Oxygen: A special kind of baking agent

Dr.-Ing. R. Berghoff

1. Introduction

When I heard about the use of oxygen for dough production after my presentation on cryogenic flour cooling with liquid nitrogen or carbon dioxide, my skepticism was high. "This may be all well and good in the lab, but where is the practical application?"
The unbroken rousing optimism of Prof. Dr. K. Lösche, Northern Food Tec GmbH, prompted me to present the process to baking companies known to me and to introduce it as a test phase. First results are available. It requires a bit of pioneering spirit, but it is worthwhile and pays off in the end, not only in terms of savings on baking agents, but especially in terms of a much simpler baking process.
All the pioneers have stuck with it and are using the process.
In the new type of processing - from wheat to mixed rye doughs - the property of oxygen is used to initiate the necessary redox reactions already at the beginning and along the kneading process. For the active utilization of oxygen, the length of a kneading process or the principle of the respective kneading operation is insignificant. The use of an increased oxidative potential, generated by the novel oxygen process, dough and baking properties, which are of unprecedented quality. Excellent machinability, excellent proofing, cooling, freezing and thawing stability can be achieved, simplifying baking processes and improving product quality. Figure 1 shows oxygen bubbles after introduction into bulk water directly before the kneading process.

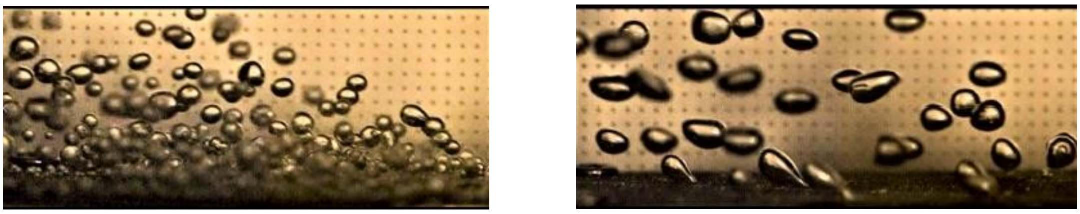


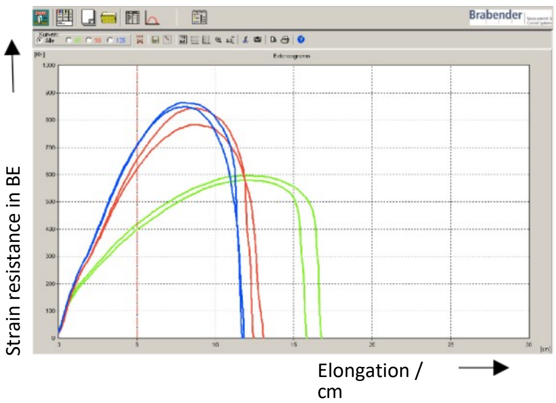
Fig.1: Input of oxygen bubbles into bulk water for a direct oxidation [1].

2. The kneading process is decisive for dough workability and baking properties

Conventional or typical kneading processes are characterized primarily by the fact that, in addition to mechanical energy input and a dough temperature of approx. 25 °C, kneading is typically atmospheric (i.e., in the presence of air-oxygen). Today, this can be achieved in many ways, both in discontinuous (batch process) and in continuous process control.
However, it is noticeable that the resulting dough properties are generally such that a dough resting time of approx. 15 to 30 minutes is necessary. This resting time is necessary because conventionally produced wheat doughs are usually too elastic but not plastic enough (Fig. 2, left) and too moist (too sticky) directly after the kneading process. These properties result, among other things, from unreacted redox processes. Under the usual kneading conditions, this leads on the one hand to a maximum of gluten formation (maximum of dough formation and development) and on the other hand to dominantly elastic dough properties (Fig.2, left).

