On the track of dough development

A NEW DOUGH MANUFACTURING PROCESS USING THE RAPIDOJET WAS INTRODUCED A FEW YEARS AGO. THERE HAVE BEEN FURTHER STUDIES, KNOWLEDGE AND SUCCESSES IN THE MEANTIME, WITH WHOLEMEAL DOUGHS AMONG OTHER THINGS

++ figure 1
Distribution after adding water, immediately after addition (left) and after a few kneading movements

++ figure 2
Light and dark dough after 40 kneading movements

Good bakery products can only be manufactured if the dough has been well developed. Experts in the profession agree on this point. However, opinions differ greatly on how to develop dough well, depending on the product, available kneading system, company philosophy and emphasis in relation to energy efficiency, labour costs, operating procedure and space requirements.

There are numerous studies, some from the nineteen sixties and seventies, attempting to describe the conditions during dough preparation. Basic knowledge was gained here, but much of the knowledge was not translated into machine technology [3, 8, 9, 15, 16].

From particles to dough

But what is it that develops a dough? How does a moist inelastic mass turn into a smooth, extensible dough able to hold the fermentation gas that is formed, thus enabling a well leavened bakery product? It is agreed that the gluten consisting of gliadin and glutenin is responsible for the special properties of dough [10]. No substance with comparable properties has been found up to now, nor has it yet been possible to replicate it artificially. Whereas glutenin in isolation is extremely cohesive and represents a coherent elastic mass, gliadin acts as a "lubricant" and separating agent, and would on its own flow like honey. The characteristic property of gluten occurs only as a result of the interaction between the two components.

Amend [1] showed that gluten threads visible under the microscope form spontaneously at the flour-water-air boundary layer as a result of wetting flour. This process occurs really "explosively", so it can be assumed that in itself the formation of gluten is a very rapid process that takes place without any problems, and which moreover needs no energy at all either. The gluten threads

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(fibrils) aggregate to form larger units that are transformed from a compact state into the desired structured state by kneading. According to Kieffer [7], the proteins develop at the water/air interface and spread out from there.

In a comprehensive paper, Unbehend [19] showed that a viscoelastic mass is formed merely by bringing flour and water together, without any expenditure of energy. However, this mass differs significantly in its rheological properties from a fully developed dough.

Whereas it was accepted until the nineteen sixties that dough development was achievable only through prolonged bowl proofing, and relatively little energy was used for kneading, the situation changed thanks to the "Chorleywood" process, which revolutionized bakeries in England and in the countries under English influence. The catchphrase was "mechanical dough development", MDD. Dough no longer needed hours of proofing if high-speed mixers were used to produce it in 3 minutes. Although a large amount of energy was input in a short time, in the final analysis far less energy was needed to develop dough than was the case previously when using other kneading methods. The "kneading energy" was used for the first time as a yardstick to assess the kneading process. It is assumed to be 11 kWh/t of dough in the Chorleywood process. On the other hand a spiral kneader achieves a developed dough with 15 kWh/t.

A process that is so energy-intensive is accompanied by tremendous heating of the dough, and cooling the kneader by a double jacket and coolant fluid is a technical precondition for successful doughs.

The question of how much energy a dough needs was the subject of much discussion. In the past less effort was devoted to the question of which energy is needed and how the energy can be employed in the most efficient way.

Therefore a slightly deeper examination of the processes that play a part or could play a part in dough development will be ventured here.

The focus is not on the mixing itself. The flour particles have already been well mixed together by the mill. The first difficulty is that of wetting the flour with water.

Dry flour resists wetting, and a water droplet can remain on a flour surface for a very long time without penetrating into the interior of the flour. Zehle [20] gave an impressive demonstration of this.

