of a product in powder form is adjusted in a deliberate wetting or mixing process.

In rheological terms the interface (of the dry substance) is brought into contact with a high level of free energy (σ_{SG}) by an interface with a low level of free energy (liquid - σ_{SL}) when the dry substance is wetted (Fig. 250). This causes the droplet of liquid to spread – the dry substance is wetted. The free energy of the interface LG increases in the process.

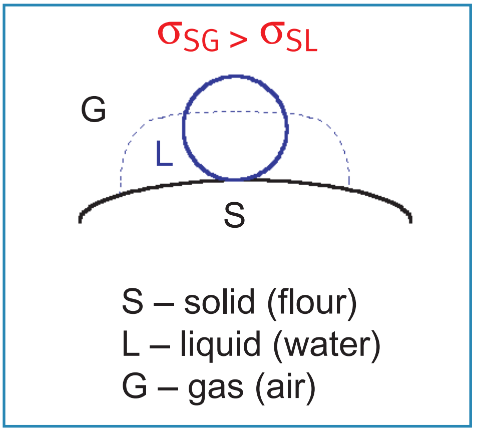

Fig. 250: Wetting at the interface between the phases

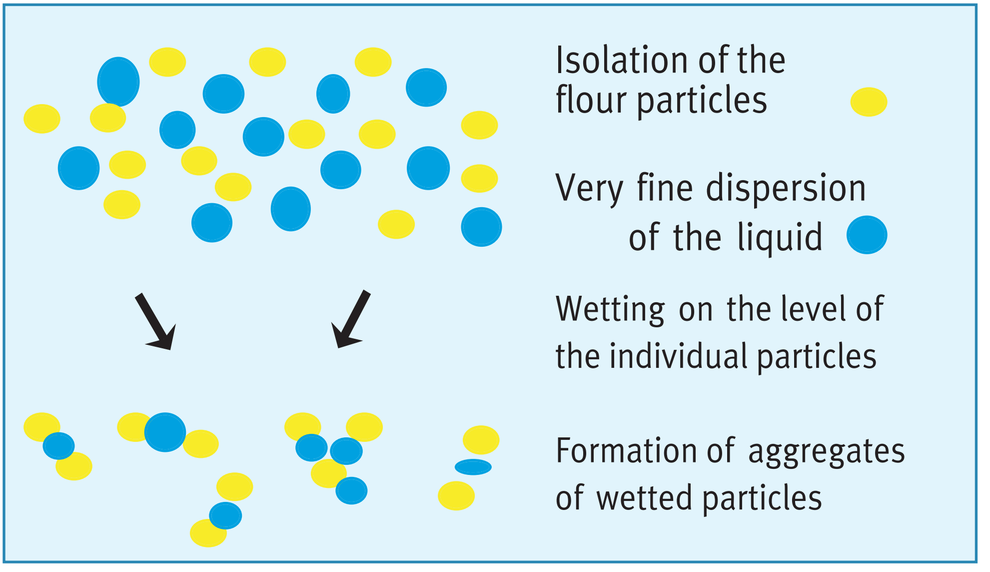

Fig. 251: Isolation of the dry components, wetting and formation of aggregates

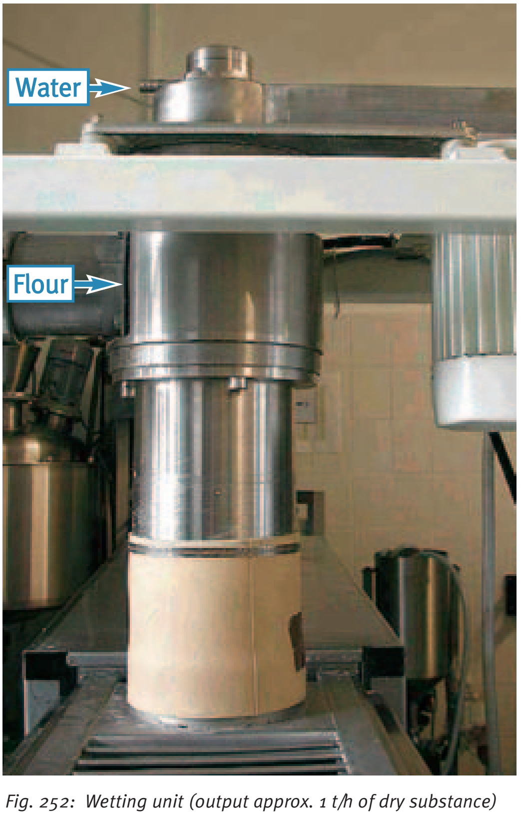

Fig. 252: Wetting unit (output approx. 1 t/h of dry substance)

The interactions responsible for the spreading of the droplet and thus the wetting of the dry substance are adhesive forces between the volume phases of the solid and the water.