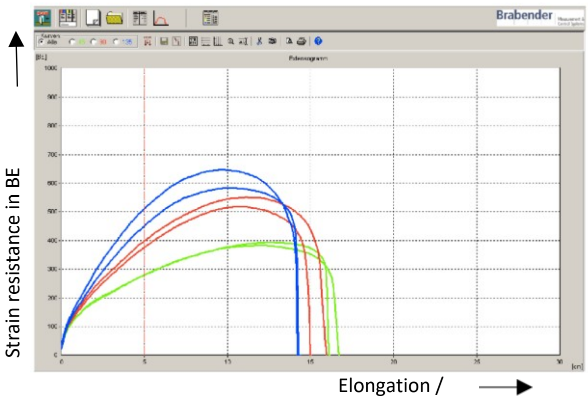
The redox reactions that take place inadequately in the conventional kneading process decimate the water binding strength of the dough matrix on the one hand and lead to a reduced water binding quantity on the other (in addition, the water absorption capacity or dough yield of a wheat dough shows a minimum at approx. +25 °C), which explains, among other things, the increasing stickiness of such doughs.
In order to nevertheless ensure faultless processability and machinability, the bakery is dependent on relaxing the doughs during a resting phase and, in particular, before machine processing, and also on drying them (minimizing stickiness).

Dough process without oxygen process



Firm, tough (elastic) dough structure.
Elasticity (plasticity) unsatisfactory. Dough rises with difficulty during proofing.
Gladly too sticky.
Little looseness.
→ □mall round pastries, rather firm pastry crumb, risk of hole formation.
Green: after 45 minutes of dough rest
Red: after 90 minutes

Dough process with oxygen process



Blue: after 135 minutes of dough rest
O2- enrichment: balance between elasticity and plasticity. Good machinability.
Suitable for long dough runs (also pre-doughs). High fermentation tolerance, voluminous dough pieces with good dough stand.
→ Pastries with good volume, low risk of hole formation.
Legend of the curves (see left)

Fig.2: Influence of the oxygen process in the presence of a commercial roll baking agent on dough rheology (extensogram) [2].

Such a dough relaxation thus serves to convert the dominantly elastic (high elongation resistance) into more plastic dough properties (good extensibility). This is common practice because (overly) elastic doughs are very sensitive to stress and may be irreversibly damaged by compressive, tensile, or shear forces (associated with disadvantages in baking volume and pastry shape, among other things). In order to minimize such damage to the dough matrix by mechanical stress in subsequent process steps such as weighing, rounding, long working and/or laminating, a corresponding relaxation phase (dough resting phase) is generally unavoidable and this is repeatedly observed during dough working and processing via intermediate steps. During laminating steps, elastic-induced deformations are observed above all in doughs processed accordingly (puff pastry, croissants, pizza, toast, etc.), which are naturally undesirable.
Laminating lines try to cushion this situation by introducing additional dough rest phases in the course of the process line and/or by requiring, for example, several satellite head stations (so-called "stress-free" lines).

The great importance of oxygen - actively used in a new way as a kind of baking agent - also becomes apparent when bakeries use dry ice (CO_2) for dough cooling in summer months. On the one hand, the cooling capacity of dry ice is very high, but on the other hand, the CO_2 gas formed after evaporation displaces the necessary oxygen in the headspace of the kneader. As a result, the oxidation processes that are so essential can only take place to a limited extent during the kneading process, so that insufficiently developed doughs with comparatively high viscosity and stickiness are produced. Such doughs, which tend to be gray, are oxidatively underdeveloped, have limited machinability and deliver limited pastry quality (volume, shape, crumb structure, color, freshness, etc.). Effective extraction of CO_2 gas from the kneader headspace is therefore urgently required.