Wetting is promoted by a large surface area resulting from small water droplets, by flour particles separated from one another in free fall, and especially by a difference in velocity between the flour and water, which ensures impact and enforced penetration. In conventional kneading systems, however, all three factors are present in the most unfavorable variants imaginable: the water is added in a slow thick stream, the flour is already present in a compact state in the bowl when the water is added, and the velocity difference is negligible.

++ figure 2

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Using colored water, figure 1 shows what the distribution looks like after adding the water and after a few kneading movements. At first the water disappears into part of the flour, after which it must be massaged out again, which is why achieving a homogeneous batch mix takes a very long time. After 40 kneading movements, light-colored areas of dough are still visible (figure 2), and the dough mix does not appear homogeneous until 80 or more kneading movements.

The next step is to convert the mix into a developed dough. Many aspects of this stage cannot be observed. At a molecular level, the solubility relations of the various protein fractions have been resorted to – but the baker prefers to do his "window test" and checks whether the dough can be stretched out to form a thin membrane [7]. Then between these two extremes there are numerous rheological studies, and finally microscopic images allow a deeper insight into the microstructures of the dough, although these are often distorted by the preparation method, especially by drying for electron microscope photographs.

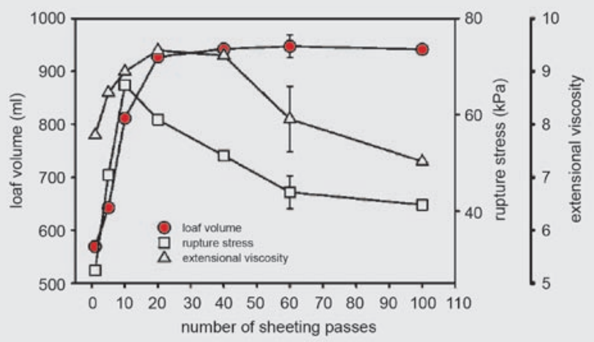
It is generally agreed that the aim of dough development is to obtain a continuous "gluten network" [14, 18]. The gluten should form a three-dimensional network consisting of the thinnest possible films. These films envelop the starch grains, and are destroyed again by over-kneading.

Gluten network formation

It is worthwhile investigating the question of how the formation of such a gluten network can be promoted.

Basically there are various processes that are regarded as "kneading-effective". From the mechanical point of view, these include shearing, folding, stretching and collision. Accompanying processes that are mentioned but are not ▶

++ figure 3



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effective for dough development include rubbing, acceleration/deceleration and pressure. Indeed, below a "critical kneading speed", processes occur that return a developed dough back to the state of an underdeveloped dough (Tipples, "unmixing", [16]). This could also explain the observation that structure-destroying processes take place as a result of relatively weak movements, e.g. emptying a bowl kneader.

In addition to these kneading-effective macroscopic movements, it must be remembered that the microscopically small starch grain constitutes the smallest kneading element in the dough, which as a solid particle is able to deform a gluten structure and to promote the development of a film (Meuser, [11]).

The fact that disulphide bridges play a central part in relation to the properties of gluten is undisputed, as is the fact that thiol groups are involved [10]. What is disputed is the extent to which it is necessary to create new covalent bonds at all, and whether this process actually occurs [15]. It is impossible to exclude the fact that new contact surfaces are created merely by enlarging the "internal area", thus enabling new forms of bonding.

In addition to mechanical dough development, there is also "chemically supported" dough development. Cysteine deserves special mention here, which at a concentration between 30-100 ppm is able to reduce the required kneading energy to half without softening the dough excessively or making it sticky. This has been studied by several authors [8, 12].

Dough temperature is a parameter that can be monitored during kneading. As a rule an attempt is made to achieve a dough temperature of 26 °C, maximum 28 °C. The exact reason for this is unclear, and various justifications for it are given. The danger of drying out the surface at elevated temperature is one reason, and synchronizing dough development and yeast activity is another.

From the kneading technology viewpoint there is one additional aspect: As the dough temperature increases, the dough becomes softer and the kneading tools no longer encounter any resistance, thus increasing the duration of kneading more than proportionately, which consequently increases the dough temperature still further. Therefore it is strongly advisable not to get into this trend in the first place.

