SIXTH FRAMEWORK PROGRAME
PRIORITY 5
Food Quality and Safety

Project acronym: EU-FRESH BAKE
Project full title: Freshly baked breads with improvement of nutritional quality and low energy demanding for the benefit of the consumer and of the environment
Proposal contract no: 036302

BAKE OFF TECHNOLOGY GUIDE OF GOOD PRACTICE

VERSION N°1
4th Jan 2010

GUIDE OF GOOD PRACTICE FOR THE BAKE OFF TECHNOLOGY

INTRODUCTION

This guide of good practice has been established by the consortium of the EU-FRESHBAKE project 'FOOD-CT-2006-36302) (see details of the consortium in ANNEXE 1). This research project funded by the European commission (Oct 2006 – Nov 2009) focuses on the bake off technology. The bake off technology (BOT) concerns bread making processes containing one or several interruption within a conventional straight bread making procedure. During this interruption, a prolonged storage is used being in frozen or non frozen state. After the interruption, the bread making procedure is continued until the final preparation step (final baking, "refreshing", …). Then the product is ready for consumption once its temperature comes back to room temperature. BOT is not just an alternative to conventional baking; it brings new solutions in bread making. BOT offers convenience to the consumers and the possibility to have freshly baked breads available all day long. This guide has the following objectives:

- To propose a report on the different technologies of BOT including recent scientific results (from EU-FRESHBAKE and from other sources). Key points are stressed out for each technology.
- To give an overview on energy in bread making with a focus on BOT (which are much highly energy demanding) vs. conventional scratch baking which is the reference process.
- To propose some strategies to optimize the practice versus energy consumption when using bake off technologies.

Nomenclature

ALA	alpha-linolenic acid
AS	Antioxidant Status
BOT	Bake Off Technology
BV	Biological Value
BCG	Baked Cereal Goods
CS	Chemical Score
DATEM	Diacetyl tartaric acid esters of monoglycerids
db	Dry Basis
DF	Dietary fibres
EAA	Exogenic Amino Acid index
EEI	Energy Efficiency Index (dimensionless)
ERI	Energy Ratio Index (dimensionless)
EFSA	European Food Safety Agency
FBF	Fully Baked Frozen
FB-MAP	Fully Baked Un Frozen (stored in Modified Atmosphere Packaging)
FD	Frozen dough
FFD	Fermented Frozen dough
GI	Glycaemic Index
H or H(T)	Enthalpy function in J/g or kJ/kg
LP	Lipid profile
NPU	Net protein utilisation
NQI	Nutrition Quality Index
PBF	Partially Baked Bread Frozen
PBUF	Partially Baked Bread Unfrozen (stored at room temperature)
PER	Protein efficiency ratio
PFF	Pre Fermented Frozen (dough)
SEF	Specific Energy Food kJ product / kg product
SEP	Specific Energy Process or Unit Operation kJ process / kg product
Q	Amount of heat in J, kJ or MJ
Q_{SEF}	Specific Energy for the Food for a process or for a unit operation (kJ/kg product)
Q_{SEP}	Specific Energy for the Process or for a Unit operation (kJ/kg product)
QI	Quality Index
TD	True digestibility
UFD	Unfermented Frozen Dough
UO	Unit Operation
wb	Wet basis
υ	**Conversion ratio (dimensionless)**

TABLE OF CONTENT

GUIDE OF GOOD PRACTICE FOR THE BAKE OFF TECHNOLOGY 2
I – Introduction on the different bread making processes and the "bake off technology " (BOT) 5
I-2 Prefermented frozen dough 8
I-3 Partially baked and Unfrozen bread 11
I-4 Partially baked and frozen bread 12
I-5 Fully baked and frozen bread 18
I-6 Packaging 19
II – Energy demand for bread making 21
II-1 Introduction on Energy Assessment & Energy Indexes 21
II-1-a ENERGY DEMAND OF A GIVEN UNIT OPERATION 22
II-1-b ENERGY OF A GIVEN PROCESS (SUCCESSION OF SEVERAL UNIT OPERATIONS) 23
II-1-c ENERGY NEEDED FOR THE PRE HEATING OR THE PRECOOLING OF AN EQUIPMENT 24
II-2 Enthalpy of bread and dough and energy related to evaporation 24
II-2-a-ENERGY LINKED TO EVAPORATION OF WATER DURING BAKING 24
II-2-b ENERGY DEMAND FOR THE DOUGH (FREEZING or BAKING) : ENTHALPY FUNCTION 25
II-2-c ENERGY DEMAND FOR THE BREAD : ENTHALPY FUNCTION 25
II-2-d ENERGY DEMAND FOR STEAMING 26
II-2-e ENERGY LINKED TO EVAPORATION DURING POST BAKING CHILLING 26
II-3 Energy demand for the Bake Off Technology: a benchmark study done during EU-FRESHBAKE 27
II-3-a Energy demand; Small scale study (TEST A) to compare conventional and part baked frozen 27
II-3-b Energy demand; Large scale study (TEST B) to compare conventional and part baked frozen 29
II-4 Energy in the baking industry – a general approach 31
III – Tracks to reduce the energy demand and to optimize the quality in BOT 32
III-1 GENERAL RECOMMENDATION: BAKING and STEAMING 32
III-2 GENERAL RECOMMENDATION: CONTROL OF THE FREEZING STEP (FINAL FREEZING TEMPERATURE) 32
III-3 Unfermented frozen dough 33
III-4 Pre-fermented frozen dough 33
III-5 Partially baked non frozen bread 34
III-6 Partially baked frozen bread 34
III-7 Fully baked and frozen bread 35
V– CONCLUSION 36

References
Annexes 1-2-3-4-5

I – Introduction on the different bread making processes and the "bake off technology " (BOT)

The BAKE OFF TECHNOLOGY (BOT) is an alternative to conventional baking. BOT is used as well in catering and in craft bakery. BOT products are retailed in baking stations installed in supermarket, shopping mall, train station, airport, down town area, …. The BOT is also of interest for traditional bakers. The concept of BOT lies in a concentration of know how when the product is prepared (usually in industry). Then, minimally skilled staff can prepare these products on demand using basic equipments such as a proving cabinet and an oven. If the total bread consumption per capita is slowly decreasing, it appears that the market share of BOT is growing at a very high rate (more of less around 10% per year).

NAME	ACRONYM	Brief description of the process
Fully Baked Unfrozen or Conventional	FB-U	Main steps are Mixing – Rest – Dividing – Shaping – Fermentation – Baking - Refrigeration
Fully Baked Frozen	FB-F	The bread is obtained from FB-U process and is frozen
Partially Baked Un-Frozen	PB-UF	The bread is obtained from FB-U except that baking is stopped before crust colouration. Bread is cooled and is stored in packaging at to room temperature
Partially Baked Frozen	PB-F	The bread is obtained from FB-U but baking is stopped before crust colouration. Bread is cooled and is frozen in packaging at freezing conditions (i.e; - 20°C)
Unfermented Frozen Dough	U-FD	Dough is prepared as for FB-U; the rest period is shortened and care is taken to limit the fermentation before freezing. Freezing is done quickly after shaping. A slow freezing is usually recommended to preserve baking performances.
Fermented Frozen Dough	F-FD	Dough is prepared as for FB-U; the fermentation is started and is stopped before full development. The fermented dough is then frozen. A quite rapid freezing is usually recommended. Final Baking is most of the times done in one process (frozen – ready to bake) or after thawing

Table 1

Acronyms of the conventional and Bake Off Technology bread making processes
(Published in [1])

Several technologies of bread making exist on the market and are listed in Table 1. The process pathways of selected BOT processes are presented in Figure 1. The three main technologies of BOT are the **Un-fermented Frozen Dough** (UFD), the **Partially Baked Frozen Bread** (PBF) and the **Partially Baked Un Frozen** (PBUF).

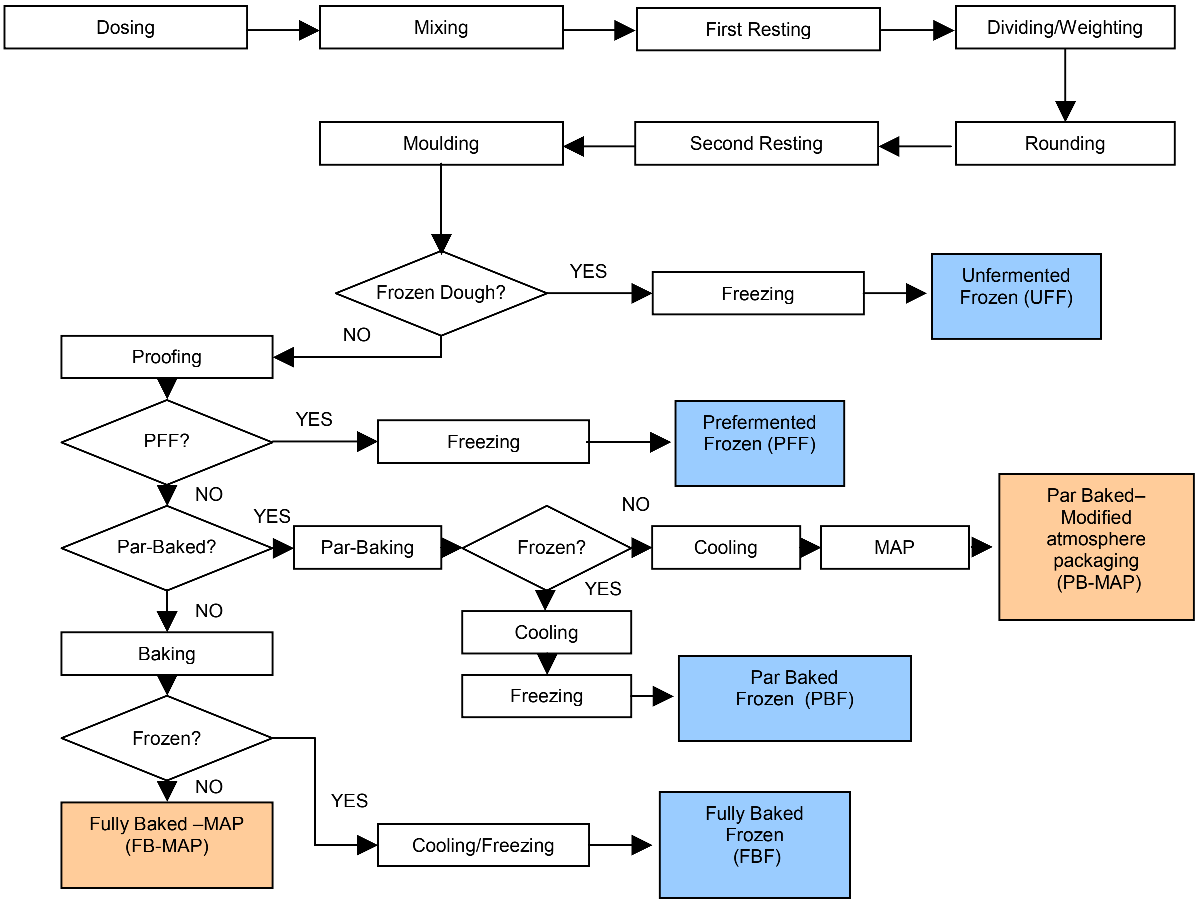


Figure 1

Process pathways of selected technologies for bread making using Bake Off Technology (BOT) Production processes of Un fermented frozen Dough (UFD), Partially baked frozen products (PBF), partially baked non packaged in modified atmosphere (PB-MAP), Fully baked frozen (FBF) and Fully baked and packaged in modified atmosphere (FB-MAP)

I-1 Unfermented frozen dough

DESCRIPTION OF THE TECHNOLOGY

The application of low temperatures in breadmaking provides an easy way of processing different types of bread and forms (fresh, refrigerated and frozen) that guarantees a steady rate of growth of this field. The production of frozen dough has undergone a significant increase during the last few decades, due to the variety of products that can be obtained after proofing and baking in the "baking stations". Frozen dough allows large scale centralized production, storage and distribution in frozen state and proofing and baking in the baking stations as well as in craft bakeries. It requires additional cost for freezing, transportation, frozen storage and some training and experience are necessary for finishing the product in the in store bakery. The use of frozen dough is very attractive because of the low volume of the unfermented dough, which is very convenient when storage is involved. Frozen dough is obtained from highly mechanized processes in big companies, which can reduce production costs. Manufacturers can supply to retailers a product of uniform and steady quality at any time. However, the production of frozen dough has created new requirements for the breadmaking process concerning raw materials, machinery, package and transport (see recent review of [2] [3].

FORMULATION

The technology used for the production of frozen dough has been known since 1950, although bakers began to use it in United States only in the 1970s. This delay was caused by the research and development required for setting up the new technology. In fact, initially the baked products from frozen dough had low volume and coarse texture, and shorter shelf life [4]. Nowadays, these problems have been overcome, extending the shelf life of the frozen dough up to six months. The freezing and thawing processes exert some stress on the dough that causes deterioration in the quality of the baked product. For this reason, wheat flour for frozen dough must have greater strength than that used in conventional bread making [5]. It is advisable to use flours from wheat varieties with strong gluten [6], [7] [8] or to make appropriate blends for obtaining the desirable strength [9] [10]. Extensive research has been focused on the development of yeast cells with high tolerance to freezing and frozen storage, due to the impact of freezing and frozen storage on their viability [11]. Considerable differences of the yeast cell cryotolerance among the commercial samples have been described, which indicate the importance of the growing conditions for obtaining uniform cryotolerance. Baked bread from frozen dough made with flour, yeast, salt, and water shows the same problem than those obtained from conventional process, namely a very short shelf life. Additives and technological aids used in conventional breadmaking [12]; [13] are appropriated also to produce frozen dough [14] [15]. [16] proposed for example a study on the combined effect of mixing time, ascorbic acid and amylase on the performance of frozen dough. Ascorbic acid is a well-known improver but a sufficient mixing time is needed to obtain a positive effect on the final bread volume as shown in Figure 2

MIXING

[17] stated the importance of the mixing energy input, type of mixer, water amount in the formulation, presence of oxidants and dough strengtheners, proofing and resting times and freeze-thaw cycles on the baked bread quality from frozen dough. **The final temperature at the end of mixing and the prevention of start of fermentation before freezing is an important point. Indeed, several authors pointed out [18] [19] that the start of fermentation before freezing will reduce the yeast activity after thawing**. The control of the final temperature of the dough can be obtained by using refrigerated ingredients. Usually, it is recommend to introduce in the mixer yeast first and then later the salt once the yeast is well distributed in the dough to prevent direct osmotic stress (contact of yeast and salt).

FROZEN STORAGE

Along with the selection of the desirable dough temperature after mixing the **time of frozen storage is also important [20]**, because prolonged storage increases yeast damage [21]. In general, low temperatures after mixing and short resting time lead to dough with highest quality and stability during frozen storage [22]. [23] indicated that large temperature fluctuations (from -18˚C up to -8˚C) during frozen storage resulted in significantly more rapid loss of dough and bread quality than storage at constant and controlled temperatures (-18˚C ± 0.1˚C). [24] showed that very stable storage temperature can result in a much longer shelf life (see in Figure 3). Temperature oscillations as small as 1 or 2 °C amplitude can have a very significant impact on the final quality of the dough. Those temperature fluctuations are responsible of loss of yeast viability (low CO2 production) resulting in a lower bread specific volume and an increase in breadcrumb firmness. In the average, it seems that most of the frozen damage is done within the first two weeks of storage and evolutes slowly during further storage.

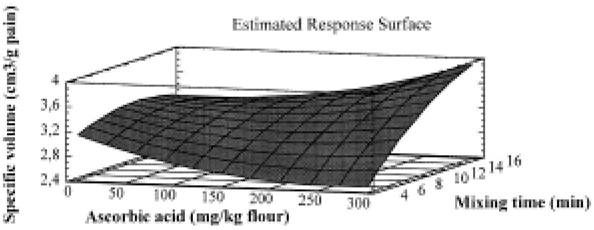


Figure 2

Impact of ascorbic acid and mixing time on the specific volume of bread made from frozen dough. Ascorbic acid is a basic improver for frozen dough. Its efficacy is effective if the dough undergoes an appropriate mixing time [16]

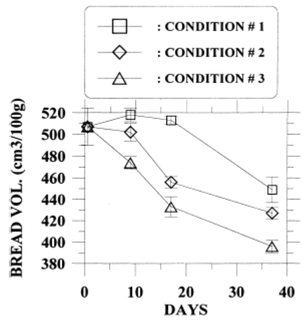


Figure 3

Influence of frozen storage condition on final bread volume made with frozen dough. Condition 1 = high stable (-22°C), condition 2 = exposed to cold room fluctuation (+/-2.5°C) and condition 3 = condition 2 + rupture of cold chain one day before processing the dough (rise top -8 °C).[24]

FREEZING RATE OF UFD

The freezing rate is also an important point. Irrespective to most foods, a rather slow freezing rate yield in a better preservation of yeast activity and dough rheology as shown by [25]. [26] showed that larger bread volume was obtained when a dough was withdrawn from the freezer when its temperature was -10 °C (freezing being completed in a static freezer) instead of -18 °C.

NEW NUTRITION ASPECTS IN THE CASE OF UFD FROM EU-FRESHBAKE

Bread can represent a significant source of minerals. In the case of whole mill bread, phytic acid may form complexes with minerals resulting in the presence of phytate (inositol Hexaphosphate). Phytate must be reduced by phytase (endogenous or added) to increase the availability of minerals. Recent results obtained within the EU-FRESHBAKE project [27] showed that the frozen storage of dough has a significant effect on the degradation of phytates. It is envisaged that freezing and frozen storage act on the cell walls and finally favour the accessibility of the phytase to the phytate compounds. Further investigations are carried out on these tracks, which show that the use of refrigeration and especially freezing in breadmaking can have other interests than just extending the shelf life of products.

FINAL THAWING AND PROCESSING OF UFD

Frozen dough should be thawed and fermented before baking. Proofing of thawed dough should be performed as in the conventional practices; the unique difference is that the relative humidity of the proofing cabined should be reduced (i.e. to 75%) for the thawed dough, otherwise condensation spots could appear on the surface producing dark spots in the baked breads.

I-2 Prefermented frozen dough

DESCRIPTION OF THE TECHNOLOGY

A baker's life has definitely not become simpler in the past 15 years. Consumers' demands become more and more specific; fresh bread all day long, a wide variety every day, new flavors, new shapes and new sizes. It is clear that the traditional baking processes are sometimes too limited and inflexible to fully satisfy consumers.

Over the last decades, the use of frozen bakery products is growing at a rapid pace. Diversification, rationalization and convenience are the driving force both for producers and users of frozen goods.

Well known are unfermented frozen dough and frozen par baked. A remaining target in the business is the handling of frozen fermented bread and roll dough's that can directly be baked. This dough can be made in central bakeries: after mixing and make-up of the dough, the product will be proofed, frozen and packed. Once distributed to the bakery outlets, the frozen dough can be put from the freezer on the tray's, directly into the oven. No additional fermentation is needed before baking. Devos (2003) summarises some serious advantages of prefermented frozen dough (PFF) compared to unfermented frozen (UFF) and par baked frozen (PBF).

- better quality of crust and crumb remaining longer fresh (PBF)
- more convenience (UFF), allowing fast answers when running out of stock
- less equipment needed in the bake-off shop (UFF)
- less freezer storage room (PB), down to 50%. The double amount of pieces can be wrapped in the same box!
- more consistent quality (UFF): less dependent of skills in the bake-off
- possibilities for "show finishing" of the frozen goods allowing to offer a wide range of diverse bakery products
- rationalization in the bakery: less but larger production runs of products with reduced rotation
- …

Frozen dough are widely used in industrial bakeries, making fresh bread available to consumers for the whole day, to facilitate transportation, to reduce labour costs, and to diminish the need for skilled bakers.