If the objective of a technological process is to adjust the moisture content of a product very precisely, these general theoretical aspects have to be taken into account. The smaller the desired percentage by which the moisture content of the product is to be raised, the greater are the demands on the mixing or wetting system.

For an optimum mixing or wetting process it is advisable first to isolate the two phases to be mixed as completely as possible (Fig. 251) and then combine them at the particle-size level. It is the only way to ensure that each particle of the dry substance receives the proper amount of liquid.

This is best achieved in a continuous process in which the components to be mixed can be combined in small volume units (amount of the substance per unit of time) rather than in a batch process with large lots.

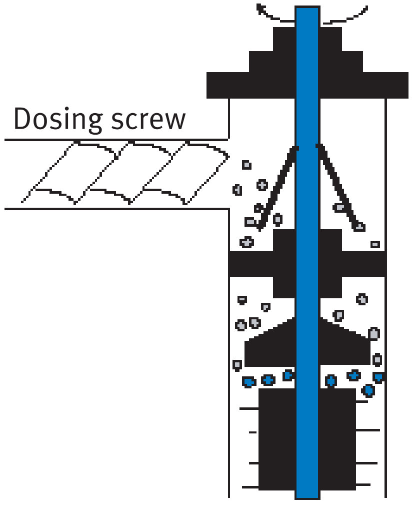

Fig. 253: Principle of the wetting unit

24.4.3 Technical Realization

Continuous Flour Wetting

In the following continuous wetting and mixing system (Fig. 252) the theoretical aspects described above are used to great effect.

The dry substance to be wetted is first dosed into the cylindrical wetting unit with a spiral conveyor. After leaving the spiral conveyor the flour drops freely onto a revolving (> 1,000 min^{-1}), conical part of the cylinder with special guide fittings; this disperses the dry substance practically down to the single particles.

The powder finely dispersed in this way then falls through a film of liquid created by a centrifugal atomizer and is thus wetted. The liquid is added through a hollow shaft. In a downstream mixing zone, further fine dispersion is carried out by a pin mixer; the desired moisture content of the product can be adjusted to almost any requirements by the amount of liquid added.

The mixing time is not more than 2 seconds, and there is relatively little heating of the dry substance during the mixing process itself. The degree of heating depends on the initial temperatures, the throughput of dry material, the quantity of liquid used for wetting, the speed of the rotor and the characteristics of the raw materials to be mixed resulting from the nature of their ingredients. If the moisture content of wheat flour is raised from 14% to about 26%, heating is about 3 - 5 °C.

By directly linking the process steps isolation, wetting of particles and intensive mixing, the principle on which this continuous system works permits a wide range of applications for the moisture-conditioning of bulk goods in powder form. Further applications in the field of continuous mixing are also possible.

Fig. 253 shows the principle of the wetting unit.

Flour Wetting in Batches

A *discontinuous* system has been developed to enable wetting in batches (Fig. 254). The *discontinuous system* works on the same lines as the continuous process although the basic module (see Fig. 251) has a higher throughput. However, the overall requirements for the batch process are much greater than for the continuous process.

A plant was developed and built that:

- serves to prove the suitability of a discontinuous process;
- permits further tests;
- can be used for practical trials and demonstrations.

The plant was designed to be as small and simple as possible, but it is nevertheless highly flexible in respect of its uses. Its main feature is the wetting unit, which was re-designed and specially built to meet the more demanding requirements. The wetting unit is integrated upstream of a flour balance of the usual kind.

Fig. 254: Discontinuous flour wetting plant

From the technical point of view the main problems to be solved when operating a flour-wetting unit to meet the special requirements of discontinuous dough preparation are as follows:

- The wetting unit is operating in a batch dosing mode, i.e. each batch requires a starting and a stopping procedure. This means that the starting and stopping procedures have to be controlled in such a way that the mixing ratio, the quality of the mixture and accurate dosing are guaranteed during these phases too.
- On discontinuous plant there are frequent changes of product, i.e. rapid adjustments must be possible, for example from wheat dough to rye dough production. Technical problems to be solved here are fast cleaning and complete emptying of the unit.

Because of the starting and stopping procedures and the time required for removing the batches, the maximum throughput of the unit is 2 t/h.