Dough development by lamination

Based on these preliminary considerations, the following mechanical processes should help to develop a gluten network:

+ two-dimensional stretching of the initially spherical gluten aggregates to achieve thin films [18].
+ creation of a large "internal surface area" by repeatedly combining (folding) the stretched surfaces without changing their orientation.

If an attempt is made to achieve these two processes in a single technical process, this leads directly to the lamination process. By rolling out the dough and folding it together, this achieves both two-dimensional stretching and also the creation of new contact surfaces, while retaining the orientation.

As mentioned at the outset, there is no lack of fundamental studies of this, which were already carried out in the nineteen seventies [3, 4, 8, 9, 16, 17].

A direct comparison of the development of dough by a kneader and by repeated rolling out and folding together has shown that mechanical development of the dough is achievable just as completely by lamination [3, 15].

This yielded astonishing knowledge:

+ Doughs only need between 20 and 40 lamination operations to develop fully (figure 3).
+ The development of the dough needs only 15 % of the energy otherwise necessary [15].
+ The dough warming is negligible.
+ It is practically impossible to over-knead laminated doughs.

The efficiency of the lamination process is easily understandable in a baking experiment. All the ingredients are mixed together roughly until free flour is no longer present. The mix is then allowed to rest for 45 minutes. A dough development process is already clearly noticeable simply due to the time that has elapsed. The dough is now put onto the working surface and is stretched out so that it can afterwards be folded in 3 layers, then again into 3 layers in the other direction. Ideally this yields 9 layers. The process is

++ figure 4

++ figure 3
Dough development resulting from repeated sheeting and combining [15]

++ figure 4
Comparison of the mixing effect of kneading operations and lamination steps

repeated, after a resting phase of 45 minutes and 90 minutes each time. By simple arithmetic, this yields 9 x 9 x 9 = 729 layers, or in other words the internal surface area has been enlarged by a factor of 729. In American language usage this is called the “Stretch & Fold” method.

This yields baked products with a fine pore structure (which cannot be compared to “No Need To Knead” dough, with which no further operation takes place after the initial mixing and which yields a very coarse, non-uniform pore structure with thick pore walls).

Tipples [17] discovered that the kneading energy required can be reduced greatly if the dough is left to its own devices after wetting. This is also called “Autolysis Flour Moisturization”.

If the mixabilities of doughs by kneading and by laminating are compared, it is found that a comparable state of mixing is achieved with 5 laminations or with 40 kneading operations, as is apparent in figure 4 by the use of colored and uncolored dough. This underlines the high efficiency of lamination.

Translation into new processes

The Rapidojet high pressure jet process

In the Rapidojet process (rapid = fast, do = dough, jet = powered by a water jet), the dough-forming activities are employed effectively from many points of view.

In 2002 the author reported for the first time the production of dough by using a high-pressure water jet to wet flour [12].

The flour and other dry ingredients are dispensed continuously into a mixing tube via a metering screw or flour sieve (figure 5). The freely falling flour particles are now captured and wetted by a high pressure jet. The speed of the high pressure jet is 250-500 km/h. The mixture is actively ejected from the mixing tube. The residence time is only fractions of a second. Calculations based on a high speed camera assessment showed that only less than 2% of the mixing tube is filled with dough. Thus effectively the dough formation takes place in the air. The dough is in a “dough mist” state until it ▶

++ figure 5
Rapidojet mixing tube with built-in rotation nozzle

++ figure 6
Discharge of the "dough mist" from the Rapidojet (in this case with coarse recipe ingredients dispensed into a rotating kneading bowl)

++ figure 7
"Window Test" of the dough from the Rapidojet after a short resting phase

passes into a container or onto a conveyor belt (figure 6). This was visible particularly by using high speed photographs.
The required pressure is between 35 and 150 bar, which is provided by a high pressure pump.
A "small" plant of this type has a capacity of 1000 kg of dough/h. This needs only 1.3 kWh (cf. 11 kWh for the Chorleywood process). Larger plants with up to 3.5 t/h are in industrial use in various countries.
Despite their large capacity, these plants are very compact. The mixing tube has a length of 50 cm and a diameter of 6-12 cm. The space requirement is determined by the flour metering plant.

