24.2 Mechanical, Thermal and Hydrothermal Modification of Flour

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24.2.1 Introduction

Numerous processes are available to the milling industry for achieving specific effects on the functional properties of flours. They include conventional grinding of defined lots of grain, "selective" grinding (multiple-passage milling), fine grinding followed by fractionation and thermal or hydrothermal methods.

Special flours produced by the mills solely by physical means do not require modified ingredient statements, and this is one of the reasons why customers often ask for them.

Moreover, special flours of this kind permit new combinations with additives for optimizing the process or products; this further widens the scope for making up customized raw materials based on cereals.

24.2.2 Milling Methods

Conventional Grinding

Flours are usually made from analytically defined lots of bread cereal that conform to the regulations of the country concerned. It is primarily the formulation for grinding the grain that results in the analytical values and functional properties of the flours; in the case of wheat, for example, these are the protein and wet gluten content, gluten quality, sedimentation value, enzymatic activity and water absorption.

By selecting individual multiple-passage flours and combining them according to a "flour recipe" it is also possible to exert a certain influence on further properties in addition to the above parameters, for example mineral content, colour, brightness and particle-size distribution. However, when specific customer requirements have to be met, these possibilities are limited by the diagram of the milling system and/or the availability of a particular grain quality. For that reason, both conventional and multiple-passage flours are more and more often subjected to processes that have a much greater effect on the constituents and functional properties.

Fine Grinding and Air Classification

Of course milling is not simply a question of grinding on cylinder mills. Millers have long used combinations of different grinding methods to produce specific flours. But it has only recently become possible to achieve further really significant changes in respect of constituents, for example with special impact mills and subsequent fractionation.

If conventional grinding (possibly of selected wheat varieties) is followed by fine grinding using pin or impact mills and air classification, it is possible to influence criteria such as particle size distribution, water content, colour, brightness, water absorption and the rheological properties of doughs over a very wide range.

Fig. 225 shows the principle of an impact mill with an integrated vane ring classifier to ensure a defined upper limit to particle size. Flour re-ground in this manner has a different particle size distribution, as Fig. 226 shows.

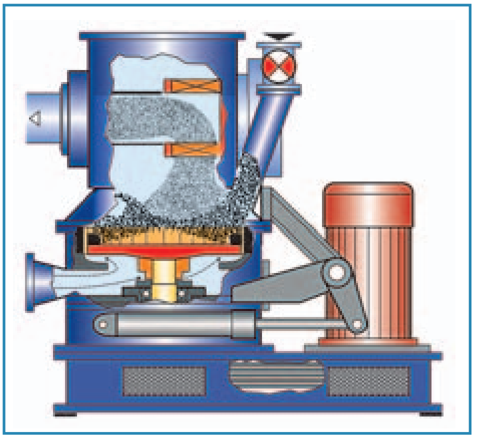

Fig. 225: Alpine Zirkoplex classifier mill, ZPS (Courtesy of Hosokawa Alpine AG & Co. OHG, Augsburg, Germany)

In a second unit, the fine classifier, the ground product is divided into two fractions with different particle size distribution and specific gravity by a further vane ring classifier (Fig. 227). Separation can also be performed by means of cyclones instead of the vane ring classifier.

Fig. 228 shows the particle size distribution of the two fractions. However, the real achievement of this grinding and separation process is not the particle size distribution but the "shift" of constituents in the fractions resulting from the morphological condition of the wheat endosperm.

Fig. 229 shows the mix of particles consisting of small-grain starch and protein in the fine fraction of the flour. Fig. 230 shows cleanly separated large-grain starch practically without adherent protein.
Intensive fine grinding removes most of the proteins adhering to the starch grains of the wheat endosperm. Some of the "wedge protein" is released, and some of the "adherent protein" is detached from the starch grains. The fine classifier separates this protein off together with small wheat starch grains and makes it accessible for further special applications. The "coarse" fraction of the original flour is removed via a lock at the bottom end

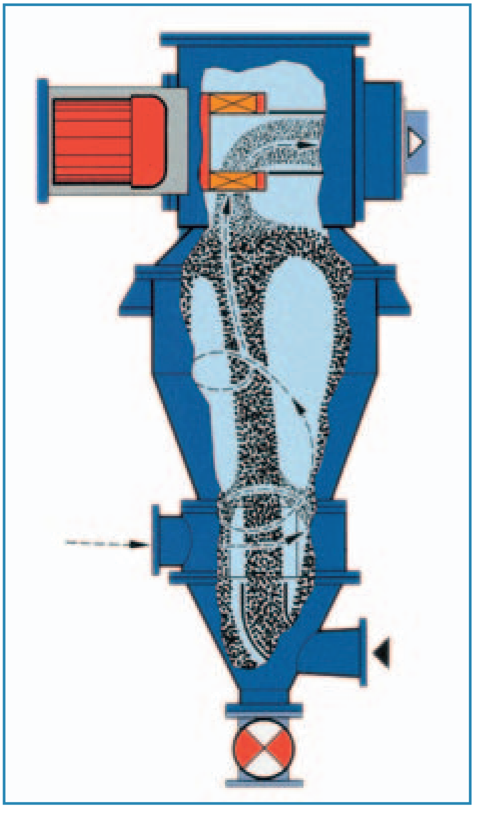

Fig. 227: Alpine Turboplex Classifier, ATP (Courtesy of Hosokawa Alpine AG & Co. OHG, Augsburg, Germany)