Dust Characteristics of Moist flours

The wetting procedure causes considerable changes to the running properties of the flour, depending on the amount of water added. Whereas non-wetted flour (approx. 14% moisture) leaves the wetting unit in a big cloud of dust, no dust is visible at all at a moisture content of 28%. The reason for this is aggregation of the wetted flour particles in the mixing zone of the wetting unit, which is more or less pronounced according to the amount of water added. This can be proved by re-drying the flour gently immediately after wetting (20 hours at 40 °C and 50% relative humidity) and then submitting it to a sieve analysis (Fig. 255).

As the moisture content of the flour increases, so the proportion of fine particle size fractions (‹ 90 µm and 90 - 112 µm) falls drastically. There is a correspondingly noticeable increase in the proportion of coarser particle size fractions (› 250 µm), the biggest increase being in the flour moisture range between 25% and 30%.

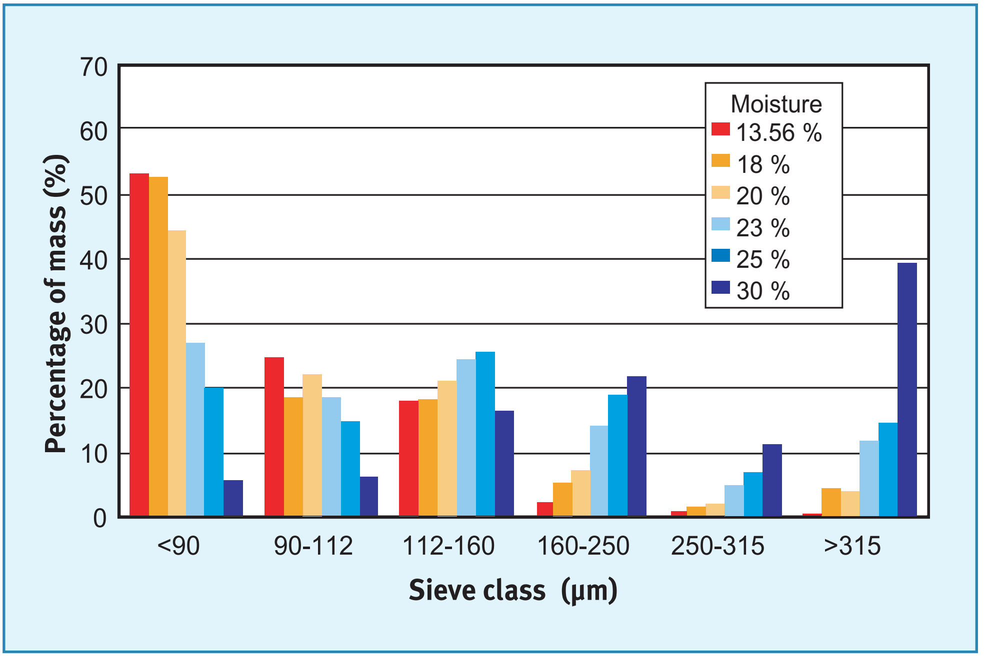

Fig. 255: Particle size distribution (sieve analysis) of flours that have been wetted and subsequently re-dried
Preparation for measurement: drying of the wetted flour at 40 °C / 50% rel. humidity for approx. 20 h;
Sifting machine: RETSCH AS 200 control; amplitude 2.5; sifting time: 5 min;
throughput of wetted and non-wetted flour: 120 kg/h; conveyor: 500; rotor: 750

This clearly demonstrates the influence of the amount of water added on the degree of aggregation of the wetted flour.

In order to assess the dust characteristics of moist flour, the sedimentation properties of flour samples were analyzed in the Hartmann tube. This showed the moisture content of the product to have an effect on the dust characteristics. In spite of the comparatively small differences in moisture content (a maximum of 4%) between the fractions, it was possible to measure definite, reproducible values (Pfeiffer, 1999).
Increasing the moisture content of the flour from 14% to 25% also drastically reduced the sedimentation time from over 12 s to less than one second, and the quantity of dust fell by about 2/3 (Fig. 256).

Summary in respect of dust characteristics:

- From a flour moisture content of about 28%, hardly any dust is found at the outlet of the wetting unit.
- The maximum moisture content is about 30%; above this level, dough starts to form.
- The dust characteristics of the product wetted depend on the amount of water added.