A common finding is that prolonged frozen storage of dough leads to a reduced volume of bread. The deterioration of baking performance of unfermented frozen dough has been ascribed to the loss of yeast viability and to the formation of ice crystals. The application of fermentation before freezing eliminates the need for viable yeast after freezing and frozen storage. In this way thawing is less time consuming, no specific proofing equipment is necessary, in fact the prefermented dough piece can be directly put in the oven.

PREFERMENTED DOUGH FOR PFF: A FRAGILE STRUCTURE

Fully fermented frozen dough pieces that go directly from freezer to oven allow serving a fresh baked product within a normal baking time. The main challenge using this technology however is to overcome the damaging effect of freezing to the gluten network. Some typical quality defects that occur are: deficient oven jump and volume, irregular coarse crumb with some big holes and collapsing of dough piece in the oven [28]. Opposite to laminated dough where the dough/fat layers take care of stabilization during freezing, normal bread and roll dough are characterized by a continuous dough phase with embedded air bubbles (see Figure 4). Once fermented, this dough becomes very sensitive to freeze damage, which results in a coalescence of the gas cells upon baking.

The dough model with liquid layer (see Figure 4), presented by [29] can explain this phenomenon. Up to the first stages of fermentation, gas cells in dough are embedded in a continuous starch-gluten matrix, which becomes thinner during further expansion. At the end of fermentation and early stages of baking, this matrix fails to enclose the gas cells completely, leaving areas with a thin liquid film to maintain the integrity of the gas cells. Dough in this stage is much less stable. Further oven rise will end as the liquid phase ruptures. As explained by the above mentioned dough model, the best resistance to freezing will be achieved when still sufficient thick gluten-starch matrix is present around the gas cells.

This will be obtained by shorter proofing. Furthermore, optimal visco-elastic properties of the dough matrix by using strong flour, special dough conditioner and a decent mechanical make-up will supply additional stability [28].

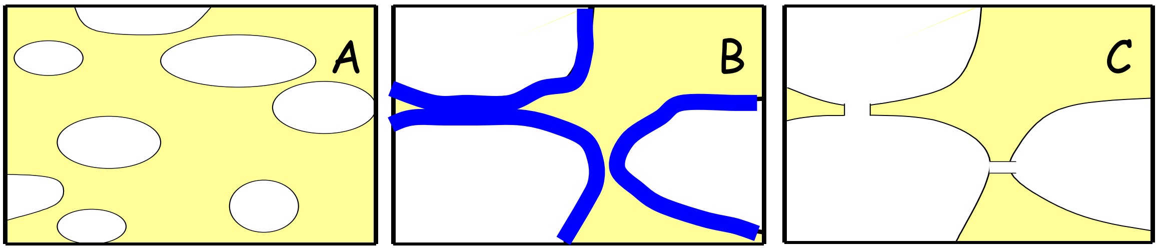


Figure 4

A. Early stage of proofing, expanded gas cells embedded in starch-protein matrix
B. Further stage of proofing and early stage of baking. Gas cells are surrounded by thin liquid films.
C. End of oven jump. Rupture of liquid films. - [29]

Damage occurs when dough is frozen after proofing and transferred to the oven in the frozen state [30]. The porous structure is affected by the solubilisation of CO2 which increases at low temperatures [31] and by mechanical damage of the gas cell membrane caused by ice crystals [32]. In addition the growth of ice crystals in the gas pores contributes to a redistribution of water in dough [33].

Re-crystallization refers to the tendency of ice crystals to minimize their free energy as manifested by changes in size, number and shape of ice crystals during frozen storage. Different mechanisms of ice crystallization have been described by [34]. [30] observed ice crystals in the gas pores of frozen dough. These crystals where already present 1 hour after freezing. Crystal growth and rounding of by re-crystallization was observed after 1 day frozen storage. After 149 days of frozen storage the authors measured crystal sizes of several 100 µm. It is concluded that the ice fraction remained constant during frozen storage and that the growth of ice crystals leads to redistribution of water in the dough mix as a form of ice, which in turn affects the properties of polymeric compounds in dough and reduces the baking performance of PFF dough's. When PFF dough is baked in a preheated oven without previous thawing, as is done in in-store bakeries, the time for reabsorption of the water in the pores by the gluten and starch is very limited because the fast temperature increase. This will increase the liquid phase and by consequence decrease dough stability. Hence the importance in fully fermented frozen dough processing is the control of free water. Here the reduction of water in the recipe and the use of selected hydrocolloids in the improver are indispensable [28]. The outer zone of a dough piece is more affected by temperature fluctuations, which explains the finding that ice crystals tend to be larger in this zone. Upon storage, ice crystals tend to grow (re-crystallization, water migration) and concentrate into large patches of crystals in the dough. This will increase the liquid phase and by consequence decrease dough stability. Hence the importance in fully fermented frozen dough processing to control the free water. Here the reduction of water in the recipe is indispensable.

Only a maximum stability could be obtained by combining optimal recipe and process parameters with innovative ingredients [28]. Basic Ingredients in the Recipe and most important process parameters are described by the author.

FORMULATION AND QUALITY OF INGREDIENTS FOR PFF

The flour is very important to have sufficient strength in the dough; therefore good quality flour is needed. Numerous plant tests have shown that flour should at least have the following characteristics: protein > 12.5% d.m., Alveograph W > 300 and P/L > 0.5-1.0, and Farinograph Baking absorption: 54-63 and stability (E) < 40

The amount of water in the recipe depends on the required visco-elastic properties (strength and machinability) of the dough and is also related to the "liquid-layer" theory. An excessive amount of free water in dough reduces the volume and shape of baked product. The higher the free water level, the thicker is the liquid layer on the dough gas interface. In general water is reduced by 0 to 3% according to the application. During the PFF make-up process dough is exposed to a lot of stress. A specific bread improver will give the dough more tolerance and freeze-stability. The final product will be more homogeneous and have a moister crumb, longer shelf-life and excellent crust-properties. No special yeast properties are necessary, a standard quality will be sufficient.

CONTROL OF THE FERMENTATION STEP: AN IMPORTANT ISSUE

Using a special designed improver will reduce the susceptibility to process variations. However, it remains key that the following process steps are fully under control. Well formed dough with enough visco-elastic property is needed for gas retention and machinability. As the dough is usually stiffer, a longer mixing time is required for optimal performances. Taking care of good rounding and moulding is needed to build strength into the dough.

The final proof is of utmost importance to assure quality PFF products. The degree of fermentation – depending on temperature, time, amount of yeast, dough consistency – needs to be within a certain range. If the dough is under proofed, then the baked product has less volume and breaks too wild; when over proofed, volume goes down, holes appear in the crumb and the cuts close completely (see **Figure 5**). Also other parameters like proofing temperature will determine the final quality.

In the case of frozen dough, it is recommended to reduce the fermentation phase to its minimum to prevent the start of fermentation. Indeed, the tolerance of yeast to freezing is better in such conditions as shown by several authors [18, 35]. For PFF a fermentation ratio of 1/3 to 1/2 in comparison to full fermentation is usually recommended in the literature. Frozen storage stability of pre-fermented frozen bread dough was investigated by Rasanen who gathered several interesting publications on the subject [35-37] with frozen storage times of 14 days at –20 °C. A shorter pre-fermentation times (25 min vs 40 min) prior to freezing improved the freeze-thaw stability of frozen dough resulting in an increase of loaf volume by 20%, a more uniform pore structure and a thicker network of gluten around gas bubbles. No difference in storage stability of frozen dough was observed after 25 and 40 min pre-fermentation, most of the damage being done during the first week of storage. A reduced moisture content (minus 2% versus optimum content in fresh dough) resulted in a higher volume. More recently, [38] showed that a half prefermentation (tested between half and full fermentation before freezing) and a faster freezing rate resulted in the bigger volume. The authors concluded that lower degree of pre fermentation should be investigated.

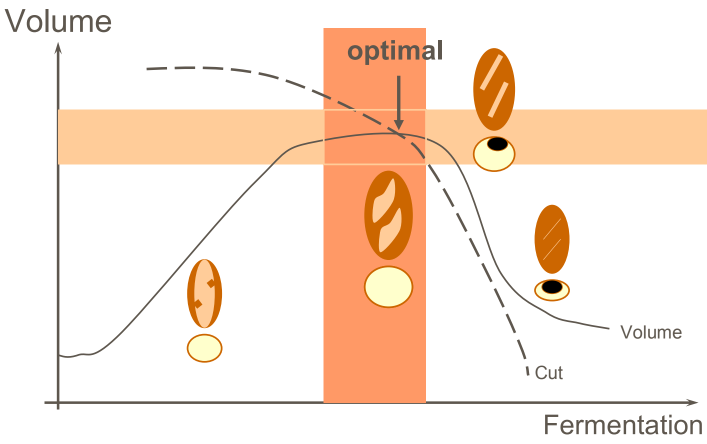


Figure 5

Establishing the correct fermentation duration of PFF products for maximised specific volume of bread (bold line) and avoidance of large bubbles (as schematised on cross sections of final bread) and full opening of the cuts (dotted line + schematised top views of bread). Too short proofing will give reduced volume and an uncontrolled oven jump during baking. Over proofing will result in insufficient volume, small cuts and **holes in the crumb** (black cavity in the bread in the figure above).

FREEZING OF PFF

The freezing time depends on the weight and dimensions of the dough pieces. Below 400 grams quick freezing at -35°C is recommended. Above 500 grams cooling down prior to the quick-freezing at -35°C might be beneficial. Too fast freezing of the outer part of big dough pieces comes in conflict with further internal fermentation and volume expansion of freezing water, **causing holes in the crumb** (see **Figure 5**). Rapid freezing applied to baguettes gave better results as presented by [38]. Nevertheless, the prefermented dough may collapse during freezing in the case of abusive pre fermentation. Excessive airflows or freezing times should also be avoided as they result in deficient colour and crust properties after baking. Storage of fermented frozen products should be below -18°C, by preference under constant temperatures and wrapped in a closed carton box with PE bag.

FINAL BAKING OF PFF

A bake off oven for PFF products requires a steam-unit. The baking temperature will be slightly lower than average. Slight thawing before baking is optional but not mandatory [28].

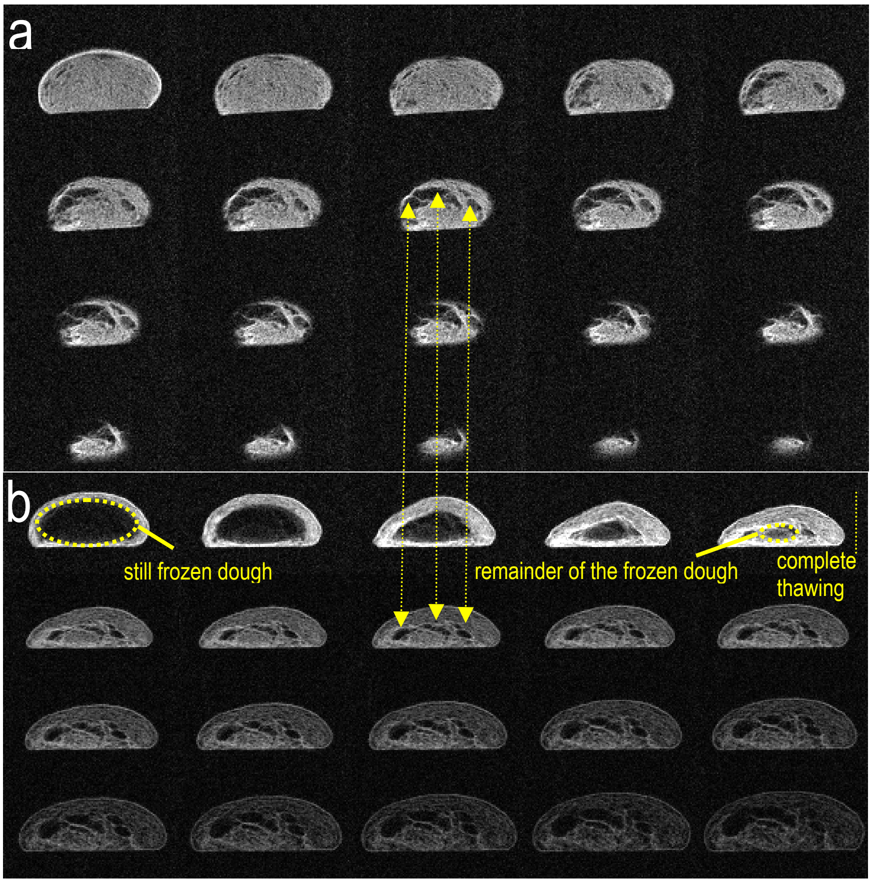


Figure 6

Raw MRI images for run 05 during freezing (a) and combined thawing-proving (b) of PFF80% rolls stored for 5 days. One image every 2.8 min and 7.2 min respectively. The rolls have been proved for too long. During freezing, the size of the roll section was decreasing with the processing time because of the crystallisation of water. In the operating conditions used for this study, total disappearance was noticed at 45% of ice fraction. The formation of large bubbles into the dough was also observed during freezing. Although slightly collapsed, these large bubbles were still present in thawed dough.

I-3 Partially baked and Unfrozen bread

DESCRIPTION OF THE TECHNOLOGY

PB-UF (partially baked –Unfrozen bread) technology has developed a lot among other BOT. Breads are undergoing a process similar to PBF (see section on PBF) except that after the partial baking, bread is packed in a plastic bag with a modified atmosphere (MAP or Modified Atmosphere Packaging).

One of the advantages of this technology in comparison with part baked frozen is that no freezing step is required. The final baking step is therefore faster. In the case of domestic use, the final baking can be done quickly in a toaster for example or eventually in a domestic oven. One of the disadvantages of the PB-UF is that specific packaging must be used with good barrier properties for moisture, oxygen. A MAP is usually used.

CRUST FLAKING – BREAD CONTRACTION

The crust flaking problem is more specific to PBF technology. Nevertheless, as for frozen part baked, a partial baking may results in a non stabilized crumb that may collapse during chilling. This may results in default at surface of the bread such a crevasses

Figure 7

Picture of an unfrozen part baked bread stored at positive temperature in MAP. One can see on the picture a crevasse due to the contraction of the crumb during chilling. The collapse is located on the flank of the bread which corresponds to the spot which has the thinner crust.

During EU-FRESHBAKE, the impact of the degree of baking on the contraction of a loaf (70 g – ball shape) during post balking chilling has been investigated. The volume of the loaf was measured at the end of baking and then at the end of the chilling [39]. A specific "volumeter" was used; this system used a laser beam to determine the volume of the bread so that there was no compression effect as it would have been the case when using a rapeseed displacement method. Results presented in Figure 8 show that the volume contraction of bread is much higher for the shortest baking conditions. In this figure, the conditions on the x axis are the temperature and eventually dwell time observed at centre of the bread during baking. The volume contraction will result in a strain on the surface of the bread. If the thin crust present at the surface is too dry, it will result in a higher risk of crust flaking.

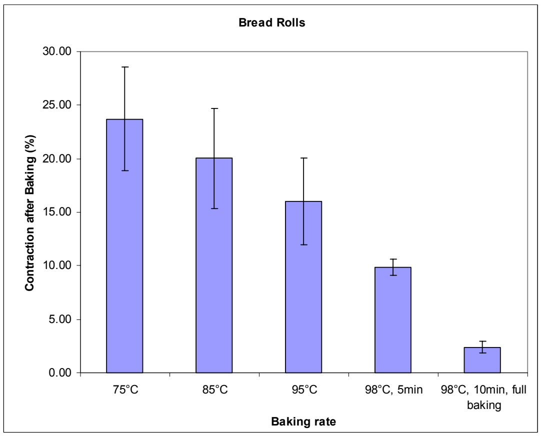


Figure 8

Impact of the baking condition on the percentage of volume contraction of bread during chilling after partial baking [39]. 75 °C to 95° means that the baking has been interrupted once the centre of the bread reached the indicated temperature. For 98°C / 5 and 10 min, the baking was interrupted after 5 and 10 min plateau at 98°C.respectively (centre temperature of the bread).

MOULD & FUNGI GROWTH

One of the problems that may arise during long storage at room temperature is the presence of mould and fungi growth at surface and even at core of the bread. This phenomenon can be postponed by using specific chemical additives that may prevent the growth of these undesired spoilages. Among them, calcium propionate (CAP) is the most common. Alternative routes [40-44] are investigated to reduce the use of this chemical. Specific Lactic Acid Bacteria have anti fungal effect and can have a synergistic effect with CAP as presented by [42]. Other technological routes are used in the industry such as spraying alcoholic solution on the surface of breads after baking. This last solution may result in a alcoholic aroma that may not be liked by consumers.

I-4 Partially baked and frozen bread

DESCRIPTION OF THE TECHNOLOGY

PBF (partially baked frozen bread - also called Parbaked bread or part baked bread) is usually made with a more or less conventional bread recipe. PBF technology is among the most used of all BOT. One of the advantages of the PBF technology is that bread can be prepared in less than 1 hour with a simple oven and with a minimally trained staff. Before the final baking, a partial thawing is usually recommended.

Baking aids are used most of the time by industry to allow some tolerance of the product to the rough conditions imposed by industrial conditions (conveyors, …). The dough is then proved, partially baked, chilled and frozen. It is thereafter stored and delivered to stores or restaurants. Partial baking consists in baking bread usually at a lower temperature in comparison with conventional baking and to stop just before coloration of the crust. Then the bread is frozen in a two steps process; chilling first and then freezing. The final thawing-baking is usually done in one single operation. Therefore, the superficial area (crust in general terms) undergoes severe hydrothermal treatment including dehydration during chilling-freezing and also storage in the frozen state.

PARTIAL BAKING AND FINAL BAKING

The literature available on PBF has increased a lot recently. A patent on baking of part baked bread has been proposed by [45]; it is based on specific baking temperatures. [46] proposed some very general information on the PBF process. [47] proposed a detailed study (in French). They mentioned that water loss of PBF is higher than in the case of a conventional process (4 % vs. 2.5 %); this can be overcome by reducing the post baking chilling time and by starting the freezing earlier or by increasing the air humidity during chilling. The final baking is usually combined with thawing. [47] compared different final baking conditions (10 min at 210°C - 15 min at 190°C - 20 min at 170°C); the lower the baking temperature, the longer the baking and the higher the water loss. Therefore, a rapid final baking with high temperature is usually used for these products. Investigations have been carried out during the EU-FRESHBAKE project on the impact of the baking duration on the properties of bread such as contraction and staling as presented at follow.

CRUST FLAKING OF PBF

[48] has proposed a detailed study on the impact of processing parameters on crust flaking. Several process parameters were considered: air humidity during fermentation, use of steaming during baking, post baking cooling conditions (done in more or less humid air) and temperature at entrance of the freezer (55 °C or 35 °C at core). Results showed that the processing conditions are strongly linked to the occurrence of flaking. The relative humidity of air during post baking chilling is the most influent parameter; a moist air must be used. Then the lack of moisture during fermentation comes second in term of significant parameter. These two process parameter will have a direct impact of the moisture of the crust (the crust of part baked bread is more like a skin); a dryer crust surface will not support the contraction of the crumb during chilling and freezing. It will separate physically from the crumb and the flaking off will appear during the final baking. Of course, prolonged frozen storage combined with poor conditions (fluctuating temperature) can make increase the crust flaking problem; nevertheless, the control of the process at the initial stages of production play obviously a major role.

Figure 9
Crust flaking on flanks of part baked bread (French baguette) after final baking.

Figure 10
Crust flaking (or crust peeling) on tip of part baked bread (French baguette) after final baking.

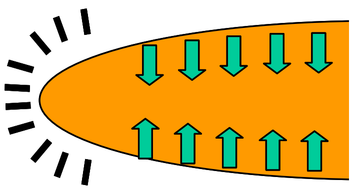


Figure 11
Scheme explaining the impact of crumb contraction on the tips of a baguette ("clamp" effect).