3. Importance of oxygen for wheat dough

If you measure the oxygen content in dough, you will initially measure about 7.2 mmol O_2 / kg. Immediately after the kneading process and already after about 1 minute, presumably more than 70% of the dissolved oxygen will have been consumed, caused primarily by the activity of the baker's yeast (also lactic acid bacteria) and the flour's own enzymes (especially oxidases such as lipoxygenases). The remaining small amount of oxygen in the dough is reversibly absorbed mainly by hydrated starch and the gluten. As a result, the dough now characterizes itself as primarily anaerobic, which eventually and on the one hand causes the metabolism of the baker's yeast or also the sourdough bacteria to ferment.
Competitive reactions for the remaining residual oxygen then influence the gluten matrix and thus the dough rheology with all the resulting consequences. Doughs with O_2 deficiency therefore structure, among other things, a reduced gas holding capacity on proofing (cf. Fig.3 left and right for identical dough masses).
Redox processes in the dough during the kneading process desirably cause numerous linkages of protein SH groups to disulfide bridges in the gluten network - associated with the increase in elongation resistance - or the oxidative linkage of ferulic acid residues to the hemicelluloses (pentosans), which positively influence the water-binding ratios. The enzymatic oxidative conversion reactions, for example of the flour peroxidases, ascorbate oxidase or glutathione dehydrogenase, lead to a specific equilibrium situation for ascorbic acid and its dehydro form.
These reactions (supported by prooxidants such as metals or alkaline earth metals) are parallel and/or convergent redox reactions initiated and/or catalyzed by oxygen. This generates the desired gluten-stabilizing effects, but also color lightening, in that, among other things, the yellowish carotenoids typical of wheat flour are partly bleached by oxidation, as is known to be achieved by lipoxygenases during flour ripening. With these and similar enzymatic supports, doughs are oxidatively stabilized, the pore structure in doughs and the bread crumb generate more stable, finer and lighter (light, whitish, stable crumb) with improved shape stability and an increased volume of the baked goods.

However, due to the limited oxygen supply in the dough, these and other redox and oxidation reactions do not take place exhaustively or only slowly during the kneading process and in the course of dough working and processing.

This is mainly noticeable when the doughs are already in the fermentation room and are only oxidatively stabilized there to such an extent that a correspondingly increased fermentation tolerance is made possible.
The above-mentioned limited oxidative potential forms an interesting field in baking technology for the innovative use of oxygen as a kind of novel baking agent, at the same time associated with a "clean label" promise, as a result of reduction of conventional baking agents.

From the baking point of view, favorable dough properties are those which have good or machine-compatible properties directly after kneading, i.e. doughs which are dry and plastic-dominated but have not lost their elastic component or have lost it uncritically (Fig. 2). They then generate overall favorable working, processing and baking properties. Dough resting phases can be shortened or even skipped.

Oxygen stabilizes wheat doughs along their treatment and processing

Left: Roll dough with **4 %** baking agent related to flour
after 45 minutes proofing time (35 °C) Identical flour masses, dough volume 266 ml

On the right: bread roll dough with **2%** baking agent re. a. flour,
with oxygen process after 45 min proofing time (35 °C) Dough volume 304 ml, 14% more volume

Fig. 3: Influence of the oxygen process on fermentation stability, gas holding capacity and color of roll doughs (standardized conditions) [3].

The impregnation of bulk water with oxygen before kneading is an essential step towards the desired dough properties. It causes a sufficiently high oxygen supply already at the beginning and during the kneading process, in order to generate above all exhaustive redox reactions. This results in better dough characteristics, better processability of the doughs and more favorable cooling, freezing, dew
fermentation and baking properties. The not infrequently observed hole formation in the crumb of baked goods, for example, will occur after active oxygen utilization, if at all, then significantly decimated. Depending on the flour quality available

Dough properties are accessible, which, among other things, greatly increase the effectiveness of baking agents, so that their dose can be lowered (instead of e.g. 4% rel. a. flour then 2%; cf. Fig.2 -4).