Flour Wetting at the Mill

The above information shows that flour wetting offers a number of advantages in the production of baked goods. A high moisture level in the flour prevents the formation of dust, which is a health hazard, and it also improves the properties of the doughs made from the flour. From the economic point of view, too, a 2 percent increase in the dough

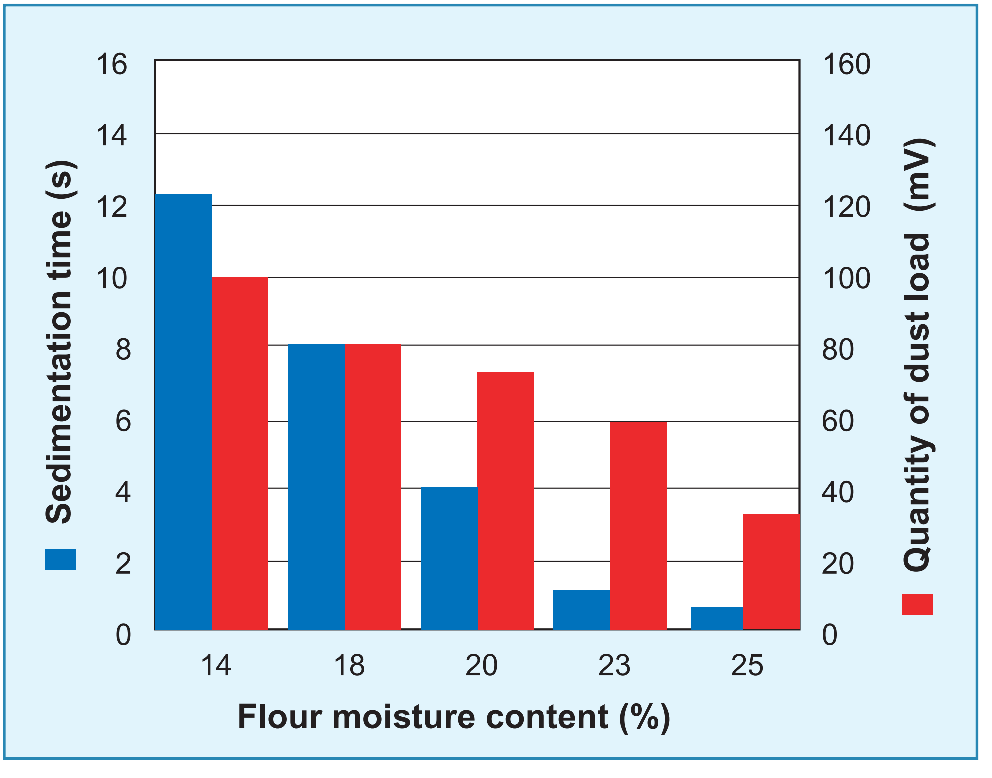

Fig. 256: Influence of flour moisture content on dust characteristics: dust measurement in the Hartmann tube
Sample quantity: 40 mg
Pressure applied: 8 bar
Sedimentation time: measurement over time (modified from Pfeiffer, 1999)

yield is doubtless interesting. And financially and technically interesting applications may emerge for the milling industry.

One possible application at the mill is standardization of flour in respect of its moisture content. Although fluctuations of one or two percent in the moisture content of the flour may seem insignificant at first sight, the large volumes involved result in considerable figures. First the miller will make sure he does not supply too much solid matter within the scope of the specification; then the baker will determine the minimum amount of water required to ensure the quality of his goods. The dough yield, i.e. the amount of water to be added to a certain quantity of flour, is important both for the shelf-life of the baked goods and for the baker's calculations. If flours always have the same moisture content irrespective of the weather during harvest, the baker can always add exactly the same amount of water to make exactly the same dough. But in practice the mills supply flours with a varying moisture content, and bakers do not take these differences into account in their recipes with the result that there are fluctuations in the quality of the baked goods and the financial result is not ideal either. The following example serves to illustrate the opportunities for the milling industry that lie in wetting the flour.

If 60 litres of water have to be added to 100 kg of flour at a flour moisture content of 15%, the dough contains 85 kg of solids apart from the other ingredients. If the moisture content is only 14%, only 99 kg of flour can be weighed in for the same quantity of water in order to maintain quality and profitability. But it is difficult for bakers to react to technical fluctuations because their automatic weighing systems do not permit much flexibility. Moreover, they are often unaware of the moisture content of flours or do not pay enough attention to it. As a result, the doughs are not made with the optimum amount of water at the bakery; their moisture content varies. This common situation has the following disadvantages in the production of baked goods:

- Fluctuations in the solids content of wheat flour result in doughs with different properties.
- The rheological optimum for making up the dough is not achieved.
- The quality of the products is too dependent on the raw material.
- Profitability is below the optimum.