Indeed, during chilling and freezing, the crumb is contracting as shown by [49] – see Figure 13 . The contraction phenomenon has also been evidenced for a "real" bread as shown in Figure 8. A densification of the crust crumb zone has been identified using NMR and MRI by [50]. It has been assumed by the authors that this contraction is caused by the contraction of the gluten network during the chilling phase. In the case of partial baking, the amount of amylose leached outside the swollen starch granules is lower because of the shorter baking duration in comparison with conventional baking. The weaker amylose gel located schematically between the ghosts of starch granules and the gluten network does not exert a sufficient viscous force to counter balance the contraction of the elastic gluten network.

During freezing, an additional phenomenon takes places namely dehydration due to the cryoconcentration effect of ice crystal formation. In parallel, during chilling and freezing, the baked crumb passes over a temperature gap for which the staling is accelerated as shown in Figure 12. The staling corresponds to the retrogradation (recrystallisation) of starch constituants. This concerns mainly amylose during the perdio following immediately the baking steps and then amylopectine a ramified macromolecule of starch for prolonged storage. Globally, it is assumed that the contraction is linked to the elastic behaviour of the gluten net work and is magnified by starch (amylose) retrogradation and by the dehydration – contraction caused by the cryoconcentration phenomenon.

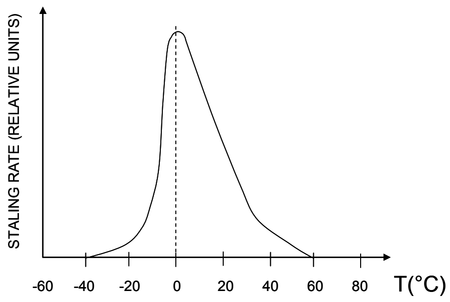


Figure 12
Staling rate of baked crumb as function of temperature (graph done from data in [51]

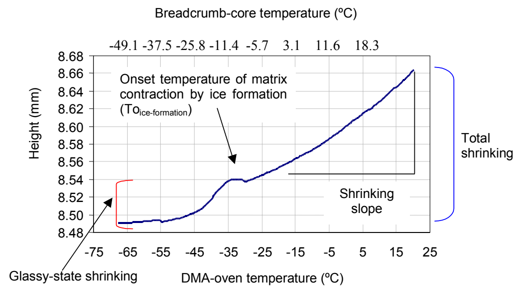


Figure 13
Graph showing the contraction of a bread crumb during chilling and freezing. The magnitude of the strain is around 2 – 3% between 20°C and -50°C. [1, 52, 53]

It has been attempted to assess the impact of enzymes on the extend of contraction; this could obviously be a track to limit the contraction a crumb [52, 54] but the effect depends on the enzyme. On the other hand, it is well known by technologists that the duration of the partial baking is also linked to the amplitude of the contraction; the longer the baking, the lower the crumb contraction (this has been confirmed by EU-FRESHBAKE – see Figure 8).

The concentration of ice crystals below the crust is also proposed as an explanation to crust flaking. During chilling and freezing after partial baking, moisture diffuses from the centre of the bread towards the crust area due to a large vapour pressure gradient. Ice crystals might even aggregate in the superficial zone or in the crumb due to the presence of the freezing front, whereas at the same time the centre of the bread which is still warm generates water vapour that diffuses towards the freezing front where the partial vapour pressure is minimum. A higher amount of moisture below the crust has been identified by [55-57]. Nevertheless, the amount of water that freezes below the crust is relatively small and could not be sufficient to explain the crust flaking phenomena.

Therefore, crust flaking of PBF appears as problem caused by several factors. Some tracks to control crust flaking are proposed in [1] and can be summarized as follow:

- A good control of the moisture during fermentation is a very important point. More humidity means more hydration of the crust and therefore more plasticity (tolerance to deformations) of the crust during chilling and freezing.
- Focus on partial baking conditions. It seems that a milder (shorter) baking results in a higher crumb contraction, presenting the partial baking process as a “risky” process. Specific time-temperature profiles may be needed depending on the geometry of the product and on the baking oven.
- Post baking refrigeration phase: a good control of air temperature and air moisture is very important. Moist air is needed. Chilling must be done to low temperature (around 30°C at core) before going to freezing to reduce the energy demand and to prevent frosting of the freezer.
- The freezing velocity will interact with the thermomechanical problem of crust – crumb differential contraction. Tests have to be done to optimise the processing conditions. Low temperature freezing (-25°C or less) can be recommended as it will allow a reduction of the energy demand. However, a good control of the final temperature of the product must be done to effectively minimize the energy demand. Withdrawing the bread when the centre temperature reaches -15°C is most of the time sufficient (see the freezing – energy section about this).
- The measure of the outer dimensions of bread at the end of partial baking, end of freezing and end of final baking can be a good mean to assess if there will be some risk of crust flaking. The changes in dimensions might permit to predict crust problems. The impact of fermentation duration, expansion ratio during fermentation, partial baking duration, … should be considered to reduce the contraction.

STALING OF PBF:

Staling is a complex phenomenon in which multiple mechanisms operate[58]. The macromolecules contained in starch are gelatinized during baking. Amylose, a linear biopolymer is leached outside the starch granules resulting in a gel like structure which acts as a cement in the crumb matrix. During storage, the "retrogradation" (re crystallisation) of amylopectin occurs, and because water molecules are incorporated into the crystallites of amylopectine. Therefore, the distribution of water is shifted from gluten and amylose gel toward the starch/amylopectin crystallites, thereby affecting the mechanical properties of the gluten network and finally the overall texture of bread. The role of additives may be to change the nature of starch protein molecules, to function as plasticizers, and/or to retard the redistribution of water between components.

Differential scanning calorimetry can be a useful tool to monitor the retrogradation phenomenon. The melting of amylopectine crystals is related to the staling phenomena [59] even though the firming of the crumb is indirectly linked to it. Retrogradated amylopectine corresponds to an endothermic peak usually between 40°C and 60°C (depending on the water content). Recent results obtained within the EU-FRESHBAKE project showed that PBF breads had a rather slower kinetic of staling in comparison with conventional breads. Further study has been carried out to assess if the difference can be explained (i) by a lower amount of crust for part baked bread resulting in a lower amount of water transferred from the crumb to the crust during storage (moisture re equilibration resulting in a more pronounced dehydration of the crumb for conventional bread) or (ii) by a difference in the degree of baking of starch (difference in starch swelling – see Figure 19). Preliminary results [60] obtained in baking the dough without crust seem to indicate that the longer the baking, the slower the staling rate. Thus, the first explanation (difference in the amount of crust) should be considered to explain a slower kinetic of staling of part baked bread. Within EU-FRESHBAKE, [61] studied the impact of the kinetic of baking on the staling rate. A miniaturized oven was used to mimic the kinetic of baking observed on loafs of 70 g baked in a real oven. The samples that were obtained were slabs of 3 mm thick (degassed crumb). In these experiments, the texture of the degassed crumb was measured by compression tests. These tests gave a value called the Young modulus which represents "hardness" of the material (in the elastic domain); the higher the young modulus, the more resistant is the material to deformation. The evolution of the Young modulus during staling was modelled using a first order kinetic model as presented in equation (1) where E(t) is the Young modulus in function of time t, and E_0 and E_∞ are the Young modulus at the beginning and at the end of the staling. The time is "t" and the time constant "τ" appearing in the exponential function is a characteristic time (same unit as t). For time equal to 3 times τ, the value of E(t) has reached 95% of the final value.

$$E(t) = E_\infty + (E_0 - E_\infty).e^{\left(-\frac{t}{\tau}\right)} \qquad (1)$$

Bread baked in an oven at 180°C, 200°C and 220°C underwent heating rates of 7.8°C/min, 9.8°C/min and 13 °C/min respectively. These heating rates were reproduced in the miniaturized baking oven. Results [61] showed that a faster heating rate resulted in a faster kinetic of staling, meanwhile the texture of the crumb at the end of staling was not significantly affected. However, the difference was not very important. Other results (unpublished) obtained with the same miniaturized baking system with organic bread formulation (whole meal flour) are presented in Figure 14 and Figure 16. It showed that a longer baking plateau at 98°C (baking temperature of the crumb) resulted in a harder crumb at the end of staling. The evolution of the kinetic parameter ("τ" in equation (1)) and of the final Young modulus (E_∞ in equation (1)) are presented in Figure 16 and in Figure 17 respectively. Both values increased with increasing duration of the baking. However, the value of τ was minimally affected (~ + 10% indicating a slower staling for longer baking) whereas the texture of the crumb (Young modulus) was significantly affected (+30% from 0 to 8 minutes baking plateau at 98°C).

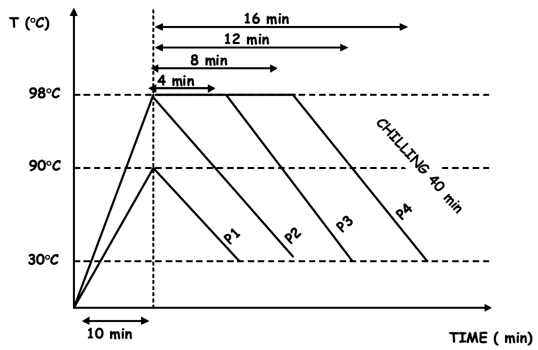


Figure 14
Time – temperature evolution during baking tests done with a slab of degassed dough (miniaturised system to mimic bread baking).

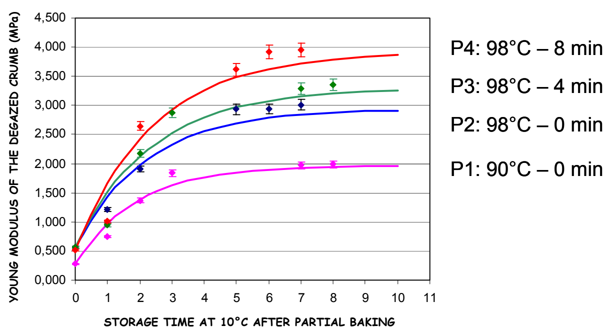


Figure 15
Young modulus of a degassed bread crumb (whole meal flour) in function of storage time at 10°C. The baking was done according to the evolution shown in Figure 14.

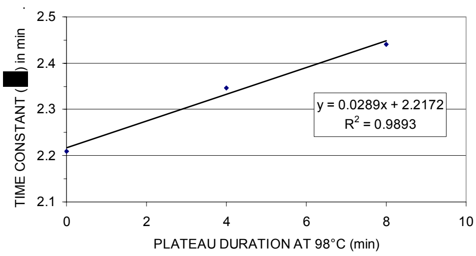


Figure 16
Time constant "τ" of equation (1) in function of the duration (in min) of the baking dwell at 98°C (from results of Figure 15 obtained with organic bread).

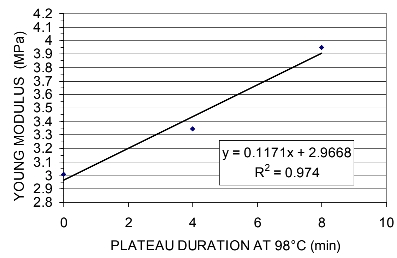


Figure 17
Young modulus "E_∞" of equation (1) in function of the duration (in min) of the baking dwell at 98°C (from results of Figure 15 obtained with organic bread).

As a conclusion, it seems that the longer the baking (temperature plateau at around 98°C), the harder will be the crumb at the end of the staling phenomena. This observation is supported by the fact that for longer baking times, a larger amount of amylose is leached outside the starch granules resulting in a more resistant crumb (mechanical point of view). The SEM pictures presented in Figure 19 later on show that for prolonged baking the starch granules change in form and it seems also that more material is leached outside the ghosts of the starch granules.

STALING DURING FROZEN STORAGE

Staling of part baked bread is effective during frozen storage even though the kinetic is significantly slowed down. [59] presented relevant results on this point. In the case of part baked bread, it seems that the duration of the frozen storage affects minimally the retrogration-recrystallisation of amylopectine [59]. It has been shown that the staling rate was increased for lower storage temperature (see Figure 12) with a maximum at around 0°C. Therefore, it is important to store the frozen part baked bread at a temperature below -18°C to prevent any accelerated staling during the frozen storage. The impact of storage temperature at subfreezing temperature on final quality and staling has not been investigated as such in the literature. [59] studied the effect of part baking, freezing, storage and final baking on the staling of PBF. Pieces of dough were placed in differential scanning calorimetry (DSC) pans and were kept in these pans to simulate all steps of the process by running specific time temperature history that mimic baking, freezing, …. As indicated before, the frozen storage didn't have a very significant impact on the staling of the crumb even though some staling occurs in the long run.

[62] studied the effect of storage of selected types of frozen part baked bread. Texture, colour, sensory analysis and soluble starch were evaluated according to the storage time. There was no real explanation of the quality change of the products; the acceptable storage life was in the range of 12-20 weeks under their experimental conditions. Specific ingredients may be used to improve the tolerance of PBF to frozen storage. [63] presented a study on the effect of yeast and vegetable shortening on the physical and textural parameters of frozen part baked French bread. Different formulations were evaluated with or without shortening and with different amount of compressed yeast. Higher volumes were obtained with higher yeast content and shortening tends to soften the bread. Hydrocolloids seem to be an interesting track to improve the final quality (texture, staling rate, …) of PBF. Several studies such as [59, 64-66].

SECOND BAKING OF PART BAKED FROZEN BREAD

If the partially baked bread is frozen, a partial or a complete thawing before the second baking is usually recommended. It will result in a more uniform second baking and in a better warm up of the inside of the crumb. This last point is important; indeed, during the warming that occurs during the second baking, amylopectine crystallites that have been formed during the storage (corresponding to staling) will be melted over the temperature interval comprise between ca. 40°C and 60°C. This will allow the "refreshment" of the crumb and the release of the water trapped in the amylopectine crystallites. The crumb will then be softer. If the crumb is frozen, there is a risk that the heat will not penetrate until the centre of the bread resulting in a partial "refreshment" of the bread. Thawing the bread should also be considered as a good practice to minimise the risk of flaking. Some condensation will occur at the surface resulting in a plasticization of the crust and in a better tolerance of the heat shock during the first moments of baking. Steaming is done some times and permits to compensate the drying of the surface of the bread that will occur in the beginning of the baking step; however, the amount of steam is very often quite low. .

AROMA OF PBF BREAD

There is a lot of controversy on the aroma of PBF breads. The evaluation of bread aroma is a difficult task. Indeed, the aroma (volatile compounds) is changing quickly during post baking chilling and during storage. Beside, extraction methods may be time consuming. Therefore, a balance must be found between the performance (in term of similarity of the aroma) of the extraction process that is needed to trap the aroma and the time needed for the extraction. An extraction method has first been optimised as presented in [67]. A principal component analysis has been carried out to compare and quantify volatile compounds of bread made with selected bread making processes. Frozen and non frozen partially baked breads were characterised by lower amounts of the compounds coming from the Maillard reaction, whereas they contained more compounds issued from the fermentation and/or the lipid oxidation. Compared to the results obtained from a discriminative sensory analysis, it was demonstrated that these analytical differences had an impact on bread odorant perceptions. Indeed, the odours of fully baked breads were perceived differently from the ones of partially baked breads. Further investigations are carried out to optimize the processing conditions with respects to aroma criteria. The process conditions (fermentation, baking) are obviously very influent on the aroma.

NEOFORMED COMPOUNDS AND PARTIAL BAKED BREADS

The concept of partial baking is often linked to the appearance of crust colouration, which is the criterion used to determine the end of partial baking. In fact, the start of the colouration of the crust depends rather on the moisture of the crust than on the time. The control of the duration of the partial baking step could be improved by a control of the steaming procedure which could be continuous during the partial baking instead of being done in one "shot" at the beginning of baking. Such a procedure can also help in retarding the appearance of acrylamides (neoformed compounds) as presented in [68].

GLYCAEMIC INDEX OF PART BAKED BREAD

A lot of research effort is devoted both by scientists and industrial companies to reduce the glycaemic index (GI) of food. In most cases, a focus is done on the formulation of food, whereas poor or little attention is paid to the processing conditions. This aspect is one of the focuses of the EU-FRESHBAKE project. A detailed report is proposed in [69]. A comparative test showed that frozen partially baked bread (PBF) had a significantly lower GI than conventional breads as shown in Figure 18. Frozen part baked bread making process resulted in a GI of 60.66 whereas conventional bread making processes (with full baking) resulted in a GI between 73 and 83. Two assumptions were proposed to explain the lower GI. On the first hand, the lower degree of baking obtained with PBF yield in less swelling of the starch granules (as shown by SEM images – see Figure 19 [70]) and therefore in a reduced GI. On the other hand, a possible explanation is that freezing may result in the formation of starch crystallites that would be less digestible.

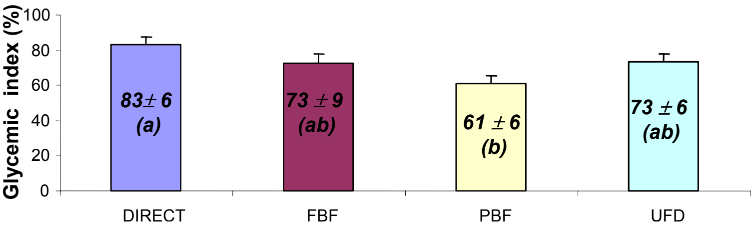


Figure 18

Impact of the baking process on Glycaemic Index. DIRECT = conventional direct baking, FBF = Fully baked frozen, PBF = Part baked frozen, UFD = unfermented frozen dough. [69]

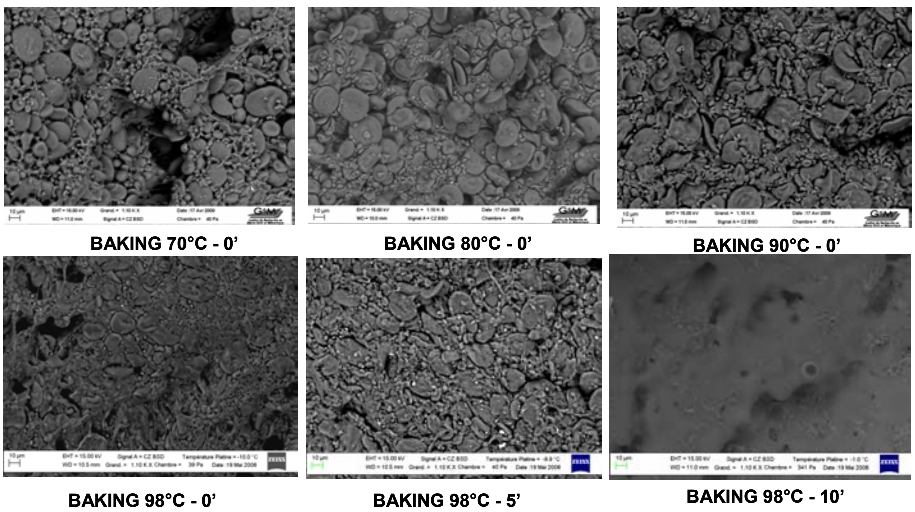


Figure 19

Impact of the impact of the baking duration on the microstructure of the crumb (Environemental SEM) [39]

The impact of the baking process on the integrity of starch granules has been studied by [39, 70] Pictures (see Figure 19) were taken by Scanning Electron Microscopy in environmental mode (the sample was not coated with metal; it was observed with a controlled partial vapour pressure). Baking was done on a miniaturized baking system with well defined time temperature history. When 0' time is indicated, it means the crumb has been heated from 20 °C to the indicated temperature in 5 minutes and cooled down to room temperature thereafter. One can see that the starch granules are more and more deformed when increasing the baking duration. There is also more compounds leached outside the starch granules, which is likely amylose. For the longer baking, ghosts of the starch granules are almost non identifiable.