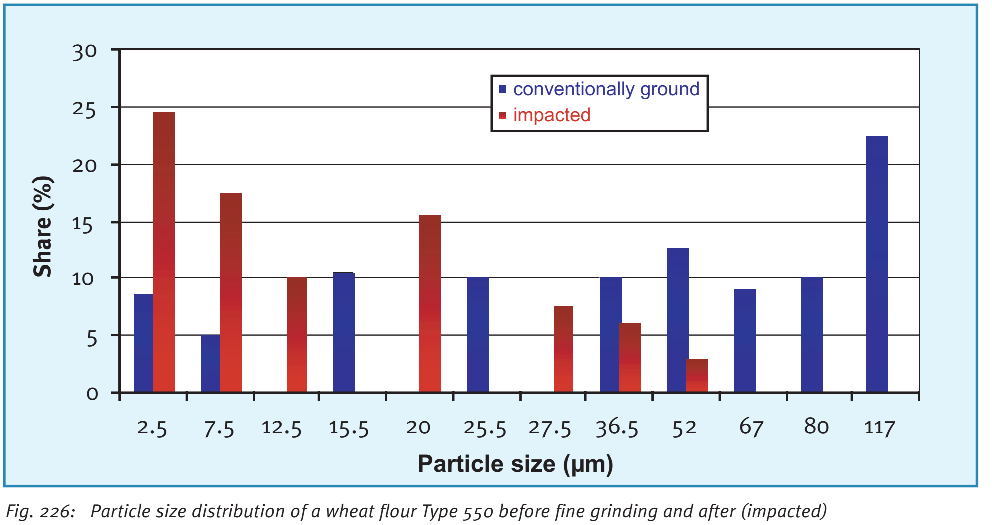

Fig. 226: Particle size distribution of a wheat flour Type 550 before fine grinding and after (impacted)

of the classifier. It consists mainly of the large and medium-sized wheat starch grains.

Tab. 137 shows that flours produced by this method undergo a number of changes in respect of their constituents, which are related to the significant differences in protein content.

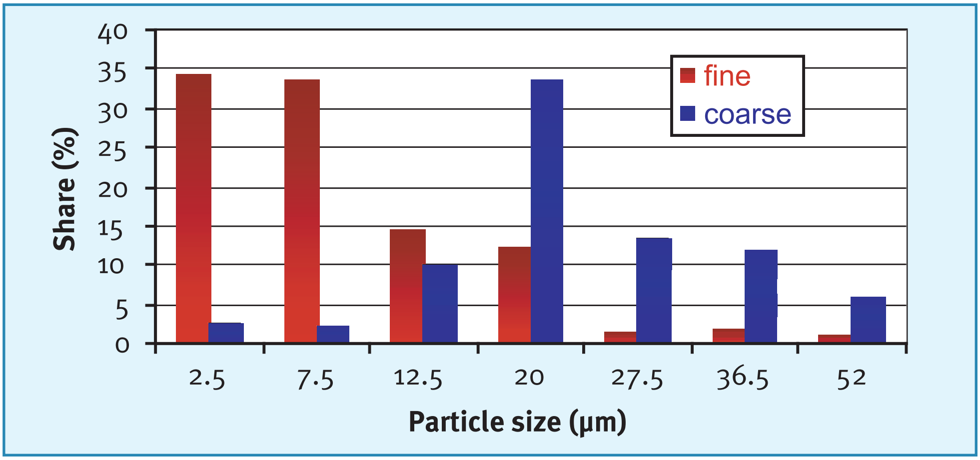

Fig. 228: Particle size distribution in the fine and coarse fractions

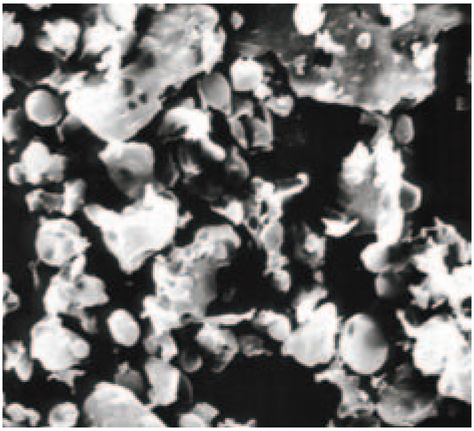

Fig. 229: Fine fraction (1000x)

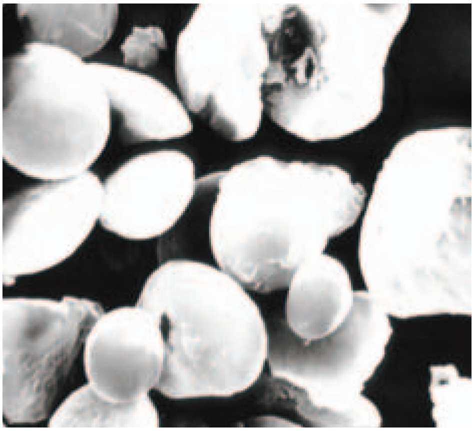

Fig. 230: Coarse fraction (1000x)