At present the mills supply flours with different solids contents; their customers are dissatisfied, and profitability falls short of the optimum.

Changing weather conditions during the harvesting period and storage of the grain and/or flour for different lengths of time and under different conditions quite often lead to deviations from the desired moisture content of the flour. Since pneumatic conveyors are practically the sole method used for moving grain and flour within the mill, the goods to be conveyed are also affected by atmospheric moisture.

If the relative humidity is low the flour is dryer; otherwise it may easily absorb water, the former case being more common than the latter. Since the amount of moisture lost during pneumatic conveyance is known, this loss can be made up to the moisture content desired by the customer during the wetting process. In this case, too, accurate wetting of the flour will increase the profitability of the mill considerably.

When rye is ground there is usually no conditioning carried out, and so rye flour generally shows much greater fluctuations than wheat flour. Analyses in Germany have revealed moisture levels between 1 and 15 percent. For the marketing of rye flours, flour wetting has shown itself to be a very important technology for meeting quality expectations and increasing profitability, for both the miller and the baker.

Moreover, this wetting and blending technology makes it possible to push ahead with the development of special products in the milling industry. The ability to transport certain active substances directly onto or into the endosperm in the wetting fluid is one example; a highly efficient, continuous mixing of dry

substances and fluid media in general is another. Ultimately it is practically "only" the flow properties of the wetting medium and the characteristics of the end product that decide whether a method is technically feasible.
batch process with large lots.

24.4.4 Flour Wetting at the Bakery

Dough Rheology and Baking Tests

For comparative tests on doughs made from flours with different moisture levels, simple model recipes were first made up using flour, water, yeast and salt. After the mixing process these were tested from the point of view of dough rheology in the

- Farinograph
- Extensograph and
- Rheofermentometer.

Selected tests were continued up to the baking stage, and the suitability of the doughs for making up and the results of baking were evaluated.

Assuming that the sample sizes remain the same, subsequent mixing in the Farinograph of doughs that have been mixed already makes it possible to assess the consistency of the dough that has formed depending on the degree of development in the main mixing process.

A comparison of the model doughs with the same water balance (i.e. containing the same amount of water) but made from flours whose moisture content differs (Fig. 257) shows that the consistency of the dough increases with the moisture content of the flour. This trend can be demonstrated in the dough yield range of 154 - 159%, and the difference between the maximum consistencies is found to decrease as the dough yield increases.

These results lead to the conclusion that hydration of the cellular network of the gluten is so much improved by specific pre-wetting of the flour that a more complex structure is able to form in the dough matrix on the basis of

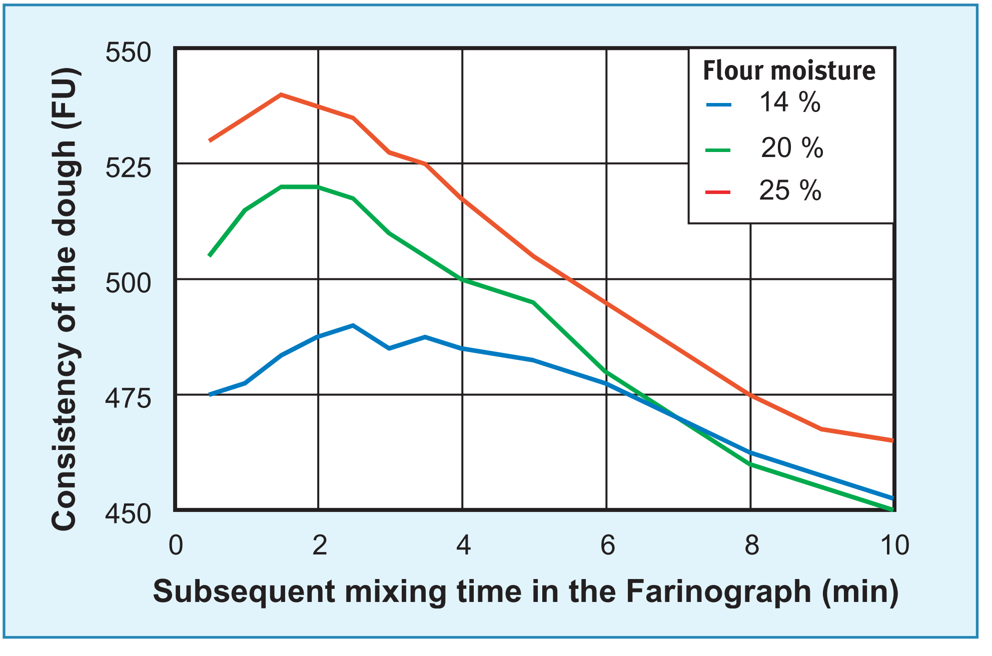

Fig. 257: Subsequent mixing properties of the model doughs: comparison of the mixing curves of doughs with a dough yield of 157, different flour moisture levels.
Weight of dough in Farinograph: 480 g; heating of dough to 30 °C; measurement after 10 min dough resting time