I-5 Fully baked and frozen bread

DESCRIPTION OF THE TECHNOLOGY

Frozen conservation of fully baked products (FBF) was the first application of freezing in the baking trade. This process is largely used for bakery products with high levels of fat and sugar: ex. buns, soft rolls, sweet dough, flat bread & yeast raised donuts and Berliners. It can also be applied to lean bread dough formulation. FBF bakery products are frequently used by fast food chains and institutional food services.

This type of products gives the manufacturer the advantage of limited freezer sensitivity upon distribution but the disadvantage of the highest storage & distribution cost. The advantages of FBF products for the end-user are multiple: availability all day, fastest response in time, no need for skilled labour and no in store bakery (ISB) investment. Fully baked products are shipped frozen and can be left at room temperature up to 5 days. The commercial look of fully baked products is less positive as the products are not freshly baked on the premises.

QUALITY OF FBF AND SHELF LIFE

Quality and shelf-life of bakery products are normally limited by a physicochemical deterioration called staling, leading to hard and crumbly texture and loss of fresh-bake flavour. Bread staling is a complex process. Starch retrogradation, specifically amylopectin retrogradation, has been identified as a key factor but it is becoming increasingly evident that amylopectin retrogradation alone is not responsible for bread staling. Evidence has accumulated that gluten proteins are important and that gluten-starch interactions play a role. Moisture transfer seems also to be involved in staling [58]. Next to staling, microbiological spoilage is a second form of bread deterioration.

Deep freezing of fully baked bread can be used to prevent the process of staling and inhibiting microbiological activity in bread. However, when the maximum benefit is to be achieved it must be taken into account that after thawing, staling resumes and appears to proceed at a faster rate than in the unfrozen loaves [71]. During the freezing and thawing process the bread passes through the temperature range at which it stales fastest. Bread stales more rapidly in the refrigerator than at ambient temperatures. The fact that the staling process gets faster as the temperature is reduced is explained by polymer theories of recrystallization which apply to partially crystalline polymers such as starch. The polymerization of polymer systems such as gelatinized starch are actually two separate events. The first of these two events is nucleation and the second crystal growth or propagation. Crystal nucleation is favoured at lower temperatures but crystal growth is favoured at higher temperatures when polymer chains are more mobile so that double helixes can aggregate or pack together to form crystallites. So we can conclude that the rates at which optimum nucleation and growth occurs are different. The results is that as the temperature of the product is reduced towards **the glass transition temperature (Tg)** the rate of the overall crystallization process increases to a maximum, then falls. At storage temperatures below 0°C, the most important single parameter which determines the storage stability potential of a food product is the glass transition temperature [71]. [72] introduced the idea that foods could achieve mechanical stability if the freeze-concentrated, unfrozen water fraction is a glassy state. For maximum storage stability a product must be stored at a temperature below its Tg [72]. [73] indicated that frozen storage stability is controlled by the difference between the freezer temperature and the glass transition temperature. Different values for Tg of bread, below which the staling process is inhibited, are published: Levin and Slade (1990) report Tg of bread at -7 to -9 °C; [74] publish -18 to -20 °C while [52] measured -25 to -30 °C. The determination of Tg depends a lot on the technique used (calorimetry, mechanical approach) and on the moisture of the crumb. **One may consider a temperature level of -20 °C to -25°C as a temperature for which frozen storage of bread products is stable**. The freezing of bread can be achieved in a variety of ways. The most common way is cold air blown over the product. The air temperature and the air velocity will affect the rate of heat removal or freezing rates. The effect of freezing rates on bread crumb quality is related mainly to ice crystal formation. Slow freezing favours the formation of large crystals, while fast freezing favours the formation of small ice crystals. Freezing rates control the amount of unfrozen water in the matrix. This has a significant effect on the glass transition temperature of the product. **Faster removal of the heat enables the product to achieve a glassy state at a higher temperature, thus improving its frozen storage stability** [75]. It is important therefore to reduce the product temperature below its Tg as quickly as possible. Dehydration of the loaves is likely to occur with prolonged frozen storage time. This arises from the low humidity of the frozen air and can be avoided by adequate wrapping of the products in low-moisture permeability film and close packaging of the frozen loaves **in the freezer** [71]. On the opposite,

during freezing, bread must not be wrapped to ensure a good heat transfer and a rapid freezing. Indeed, during freezing a significant part of the refrigeration energy is taken by the fans (ca. between 30 and 50 % of the total refrigeration energy). In the case of wrapped product, the air layer located between the product and the packaging will act as a thermal insulation resulting in a situation that could be almost compared to static freezing (still air). In such conditions, the freezing time will be extended resulting in a higher demand from the fans and in turn in a reduced energy efficiency (higher specific energy demand).
As a conclusion, it can be recommended to freeze fully baked bread as well as part baked bread once they are correctly chilled after baking (ie temperature of around 30°C). Then freezing of individual unwrapped breads can be done if possible rather quickly and in a low temperature air (set point of around -25°C to -30°C). Bread can be removed from the freezer and transferred to frozen storage once their temperature is around -15°C (to save energy – see further chapter on energy for freezing). Frozen storage temperature can be around -20°C or lower even though this will induce a higher energy demand. Modified atmosphere packaging combined with specific formulation (i.e. use of sourdough, use of calcium propionate, …) may be a good alternative to frozen storage resulting in a significant reduction of the total energy demand.

I-6 Packaging

INTRODUCTION

Breads and cakes are category of baking products with comparatively low shelf-life. These products have high moisture content (>12%), supple texture and high water activity between 0.6 to 0.85 with low resistance and tendency to crumble and go stale. Since it contains hydrated starch it is prone to staling, thus limiting its shelf-life. It has low fat content and short distribution life hence it does not need protection against oxygen. Bread is also susceptible to loss in aroma/flavour, so the packaging material used must prevent pick up of undesirable off-flavours [76]. The undesirable changes during storage include moisture loss, staling and loss of freshness. The inner portion of bread has equilibrium humidity in the range of 90%. Hence a re equilibration of moisture will occur during the first steps of storage between the crumb and the crust. This results in a hardening of the crumb. A bread with crust stales faster than without crust as shown by [77]. Staling of bread involves several aspects linked to moisture re distribution between crust and crumb and also in trapping of water molecules by recrystallised starch macromolecules resulting globally in dehydration of the gluten network and in firming of the crumb. The kinetic of staling depends on the formulation and on all steps of the bread making process. It starts within 3-4 days of manufacturing [78]. An effective packaging material must protect the bread until staling occurs.

Hence the packaging material selected must conserve the moisture content, prevent staling and keep the bread in a fresh condition as long as possible. The ideal bread packaging material must be attractive, strong and inexpensive. It must have adequate moisture barrier properties to improve the shelf-life, able to run on automatic machinery and lastly should protect the shape of the product. [79].

PACKAGING OF FRESHLY BAKED BREADS – VENDING SHOP – BAKERY RETAIL:

The choice of the packaging material depends on the type of storage. Packaging for short period of time such as bread sold in vending shop can be done with material having minimal barrier properties. Excessive moisture barrier has effect of promoting mould growth on the bread and allows the bread to become soft. Beside, if a poor barrier film is used, the bread will tend to dry out and stale. The most commonly used material for bread packaging used to be glazed imitation parchment (GIP), impregnated on both sides with a paraffin wax contained polyethylene (PE) and other additives, or cellulose film.

PACKAGING OF FRESH OR FROZEN BREADS FOR LONG TERM STORAGE (several weeks)

Bread is today usually packaged in a low density polyethylene (PE-LD) bag (nearly 80%) in which the end is twisted and sealed with a strip of adhesive tape. This form of packaging helps retard one mode of deterioration in bread i.e., moisture loss. Plastics films in combination such as linear low density polyethylene (PE-LLD) and PE-LD and polypropylene (PP) are also used (Table 2). Also, auto-bagging machines require high slip PE resin i.e. pouches with good openability. PE-LLD/PE-LD bags of 1 to 1.5 mm thickness secured by plastic clip or twisted wire ties are normally used. Modified atmosphere packaging allows a better preservation of bread. In particular CO2 has a beneficial effect. 20 % and 70 % CO2 concentration in overhead of part baked bread allow an improvement of mould free shelf life by 80 and 200 % respectively [71] – page 246.

Table 2

Selection of packaging materials used for bread

The packaging material must possess moderately effective moisture barrier properties.

Food application	Packaging material	Packaging material abbreviations
Fresh bread, bun, sandwich	Nitrocellulose coated cellophane	MS
	Low density polyethylene	PE-LD
	Polypropylene	PP
Bread, sandwich, frozen food	Linear low density polyethylene	PE-LLD
Bread crumbs	Polyethylene/Polypropylene	PE/PP
Baked products	Poly(ethylene terephthalate) /Polyethylene	PET/PE
	Polyamide (Nylon)/ Low density polyethylene	PA/PE-LD
Baked products - Modified Atmosphere Packaging (MAP)	Polypropylene/ Ethylene vinyl acetate	PP/EVAC
	Metallized poly(ethylene terephthalate) /Polyethylene	PETmet/PE
	Polypropylene/Low density polyethylene/Ethylene vinyl acetate	PP/PE-LD/EVAC
	Oriented poly(ethylene terephthalate)/ Polyvinilydene chloride/ Polyethylene- Poly(vinyl chloride)/ Polyethylene	OPET/PVDC/PE-PVC/PE
	Oriented metalized poly(ethylene terephthalate)/ Polyethylene	OPETmet./PE
	Oriented poly(ethylene terephthalate)/ Polyvinilydene chloride/ Polyethylene	OPET/PVDC/PE
	Polyamide/ Polyethylene	PA/PE

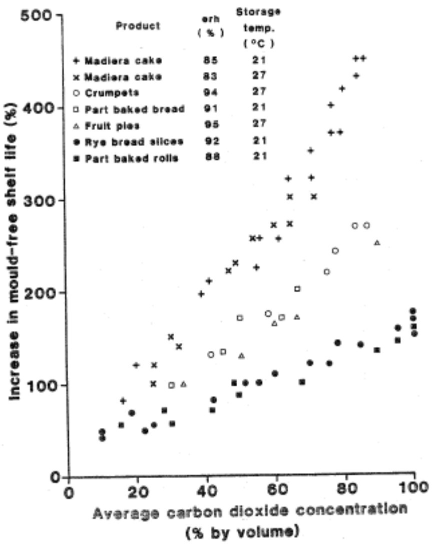


Figure 20

Impact of gas concentration of shelf life of packed breads – reference [71]

The oldest flexible film to be used was cellophane because of its excellent gas barrier properties and heat sealability. MST, MSAT, Coated Cellophane (MXXT) offer excellent moisture barrier, heat sealability and gloss. Cellophane became less popular when it became too expensive and with the introduction of new materials with better properties.

In recent years this combination of material has been replaced to a large extent by Biaxially Oriented Polypropylene film commonly known as BOPP. For less demanding applications BOPP monofilm is used while for higher quality products, duplex BOPP or BOPP combinations (pearlised or metallised) such as BOPP/PE, BOPP/PET etc. are used (Table 2).

II – Energy demand for bread making

II-1 Introduction on Energy Assessment & Energy Indexes

ENERGY UNITS

The official unit for energy in the International System is the Joule (J). In the case of processes powered by electricity, the kWh is more often used (kWh = Kilo Watt Hour). One kWh is equal to 3.6 kJ. For practical reason, the energy is often given in MJ (Mega Joule or 10^6 Joule). The most commonly used units are presented in

. All experiments done in EU-FRESHBAKE have been carried out with equipments powered by electricity. However, the methodology used for the energy balance can be adapted to the case of oven powered by fossil energy. Counting the energy consumption is often related to a unit of mass of product (kg).

Table 3

Units used for energy

	Joule	**MJ Mega Joule**	**kWh**	**Calorie**
1 Joule =	1	1.E-06	2.78E-04	0.23923445
1 MJ = Mega Joule	1.00E+06	1	277.8	2.39E+05
1 kWh =	3600	0.0036	1	861.2
1 Calorie =	4.18	4.18E-06	1.16E-03	1

In the case of an oven powered by fossil energy (gas, fuel, …), the comparison with electrical energy can be tricky. Indeed, one Joule (J) of electrical power dissipated in a resistance will provide 1 J of heat. On the other hand, the energy contained in one m^3 of fossil fuel (very often the volume is considered instead of the mass to count the fossil fuel) will be converted to heat via combustion. The efficiency of the combustion is function of the amount of air used and of the temperature of the exhaust gases; in brief it depends on the design of the equipment. A value of 0.8 can be considered as a minimal value; this is based on Lower Heating Value which means that the heat that could be recovered via condensation of the moisture contained in the exhaust gases is not considered. The fumes that will be extracted of the combustion chamber represent wasted energy. The comparison between electric and fossil energy could start at the level of basic energy used to produce electricity. However, the comparison is quite complicated because of the variety of technologies used to feed the electric network of a country (i.e. mixing nuclear power, hydro power, gas power, …). Values of the efficiency in electricity generation and therefore on the technology used to make the electricity are shown in Figure 21.

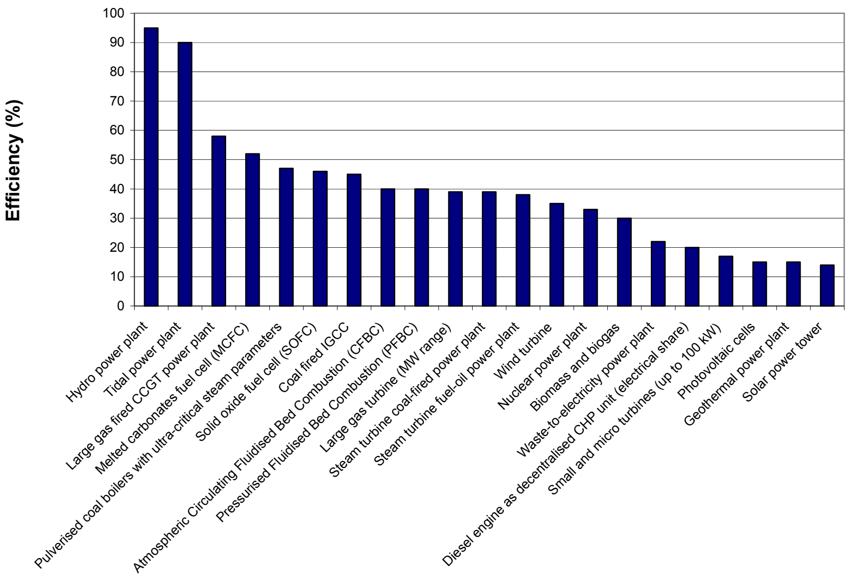


Figure 21

Efficiency in Electricity Generation from "Energy efficiency in power plants", power point presentation by Frans van Aart (KEMA), Conference "Energy Efficiency in IPPC installations", Oct. 21, 22 2004 Vienna – AUSTRIA
http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/industrie/IPPC_Konferenz/donnerstag_kraftwerke/6-_Van_Aart.ppt

A synthetic comparison is proposed in the Figure 22 taking into account the conversion factor for electricity production for a gas powered electric station (~0.58) and the efficiency ratio in the case of direct combustion of fossil energy (~0.8). The global trend is that it is more efficient from the conversion point of view to use fossil energy in a baking oven. Fossil energy is largely used in the big baking industry because of its high specific energy is high (high electric power demands big cables and infrastructure…) and because it is less expansive. Beside, most of the medium scale oven and almost all small scale oven are powered by electricity because it is more convenient and flexible and there are less safety constrains; this is the case of small and medium size baking industries, craft bakeries, baking stations, ….

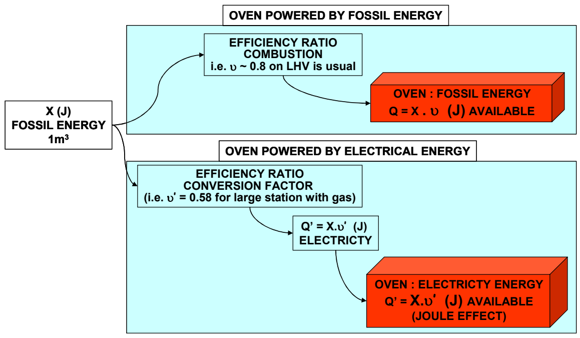


Figure 22

Synthetic scheme for the comparison of an electric and of a fossil energy powered ovens.

II-1-a ENERGY DEMAND OF A GIVEN UNIT OPERATION

Several statements can be considered to present the energy efficacy of a given unit operation (UO) such as baking, fermentation, …. The Specific Energy refers to an amount of energy (in kJ, MJ, …) related to a “functional unit” which is most of the time one kg of food. The Specific Energy demanded by the equipment (or process) for a given unit operation (Q_{SEP} for Specific Energy Process) represents the global primary energy demanded by given equipment during a given operation for 1 kg of food. The Q_{SEP} encompasses the energy effectively “taken” by the product named Q_{SEF} (Specific Energy Food) and of course other demand such as energy losses toward the ambiance (Q_{LOSS} = heat losses through the walls, renewing of air …) as indicated in equation (1) and presented in Figure 23.

$$Q_{SEP} = Q_{SEF} + Q_{LOSS} \quad (1)$$

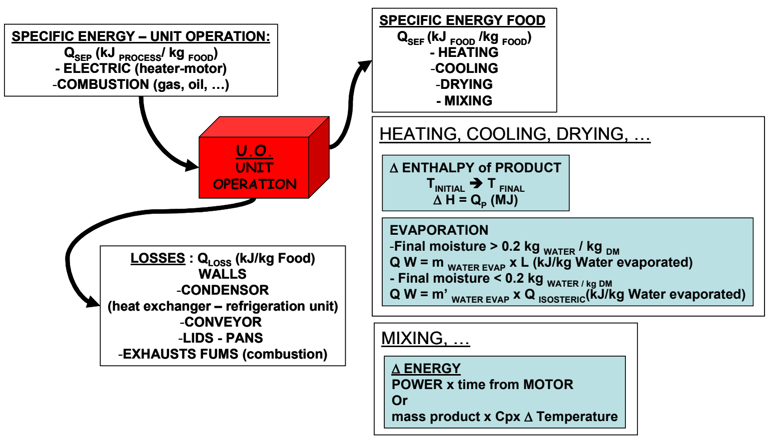


Figure 23

Scheme of energy evaluation in a given UO (Unit Operation).
The Specific Energy – Unit Operation (Q_{SEP}) can be subdivided in two principal amounts:
Q_{LOSS} and Q_{SEF} (Specific Energy Food).

The energy consumption depends of course on the equipment that is used. All ovens do not have the same performance for example. When comparing the energy demand of technologies used for bread making, it is difficult to design a unique procedure or to give a unique value. Indeed, there are many ways of using a given equipment. The energy demanded by the product can be determined accurately by calculating (Q_{SEF}). It is necessary to make experiments to determine the specific energy demand of the Unit Operation (Q_{SEP}) using an energy counter. In the case of equipment powered by electricity, a specific energy counter can then be used (see Figure 24). It consists in counting the overall electrical energy demand of a process. In Figure 25, one can see the measure of the energy demand of a freezer during freezing of part baked bread. In this example, the set point of the temperature of the air in the freezer was -20 °C; one can see that the motor of the compression unit (refrigeration system) is switched on and off by the controller of the freezer which shows that the refrigeration system is too powerful for the refrigeration energy demanded by the product being frozen. The energy demand of the product corresponds to the total energy from the beginning until the end of the freezing process. The criterion used for the “end” of the process must be clearly defined by defining a given final temperature to be reached by the product or any specific parameter. In the case of fossil energy, a mass or a volume flow meter must be used and the consumption must be converted in energy in Joule.