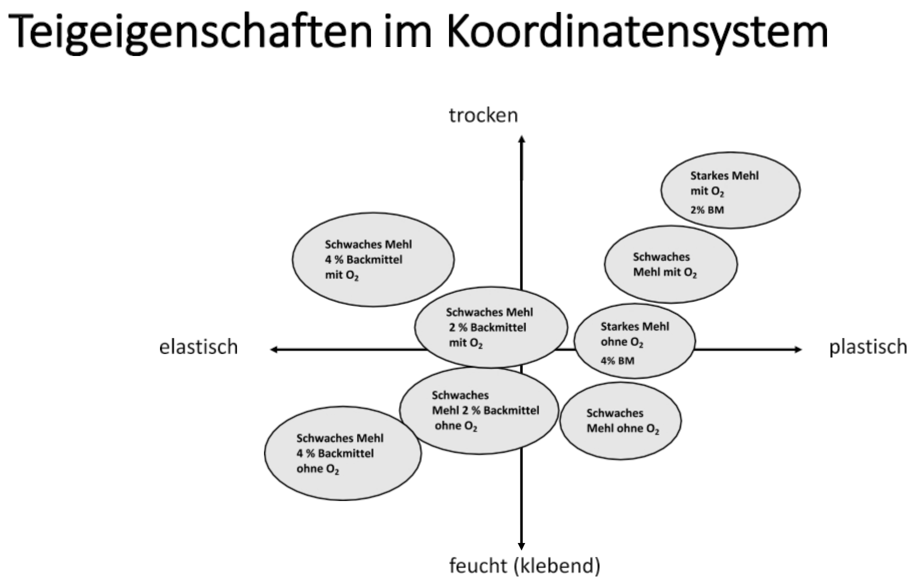


Fig. 4: Influence of the oxygen process on dough properties as a function of flour quality (schematized); BM = baking agent [4].

From the above, it is clear that oxidative processes in the dough and its interactions with the surrounding atmospheric oxygen are significant and essential reactions that play a major role in defining dough formation and development, the rheological dough properties along the entire process path and thus the processability of the doughs and finally their baking properties. In current dough production, however, these processes take place only to a limited extent because the oxygen supply is very low, especially in fermenting doughs.

4. The oxygen process

The oxygen content in the air is approx. 21%. With this oxygen supply, the baking operation in the kneader can produce a dough quite well. However, the bulk water used contains significantly less oxygen than the ambient air, so that this represents a significant and therefore limiting factor.

Oxygen solubility in water depends on pressure and temperature. The solubility increases with increasing pressure and decreasing temperature. At 0 °C, 14.16 mg/l oxygen (= 14.16 ppm - part per million) dissolve from air under normal pressure (oxygen partial pressure of 212 hPa**)** at equilibrium.

Power water at about 8°C has about 8 ppm dissolved oxygen.

Therefore, to enrich bulk water with oxygen and to use its effects, a targeted impregnation of the cold bulk water (preferably < 5 °C) with oxygen approved for the food industry, the so-called BIOGON® O, is required.

All gases intended for use in food processing must meet the requirements of the relevant German and European food legislation. These include, in particular, the European regulations VO (EC) No. 852/2004

and Regulation (EC) No. 178/2002 as well as Regulation (EC) No. 1333/2008 and Regulation (EU) 231/2012. The product complies with EN 12876, quality A (products for the treatment of water intended for human consumption - oxygen).
The production of BIOGON® gases is subject to special requirements with regard to process control, auxiliary components, plant materials, batch tracing, minimum shelf life, control and many other parameters. BIOGON® gases approved for food processing are not to be confused with technical gases, which may have the same degree of purity, but do not meet the above-mentioned manufacturing process.

The enrichment of the bulk water takes place in such a way that oxygen is introduced via a special impregnation system and over a relatively short period of approx. 1-3 minutes. Depending on the target (flour quality, type of baked goods) and the desired oxygen content, this is done atmospherically or, if necessary, also under pressure. In most cases, it is sufficient to treat only partial quantities of the respective bulk water accordingly.
The apparatus for enriching the bulk water with oxygen can satisfy different degrees of automation. To gain initial experience with the new "Baking agent", a manual system as shown in Figure 5 is certainly sufficient for baking operations. After successful use under precise knowledge of the application, an automated, closed and thus more efficient system will quickly follow.

Fig. 5: Manual O2 impregnation of the bulk water with Linde equipment.
Trial conducted by Linde GmbH when used in baking operations.