more "binding sites". This is measured in the Farinograph as an increase in the consistency of the dough, although the latter must initially only be regarded as an increase in the firmness of the dough.
A further analysis of these doughs in the Extensograph gives more precise rheological information on this basic property of doughs made from wetted flours by measuring the ratio of resistance to extension (Fig. 258).

Whereas the extensibility of the model doughs remained largely unaffected by the preceding treatment of the flour, their resistance to extension differed considerably as a function of the moisture content of the flour, assuming optimum mixing in each case.
Resistance increased along with an increase in the moisture of the flour. This confirms the assumption that specific wetting of the flour creates conditions in which a more complex structure of the dough matrix forms in the course of mixing. This, in turn, leads us to expect different dough processing properties. To substantiate these results further, samples of the doughs were tested in the Rheofermentometer. This device makes it possible to evaluate the fermentation properties of doughs.

A sample of dough of defined mass is placed in a hermetically sealed fermentation chamber and left to ferment under defined conditions under stress (application of a weight). A built-in CO_2 sensor makes it possible to determine the time at which the dough matrix is no longer able to retain the fermentation gas developing in the dough because of the increasing pressure, and allows it to escape. Once this time is known it is possible to deduce the structural stability of the dough in the test. In this way it is possible to differentiate between the gas retention properties of doughs.

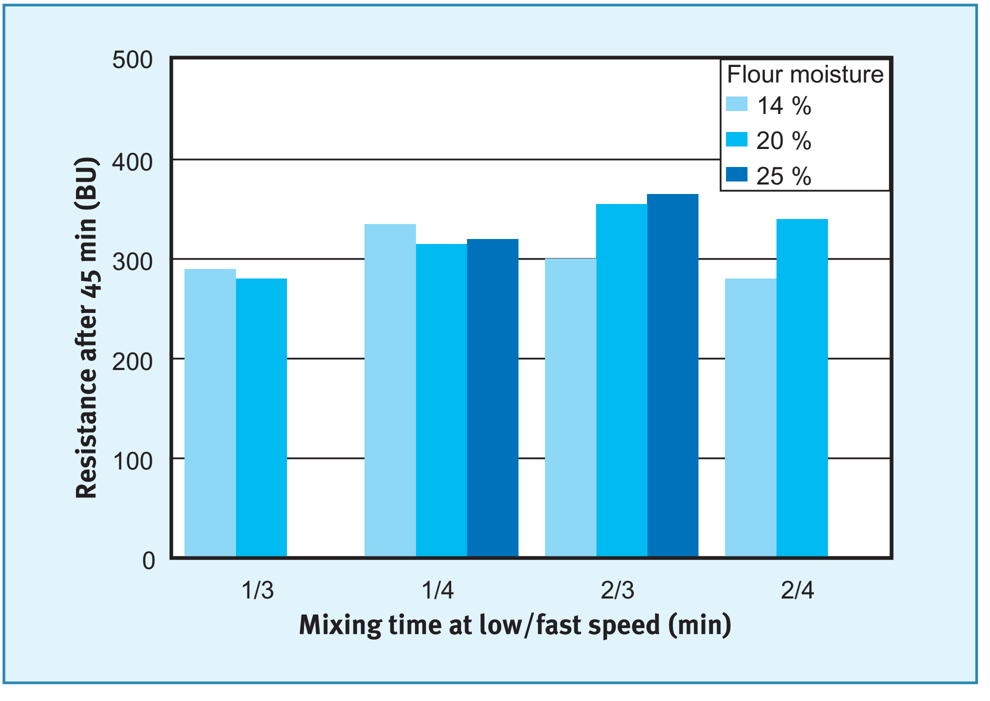

Fig. 258: Dependence of the resistance (after 45 min) on mixing time (OASE laboratory mixer) and flour moisture in a model dough with a dough yield of 157.
Weight of dough in Extensograph: 150 g Heating to 30 °C;
sample prepared after 10 min dough resting time

A comparison of the data thus obtained (Tab. 147) reveals that wetting of the flour has a definite influence.