Tab. 137: Changes in respect of constituents resulting from fine grinding and air classification

Property		Fine fraction	Original flour	Coarse fraction
Moisture	%	10.8	14.6	9.5
Protein (d.b.)	%	7.0	11.8	24.2
Wet gluten	%	20.3	27.7	not extractable
Sedimentation	mL	diffuse	39	diffuse
Falling Number	s	342	309	190
Water Absorption Index	g/g	2.1	2.2	2.8

Tab. 138: Applications of finely ground and separated wheat flours

Low-protein flour (coarse fraction)	High-protein flour (fine fraction)
Wafers	Heavy yeast doughs
Wafer-thin biscuits	Rusks
Madeira-cake mixtures	Sandwich / toast slices
Sponge mixtures	Processing methods such as: - Retarded fermentation - Freezing - Frosting

Applications of Finely Ground Wheat Flours

The changes in the constituents of finely ground and separated flours result in significant differences in respect of the functional properties of the flours, and these in turn open up different applications as Tab. 138 shows.

24.2.3 Thermal and Hydrothermal Modification of Flours

Millers have long been familiar with thermal and hydrothermal processes for modifying cereals and flours. In particular the drying of grain in years with a wet harvest is still one of the important and hygienically relevant quality assurance measures carried out at mills. For decades, flours with a water content reduced by pneumatic conveyance have been part of the standard product range of cereal mills.

For some years mills have also been making a close study of various different thermal and hydrothermal methods of modifying flours.

In fact there are a number of very different cooking and/or drying methods available to the milling industry. They include fluidized-bed drying, drum drying, high-temperature short-time extrusion cooking, the turbo thin-layer technique, puffing, micronizing, combined steaming and drying methods and various roasting techniques.

Drum-Drying

In this method a flour-and-water suspension is dried on chromium-plated rollers heated by steam. The result is a thin, dry film of product with a high degree of gelatinization of the starch component. The film of product is ground and classed in order to achieve a particle size distribution resembling that of flour. Further characteristics of drum-dried products besides a high degree of gelatinized starch and the resulting high viscosity when cold are a very good microbiological status and denatured protein.

HTST Extrusion

Although it works with a comparatively low water content in the raw materials, high-temperature short-time (HTST) extrusion cooking may be regarded as a hydrothermal method of modifying flours. Changes to the constituents of the extrudates as compared to the initial raw materials result from the simultaneous effects of pressure, temperature, shear forces and water content. This basic principle applies both to single and double screw extruders, although processing with the latter permits a wider range of modifications in respect of constituents and functionalities. As a rule, products made by HTST extrusion are subsequently dried, then ground and classed. Like drum-dried products, ground extrudates have a high degree of starch gelatinization and thus high viscosity in the cold state. On the other hand, a large proportion of soluble components is also typical of ground extrudates. A further feature of such products is a very good microbiological status resulting from the process.

Flour Heat Treatment (FHT)

In this method, a combination of steaming and drying, flours are first treated with a defined amount of steam or water. The flour thus moistened/heated is agitated by means of heated screws and held at a defined temperature. At the end of the holding time the flour is cooled and classed. Agglomerated particles are ground and added to the main product in specific amounts. From the point of view of constituents/functionalities the method has the advantage of permitting different levels of starch gelatinization and thus a range of cold and hot viscosities. The procedure is also capable of improving the microbiological status of flours. Roasting is not possible, however.

Turbo Thin-Layer Technique

Modification of flour by the turbo thin-layer technique (TTLT) can be carried out alternatively by one or two units of the same type (cooker/dryer). Both consist of double-walled cylinders arranged horizontally, with fast-running paddle shafts. The inner surfaces of the cylinders are heated by thermal oil or steam. The position of the paddles and the speed of the shafts can be varied over a wide range. The rotating paddles take up the flour and convey it to the heated inner surfaces of the cylinders. Immediately after this the product is taken up by paddles again; a moving film of product is formed and constantly divided and re-heated. In the broadest sense this principle may be termed a high-temperature short-term process with the corresponding benefits in respect of the functionality of the constituents, for example gluten. Steam can also be introduced into both units. Moreover, the dryer can work with hot air and hot water can be fed into the cooker. The hollow shaft of the cooker also enables various liquids to be added.

Modification of the Functional Properties of Flours

With regard to the objectives to be achieved in the product there are five main fields in which thermal or hydrothermal modification is appropriate:

- **Drying of flour**
- **Reduction / inactivation of the enzymes in the flour**
- **Positive effect on the microbiological status of the flour**
- **Influence on the rheological properties of the dough**
- **Effects on hot or cold viscosity**
- **Effects on colour or taste.**

The most important results of the changes that take place in the starches and proteins of the cereals are the rheological changes to thermally modified flours and the possibility of achieving very different hot and cold viscosities. In the case of wheat flour, for example, thermal modification can stabilize the proteins of the gluten that are necessary for making baked goods. But if the function of the gluten is not needed, or if it is even undesirable, it can also be inactivated by the use of heat. (Tab. 139).