The following factors favor the kneading process in the high pressure jet method:

+ The yeast and salt can easily be pre-mixed with water and are metered in as a mixture through the high pressure nozzle, thus eliminating the need for a subsequent mixing step.
+ The flour is dispensed in free fall and thus has optimum accessibility for wetting.
+ The water is broken up into very fine droplets by the high pressure and impact against the mixing chamber wall, and here again a large surface area is formed.
+ The water has a high velocity at the moment when it impacts onto the flour particles, and thus penetrates fully into the flour particles.
+ The water is enriched in oxygen due to the large water surface area, thus promoting the oxidation of the dough; measurements showed that the oxygen concentration in the water increased by 50%.
+ As a result of the small amount of energy needed and the absence of internal friction, there is practically no warming of the dough; a dough temperature rise of less than 1 °C can be assumed. Thus the dough temperature can be adjusted via the water temperature alone. There is no need for the doughs to be cooled, and the addition of ice can be omitted.
+ The dough emerges from the mixing tube as soon as the plant is started, there are no start-up and shut-down losses; in addition there is no need to wait, as with other continuous systems, until a stable operating state has become established after a considerable amount of dough. Despite the high throughput rate, the process is suitable even for quite small bakery operations; the minimum practical amount of dough is 5 kg (= 18 seconds).

Dough assessment of doughs from the Rapidojet
Due to the completely different kind of dough preparation, doughs from the Rapidojet can also be expected to have a different dough development. Doughs immediately after production initially give the impression of an under-kneaded dough. Often the "window test" is not yet possible. On the other hand the test can be performed after a resting time of 5-10 minutes (figure 7). Obviously the brief but intense momentum of the water onto the flour stimulates a process that completes itself afterwards without any further kneading movements.
Comparative baking trials using dough with and without post-kneading showed that despite a completely different initial assessment, the differences in dough behavior practically disappear during processing, fermentation and baking.
Farinograms downstream of the Rapidojet still show a slight rise, whereas baking tests show that the dough development is complete, since

++ figure 6

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++ figure 7

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post-kneading does not necessarily cause any improvement in the outcome of baking.
On the other hand farinograms are extremely suitable to explain the time dependence of the processes after the Rapidojet. The consistency increases by 100 units in the period of time up to 30 minutes, after which it decreases again. The consistency maximum is reached 20 minutes after dough preparation (Hübner, [10]).

Dough firmness
At identical hydration, doughs from the Rapidojet are firmer than conventionally kneaded doughs. Thus more water is metered in to obtain the desired dough firmness. For the baker this is an attractive economic factor, since increasing the amount of water in the dough by at least 5% means a considerable saving of flour. Because the water is bound in the baked product and cannot escape again as a result of baking loss, the consumer can also enjoy an improved retention of freshness.

The following explanation models will be discussed:
+ The improved wetting ensures a quantitatively larger binding of water.
+ The structure-destroying components of other kneading systems are absent, the dough is "unstressed" and therefore does not give off any water again.
+ The phenomenon of "starch activation".

"Starch activation" is understood here to mean that the dilatant behavior of the starch is activated by the effect of the high water velocity [5]. A starch suspension solidifies under a sudden load. This is demonstrated by numerous experiments. Probably the most spectacular is a swimming pool filled with a starch suspension, which people can walk across if they are quick enough. The starch suspension solidifies so powerfully under the movement of the feet that one can almost walk on water. If a person remains stationary, he will sink into the pool.
Now starch is quantitatively the largest fraction in flour. Therefore it is easy to imagine that the starch is solidified in this way, and that immediately afterwards this state is "frozen in" by the gluten network.