It seems that bonding of the cellular gluten network is promoted even at low moisture levels in the flour.

These results permit the conclusion that the better gas retention capacity of doughs made from wetted flours should also increase the volume yield of the baked products. This was confirmed by carrying out baking tests with small wheat products (Fig. 259).

At a maxium of 30 units of volume the divergence from the corresponding blank tests was comparatively small. Nevertheless it is possible to say that doughs made from wetted flours tend to have the effect of increasing the volume of the products made from them (Fig. 259).

Tab. 147: Comparison of times of the first escape of gas from model doughs (in minutes) made from flours with different moisture contents

Flour moisture	Dough yield, %		
%	155	157	158
14	64	61	60
18	75	75	69
23	73	70	65
28	72	83	72

The rheological properties of doughs made from wetted flour (wheat) may be summarized as follows:

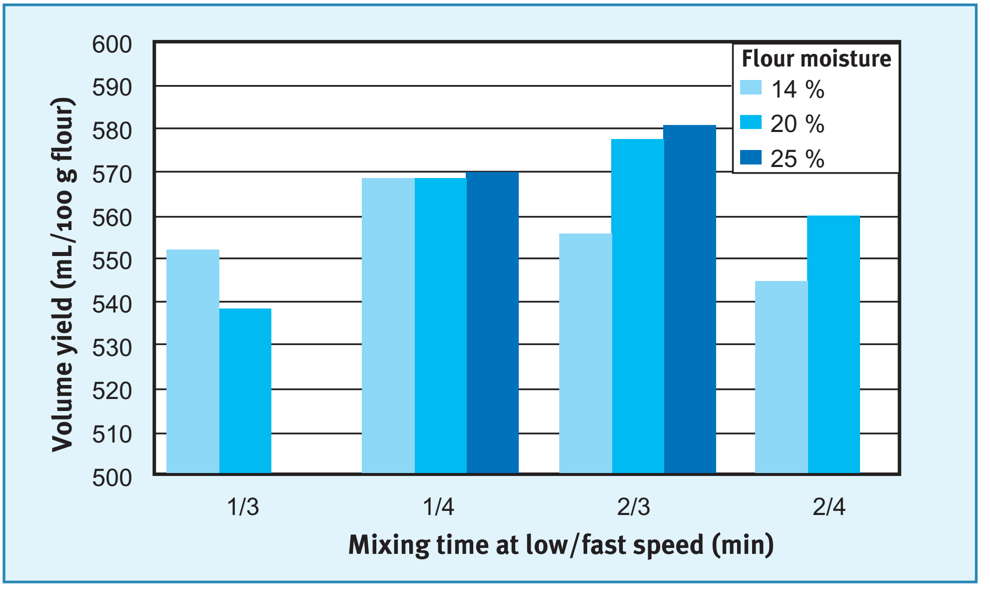

Fig. 259: Comparison of baking tests: dependence of the volume yield on mixing time and flour moisture in a model dough with a dough yield of 157.

Mixing:	Oase LK
Dough resting time:	10 min
Dough weight:	1,800 g
First proof:	10 min
Rounding:	Habämfa
Relaxation:	3 min
Moulding:	Frilado
Proving:	30 min, 32 °C, 75% r.h.
Baking:	240 °C, 20 min, INFRA deck oven

Fig. 260: Dough for bread rolls (dough yield 158) made from non-wetted flour after rounding

Fig. 261: Dough for bread rolls (dough yield 158) made from wetted flour after rounding

- More complex structure of the dough matrix
- Faster water absorption during mixing
- Marked additional stiffening during the dough resting time
- Good fermentation tolerance
- Greater baked volume
- More even texture (especially at high dough yields)

These properties were found for a flour moisture range of 18% to 30%.