Tab. 139: Thermal processes and their influence on the functionality of the gluten in wheat flour

Modification	Gluten vitality
Native flour	+
Flour merely dried	+
TTLT - less intensive	+
TTLT - intensive	-
FHT - combination of steaming and drying	-
Drum-drying	-
HTST extrusion	-

Using thermal and hydrothermal methods, the starches naturally present in the grain can be made to differ widely in their degree of gelatinization and thus in their functional properties. But thermal modification in conjunction with mechanical stress on the biopolymers may also increase the proportion of soluble substances in the end products, as Tab. 140 shows.

But for special purposes the possibilities of specifically influencing the enzymatic activity of flours and their microbiological status are also very interesting.

Since enzymes are in the nature of proteins, it is fairly easy to inhibit their activity by thermal treatment, although this depends on their specific actions. Amylases, for example, can be inactivated quite easily, but to inactivate peroxidases completely is much more difficult. Tab. 141 is a comparison of various different thermal and hydrothermal processes from the point of view of modification of enzymatic activity, expressed indirectly by the parameters falling number, degree of gelatinization and gelatinization temperature.

In particular the more recent developments in foods with a long shelf life and high-convenience products require the use of flours with a "non-critical" microbiological status. All thermal and hydrothermal processes bring about positive changes in respect of the microbiological quality of flours; a few can even produce flours in "dairy quality" by a

Tab. 140: Thermal processes and their effect on the properties of the starch (wheat)

Modification	WAI g/g	WSI %	Degree of gelatinization %	Damaged starch %
Native flour	2.3	6.0	Approx. 15	4.7
Flour merely dried	2.2	6.6	Approx. 20	6.2
TTLT - less intensive	2.3	6.2	Approx. 20	6.6
TTLT - intensive	2.7	4.7	Approx. 50	13.1
FHT - combination of steaming and drying	2.8	5.0	Approx. 50	19.0
Drum-drying	9.6	8.8	100	43.4
HTST extrusion	9.0	16.8	100	54.5

Tab. 141: Thermal processes and their effect on the enzymatic activity of wheat flour

Modification	Falling Number s	Peak viscosity AU
Native flour	265	280
Flour merely dried	275	290
TTLT - less intensive	290	330
TTLT - intensive	430	590
FHT - combination of steaming and drying	410	480
HTST extrusion	70	300
Drum-drying	85	430

kind of pasteurizing effect, or even sterilize the flour (Tab. 142). In both cases use of the flour as a raw material for baking is restricted, but the baking capability that remains nevertheless makes it possible to produce a small selection of baked goods.

Tab. 142: Thermal processes and their effect on the microbiological status of wheat flour

Modification	Total bacterial count CFU/g
Native flour	> 10,000
Flour merely dried	3,000 - 8,000
TTLT - less intensive	< 100
TTLT - intensive	< 10
FHT - combination of steaming and drying	< 100
Drum-drying	< 100
HTST extrusion	< 100

Under certain conditions thermal processes can also modify the taste and colour of flours. This applies especially to methods with a longer dwelling time and the direct effect of contact heat. Under these conditions it is quite possible to produce roasted flours for use as recipe ingredients to add flavour or colour to

Tab. 143: Thermal processes and their effect on the colour and taste of flours

Modification	Colour	Taste
Native flour	0	0
Flour merely dried	0	0+
TTLT - less intensive	+	+
TTLT - intensive	++	+++
FHT - combination of steaming and drying	+	+
Drum-drying	+	+
HTST extrusion	0+	++

the baked products. Tab. 143 gives an overview of the different processes in respect of colour and taste.

In practical terms the most relevant possibility is that of modifying the rheological properties of flours by thermal or hydrothermal methods.

The following comparison of two Farinograms, one of a native wheat flour and the other of the same flour after treatment by the turbo thin-layer technique, serves to illustrate the considerable possibilities (Fig. 231 and Fig. 232).