In addition to the special requirements for food gases and their manufacturing process, special guidelines must also be observed for all plant components which, on the one hand, are in contact with food as mentioned above and, on the other hand, are specifically in contact with pure oxygen. Oxygen does not burn, but it supports combustion enormously. Combustion processes run completely differently with pure oxygen than our experience with normal atmospheric oxygen would suggest. Combustion processes start at significantly lower ignition energy, so a simple pressure surge when opening a valve, for example, can cause a fire. The rate of fire is much higher and combustion is aggressively violent and hotter than with atmospheric oxygen, it is more like explosive combustion. Oils and fats must be kept away, not only plastics, as e.g. seals can suddenly burn, even pipelines made of metal become fuel themselves, i.e. they not only melt but burn. Only with professional installation, e.g. by one of our Linde employees, and proper application, the process can be operated safely.

In general, it can be deduced that the more of the total bulk water for a dough batch is enriched with oxygen in this way, the better (more stabilized and flexible) the dough properties or the pore membranes in the dough will be in principle.

Linde suspects that the high oxidative potential of the oxygen-enriched bulk water is additionally responsible for specific redox reactions that typically occur only slowly and incompletely in the dough.

The appropriately treated bulk water is fed directly to the kneader and the kneading process can proceed with an increased dough yield (TA) of about two points more than usual.
As a result, the bakery obtains doughs in which the above-mentioned reactions take place more intensively and very rapidly - to a large extent still during kneading - and which are characterized by increased plastic and dry properties (balanced ratio of elastic to plastic properties, see Fig. 2, right):

Observed benefits:

- Increased dough yield
- Shortened dough resting times, possibly no dough resting time necessary
- Improved machine runability
- No or reduced re-deformation, e.g. after lamination
- Less grit
- Less residual dough
- Increased baking agent effect
- Less baking agent (> 50%)
- Increased cooling, freezing and thawing stability of the doughs
- Increased fermentation tolerance, pronounced gas retention capacity
- Improved shape and baking characteristics
- Increased cookie volume
- Stabilized crumb structure
- Reduced hole formation in baked goods
- Increased freshness
- and more

The treatment of the bulk water for mother doughs (main doughs) with oxygen provides very interesting effects on the dough and pastry level, which positively influence, among other things, the pastry volume, the pastry shape stability or also the crumb structure (color, pores, stability) (Fig.6). In particular, the stabilization and flexibilization of the pores of the dough are of great importance.

Membranes that stabilize the pore cells in the dough in such a way that it can, for example, protect against the formation of holes in baked goods whose dough often comes from fermentation control processes.