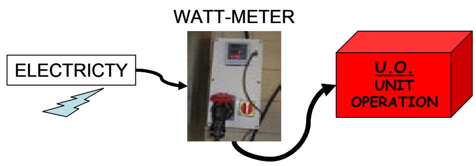


Figure 24

Scheme on energy measurement using a “Watt Meter” (electricity counter) with a Unit Operation.

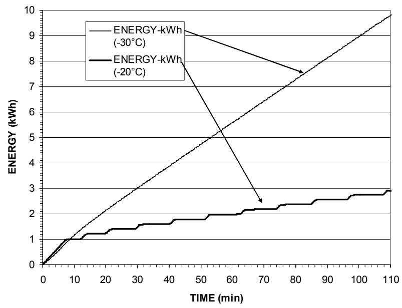


Figure 25

Electrical energy (kWh) in function of time during the freezing of part baked bread. With a -20 °C set point, the compression unit (refrigeration system) is undergoing “run” and “stop” periods as can be observed on the energy plot. Between two run periods, the energy demand corresponds to the energy for the fans only.

ENERGY EFFICIENCY INDEX (EEI) OF A GIVEN UNIT OPERATION

The assessment of the efficiency of a given UO can be done by measuring the Energy Efficiency Index (EEI). The EEI will give an indication of the efficacy of energy transfer within the equipment from the primary energy to the product. It will be obtained in dividing Q_{SEF} by Q_{SEP} as proposed in equation (2). In our EU-FRESHBAKE tests, the QSEP was calculated from the sum of the energy for baking plus the energy for reheating the oven (set point ready).

$$EEI = Q_{SEF - GIVEN\ PROCESS} / Q_{SEP - GIVEN\ PROCESS} \quad (2)$$

ENERGY RATIO INDEX (ERI) OF A GIVEN UNIT OPERATION

The Energy Ratio Index (ERI) can be used to make a comparison between two different operating conditions using the same equipment OR between two different equipments using the same operating condition. The ERI can also be used to compare a succession of Unit operations using the same equipement or two different equipments. The ERI is obtained from the ratio of the Q_{SEP} for the two conditions that are considered as proposed in equation (3).

$$ERI = Q_{SEP - NEW\ PROCESS} / Q_{SEP - REFERENCE\ PROCESS} \quad (3)$$

II-1-b ENERGY OF A GIVEN PROCESS (SUCCESSION OF SEVERAL UNIT OPERATIONS)

A process can be defined as a succession of several unit operations. For example in the case of bread making, mixing, fermentation, baking, post baking chilling, eventually freezing are as many UO that can be considered. One of the main important issues in the EU-FRESHBAKE project is the question of energy consumption needed in each of the Bake Off Technologies compared to a reference process. Above all, it is important to have an instrument like an index number, to be able to express objectively the differences in energy consumption through the implementation of different BOT processes.

Considering the globosity of a process, one can define an EEI and an ERI indexes, taking into account (eventually) different aspects such as preheating of an equipment (oven) or even pre refrigeration of a freezer, energy demanded to come back to the initial set point (i.e. reheating of an oven before going for a further baking)…. . As an example, the expression of the ERI for the proofing step is proposed in equation (4). An example concerning the determination of the ERI for a full process (new process against reference process) from kneading to freezing is proposed in equation (5).

For EEI a general equation (6) is proposed for the unit operation. EEI for a full process of part baked and frozen food is proposed in equation (7). The following under scripts have been used :

PH = Preheating (Room Temperature to set point) WT = Waiting time (Hold set point)

PC = Pre-cooling (Room Temperature to set point) RH = Re-heating (actual point to set point)

$$ERI_{\text{Process, Equipment}} = \frac{\sum \text{Energy of } \left. \frac{PH_{\text{Proofing chamber}} + \text{Proofing}}{\text{kg pastry}} \right|_{\text{new process-equipment}}}{\sum \text{Energy of } \left. \frac{PH_{\text{Proofing chamber}} + \text{Proofing}}{\text{kg pastry}} \right|_{\text{reference process-equipment}}} \quad (4)$$

$$ERI_{\text{Process, Equipment}} \text{ [kJ/kg pastry]} = \frac{\sum \text{Energy of } \left. \frac{\text{Kneading} + PH_{\text{Proofing chamber}} + \text{Proofing} + PH_{\text{Oven}} + \text{Baking} + WT_{\text{Baking}} + RH_{\text{Baking}} + PC_{\text{Freezer}} + \text{Shock freezing}}{\text{kg pastry}} \right|_{\text{new process-equipment}}}{\sum \text{Energy of } \left. \frac{\text{Kneading} + PH_{\text{Proofing chamber}} + \text{Proofing} + PH_{\text{Oven}} + \text{Baking} + WT_{\text{Baking}} + RH_{\text{Baking}} + PC_{\text{Freezer}} + \text{Shock freezing}}{\text{kg pastry}} \right|_{\text{reference process-equipment}}} \quad (5)$$

$$EEI\ [\%] = \frac{\frac{\text{kJ (Energy of Equipment)}}{\text{kg pastry}}}{\sum \frac{\text{kJ } (\Delta \text{ Enthalpy})}{\text{kg pastry}}} * 100 \quad (6)$$

$$EEI\ [\%] = \frac{\sum \frac{\text{Kneading} + PH_{\text{Proofing chamber}} + \text{Proofing} + PH_{\text{Oven}} + \text{Baking} + WT_{\text{Baking}} + RH_{\text{Baking}} + PC_{\text{Freezer}} + \text{Shock freezing at } -18°C}{\text{kg pastry}}}{\frac{\text{kJ } (\Delta \text{ Enthalpy})}{\text{kg pastry}}} * 100 \quad (7)$$

II-1-c ENERGY NEEDED FOR THE PRE HEATING OR THE PRECOOLING OF AN EQUIPMENT

Taking into account the preheating (oven) or the precooling (freezer) of equipment can result in a significant difference in the specific energy. The situation is comparable to evaluating the consumption of a plane taking into account (or not) the fuel demand for take off. In the case of a baking oven, apart of the energy demanded to preheat the internal parts of the oven the preparation of the device affected to steam production ("steam box") can demand a lot of energy. It is quite common to have 30% of the total power of the heating element of a baking oven that are affected to steam preparation. The energy demand corresponding to the production of steam at the beginning of the baking can be very high and represents a lot of energy. It is thus necessary to store the energy so that the oven can vaporise the amount of steam needed. . Some of the data provided in this report have been evaluated taking into account the preheating and/or the precooling energy as well as the energy needed to come back to the initial set point (for example reheating of an oven before a second baking). This detail is important and must be carefully considered for any evaluation of the total energy demand.

II-2 Enthalpy of bread and dough and energy related to evaporation

II-2-a-ENERGY LINKED TO EVAPORATION OF WATER DURING BAKING

Baking can be considered as a drying process. The formation of a crust is the result of different steps. At first, the temperature of the surface of the bread must pass the 100 °C threshold corresponding to the boiling temperature of water at atmospheric pressure. Then the moisture is evaporated from the surface of the bread. The temperature of the surface of the bread will go higher than the boiling temperature once enough water is evaporated allowing to quit the boiling temperature level. The Maillard reactions are made of several reactions which will start above specific temperature and for selected values of pH. The colouration of the crust and the development of specific aroma will accompany the crust colouration.

It can be misleading of not considering the energy linked to moisture loss during baking. In our case, the energy linked to evaporation has been evaluated separately for baking. As a first evaluation, the energy linked to the moisture evaporation during baking was evaluated as being equal to the mass loss multiplied by the latent heat of evaporation of water as proposed in equation (8). :

$$Q_V = m_{V-100}\ L_V \quad (8)$$

With m_{V-100} = water vaporized from the crust below or at 100 °C (kg) and L_V = 2258 kJ/kg

In fact, the evaluation of the heat needed to dry the crust according to equation (8) is valid in the case of water content higher than around 0.2 g water / g product (wb). Above 100 °C, and in fact from a certain moisture content of the crust, the extraction of the water requires more energy than just the latent heat of vaporisation. For lower values of moisture, the energy to consider is called the isosteric heat of sorption [80]. It corresponds to the latent heat of evaporation plus a term linked to the sorption or desorption energy as proposed in equation (9) with L_{WATER} = latent heat of vaporization of water, R the constant for perfect gas, T the temperature in Kelvin, a_W the water activity and x the absolute water content. The isosteric heat can be up to 2 times higher than the latent heat of evaporation. The lower the water content, the higher the isosteric heat.

$$Q_{ST} = L_{WATER} + R.T^2 \left[\frac{d \ln(a_W)}{dT} \right]_x \qquad (9)$$

II-2-b ENERGY DEMAND FOR THE DOUGH (FREEZING or BAKING) : ENTHALPY FUNCTION

The enthalpy (quoted H) refers to a value given in J/g or most of the time in kJ/kg provided as function of temperature. The enthalpy function is a state function; therefore a reference temperature T_{REF} for which $H(T_{REF})$ is equal to zero must be arbitrarily chosen. In the case of food products, the temperature of -30 °C, -40 °C or even -50°C is usually chosen.

It is important to understand that all the water (moisture) contained in a food will not be transformed in ice during freezing. The total water content can be divided in two quantities: the freezable water and the non freezable water. The non freezable water corresponds to water trapped in capillarity or bounded to the dry matter of the matrix. The only way to determine the amount of freezable water is to make a test using a calorimeter (DSC).

In the case of baking, the energy needed to bake the dough has been considered as the enthalpy difference of the dough between the initial temperature (for example end of fermentation) and the baking temperature of the crumb (98°C). The energy corresponding to the heating of the surface of the bread above the baking temperature of the crumb (98°C) has not been considered for practical reason. Indeed, it is very difficult to evaluate the temperature gradient in the surface of the bread during baking. The energy corresponding to the moisture loss of the surface of the bread has been considered separately. The energy corresponding to the biochemical reactions that occur in the dough during baking has been determined by calorimetry (DSC). This energy encompasses schematically the gelatinisation of the starch and the coagulation of the gluten proteins. A value of 1.2 J/g has been used (see [81]).

The initial freezing point temperature (T_{IFP}) may change a little bit depending on the amount of water and on the amount of dissolved salts and sugar. In the case of bread dough, an initial freezing point of -3°C has been chosen. It represents a realistic mean value. An example of enthalpy function of dough is proposed in ANNEXE 3 with and initial freezing point of -3°C and a reference temperature of -50°C. The data used for these calculations are based on determinations with DSC methods.

II-2-c ENERGY DEMAND FOR THE BREAD : ENTHALPY FUNCTION

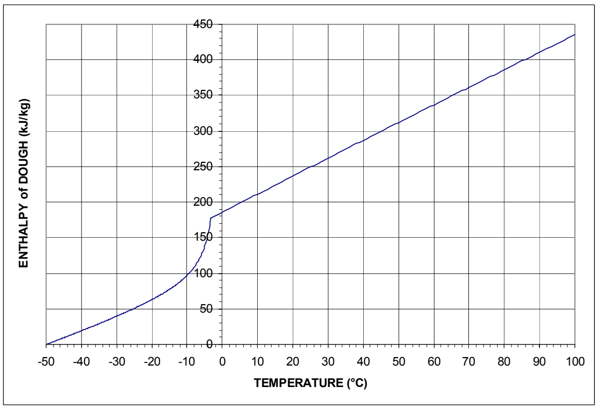
In the case of a bread, two domains must be considered; the crust and the crumb. The initial freezing point of crumb is around -5°C; it is lower to that of dough for two reasons. At first, some water has been lost during baking and second, the coagulation of the gluten that occurs during baking accompanied by the gelatinization of starch captures some water. The corresponding loss of free water depresses the initial freezing point temperature T_{IFP}.

Concerning crust, the situation is much more complex. Indeed, the definition of the crust domain is very difficult and can be understood and differentiated using different criteria:

- "Crust is the coloured outer surface of the bread" : thickness < 1mm
- "Crust is the domain in which a certain ratio of non gelatinized starch is still present" : thickness < 2 mm
- "Crust is the domain for which there is a significant difference in moisture vs. the crumb": thickness < 5 mm
- "Crust is the domain that separated from the crumb by its mechanical integrity": thickness < 5 - 7 mm

All these statements can be considered as valid and correspond physically to different domains. In the case of the EU-FRESHBAKE project, it has been considered that "crust is the domain that separated from the crumb by its mechanical integrity". The separation of crust and crumb is then done by collecting manually the centre of the bread loaf and by scrapping the crumb out of the crust without the nails, just using the tips of the fingers.

An example of enthalpy function of bread with a crust crumb ratio of 0.2 is proposed in ANNEXE 4 with and initial freezing point of -5 °C for the crumb and – 10 °C for the crust. Of course, different crust – crumb ratio, and different moisture may be encountered for conventional bread (with a fully "developed" and dried crust) and for part baked bread for which the crust will be almost similar to the crumb in terms of moisture content and of initial freezing point.



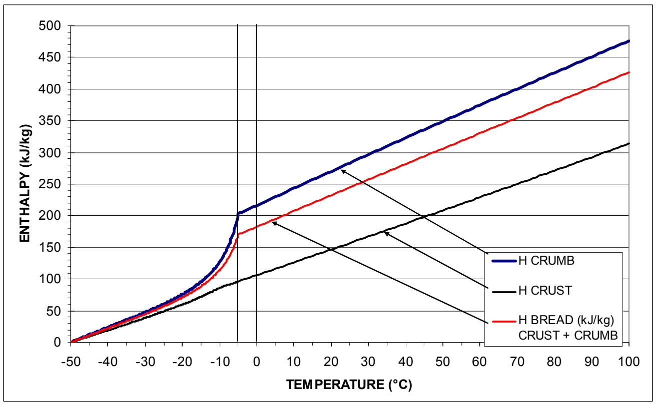


Figure 26

Examples of enthalpy functions of dough (left – see ANNEXE 3) and bread (right – see ANNEXE 4). The enthalpy difference between two selected temperatures allows the determination of the energy needed to heat or to refrigerate a product. In the case of baking, additional energy is needed for the chemical reaction linked to baking. The corresponding energy is little in comparison to the enthalpy change and can be neglected for a first approach of the energy demand.

II-2-d ENERGY DEMAND FOR STEAMING

At the beginning of baking, a steaming is done in the oven once the oven is closed. The objective of the steaming is to start the baking in a saturated humid air. Such condition will ensure the plasticisation of the crust which will better support the expansion of the loaf at the beginning of baking (oven rise).

Steaming is an important issue with respect to energy demand. A specific system is usually designed in the oven ("steamer" or "steam box") which consists in a preheated metallic surface on which water is spayed once the steaming is demanded. It is important to quote the amount of steam as a volume of water and if possible to refer the amount of steam (in ml of water) to the volume of the oven (in litres or in m^3).

Steaming has also an important impact on the quality of bread. During baking, the bread is exposed to high temperature. If the product is a fermented dough, the intense heat transfer and the corresponding temperature rise results in a expansion of the fermented dough caused by two mechanisms: (i) thermal expansion of the gas contains in the cells of the dough and (ii) vaporisation of the liquid CO2 and of the alcoholic compounds dissolved in the liquid phase of the dough. Steaming is done to plasticise the surface of the fermented dough. This will facilitate the expansion of the bread. Steaming has also a great effect on the colour and in particular the glossiness of the crust. A lack of steaming will result in a mate crust. A lack of steaming may also result in a risk of overpressure and therefore in a risk of tearing of the crust and then on a default of the shape of the bread. For lower amount of steam, the crust will have a mat outlook which can be desired for crispy rolls (baguettes). A lower amount of steam will favour the opening of the cut at surface of the bread, which will receive more pressure from the expanding dough / crumb at the beginning of baking. A larger steaming will result in a more glossy crust but with less opening of the cut.

In the case of partially baked bread, steaming is also needed for the first baking and eventually for the second and final baking. If the partially baked bread is frozen, a partial or a complete thawing before the second baking is usually recommended. It will result in a more uniform second baking and in a better warm up of the inside of the crumb as discussed before. The energy needed for steaming has been evaluated by knowing the amount of water that has been injected for the steaming at the beginning of baking. Equation (10) has been used with the latent heat of evaporation at 100° C (L_V = 2258 kJ/kg).

$$Q_{STEAMING} = m_{Steam} \, L_V \qquad (10)$$

II-2-e ENERGY LINKED TO EVAPORATION DURING POST BAKING CHILLING

Not considering the energy linked to moisture loss during post baking chilling (evaporative cooling) can result in significant errors when making an energy balance. In the case of post baking chilling, the mass of water loss is difficult to assess and depends on the refrigeration conditions (air moisture, air temperature, …). One can see in Figure 27 a graph presenting the relative importance of evaporative cooling and of convective cooling [46]. Evaporative cooling corresponds to the amount of heat corresponding to the water that evaporates from the bread (mass of water loss x latent heat of evaporation). Convective cooling represents the heat that is removed by the heat capacity of the cold air flowing around the bread. The latent heat of vaporisation is 2258 J/g at 50°C. A 1% loss of water represents 10 g for 1 kg of bread or 22580 J which represents 10.6 % of the heat load to remove from the bread (22580 J divided by 212300 J/kg which is the enthalpy difference from end of baking to the temperature of 20°C – see Table 4). The mass loss during post baking chilling is usually 2 to 3 % by mass. It means that the evaporative cooling linked to moisture loss represents between 20 and 30 % of the total refrigeration energy needed.

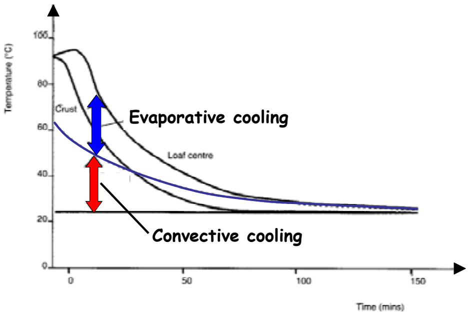


Figure 27
Evolution of the relative importance of evaporative cooling vs. convective cooling. [46]

	CRUST-CRUMB RATIO : 0.2 g Crsut/g crumb wb	MASS (g) wb	SPECIFIC HEAT Cp J/g/K	TEMP. INITIAL (°C)	TEMP. FINAL (°C)	delta T	Q (kJ)	%
BREAD	0.2	100						
CRUST	0.17	16.67	2.12	150	20	130	4.59	21.6%
CRUMB	0.83	83.33	2.56	98	20	78	16.64	78.4%
TOTAL	1.00	500					21.23	100.0%

Table 4
Table presenting the amount of heat to cool down end of baking down to 20 °C. The bread has a 0.2 crust – crumb ratio.

II-3 Energy demand for the Bake Off Technology: a benchmark study done during EU-FRESHBAKE

A benchmark study has been done during the EU-FRESHBAKE project consortium to assess the energy demand of selected bake off technologies (BOT) in comparison with conventional technology of bread making. In the results presented at follow, we have assumed (and it was the case for experiments) that the recipe was standardized and does not change in particular the amount of water. Even though several comparison have been done during the project, we have selected two tests for this report: A small scale test (TEST A) made with a deck oven of surface 1m² and a test done at a larger scale (TEST B) using a 4 decks oven with a total surface of 7.2 m². These two tests and the corresponding results are presented separately at follow.

II-3-a Energy demand; Small scale study (TEST A) to compare conventional and part baked frozen

- TEST A:

- ➔ **SMALL SCALE :** 1 DECK OVEN - 1 m² - 0.2 m³ (Electric)
- ➔ ~ 3.36 kg BREAD /TEST (~3.36 kg/m²) or less for some tests (to assess the impact of the mass of bread)
- ➔ CONVENTIONAL vs. PART BAKED FROZEN

All information linked to the experiments carried out in TEST A are available in reference [81]. The recipe is given in **Table 5**. Baking was done in a batch oven equipped with a sole made of "stone" (refractory concrete – thickness 14 mm). The volume of the oven was 0.253m³ and the internal surface 1.02 m² (0.85 x 1.2 m). Two different processes were used. In conventional baking (CONV), baking was done at 230°C for 20 min with 0.5 L of steam at start of baking. In the case of partially baked and frozen bread (PBF), baking was done with an initial set-point temperature of 190 °C which was maintained for 3 min with 0.2 L of steam at start of baking. After three minutes, the set-point temperature was lowered to 165 °C for 14 min. The baking profiles are presented in Figure 28 and Figure 29. In the case of PBF, the breads were partially baked, frozen and were stored for one week. They were then rebaked (final baking). The total corresponding energy for the two bakings and the freezing was considered in the total energy.