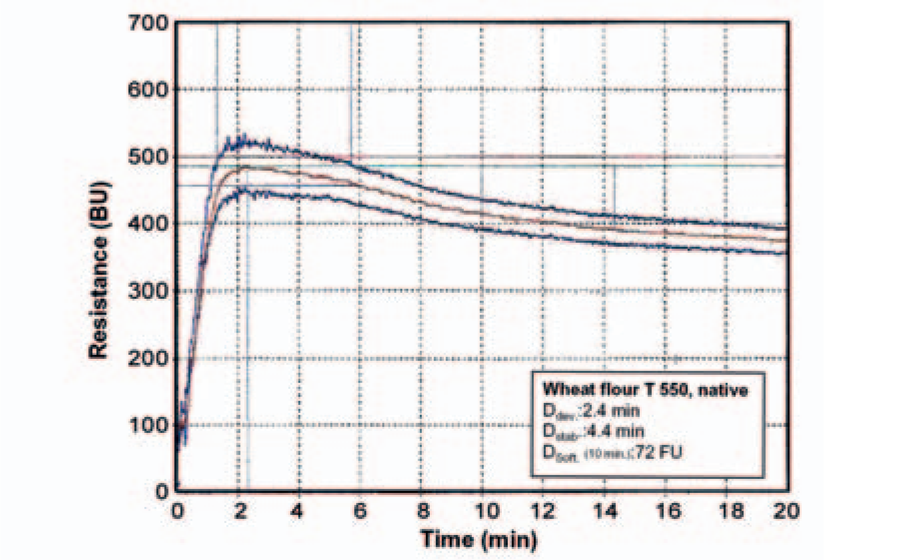

Fig. 231: Farinogram of a native wheat flour

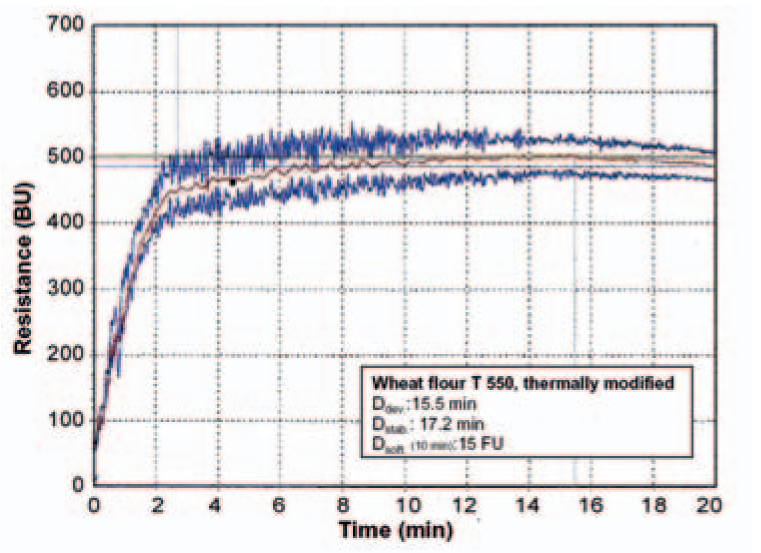

Fig. 232: Farinogram of the same flour after treatment with the turbo thin-layer technique (less intensive)

A glance at the Extensograms of these flours reveals the following information (Fig. 233 and Fig. 234):

If flour-and-water suspensions are used it is not so much the rheological properties of the dough that are of interest as the

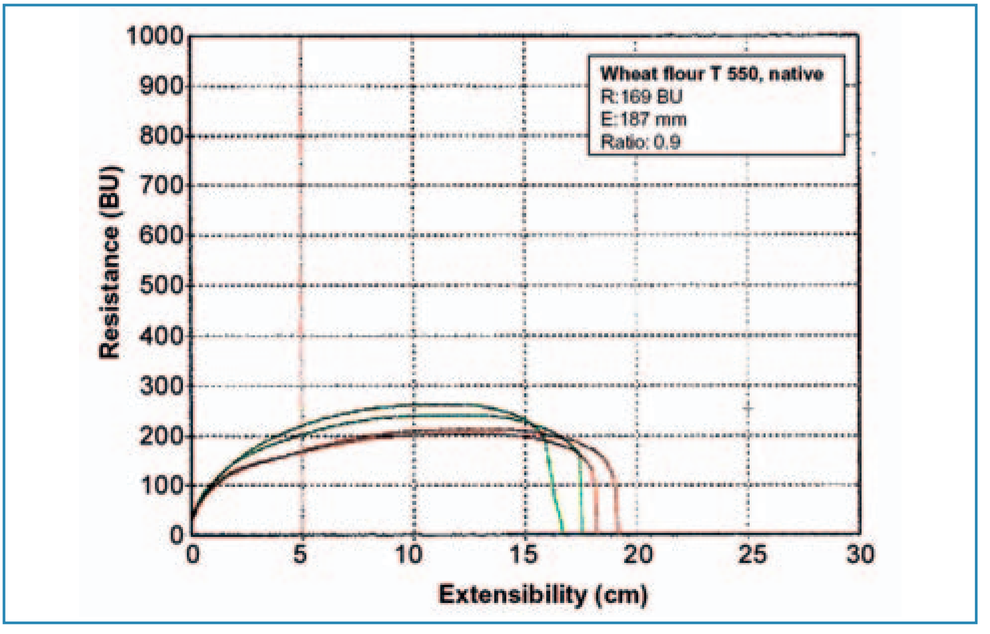

Fig. 233: Extensogram of the original flour (native wheat flour)