This is supported by the following observations:
+ After mixing with water, pure starch is solid when it comes out of the Rapidojet; a slight movement causes it to revert to a liquid state; in this case the fixing action of the gluten is absent. With potato flakes, softening also occurs after a certain time, here again the gluten is missing.
+ Comparative experiments with different nozzles showed that doughs produced with a small nozzle diameter and thus a high pressure (135 bar) were firmer than doughs with a large nozzle diameter and lower pressure (50 bar); doughs produced with less pressure were easier to subject to the "window test" and appeared more kneaded-out.

Thus, by overlaying the effect of the "starch activation", more drastic kneading (higher pressure, smaller nozzle), which actually corresponds to the requirement for a more powerful kneading effect, would lead to a dough having the appearance of being less kneaded. However, the effects largely balance out after a dough resting phase. Nevertheless: Dough is usually assessed immediately after production; this is legitimate for conventional kneading processes, but it gives a false impression in the case of the Rapidojet.
If in spite of this one still wants to stretch the dough to form a window directly after manufacture by the Rapidojet, cysteine can be added to the water. Although the baking ▶

++ figure 8

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results scarcely differ, the outcome of assessing the dough state is more favorable and the dough will be described as "fully developed".

Dough temperature

As already discussed, adherence to a maximum dough temperature plays an important role. However, since no kneading resistance is needed to bring about dough development in the Rapidojet method, it was suspected that it would also be possible to work with higher dough temperatures (although in principle the method is very suitable for cool doughs because of the absence of dough warming).

Hübner [10] studied this effect with wholemeal doughs and was able to achieve a dough temperature of 32 °C with water at a temperature of 50 °C. The volume of the baked goods was slightly larger than that of the comparison baked products with a dough temperature of 25 °C, and was significantly preferred by a test group because of the sensory characteristics. This confirmed the suspicion that there is no need to take the upper dough temperature limit into account to the same extent as with conventional kneading.

Combination with lamination

Doughs from the Rapidojet can be sheeted and obtain the stretching movement that is typical of this. Figure 8 shows a dough from the Rapidojet sheeted to 2 mm, through which it is entirely possible to read a newspaper.

Although breads made from dough from the Rapidojet and afterwards sheeted and folded several times do not display a larger volume, the doughs obtain a much larger tension, with the result that the baked products spread out far less. 3-5 operations are sufficient in this case, in contrast to mechanical dough development by lamination, where 20-40 operations are needed [3, 15]. Because laminating plants imply large equipment costs, a search was made for an alternative to enable the operations to be carried out more simply and more cost-effectively. This led to the development of the INLINE Laminator.

The INLINE Laminator

As with the Rapidojet, the processing step takes place in a stainless steel tube.

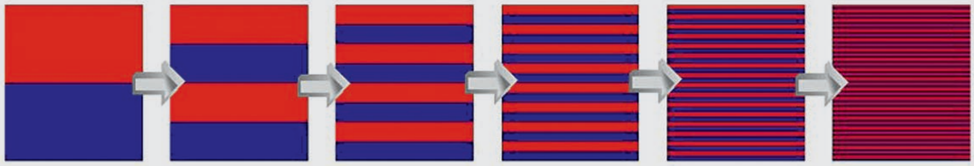
Dough is pressurized by a dough pump and forced through the tube. This tube contains shaping elements arranged one behind the other, each of which divides the dough, elongates it, widens it and then combines it together again. Thus the number of layers doubles after each element.

Two layers are obtained after the first element, 4 layers after the second element, 8 layers after the thirs element etc., until there are 64 layers after 6 elements. Further elements can follow but are not necessary, as the aforementioned experiments had shown.