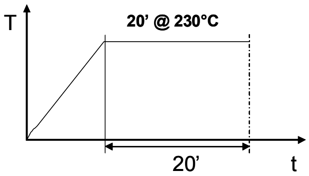


Figure 28
Set point of the oven for conventional baking process.

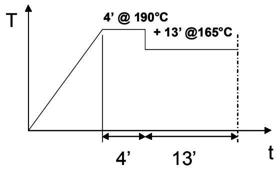


Figure 29
Set point of the oven for partial baking process.

The freezer was a blast air freezer (internal volume 1.5 m^3) equipped with 4 fans of 300 watts each which is maybe over rated for the equipment. The compression unit used R 404 a fluid. For each freezing test 13 kg (186 breads of 70 g each) of part baked bread was installed in aluminium trays. The aluminium trays were installed in a rolling rack which was laced in the blast air freezer.

Table 5
EU-FRESHBAKE recipe used for the assessment of the energy demand of selected baking technologies.

DOUGH RECIPE	
FLOUR	100 g
FLOUR MOISTURE	~ 14%
WATER	58 g
COMPRESSED YEAST	3 g
IMPROVER	1 g
SALT	1.8 g

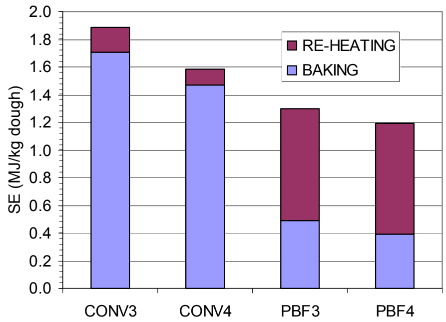


Figure 30
Effect of the opening of the chimney and of the baking conditions on the specific energy in MJ/kg dough [81]. Comparison between CONV 3 - CONV 4 (Conventional with chimney opened after 4 min or after 16 min) and PBF 3 – PBF 4 (Part baked with chimney opened after 4 min or after 16 min)

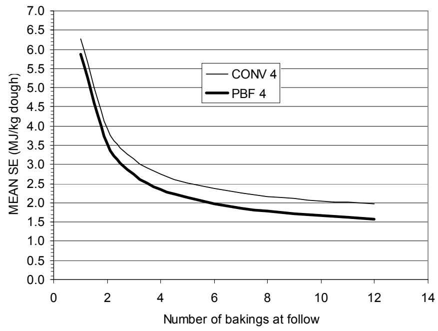


Figure 31
Effect of the number of batched baked after pre-heating on the specific energy (max. occupation ratio – see Table 4)[81]. The pre-heating energy and the energy for baking and re-heating are considered (proportionally to the number of baking).

One can see in Figure 30 that the energy demanded during the re heating of the oven (between two baking) is much larger for partial baking process than for conventional bread making procedure. This is due to the falling set point temperature of the part baked process as shown in Figure 29. The opening of the chimney had a larger impact on energy demand for conventional bread making because of the higher temperature. Indeed, all path ways of energy losses toward the ambiance (transfer through the wall, free convection in the chimney …) are driven by the temperature difference between the inside of the oven and the ambiance. One can see in Figure 31 the relative impact of the pre heating of the oven on the energy demand in the case of several baking done at follow. The greater the number of batches of baked breads, the lower the impact of the pre-heating energy. The pie charts presented in Figure 32 and in Figure 33 show that the losses to the ambiance represents the larger part of the energy taken by the oven. This encompasses the electronic control panel, the losses through the wall, the losses through the chimney and also the energy lost in the steam box. Indeed, the energy that is allocated for the steaming has been evaluated according to equation (10). The electrical energy that was effectively taken by the steam preparation system was almost double.

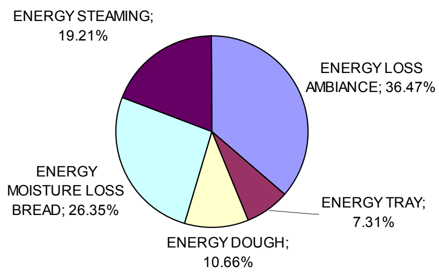


Figure 32
Energy for CONV 4 (baking + reheating).
Full occupation ratio. Chimney opened 4 min before the end of baking.

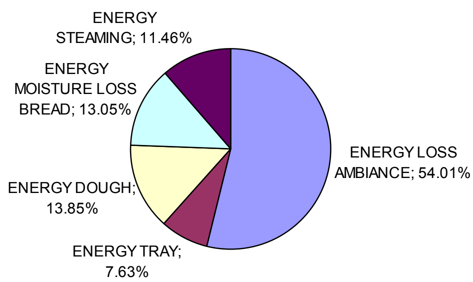


Figure 33
Energy for PBF 4 (baking + reheating).
Full occupation ratio. Chimney opened 4 min before the end of baking.

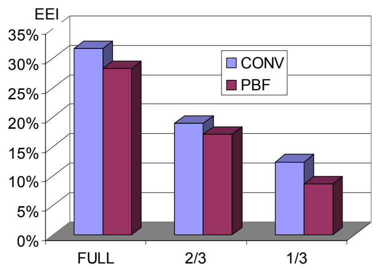


Figure 34
EEI for CONV 3 and PBF 3
The enthalpy of dough Q_D (30 °C to 98 °C) and the energy for evaporation Q_{ML} (Moisture loss during baking) are considered.

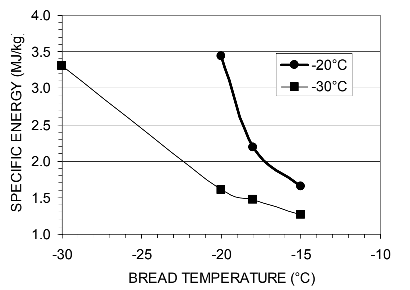


Figure 35
Specific energy demand of part baked bread in MJ/kg dough (initial temperature 30 °C) vs. final temperature of the bread.

The EEI (Energy Efficiency Index) is proposed in Figure 34. It shows that in our conditions, for a "full occupation ratio" which corresponded to 3.36 kg/m² the EEI was around 30%. This means that only 30% of the energy demanded during baking plus reheating the oven (to make it ready for a second baking) was effectively used by the dough for the rise in temperature plus the dehydration of the surface of the bread. The Specific energy for freezing is shown in Figure 35. One can see that it is much less energy demanding to freeze the bread at -30°C than at -20°C. This is explained by the fact that at -30°C the freezing is faster and then the energy taken by the fans is less even though the coefficient of performance of the refrigeration system (compression cycle) was lower at -30°C. The COP was 1.11 and 0.83 for set point temperatures of -20 °C and – 30 °C respectively (see ref. [81] for more details). The ERI is shown in Table 6 showing that in this set of experiments, the PBF (Part Baked Frozen) bread making procedure demanded around 2.2 times more energy than conventional. One could mention that by suppressing the freezing step and by using a home toaster (instead of a conventional oven) to prepare the bread, the part baked process can be comparable to the conventional process with the advantage of having fresh bread on demand and of reducing the wasted bread.

Table 6
Comparison of the energy demand (Specific Energy based on the mass of dough) between CONV (conventional) and PBF (part baked frozen) technologies. The most representative conditions have been considered for baking (condition 4) and freezing (final temperature -14.8 °C). The energy used for preheating the oven or for pre-cooling the freezer is not included.

Process	CONV (MJ/kg dough)	%	Process	PBF (MJ/kg dough)	%
BAKING CONV4	1.58	100.0%	PART BAKING PBF-4	1.19	34.1%
			FREEZING F2 to -14.8 °C	1.27	36.3%
			FINAL BAKING FB-PBF	1.04	29.6%
TOTAL	1.58		TOTAL	3.50	
ERI				2.21	

II-3-b Energy demand; Large scale study (TEST B) to compare conventional and part baked frozen

TEST B:

- ➔ **LARGE SCALE** : 4 DECK OVENS - 4 x 1.8 m² - 4 x 0.36 m³ (Electric)
- ➔ ~ 33.6 kg BREAD / TEST (~ 4.8 kg/m²)
- ➔ CONVENTIONAL vs. different Bake-off technologies

Freezing has been done in a blast air freezer with a volume of 5 m³. For each freezing, around 40 kg (540 breads of 70 g) of bread were used (occupation ration **8 kg/m³).** The freezer was equipped with 3 fans of 400 Watt each.

The following amount of water was used for the steaming in the different conditions: conventional, FBF and UFD = 500 ml, PBF, PBUF = 200 ml, PBF-improved = 200 ml, PFF-innovative step 1 = 400 ml.

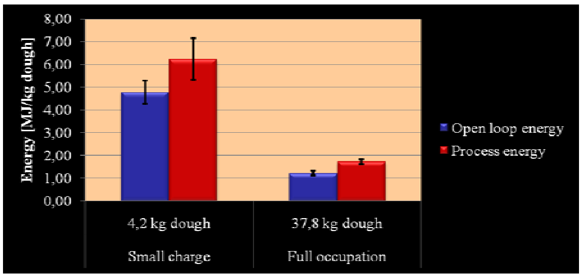


Figure 36

Comparison of the “open loop energy” (no baking – just keeping the oven warm” and “process energy” (energy during baking) as a function of the mass of dough in the large oven – conventional. For the smallest charge, the specific energy is much higher. (EU-FRESHBAKE Data)

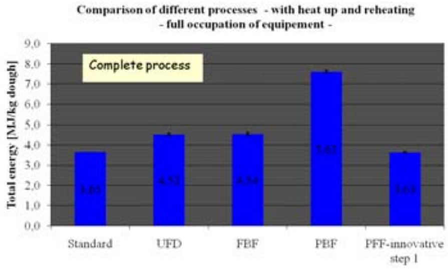


Figure 37

Comparison of the total energy demanded for the selected bake off technology processes. The pre heating of the oven plus the baking phase has been considered. (standard = conventional)

The energy demand for the baking (conventional) is shown in Figure 36. The impact of the amount of bread used for the baking is clear (small charge vs. full occupation or 4.8 kg bread per m²). The total energy for pre heating the oven plus one baking is shown in Figure 37. The partial baking process demands roughly two times more energy than the other selected baking processes. However, the fact of considering the preheating results in a much higher ratio of energy demand than when considering just the energy for baking as it was shown in Table 6. In this table the ration between PBF and CONV would be 1.41 [(1.19 + 1.04)/1.58) whereas it is 2.08 in the case of Figure 37 (7.62/3.65). The energy for freezing is shown in Figure 39 with a final temperature of the product of -18°C. The energy demanded is roughly half of the one demanded in the case of the small scale test mainly because of the power of the fan which was better adapted in condition B than in condition A. Indeed, the fan demand a lot of energy and in condition A there was 4 fans of 300 W each. The same amount of energy was installed in the freezer of test B with a volume of the freezer of 5m³ instead of 1.5 m³. The pie chart of the energy taken for the freezing of the bread in test B is shown in Figure 38. the energy for the fan was between 25 and 30% of the total refrigeration energy whereas in test A is represents more than 50% (see ref. [81] for more details).

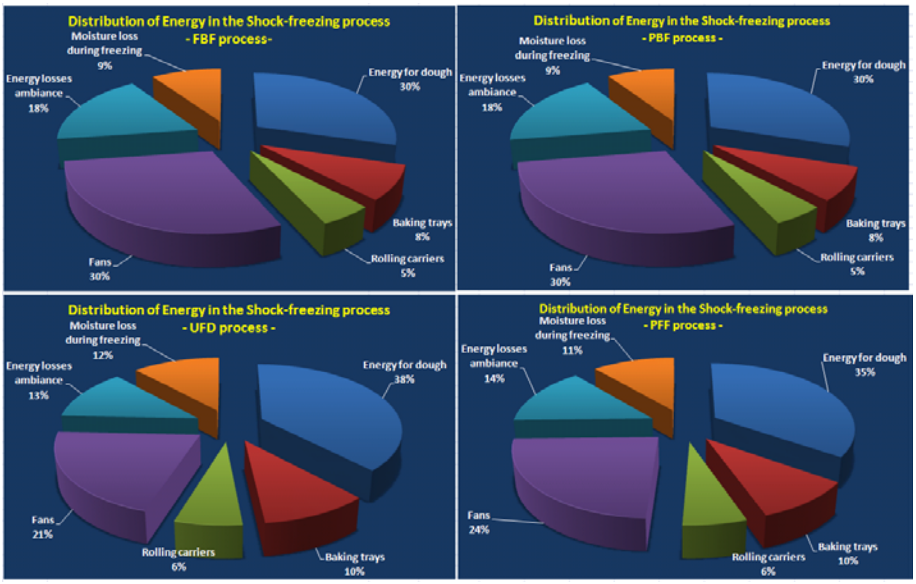


Figure 38

Pie charts showing the distribution of the energy in the freezing process. Test B of EU-FRESHBAKE (Large freezer)

The ERI is shown in Figure 40 considering this time the energy for baking + reheating and the freezing energy. One can see that as in Table 6, the Part Baked Frozen technology demands around 2.2 times more energy than the conventional . For FBF and UFD the ratio was around 1.2 indicating that only 20% extra energy was needed for these processes. PFF (Pre fermented Frozen) was the less energy demanding in comparison to FBF and UFD.

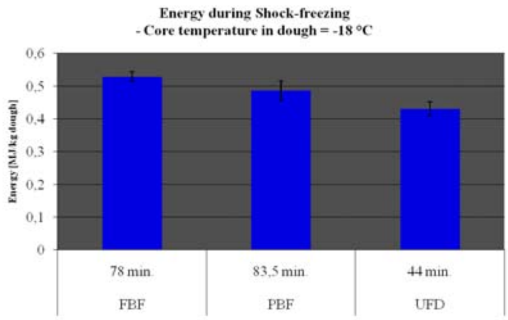


Figure 39

Comparison of the energy demanded for the freezing of selected products: FBF = fully baked frozen, PBF = Part baked frozen, UFD = Unfermented frozen dough.

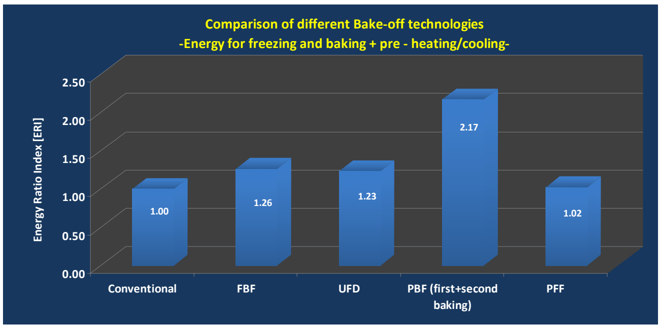


Figure 40

Energy Ratio Index (ERI) for the selected bake off technologies. The energy for pre heating + baking + freezing is considered Comparison of the energy demanded for the baking (1 pre heating of the oven + 1 baking) of selected bake off technologies versus conventional baking. UFD = Unfermented frozen dough, FBF = fully baked frozen, PBF = Part baked frozen.

II-4 Energy in the baking industry – a general approach

ENERGY FOR CONVENTIONAL BAKING

Baking, which is in fact a combined "cooking" of the dough and "drying" of the outer part of the bread is one of the most energy demanding process used to stabilize foods as shown in the Figure 41 below. The energy demand indicated in this figure is the energy needed by the equipment; the huge difference between baking – drying and other processes comes form the temperature level needed for bread baking and from the evaporation of water which is extremely energy demanding. Other data on energy for different ovens are provided in [81] and are gathered in the Figure 42. An average value coming from 23 different references (from EU-FRESHBAKE tests and from the literature) resulted in an average value of 3.67 MJ/kg of bread.

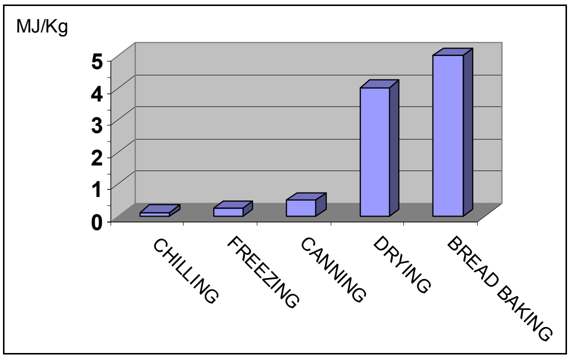


Figure 41
Energy demand of selected food processes. The energy is in MJ/kg of food. Data from [82, 83]

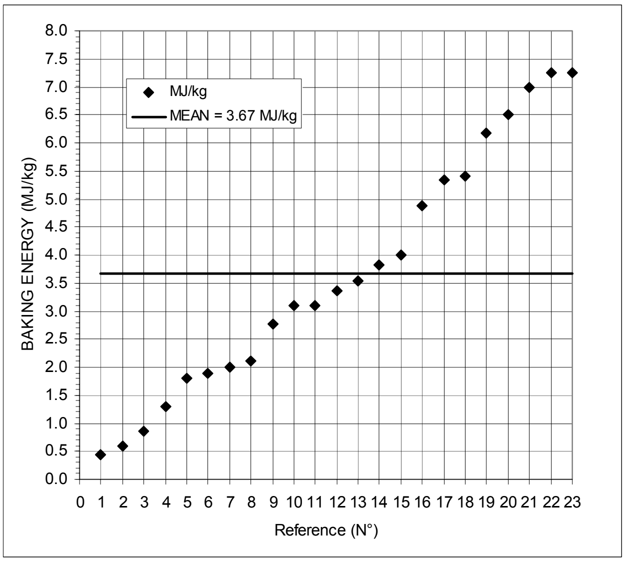


Figure 42
Energy demand for bread baking: selected data from the literature and from confidential data. (Details on the references and conditions are provided in [81]).

LARGE EQUIPMENTS: CONTINUOUS OVENS

In the case of continuous oven, the conveyor and baking support must also be taken into consideration as shown in Table 7. Finally, it turns that the energy effectively needed to heat up the dough represents between 10 and 25 % of the energy consumption and that the drying of the surface of the bread represents between 15 and 35 % of the energy consumption depending on the type of product and of equipment. Other data are provided in [81].

Table 7

Energy distribution within selected continuous ovens.

	EXHAUST GASES	EVAPORATED WATER & AIR	HEATING OF PRODUCTS	CARRIER SYSTEMS PANS-LIDS	LOSSES THROUGH WALL
MULTIPRODUCTS Bread - Cookies - Cakes 7 Ovens testsed (direct and indirect) [84]	23 - 45 %	22 - 35 %	3 - 11 %	9 - 25 %	6 -15 %
Bread Baking, Wermer & Pfleiderer Oven (Oil ovens) [85]	29%	15%	19%	17%	20%

III – Tracks to reduce the energy demand and to optimize the quality in BOT

III-1 GENERAL RECOMMENDATION: BAKING and STEAMING

➔ BAKING: STEAMING represents around 20 to 25% of the total baking energy demand for any baking process. A first general recommendation that concern any baking process using steaming could be to have a good control of the amount of water injected in the steaming system of the oven and a control of the confinement of the oven. The installation of a volumetric injection system could be a solution. Even though it is expansive, it should allow a better control of the quality and a goo control of the energy demand.