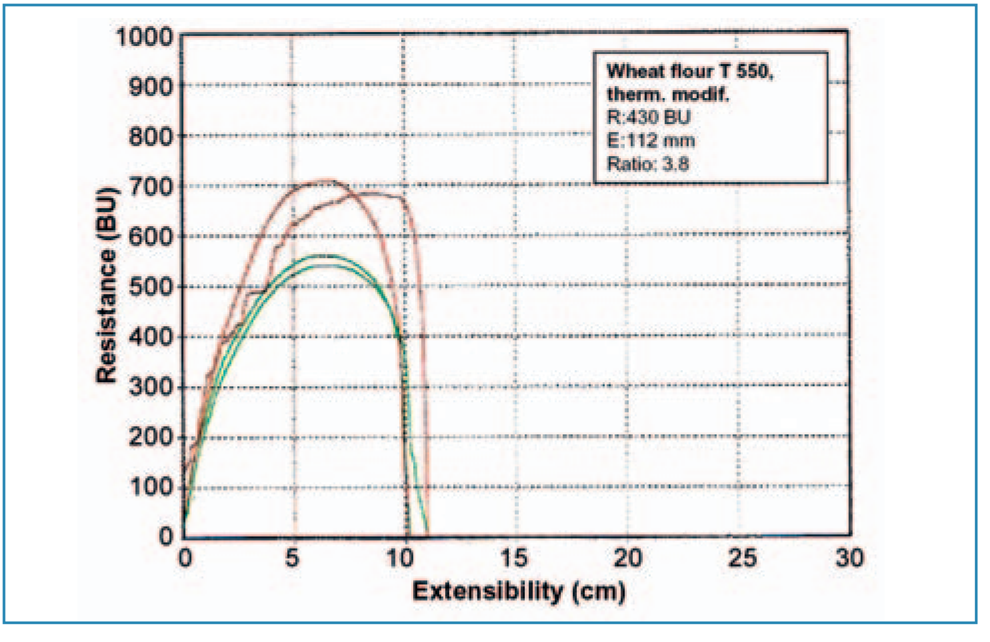

Fig. 234: Extensogram with the turbo thin-layer technique (less intensive)

dynamics and intensity of the viscosities that develop in both the cold and the hot state.
The various thermal and hydrothermal processes differ considerably in their ability to achieve very high cold or hot viscosities. In Fig. 235 - Fig. 237 below the hot extrusion method and the turbo thin-layer technique are compared as an illustration, taking the viscograms of a wheat flour as an example.

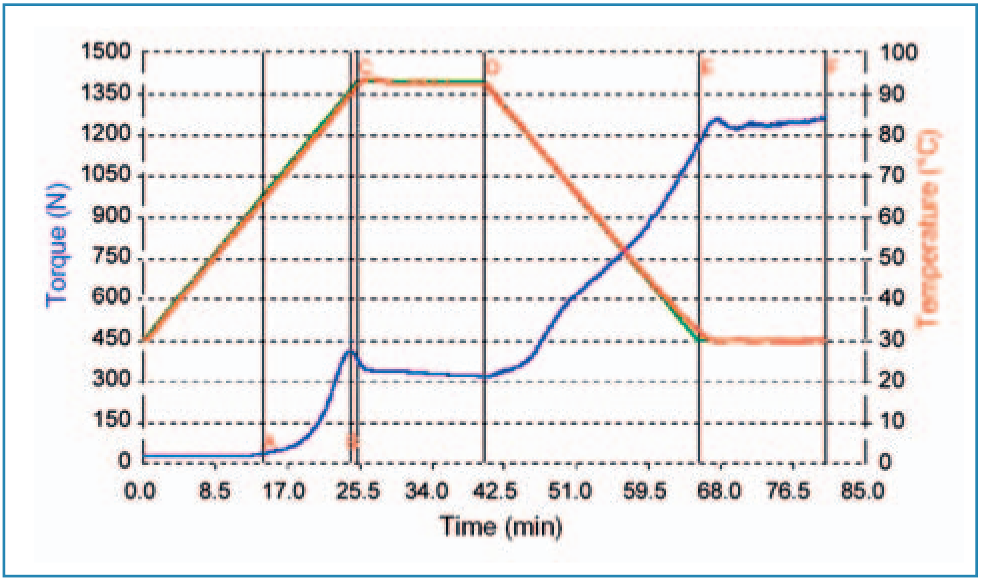

Fig. 235: Viscogram of a native wheat flour (measuring range 250 g·cm)

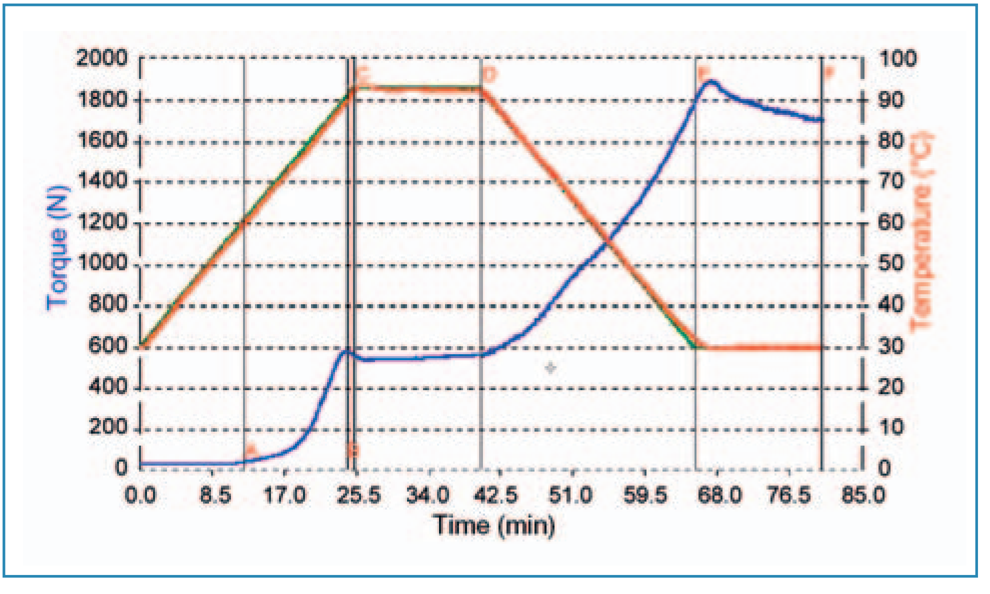

Fig. 236: Viscogram of wheat flour with the turbo thin-layer technique (intensive; measuring range 250 g·cm)