Thus the internal surface area can be enlarged by a factor of 64 within the tube, which is 80 cm long and 8 cm in diameter. The dough is intentionally stretched in two dimensions, thus achieving a gluten framework with thin films. This looks like the diagram in figure 9.

Furthermore, the multiple "Split & Recombine" cycle achieves additional effective mixing. This smoothes out even major inhomogeneities in the dough. Moreover it is possible to meter in pre-doughs or other ingredients that are not be added via the Rapidojet, and to incorporate them into the dough. Sensitive products, e.g. raisins, pass through the Inline Laminator without being damaged, since the

++ figure 9



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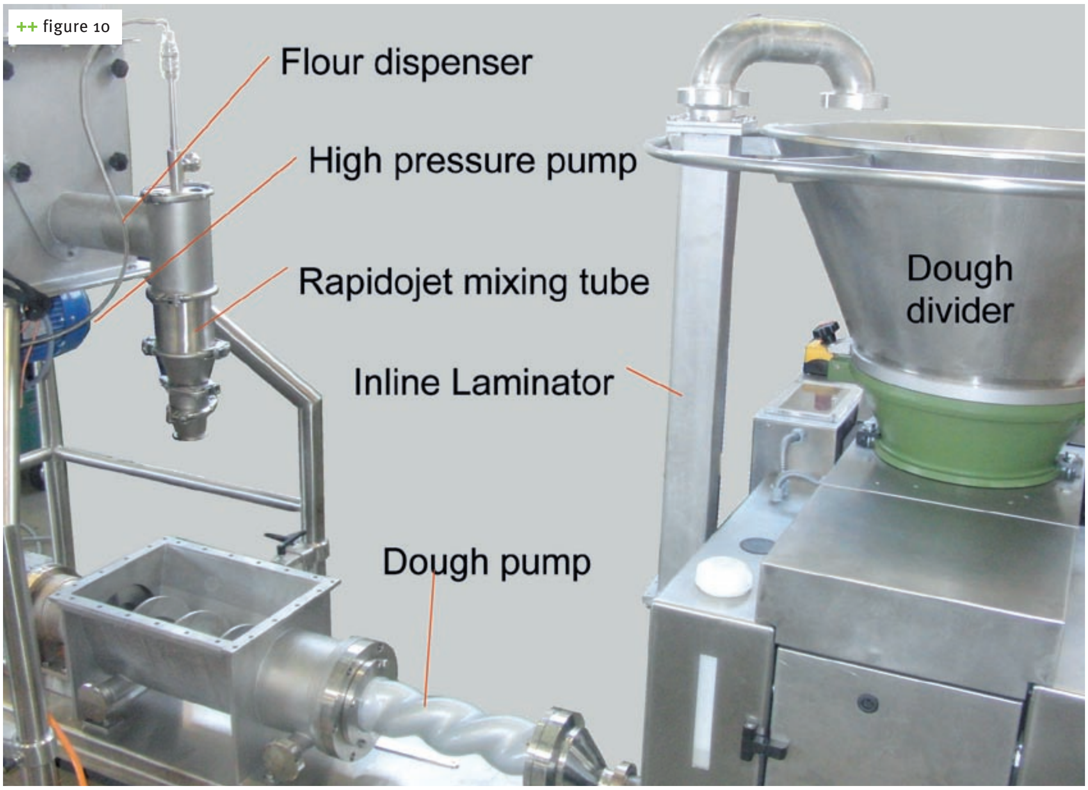
narrowest points in the device still have a free cross-sectional area of 4 x 4 cm.
Doughs processed using the Inline Laminator no longer need the resting phase which they require when they come out of the Rapidojet, and can thus be processed further immediately.
Incidentally, the Inline Laminator also solves a transport problem and can dispense the dough directly into the hopper of a dough divider, thus no lifting/tipping device is needed.
As a stand-alone equipment, the Inline Laminator needs a dough that has already achieved a certain degree of cohesiveness. With the Rapidojet this cohesiveness already exists, and with "Autolysis Flour Moisturization" or "Stretch & Fold" this state exists after the first maturation period. Full dough development by the Inline Laminator alone would require considerably more elements, e.g. 20, and would lead to a high pressure build-up. Passing the dough through several times is also conceivable, but the process is then no longer strictly continuous.
Doughs from the Inline Laminator are already "tensioned", a task otherwise assigned to the rounder. In this respect the following rounder actually only performs the shaping and can be set to handle the dough with maximum care.
Round, square or rectangular cross-sections can be achieved via various different outlet shapes, which also enables the produced dough strand to be separated off directly.
The current configuration uses an eccentric screw pump with a feed screw, with a maximum power of 4 kW. The dough throughput rate is ▶