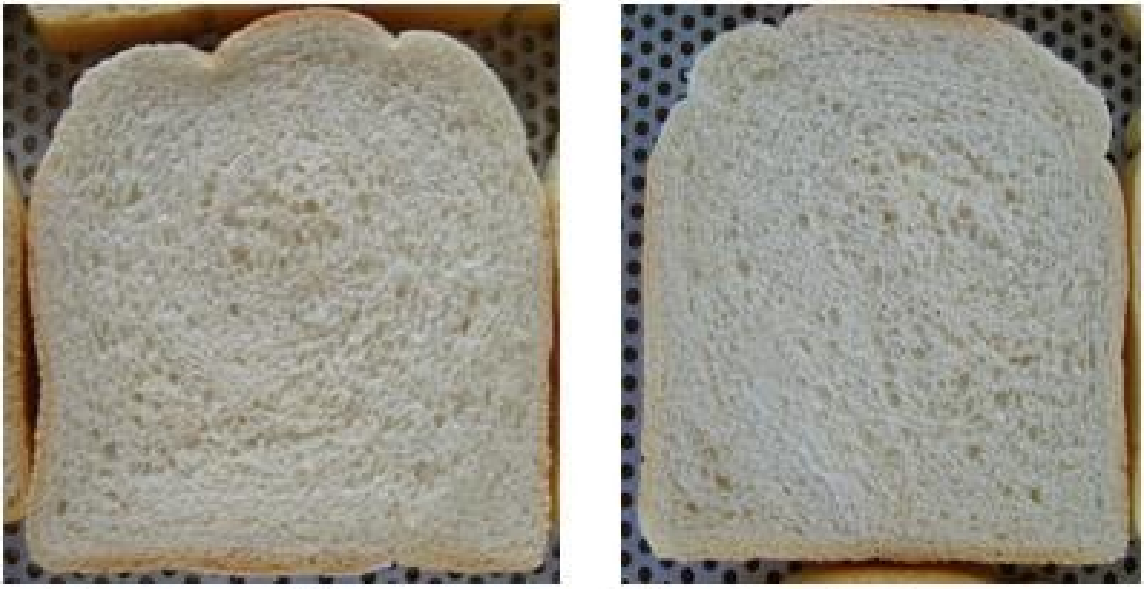


Fig.6: Influence of the oxygen process (02- impregnation of the bulk water) on the baked product properties (volume, dimensional stability, crumb color, crumb and moisture content).
pore structure) [4]

It is natural to use the oxygen process also, or especially, for predoughs.
The process principle is the same and leads to significantly more fermentation-stable predoughs (e.g. high fermentation tolerance, see Fig. 3), so that, for example, fermentation times can be extended or the proportion of predough in mother doughs increased. Finally, the appropriate fermentation of the predoughs guarantees a desired or typical pore structure in the finished baked goods, e.g. an open-pored crumb in baguettes.
The possibility of optimizing the predoughs and thus the mother dough properties associated with the oxygen process also lead to a significant improvement in the aroma, color and taste of the corresponding baked goods. Examples that are also made accessible by the oxygen process are summarized below:

- The (usual) volume loss of frozen dough pieces (green or pre-fermented frozen dough pieces) is significantly minimized.
- Fluctuations in the quality of flours can be better compensated (namely after each new harvest)
- The machinability of mother doughs is improved, even with higher pre-dough contents
- The volume of the baked product and its freshness are increased, the shape of the baked product is stabilized, or the flounce is improved and marked.

- The color, aroma and flavor of the finished baked goods are intensified by increased pre-dough proportions without experiencing the well-known disadvantages.

Bakers who treat both their pre-doughs and mother doughs with the help of the oxygen process may notice the above-mentioned effects to a greater extent.

5. Summary and conclusions

Oxidative and reductive reactions (so-called redox reactions) are essential for an optimal kneading process or for dough formation and its development. In this context, oxygen O_2 plays a key role. However, oxygen is largely consumed shortly after the kneading process and leads, among other things, to very slow and rather weak oxidative dough reactions. This is evident in the course of the kneading itself, as well as during dough working and processing.

Conventional kneaded doughs therefore require a dough resting time to relax or to generate sufficient machinability and to dry (reduced sticking).

A novel process impregnates the bulk water with oxygen prior to the kneading process, generates specific redox reactions "in statu nascendi" and minimizes undesirable competitive reactions for the oxygen along the process chain.

Doughs treated in this way are characterized, among other things, by increased machinability (direction of "stress free"), high fermentation tolerances and a pronounced gas retention capacity (gas bubble stability, distribution, size). In addition, the oxygen causes an increased effectiveness of typical baking agents, which allows their quantity to be reduced.

As a result, numerous benefits become accessible that affect overall process and product quality.

The innovative process is suitable for all common kneading systems and is easy to install and operate. It allows the bakery to exploit interesting savings potential at various levels and to develop further in the direction of "clean label" on the product side.

6. Bibliography

[1] Jacqueline Ungar, Master's Thesis, 2020
Wismar University of Applied Sciences, Process and Energy Technology
Development of an energy-efficient inline gas dissolver for fresh water

[2] NFT - Northern Food Tech GmbH, 2020
Prof. Dr. Klaus Lösche
Johannisburger Str. 20, 27580 Bremerhaven

[3] Own baking experiments with
Company BlueSens gas sensor GmbH, 2021
Snirgelskamp 25
45699 Herten

[4] ttz-Bremerhaven, presentation lecture 2006
Institute Baking and Cereal Technology
Am Lunedeich 12, 27527 Bremerhaven

Author contact details:

Dr.-Ing. R. Berghoff
Carl-Von-Linde-Strasse 25
85716 Unterschleissheim
rudolf.berghoff@linde.com