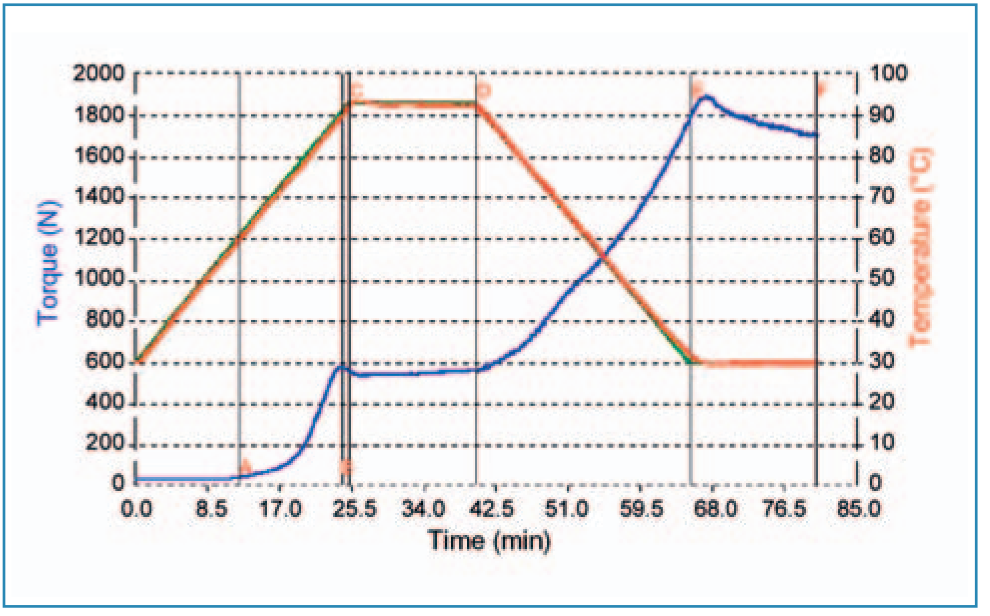

Fig. 237: Viscogram of wheat flour, extruded (measuring range 250 g·cm)

24.2.4 Applications of Thermally and Hydrothermally Modified Flours

Thermally and hydrothermally modified flours have an extremely wide range of applications. To permit an overview we have classified these applications in five groups:

a) use as a constituent of the recipe in bakery products;
b) use in binding systems;
c) benefits in the production of snacks
d) use as coatings;
e) use as a carrier.

Tab. 144: Water contents and a_W values of sandwich slices with and without TTLT flour

Length of storage d	TTLT flour %	Moisture %	a_W value
1	0	35.38	0.947
	15	37.08	0.950
2	0	34.64	0.942
	15	36.71	0.943
5	0	33.96	0.941
	15	35.65	0.942

Bakery Products

Thermally and hydrothermally modified flours can make a considerable contribution to prolonging the shelf life of bread and small baked products. They enable refrigerated or liquid doughs to be kept longer and optimize the texture of the baked goods. The use of thermally modified flours also increases the dough yield and improves the processing characteristics of doughs. Moreover, "thermal flours" usually make it unnecessary to chlorinate the flour. Taking sandwich slices as an example, the two diagrams below show the effects of a wheat flour treated by the (intensive) turbo thin-layer technique in respect of shelf life (Fig. 238 and Fig. 239).
Tab. 144 is a comparison of the relevant water contents and a_W values.

Binding Systems

As binding systems or as components of complex binding systems, thermally and hydrothermally modified flours offer various different benefits, the most important criterion being specifically adjustable hot or cold viscosities. Because of their good microbiological status and low enzymatic activity the