➔ PARTIAL BAKING: Partial baking is a very subjective situation. Most baker consider the colour of the crust as a criterion. . As shown during EU-FRESHBAKE, it should rather be the duration of the baking plateau at the baking temperature of the crumb (generally around 98°C) that should be considered. Then the control of the baking conditions (steaming, temperature level) will allow the control of the colouration of the crust during the partial baking. The fermentation condition can play a big role. A long fermentation will result in a faster colouration (but also more aroma in the bread). A balance must be found in between all these parameters. Concerning crust flaking, it seems that this is due to the duration of partial baking which has an impact on the crumb contraction. The longer is the baking, the smaller is the contraction. The measure of the crumb contraction between end of baking and end of chilling can be a good mean of evaluating if the baking is sufficient. Once again this is to be adapted on each baking process. The use of specific enzymes could allow a reduction of the magnitude of the contraction.

III-2 GENERAL RECOMMENDATION: CONTROL OF THE FREEZING STEP (FINAL FREEZING TEMPERATURE)

➔ FREEZING PROCESS : CONTROL OF THE FINAL FREEZING TEMPERATURE

The control of the final temperature of a product at the exit of a freezer has an important impact on the overall energy demand for the freezing process. The freezing process encompasses the “dynamic” freezing step (in the last air freezer, tunnel, …) and then the “equilibration” step in the frozen storage. The temperature of -18 °C is always quoted as the optimal temperature. **It should be reminded that – 18 °C is equal to 0 °Fahrenheit..** Therefore, there is no evidence on if – 18 °C is better than -17 °C or – 20 °C …. A different approach consists in considering the amount of freezable water effectively frozen in the food. The International Institute of Refrigeration (IIR) has defined that a food can be considered as frozen when its temperature reaches either -12 °C OR that 80% of the freezable water has been frozen [86]. The plots of frozen water as a function of temperature are plotted in Figure 43 for dough and in ANNEXE 4 for bread respectively. 80 % of freezable water is frozen at a temperature of -12.5°C and – 15 °C for dough and bread, which could be considered as an acceptable temperature at the exit of the freezer (dynamic step of freezing). Precise calculation of this temperature can be done as explained in ref. [86].

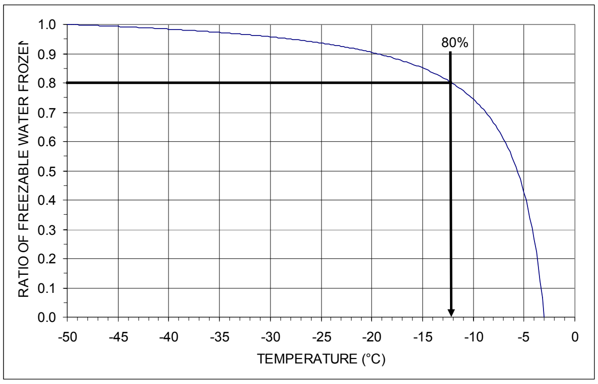


Figure 43

Plot of the amount of freezable water frozen for a bread dough according to recipe and information provided in ANNEXE 3. 80 % of freezable water is frozen at a temperature of -12.5 °C, which could be considered as an acceptable temperature at the exit of the freezer (freezing process in the freezer = phase of the freezing process during which the "quality" of the frozen product is made e.g. impact of the freezing rate on the quality).

III-3 Unfermented frozen dough

The production of unfermented frozen dough is among the BOT, the technology that demands less additional energy in comparison to conventional – direct bread making. The dough has to be frozen once and stored. The final processing consists in thawing the dough and set the dough for fermentation before baking. **Un fermented frozen dough is the best technology of BOT with respect to energy demand and final quality of the product**. However, at least 3 hours of preparation time is needed which is one the drawback of the technology.

➔ FORMULATION: Reducing the hydration of the dough will have a small impact on the energy demanded for freezing. Such a reduction is usually done for technological reason (i.e. to reduce the sticking of the dough on conveying systems). Basic improver mixes for frozen dough contain ascorbic acid, amylases and are some time containing gluten. The use of improvers containing hydrocolloids can help to better immobilize the water in the dough and finally can make that the dough will better support the freezing process and the storage. Hydrocolloids can also reduce the freezable water resulting in a lower demand of energy for the freezing process; but the energy saving will be very little on this end.

➔ FREEZING RATE AND FINAL FREEZING TEMPERATURE: It is usually admitted by most industry that the freezing rate used for freezing yeasted dough should not be very high irrespective to what is usually recommended for most food. A slow freezing rate results in a better tolerance of yeast to freezing and in a better (depends on the formulation) resistance of the dough in term of rheological properties. A slow freezing rate results in less hardening of the dough [25, 26]. The energy demand to freeze a dough will be lower with a set point temperature of -25°C or -30°C. A unique recommendation is not possible, but we think that a setpoint of -25°C in the freezer combined with a control of the final core temperature of around -12°C followed by packaging and equilibration in the frozen storage should allow to significantly reduce the energy demand and to obtain a good quality (baking performance). The control of the final temperature of the dough pieces at the end of the freezing process is an important point as shown by [24].

➔ FROZEN STORAGE: Storage temperature must be lower than -18°C. A temperature range between -18 °C and -25 °C can help to better preserve the fermentation and baking performance of the dough. The shorter the storage, the higher will be the baking performance of the dough. Temperature stability is important and lower storage temperature (ie. -25°C) are preferable.

III-4 Pre-fermented frozen dough

Pre-fermented frozen dough offers the possibility of reducing the energy demand in comparison with part baked bread in that a single baking step is needed. Beside, great care should bring in controlling the pre fermentation step and in ensuring a rapid freezing and a frozen storage at low temperature.

➔ PRE-FERMENTATION: It contains a lot of gas and it also a poorly conductive material. Available results show that the degree of pre-fermentation should be lower than 50% with respect to full fermentation. The lower the degree of pre fermentation, the more conductive the dough, the higher the freezing rate.

➔ FREEZING RATE: A pre-fermented dough is a very fragile structure. A high freezing rate is recommended based on existing literature. Therefore, a set point between -25 and -30 °C in the blast air freezer is needed. Product should be withdrawn from the freezer when fully frozen. Air impingement may affect the geometry of the product (flattening).

➔ FROZEN STORAGE: A slow frozen storage temperature is needed, such as -25°C or lower, to prevent collapse of the structure during storage. The temperature stability should be of high quality. Indeed, the surface of the pre-fermented dough is dryer than the dough and has a initial freezing temperature that can be as low as -5°C or lower. A temperature rise may result in a partial superficial thawing which could result in sticking of products in contact and thereafter in surface defaults of the crust of the baked bread.

III-5 Partially baked non frozen bread

Part baked non frozen bread is developing a lot. It offers the advantage of suppressing the freezing step in comparison with frozen part baked technology. This technology should then be preferred to frozen part baked with respect to energy demand. MAP (Modified Atmosphere Packaging) combined with adapted formulation allow quite long shelflife as demonstrated by the numerous products available on the market.

➔ PARTIAL BAKING: Partial baking is usually done at lower temperature than for conventional baking. Beside, the control of partial baking is very often limited to a control of the crust temperature. STEAMING represents around 20 to 25% of the total baking energy demand. In the case of partial baking, like for any baking process steaming is important. **A recommendation could be to have a good control of the amount of water injected in the steaming system of the oven and a control of the confinement of the oven**, as over steaming will result in energy waste without benefit for the product. Under steaming may result in a rapid dry out of the crust and in start of colouration. The criteria for the end of the partial baking process should rather be a time – temperature history at core of the crumb than a colour change of the crust. A criteria to assess the degree of baking can be a control of the length (or any dimension) of the bread at end of baking and after chilling to room temperature. The lower the change in dimension, the higher the degree of baking. As shown by EU-FRESHBAKE results, a short partial baking may also result in a reduced GI. From the results obtained so far, a time-temperature plateau of 5 minutes or less should result in reduced GI based on the fact that ghosts of starch granules remain visible (see Figure 18 and Figure 19).

➔ CHILLING AFTER POST PARTIAL BAKING: In most recent industrial installation, post baking chilling is done in a specific tunnel with a refrigeration unit ensuring a control of the temperature and of the humidity of the air. During post baking chilling, moisture loss has a refrigerating effect. A 1% mass loss represents ca. 10% of the overall heat load to withdraw to the product (see Figure 27 and Table 4). This phenomenon is called "EVAPORATIVE COOLING". In order to enhance the evaporative cooling and to accelerate the cooling, the pulverisation of sterile water on the bread just at the exit of the oven and before going in the chilling cabinet could be used and could help to reduce the refrigeration load on the chilling equipment. At this stage of the chilling step, the bread is hot and will refrigerate by free convection if exposed to the ambient air of the factory. Then the bread could enter the chilling cabinet.

III-6 Partially baked frozen bread

Part Baked frozen bread is among all the BOT the most energy demanding technology. It is also a product that encounters a great commercial success. It is therefore important to investigate tracks to reduce the energy demand linked to the processing conditions. The same remarks as for part baked non frozen applies, but with some specificities.

➔ PARTIAL BAKING:
The paragraph below is similar to the one proposed for non frozen part baked. One of the specificity of frozen part baked is that the shorter the baking, the larger the contraction of the crumb during post baking chilling. This can have an impact on the risk of crust flaking. The control of the partial baking step could be improved by a control of the steaming procedure which could be continuous during the partial baking instead of being done in one "shot" at the beginning of baking. Such a procedure can also help in retarding the appearance of acrylamides (neoformed contaminants) as presented in [68].

Partial baking is usually done at lower temperature than for conventional baking. Beside, the control of partial baking is very often limited to a control of the crust temperature. STEAMING represents around 20 to 25% of the total baking energy demand. In the case of partial baking, like for any baking process steaming is important. **A recommendation could be to have a good control of the amount of water injected in the steaming system of the oven and a control of the confinement of the oven**, as over steaming will result in energy waste without benefit for the product. Under steaming may result in a rapid dry out of the crust and in start of colouration. The criteria for the end of the partial baking process should rather be a time – temperature history at core of the crumb than a colour change of the crust. A criteria to assess the degree of baking can be a control of the length (or any dimension) of the bread at end of baking and after chilling to room temperature. The lower the change in dimension, the higher the degree of baking. As shown in the report, a short partial baking may also result in a reduced GI. From the results obtained so far, a time-temperature plateau of 5 minutes or less should result in reduced GI based on the fact that ghosts of starch granules remain visible (see Figure 18 and Figure 19).

➔ CHILLING AFTER POST PARTIAL BAKING: In most recent industrial installation, post baking chilling is done in a specific tunnel with a refrigeration unit ensuring a control of the temperature and of the humidity of the air. During post baking chilling, moisture loss has a refrigerating effect. A 1% mass loss represents ca. 10% of the overall heat load to withdraw to the product (see Figure 27 and Table 4). This phenomenon is called "EVAPORATIVE COOLING". In order to enhance the evaporative cooling and to accelerate the cooling, the pulverisation of sterile water on the bread just at the exit of the oven and before going in the chilling cabinet could be used and could help to reduce the refrigeration load on the chilling equipment. At this stage of the chilling step, the bread is hot and will refrigerate by free convection if exposed to the ambient air of the factory. Then the bread could enter the chilling cabinet.

➔ FREEZING OF PART BAKED BREAD.

Freezing of part baked bread demands a lot of energy. The efficacy of the freezing unit can be altered by the formation of snow like frost on the evaporator. This can be prevented by ensuring a significant refrigeration of the bread before entering the freezer. It means that centre temperature of the bread should be as low as around 40°C. The energy cost of refrigeration is much higher when using a blast air freezer in comparison with a refrigeration unit at positive temperature (blast air chillers). Concerning the freezing step, there is no evidence on the interest of very rapid freezing for the freezing of part baked bread. A set point temperature of the air in the freezer of around -25°C / - 30°C could be recommended. The products can exit the freezer when the centre temperature is of around -15°C (see paragraph on control of freezing temperature – beginning of the recommendation section); then the product should be placed in plastic pouch to prevent further dehydration during storage.

➔ FROZEN STORAGE OF PART BAKED BREAD.

Frozen storage temperature will interact with the shelf life and possible changes in quality during storage. A storage temperature of -20 °C should be sufficient. The temperature stability is as important as the temperature level.

➔ FINAL BAKING.

It will be better to allow a partial thawing or even a full thawing in the place of baking before starting the final baking. The partial baking must be done with a protection against excessive moisture condensation on the bread (i.e. in a plastic pouch). However, a slight condensation may have a beneficial impact by reducing the steaming step which is energy demanding. The interest of a thawing lies in that it will allow a more uniform thermal treatment of the bread; indeed, the final baking has two major objectives, namely the colouration of the crust and the "refreshing" of the partially baked crumb. This last point corresponds to the melting of the amylopectine crystallites (at around 40°C – 60°C) that forms during storage and that result in staling; the melting of these crystallites will be achieved only if the central section of the crumb reaches the corresponding temperature (around 60C°).

III-7 Fully baked and frozen bread

Fully baked and frozen bread has been the first pioneer technology of BOT. It is less energy demanding than part baked frozen as there is only one baking instead of two. This technology can result in difficulties for the crust quality of crispy rolls. Beside, it is largely used for non crispy rolls such as hamburger buns.

➔ BAKING STEP:

Like for any baking, a good control of the steaming and of the baking duration can allow energy savings.

➔ CHILLING AFTER BAKING: The same remarks as for frozen part baked bread applies. It is even more important to have a good control of the chilling phase before going into the freezer. Indeed, the crust is fully developed and can be in a glassy state (and therefore fragile). A slow cooling rate will allow a better equilibration of strains (contraction) during chilling and of the moisture that diffuses from the centre of the bread toward the crust which acts as a barrier to moisture migration. Benefit may be obtained from the "EVAPORATIVE COOLING" by spraying water at different step of the chilling step (not only just at the beginning).

➔ FREEZING OF FULLY BAKED BREAD.

Freezing of fully baked bread demands a lot of energy. The efficacy of the freezing unit can be altered by the formation of snow like frost on the evaporator. This can be prevented by ensuring a significant refrigeration of the bread before entering the freezer. It means that centre temperature of the bread should be as low as around 40°C. The energy cost of refrigeration is much higher when using a blast air freezer in comparison with a refrigeration unit at positive temperature (blast air chillers). Concerning the freezing step, there is no evidence on the interest of very rapid freezing for the freezing of part baked bread. A set point temperature of the air in the freezer of around -25°C / - 30°C could be recommended. The products can exit the freezer when the centre temperature is of around -15°C or eventually at a lower temperature if the principle of 80% freezable water frozen is respected (around -18°C - see paragraph on control

of freezing temperature – beginning of the recommendation section); then the product should be placed in plastic pouch to prevent further dehydration during storage.
➔ FROZEN STORAGE OF FULLY BAKED BREAD.
Frozen storage temperature will interact with the shelf life and possible changes in quality during storage. A storage temperature of -20 °C should be sufficient. The temperature stability is as important as the temperature level.

V– CONCLUSION

Bake Off Technologies (BOT) offer several advantages in terms of convenience. They permit to prepare freshly baked bakery products (breads, viennoiseries …) rapidly without any high skill in baking. Beside, all the BOT are more energy demanding than conventional process. Whatever is attempted, it will not be possible to demand less energy than conventional "scratch" baking when considering BOT except partially baked bread (small portion serving – i.e. 70g loaf) stored with MAP at room temperature and finally "baked" in a home toaster.

However, the energy demand for BOT can be reduced. Bullets points that could summarize the points of interest are as follow:

- Non fermented frozen dough and prefermented frozen dough ("frozen ready to bake") are among the less energy demanding of BOT. Non fermented frozen dough permits to obtain a quality similar to conventional baking and is for example the preferred BOT in France. Prefermented frozen dough is a challenging technology; care should be brought on the degree of fermentation and on the freezing phase.
- Part baked frozen bread (PFF) is the success story of BOT. Beside, it is the most energy demanding. The baking industry should promote the Unfrozen part baked technology which is developing a lot and which can provide product with a quality similar to frozen part baked. The shelf life can be extended by using MAP – Modified Atmosphere Packaging) and also by combining specific formulation (use of sourdough combined with a reduced alount of calcium propionate, etc, …) .
- Fully baked frozen technology has been the pioneer technology of BOT. It demands less energy than part baked unfrozen but there are some quality problems except for specific products such as hamburger buns, … This technology is therefore quite interesting from the energy point of view.
- Frozen storage demands around 0.268 MJ/kg bread /Month (see annex 5)

Several recommendations are proposed in this guide of good practice. The control of the baking operation (in particular the steaming step, the baking temperature, the management of the partial baking process …), the control of the refrigeration phase (with interest in playing with evaporative cooling to enhance the cooling rate …), the control of the freezing process (with an emphasis on the control of the freezing rate, the adjustment of the set point temperature of a freezer, …) are as many issues that should allow a better manufacturing practices of the baking industry as well as of the artisan baker who quite often use refrigeration to post pone the production of bakery products for peak hours. Refrigeration seems also to offer interest in nutrition; it seems that EU-FRESHBAKE has just open some tracks on this end (impact of part baked on glycaemic index, impact of dough freezing on phytase activity, …)

The EU-FRESHBAKE project is not just oriented toward industry application; more broadly it is oriented toward the consumer who expects freshly baked breads to be available easily. This summarizes the BOT and the guide line of our project.

~

REFERENCES

1. LeBail, A., N. Hamdami, V. Jury, J.Y. Monteau, A. Davenel, T. Lucas, and P. Ribotta, *Examining crust problems resulting from processing conditions with respect to freezing.* New Food Magazine - Russell Publishing Ltd, 2006. **Vol. 3**: p. 10-14.
2. Rosell, C.M. and M. Gómez, *Freezing in breadmaking performance: frozen dough and part-baked bread.* Food Reviews International, 2007(23): p. 303-319. .
3. Rosell, C.M., *Innovation in Food Engineering: New Techniques and Products*, in *Trends in breadmaking: Low and subzero temperatures*, M.L.R.C.L. Passos, Editor. 2008, Taylor and Francis, CRC Press.
4. Vetter, J.L., *Frozen Unbaked Bread Dough: Past, Present, Future.* Cereal Foods World 1979. **24**: p. 42-43.
5. Bhattacharya, M., T.M. Langstaff, and W.A. Berzonsky, *Effect of Frozen Storage and Freeze-thaw Cycles on the Rheological and Baking Properties of Frozen Doughs.* Food Research International, 2003. **36**: p. 365-372.
6. Inoue, Y. and W. Bushuk, *Studies on frozen doughs. II. Flour quality requirements for bread production from frozen dough.* Cereal Chemistry, 1992. **69**(4): p. 423-428.
7. Lu, W. and L.A. Grant, *Effects of prolonged storage at freezing temperatures on starch and baking quality of frozen doughs.* Cereal Chemistry, 1999. **76**(5): p. 656-662.
8. Boehm, D.J., W.A. Berzonsky, and M. Bhattacharya, *Influence of Nitrogen Fertilizer Treatments on Spring Wheat (Triticum aestivum L.) Flour Characteristics and Effect on Fresh and Frozen Dough Quality.* Cereal Chemistry, 2004. **81**: p. 51-54.
9. Gelinas, P., C.M. McKinnon, O.M. Lukow, and S.F. Townley, *Rapid evaluation of frozen and fresh doughs involving stress conditions.* Cereal Chemistry, 1996. **73**(6): p. 767-769.
10. Perron, C.E., O.M. Lukow, W. Bushuk, and S.F. Townley, *The blending potential of diverse wheat cultivars in a frozen dough system.* Cereal Foods World, 1999. **44**(9): p. 667-672.
11. Ribotta, P.D., A.E. León, and M.C. Añón, *Effect of Yeast Freezing in Frozen Dough.* Cereal Chemistry, 2003. **80**: p. 454-458.
12. Bollaín, C. and C. Collar, *Dough viscoelastic response of hydrocolloid/ enzyme/ surfactant blends assessed by uni- and biaxial extension measurements.* . Food Hydrocolloids, 2004. **18**: p. 499-507.
13. Collar, C. and E. Armero, *Physico-chemical mechanisms of bread staling during storage: formulated doughs as a technological issue for improvement of bread functionality and keeping quality.* Recent Research developments in Nutrition Research, 1996. **1**: p. 115-143.
14. Ribotta, P.D., G.T. Perez, A.E. Leon, and M.C. Anon, *Effect of emulsifier and guar gum on micro structural, rheological and baking performance of frozen bread dough.* Food Hydrocolloids, 2004. **18**(2): p. 305-313.
15. Rosell, C.M. and C. Collar, *Effect of various enzymes on dough rheology and bread quality*, in *Recent Research Developments in Food Biotechnology. Enzymes as Additives or Processing Aids*, P.D.P.a.L.M. R. Porta, Editor. 2008, Research Signpost: Kerala, India.
16. Rouillé, J., A. Le-Bail, and P. Courcoux, *Influence of formulation and mixing conditions on breadmaking qualities of French frozen dough.* Journal of Food Engineering, 2000. **43**(4): p. 197-203.
17. Nemeth, L.J., F.G. Paulley, and K.R. Preston, *Effects of ingredients and processing conditions on the frozen dough bread quality of a Canada Western Red Spring wheat flour during prolonged storage.* Food Research International, 1996. **29**(7): p. 609-616.
18. Zounis, S., K.J. Quail, M. Wootton, and M.R. Dickson, *Effect of Final Dough Temperature on the Microstructure of Frozen Bread Dough.* Journal of Cereal Science, 2002. **36**(2): p. 135-146.
19. Neyreneuf, O. and B. Delpuech, *Freezing experiments on yeasted dough slabs. Effects of cryogenic temperatures on the baking performance.* Cereal Chemistry, 1993. **70**(1): p. 109-111.