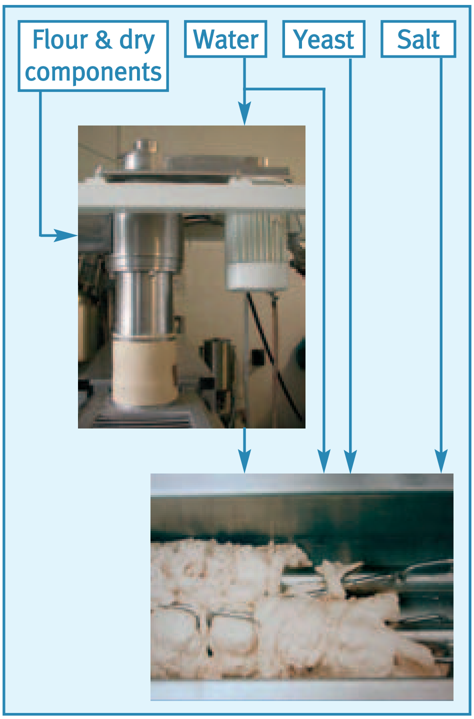

Fig. 262: Integration of the wetting unit

Making-up Properties of Doughs Prepared from Wetted Flours

It may be said in principle that flour wetting improves the making-up properties of the dough by enabling a more complex structure to form. It is difficult to measure these properties even by indirect methods, and only the evaluation of Extensograms permits anything like an interpretation. For this reason, photographs were made to support the sensory evaluation (Fig. 260 and Fig. 261).

If we compare the surfaces of the rounded dough portions made with the same recipe, we see that the dough made with wetted flour is smoother and firmer. Whereas moulding of the dough in the left-hand photograph (Fig. 260) was made difficult by wet surfaces, further processing of the dough on the right presented no problems. The surface of the dough portions was much less sticky.

24.4.5 Integration of Flour Wetting into a Continuous Process

Even at an early stage the simple integration of the wetting unit immediately before a continuous mixer (e.g. from the CODOS® series) enabled extensive applications testing (throughput up to 400 kg dough per hour).

The use of wetted flour made it possible to increase the yield of a bread roll dough to 159 (Fig. 262) without impairing the processing characteristics of the dough. If the water absorption of the flour used (59.6%) is taken into account, this illustrates the value and properties of the wetted flour.

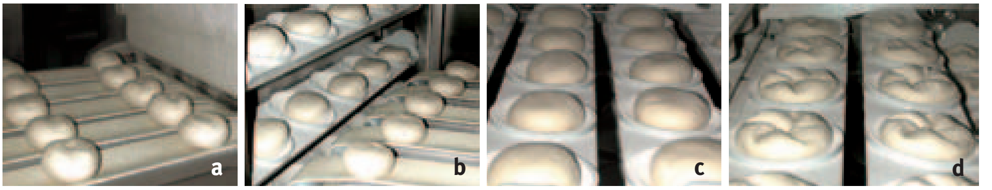

Fig. 263: Dough portions at various stages of the roll preparation process

Fig. 264: Roll baking test (dough yield 159, flour moisture content: 25%)

Further processing of the dough on normal roll-making plant (ECO-Line 4000, Messrs. Lippelt) presents no problems at all (Fig. 263 a-d). Flour dust before the embossing machine was reduced to a minimum. The appearance of the baked products was similar to those made from non-wetted flour. (Fig. 264, Tab 148).

Tab. 148: Recipe and results of roll baking test

Recipe		
	Wheat flour T 550	100 %
	Yeast	5 %
	Salt	2 %
	Oil	2 %
	Baking improver	2 %
	Dough yield	158 g/100 g
Results of baking		
	Loss through baking	20.5 %
	Volume yield	780 mL/100 g
	Yield of baked products	135 g/100 g

24.4.6 Summary

When taken together, the individual results of the rheological tests on dough reveal the innovative potential opened up by the use of pre-wetted flour:

- The wetting unit developed is an efficient piece of equipment for pre-wetting flours in a continuous or batch production system. It works very largely in accordance with the latest findings in the field of dough rheology.
- The demonstrated mechanisms of dough rheology confirm and underline the importance of hydrating the flour during the first phase of dough formation.
- The description and assessment of mixing processes, that used to be determined by the type of mixer and the amount of energy applied, now has an important new dimension: the quality of hydration. Viewing the mixing process from the angle of optimum hydration offers an interesting starting point for innovative mixing methods.
- In certain dough yield ranges the use of pre-wetted flours makes it possible to increase the amount of water added by 2-3% without impairing the making-up characteristics of the dough. A condition for this is a dough resting time of about 10 minutes.
- A flour moisture content between 25 and 30% enables the flour to be dosed virtually without dust while maintaining the desired rheological properties of the dough. The greatest source of flour dust at the bakery (dosing of the raw materials and making the dough) is very much reduced.

24.4.7 References

- *Freund W, 1995. Verfahrenstechnik Brot und Kleingebäck. Gildeverlag, Alfeld.*
- *Pfeiffer P, 1999. Untersuchungen des Sedimentationsverhaltens von Mehlproben mit unterschiedlichen Feuchtegehalten, Untersuchungsbericht der BGN-Mannheim, Bereich Prävention Gesundheitsschutz, 10/99.*