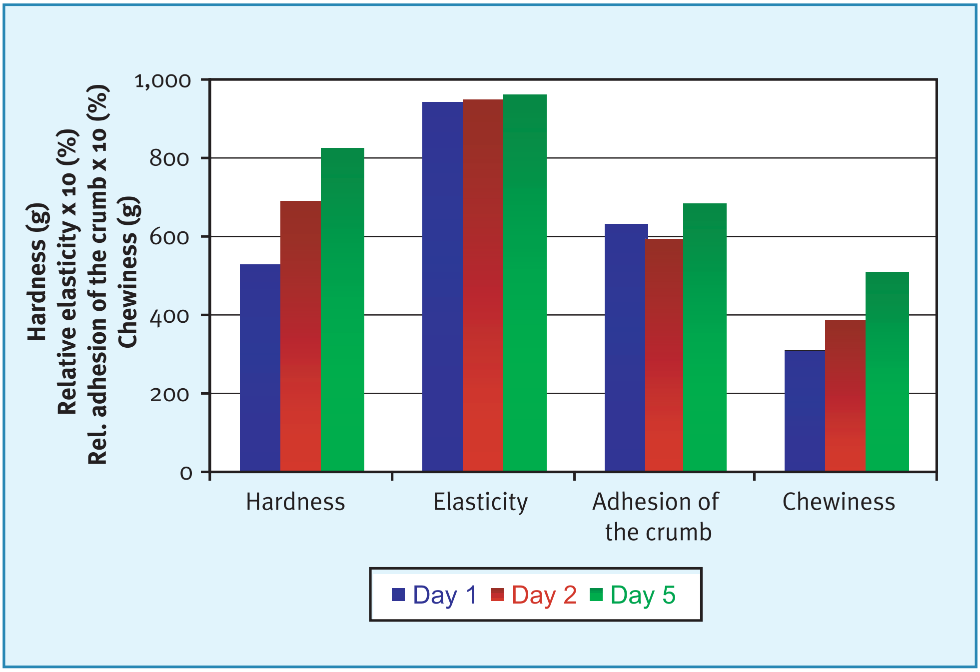

Fig. 238: Texture profile of sandwich slices made from a standard recipe

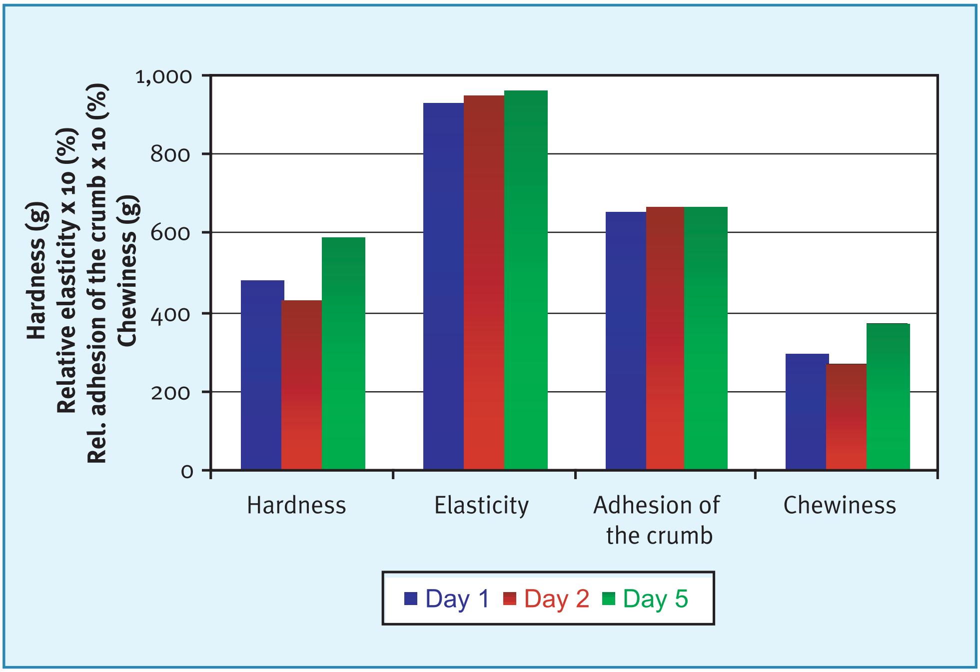

Fig. 239: Texture profile of sandwich slices made with 15 % flour treated by the turbo thin-layer technique (intensive)

products help to prolong the shelf life of the foods concerned. They can also help to optimize such quality criteria as colour, sheen and prevention of skin formation and enhance the haptic properties. As a substitute for conventional binding systems they may also reduce the cost of the formulation. No special labelling is necessary.

Snacks

In the production of snacks, the benefits of thermally and hydrothermally modified flours for the process and the products lie chiefly in their specifically adjustable degree of gelatinization. They help to optimize the shaping of snack pellets and give a more even surface to heat-extruded 3-D products. Pre-gelatinized raw materials also increase the throughput of the extruders. Moreover, thermally modified flours have advantages over other vegetable products (e.g. potato granulate) in respect of cost.

Coatings

In this sector we have to distinguish between dry and liquid applications. The liquid applications include all uses in the field of coating batters; the advantages lie in the good adherence of the products and their excellent microbiological and enzymatic status. Dry applications mainly include uses in the production of sweets, in particular products for panning and powdering.

Carriers

One field in which the functional properties of flours are of little or no importance is that of carriers. In the production of flavourings, spices or enzyme preparations, for example, there is a need for flours as carriers or fillers that contribute to the safety of foods and protection of the consumer but do not otherwise affect the end products through a "functionality" of their own. Enzyme-inactivated and microbiologically excellent products have interesting market opportunities in this field. Products of this kind do not require special labelling and often reduce the cost of the formulation as compared to carriers and fillers based on starch.

24.2.5 Outlook for the Future

Changes in the market, especially in connection with the development of new products by the food industry, will increase the demand for flour products with specific functional properties. Changing eating habits and expectations on the part of consumers, stricter requirements in respect of food safety, a further increase in the convenience of foods and a demand for specific raw materials for products that are difficult to replace are factors that will contribute to this trend. In the milling industry this development will result in a widening of the product range.

In cooperation with other manufacturers of raw materials for the food industry, too, the thermally and hydrothermally modified flours offer an interesting field of activity for product developers in the milling industry.

In the next few years the product developers of the milling industry will have to deal with the following topics in order to create further special applications for flour:

- Improve the visual transparency of flour-and-water suspensions and minimize signs of syneresis;
- Improve the freezing and thawing stability of the products; increase the stability of flour-and-water suspensions towards acids and shear forces;
- Optimize emulsifying properties and make increased use of the nutritional benefits of special flours.

In cooperation with other manufacturers of raw materials for the food industry, too, thermally and hydrothermally modified flours are an interesting field of work for the product development departments of the mills.