++ figure 8
Dough from the Rapidojet, sheeted to 2 mm and stretched

++ figure 9
"Split & Recombine" in the Inline Laminator: exponential increase in the number of layers and internal surface area (illustrated diagrammatically by different colors)

++ figure 10
Dough preparation combination consisting of a Rapidojet high pressure kneader, dough pump (hopper removed so as not to cover up the Rapidojet), Inline Laminator and conventional dough divider

++ figure 10



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PRODUCTION

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++ figure 11
Dough discharge from the Inline Laminator

1.2 t/h. The dough temperature rise caused by the pump is 2-3 °C. For very firm doughs the pump can be replaced by a twin screw.

Figure 10 shows an entire configuration consisting of a Rapidojet, dough pump and Inline Laminator. Figure 11 shows the dough being discharged from the Inline Laminator.

The strictly enforced guidance of the dough results in an advantage compared to other continuous kneading processes due to the very narrow residence time spectrum. Whereas with other methods, under-kneaded, optimally kneaded and over-kneaded dough is produced together due to the differing residence times, in the case of the Inline Laminator every single piece of dough has experienced exactly the same treatment. Furthermore the observation mentioned above, namely that it is practically impossible to over-knead doughs by lamination, also applies here.

Wall adhesion inside the apparatus is the only thing that makes the surface appear slightly rough at high exit speeds, an effect known as "Stick & Slip" and which produces a certain patterning on the surface due to the alternating predominance of adhesive friction and sliding friction. This effect can be largely suppressed by an appropriate coating.

In contrast to conventional kneaders, the Inline Laminator has no moving kneading elements whatever. It can therefore be described as a "static kneader".

By increasing or reducing the number of shaping elements, the "kneading process" can be individually adapted in the sense of a stronger or weaker kneading effect.

Table 1 contains a summary comparison of various kneading systems, including the two new "Rapidojet" and "Inline Laminator" processes.

Conclusions

A more detailed consideration of the processes in dough formation from the point of view of how these can be brought about in a specific way has led to a new dough manufacturing process. Dough preparation by using a high-pressure

Table 1: Comparison of various kneading systems

	Time	Energy	Kneading-effective movement	Equipment cost
Long floor time doughs	●●●	●	●	●
Chorleywood	●	●●	●●	●●●
Spiral kneader	●●	●●●	●	●●
Continuous double spiral kneader	●●	●	●●	●●●
Rapidojet process	●● [1]	●	●●●	●●
Stretch & Fold	●●●	●	●●●	(only possible by hand)
INLINE Laminator	●	●	●●●	●
Laminator	●	●	●●●	●●●
Autolysis Flour Moisturization	●●●	●	●	●●

[1] No point would be awardable for dough preparation time due to the short time, < 1 second; 2 points are awarded based on the change resulting from the dough resting time

water jet in a way hitherto not thought possible enables a dough production method that overcomes some of the limitations of conventional kneading systems and sets new standards with regard to energy efficiency and gentle handling of the dough.

A compact equipment for precision continuous dough development is available in the shape of the Inline Laminator, which can be combined with the high pressure water jet process.

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