20. Inoue, Y., H.D. Sapirstein, S. Takayanagi, and W. Bushuk, *Studies on frozen doughs. III. Some factors involved in dough weakening during frozen storage and thaw-freeze cycles.* Cereal Chemistry, 1994. **71**(2): p. 118-121.
21. Ribotta, P.D., A.E. León, and M.C. Añón, *Effect of Freezing and Frozen Storage of Doughs on Bread Quality.* Journal of Agriculture and Food Chemistry, 2001. **49**: p. 913-918.
22. Kenny, S., H. Grau, and E.K. Arendt, *Use of Response Surface Methodology to Investigate the Effects of processing Conditions on Frozen Dough Quality and Stability.* European Food Research and technology, 2001. **213**: p. 323-328.
23. Phimolsiripol, Y., U. Siripatrawan, V. Tulyathan, and D.J. Cleland, *Effects of freezing and temperature fluctuations during frozen storage on frozen dough and bread quality.* Journal of Food Engineering, 2008. **84**: p. 48-56.
24. Le-Bail, A., C. Grinand, S. Le-Cleach, S. Martinez, and E. Quilin, *Influence of storage conditions on frozen french bread dough.* Journal of Food Engineering, 1999. **39**: p. 289-291.
25. Havet, M., M. Mankai, and A. Le-Bail, *Influence of the freezing condition on the baking performances of French frozen dough.* Journal of Food Engineering, 2000. **45**(3): p. 139-145.
26. LeBail, A., M. Havet, and M. Hayert. *Improvement of the baking performance of frozen dough by short freezing method. Application to French baguette.* in *Rapid Cooling of Foods*. 2001. Bristol-UK: International Institute of refrigeration.
27. Sanz Penella, J.M., C.M. Rosell, and M. Haros, *Effect of fungal phytase addition, fermentation and freezing on the phytate degradation of whole wheat dough* Cereals-The future challenges. ICC Conference Proceedings, 2007.
28. Devos, F., in *Kaltetechnologie in der Backerei*, K. Loeshe, Editor. 2003, Behrs Verlag.
29. Gan, Z., P.R. Ellis, and J.D. Schofield, *Mini review. Gas Cell Stabilisation and gas Retention in Wheat Bread Dough.* Journal of Cereal Science, 1995. **21**: p. 215-230.
30. Baier-Schenk, A., S. Handeschin, and B. Conde-Petit, *Ice in Prefermented Frozen Bread Dough - An Investigation Based on Calorimety and Microscopy.* Cereal Chemistry, 2005. **82**: p. 251-255.
31. Loeshe, K., *Qualitaet von vorgegarten und tiefgekuehlten Teiglingen.* Back Journal spezial TT 1995. **1**: p. 44-48.
32. Gan, Z., R.E. Angold, M.R. Williams, P.R. Ellis, J.G. Vaughan, and T. Galliard, *The microstructure and gas retention of bread dough.* Journal of cereal Science, 1990. **12**: p. 15-24.
33. Esselink, F.J., H. Van-Aalst, M. Maliepaard, and P.M. Van-Duynhoven, *Long term Storage effect in Frozen dough by spectroscopy and microscopy.* Cereal Chemistry, 2003. **80**: p. 396-403.
34. Fennema, O.R., *Nature of the freezing process.*, in *Low temperature preservation of foods and living matter*, O.R.-P. Fennema, W.D. and Marth, E.H, Editor. 1973, Marcel Dekker Publishers New York.
35. Rasanen, J., *Prefermented frozen lean wheat doughs.* VTT Publications, 1998. **352**.
36. Rasanen, J., H. Harkonen, and K. Autio, *Freeze-Thaw Stability of Prefermented Frozen Lean Wheat Doughs : Effect of Flour and Fermentation Time.* Cereal Chemistry, 1995. **72**(6): p. 637-642.
37. Rasanen, J., T. Laurikainen, and K. Autio, *Fermentation stability and pore size distribution of frozen prefermented lean wheat doughs.* Cereal Chemistry, 1997. **74**(1): p. 56-62.
38. Le-Bail, A., C. Nicolitch, and C. Vuillod, *Fermented Frozen Dough: Impact of Pre-fermentation Time and of Freezing Rate for a Pre-fermented Frozen Dough on Final Volume of the Bread.* Food and Bioprocess Technology 2009. **IN PRESS**(DOI 10.1007/s11947-008-0142-2).

39. Ben-Aissa, F., J.Y. Monteau, A. Perronnet, G. Roelens, and A. Le-Bail, *Impact of the baking degree on the volume change of bread and bread crumb during cooling, chilling and Freezing.* Journal of Cereal Science, 2009. **In Press**.
40. Arroyo, M., D. Aldred, and N. Magan, *Environmental factors and weak organic acid interactions have differential effects on control of growth and ochratoxin A production by Penicillium verrucosum isolates in bread.* International Journal of Food Microbiology, 2005. **98**(3): p. 223-231.
41. Gerez, C.L., M.I. Torino, G. Rollán, and G. Font de Valdez, *Prevention of bread mould spoilage by using lactic acid bacteria with antifungal properties.* Food Control, 2009. **20**(2): p. 144-148.
42. Ryan, L.A.M., F. Dal Bello, and E.K. Arendt, *The use of sourdough fermented by antifungal LAB to reduce the amount of calcium propionate in bread.* International Journal of Food Microbiology, 2008. **125**(3): p. 274-278.
43. Suhr, K.I. and P.V. Nielsen, *Effect of weak acid preservatives on growth of bakery product spoilage fungi at different water activities and pH values.* International Journal of Food Microbiology, 2004. **95**(1): p. 67-78.
44. Valerio, F., P. De Bellis, S.L. Lonigro, A. Visconti, and P. Lavermicocca, *Use of Lactobacillus plantarum fermentation products in bread-making to prevent Bacillus subtilis ropy spoilage.* International Journal of Food Microbiology, 2008. **122**(3): p. 328-332.
45. LeDuff, L., *Pain Français précuit congelé et son procédé de fabrication*. 1985.
46. Guinet, R. and B. Godon, *La Panification Française*. Techniques et Documentation - Lavoisier ed, ed. C.s.e.t. agro-alimentaires. 1994. 521.
47. Bonnardel, P. and H. Maitre, *La technologie boulangère du pain français précuit.* Industries des Céréales, 1988. **51**(février 88): p. 31-37.
48. LeBail, A., J.Y. Monteau, F. Margerie, T. Lucas, A. Chargelegue, and Y. Reverdy, *Impact of selected process parameters on crust flaking of frozen part baked bread.* Journal of food engineering, 2005. **69**: p. 503-509.
49. Ribotta, P. and A. Le-Bail, *Thermophysical and thermomechanical assessment of partially baked bread during chilling and freezing process.* Journal of Food Engineering, 2006. **Accepted**.
50. Lucas, T., S. Quellec, A. LeBail, and A. Davenel, *Chilling and freezing of part-baked breads. II. Experimental assessment of water phase changes and of structure collapse.* Journal of Food Engineering, 2005. **70**(2): p. 151-164.
51. Guilbot, A. and B. Godon, *Le pain rassis.* Cahier de Nutrition et de Diététique, 1984. **19**(3): p. 171-181.
52. Ribotta, P. and A. Le-Bail, *Thermo-physical and thermo-mechanical assessment of partially baked bread during chilling and freezing process. Impact of selected enzymes on crumb contraction to prevent crust flaking.* Journal of Food Engineering, 2007. **78**(3): p. 913-921.
53. Ribotta, P.D. and A. Le-Bail, *Thermo-physical assessment of bread during staling.* LWT - Food Science and Technology, 2007. **40**(5): p. 879-884.
54. Jiang, Z., A. Le-Bail, and A. Wu, *Effect of the thermostable xylanase B (XynB) from Thermotoga maritima on the quality of frozen partially baked bread.* Journal of Cereal Science, 2008. **47**(2): p. 172-179.
55. Hamdami, N., J.Y. Monteau, and A. LeBail, *Thermophysical properties evolution of French partly baked bread during freezing.* Food Research International, 2004. **37**(7): p. 703-713.
56. Hamdami, N., J.Y. Monteau, and A. Le-Bail, *Heat and mass transfer in par-baked bread during freezing.* Food Research International, 2004-b. **37**: p. 477-488.
57. Hamdami, N., J.Y. Monteau, and A. Le-Bail, *Moisture diffusivity and water activity of part-baked bread at above and sub-freezing temperatures.* International Journal of Food Science and Technology, 2006. **41**: p. 33-44.
58. Gray, J.A. and J.N. Bemiller, *Bread Staling : Molecular Basis and Control.* Comprehensive reviews in food science and food safety, 2003. **2**: p. 1-21.

59. Barcenas, M.E., M. Haros, C. Benedito, and C.M. Rosell, *Effect of freezing and frozen storage on the staling of partbaked bread.* Food Research International, 2003. **36**: p. 863-869.
60. Boumali, K., V. Jury, S. Chevallier, D. Queveau, and A. Le-Bail. *Impact du degré de cuisson sur la cinétique de rassissement*. in *59es JOURNÉES TECHNIQUES des INDUSTRIES CÉRÉALIÈRES 2008*. 2008. Paris, FRANCE.
61. Le-Bail, A., K. Boumali, V. Jury, and F. Ben-Aissa, *Impact of the kinetic of baking on staling rate and on the mechanical properties of crumb and degassed crumb.* Journal of Cereal Science, 2009. **50**: p. 235-240.
62. Vulicevic, I.R., E.S.M. Abdel-Aal, G.S. Mittal, and X. Lu, *Quality and storage life of par-baked frozen breads.* Lebensmittel-Wissenschaft und-Technologie, 2004. **37**(2): p. 205-213.
63. Carr, L.G. and C.C. Tadini, *Inluence of yeast and vegetable shortening on physical and textural parameters of frozen part baked French bread.* Lebensm.-Wiss. u.-Technol, 2003. **36**: p. 609-614.
64. Bárcenas, M.E., C. Benedito, and C.M. Rosell, *Use of hydrocolloids as bread improvers in interrupted baking process with frozen storage.* Food Hydrocolloids, 2004. **18**(5): p. 769-774.
65. Bárcenas, M.E. and C.M. Rosell, *Effect of frozen storage time on the bread crumb and aging of par-baked bread.* Food Chemistry, 2006. **95**(3): p. 438-445.
66. Bárcenas, M.E. and C.M. Rosell, *Different approaches for improving the quality and extending the shelf life of the partially baked bread: low temperatures and HPMC addition.* Journal of Food Engineering, 2006. **72**(1): p. 92-99.
67. Poinot, P., J. Grua-Priol, G. Arvisenet, C. Rannou, M. Semenou, A. Le-Bail, and C. Prost, *Optimisation of HS-SPME to study representativeness of partially baked bread odorant extracts.* Food Research International, 2007. **40**: p. 1170-1184.
68. Ahrne, L., C. Andersson, P. Floberg, J. Rosen, and H. Lingnert, *Effect of crust temperature and water content on acrylamide formation during baking of white bread: Steam and falling temperature baking.* Lebensmittel-Wissenschaft und Technology, 2007. **40**: p. 1708-1715.
69. Borczak, B., P. Pisulewski, M. Sikora, and J. Krawontka, *Comparison of glycemic responses to frozen and non-frozen wheat rolls in human volunteers - a short report.* Polish Journal of Food and Nutrition Sciences, 2008. **58**(3): p. 377-380.
70. Borczak, B., P. Pisulewski, M. Sikora, J. Krawontka, A. Perronnet, G. Roelens, S. Chevallier, K. Boumali, and A. Le-Bail. *Impact du procédé de cuisson sur l'indice glycemique d'un pain de type français* in *59es JOURNÉES TECHNIQUES des INDUSTRIES CÉRÉALIÈRES 2008*. 2008. Paris, FRANCE.
71. Pateras, I.M.C., *Bread spoilage and staling*, in *Technology of bread making* S.C.a.L. YOUNG, Editor. 1999, Aspen Publisher: Gaithesbrug - Maryland-USA.
72. Levine, H. and L. Slade, *Principles of 'cryostabilization' technology from structure/property relationships of carbohydrate/water systems-a review.* Cryo letters, 1988. **9**: p. 21-63.
73. Levine, H. and L. Slade, *Influences in the glassy and rubbery states of the thermal, mechanical and structural properties of doughs and baked products*, in *Dough rheology and baked product texture*, H.F.a.J.M. Faubion, Editor. 1990, Van Nostrand Reinhold. p. 157-330.
74. LeMeste, M., V.T. Huang, J. Panama, G. Anderson, and R. Lentz, *Glass Transition of Bread.* Cereal Chemistry, 1992. **37**: p. 264-267.
75. George, R.M., *Freezing processes used in the food industry.* Trends in Food Science and Technology, 1993. **4**: p. 134-138.
76. Galić, K., *Odabir ambalažnog materijala za pakiranje: I - proizvoda od žitarica, pekarskih i konditorskih proizvoda, (Selection of a food packaging materials: I - cereals, bakery and confectionery goods) - in Croatian.* Ambalaža, 2000. **1**: p. 20-25.

77. Baik, M.-Y. and P. Chinachoti, *Moisture redistribution and phase transitions during bread staling.* Cereal Chemistry, 2000. **77**(4): p. 484-488.
78. Galić, K., B.I. Vujković, D. Ćurić, and I.A. Vujković. *Factors Affecting the Shelf-Life of Cereal Based Food*. in *Proceedings 3rd International Congress Flour-Bread '05 5th Croatian Congress of Cereal Technologists*. 2005. Opatija, Croatia: University of Osijek.
79. Galić, K., D. Ćurić, and D. Gabrić, *Packaging and the Shelf life of Bakery Goods - A Review.* Critical Reviews in Food Science and Nutrition journal, 2008. **In Press**.
80. Chung, D.S. and H.B. Pfost, *Adsorption and desorption of water vapor by cereal grains and their products. Part I. Heat and free energy changes adsorption and desorption.* Transaction ASAE, 1967. **10**: p. 549-551.
81. Le-Bail, A., T. Dessev, V. Jury, R. Zuniga, T. Park, and M. Pitroff, *Energy demand for selected bread making processes: Conventional versus Part Baked frozen technologies.* Journal of Fod Engineering, 2009. **doi:10.1016/j.jfoodeng.2009.08.039**(In Press).
82. Fellows, P.J., *Food Processing Technology Principles and Practice*. 1996, Woodhead Publishing: Cambridge. p. Chap. 1:54-58 and Chap. 15:314-327.
83. Dinçer, A., ed. *Heat transfer in food cooling applications*. 1997, Taylor & Francis,: New York USA.
84. Trystram, G., 1989.
85. Christensen, A. and R.P. Singh, *Energy consumption in the baking industry.*, in *Engineering and Food, Processing Applications*, B.M. Mckenna, Editor. 1984, Elsevier - Applied Science Publishers: London. p. 965-973.
86. Le-Bail, A., N. Chapleau, M. De-Lamballerie, and M. Vignolle, *Evaluation of the mean ice ration as a function of temperature in an heterogenous food; application to the determination of the target temperature at the end of freezing.* International Journal of Refrigeration, 2008. **31**(5 - August 2008): p. 816-821.
87. Lambert, J.L., A. Le-Bail, R. Zuniga, I. Van-Haesendonck, E. Van-Zeveren, C. Petit, M.C. Rosell, C. Collar, D. Curic, I. Colic-Baric, M. Sikora, and R. Ziobro, *The attitudes of European consumers toward innovation in bread; interest of the consumers toward selected quality attributes.* Journal of Food Quality, 2008. **Accepted**
88. Marcotte, M. *Reduction of energy consumption during industrial baking: A newly designed pilot oven is used to assess key parameters and elaborate appropriate strategies. .* in *International Annual Meeting of the American Association of Cereal Chemistry* 2007. San Antonio, Texas - USA.
89. Johnson, L.A. and W.J. Hoover, Bakers Digest, 1977: p. 51-58.
90. Beech, G.A., Journal of Food Sciences, 1980. **13**(3): p. 289-294.
91. Tragardh, C., Lebensmittel-Wissenschaft und Technology, 1980. **14**: p. 213-217.
92. Laukkanen, M., *Improving energy use in Finnish bakeries*, in *Engineering and Food*, B.M. Mckenna, Editor. 1984, Elsevier Applied Science Publishers: London. p. 917-926.
93. Roosen, H.P., Getreide,-Mehl-und-Brot, 1993. **47**(3): p. 36-38.

ANNEXE 1

The EU-FRESHBAKE PROJECT

Figure 44

Overview of the partners involved in the EU-FRESHBAKE project (http://eu-freshbake.eu/eufreshbake)

Table 8

Partners of the EU-FRESHBAKE project

PARTICIPANT	COUNTRY	WEBSITES
1. ENITIAA - coordinator	FRANCE	www.enitiaa-nantes.fr
2. CEMAGREF	FRANCE	www.cemagref.fr
3. KRAKOW UNIVERSITY	POLAND	www.ar.krakow.pl
4. IATA-CSIC	SPAIN	www.iata.csic.es
5. ZAGREB UNIVERSITY	CROATIA	www.pbf.hr
6. TTZ-EIBT	GERMANY	www.ttz-bremerhaven.de
7. RUSSIAN ACADEMY of SCIENCE IBCP RAS	RUSSIA	www.ras.ru
8. MIWE – Industry	GERMANY	www.miwe.com
9. PURATOS – Industry	BELGIUM	www.puratos.com
10. BIOFOURNIL – Industry	FRANCE	www.biofournil.com
11. BEZGLUTEN – Industry	POLAND	www.bezgluten.pl
12. DR. SCHÄR – Industry	ITALY	www.schaer.com

ANNEXE 2

Innovation and consumers; a European survey.

The expectation of consumers towards innovation in bakery products is a very complicated subject. In order to clarify the situation, a consumer survey has been done within the EU-FRESHBAKE project. A face-to-face interview (plus a questionnaire) has been done with 1050 consumers in 5 different countries; Belgium – Flemish county, Belgium – Walloon county, Croatia, Spain, France and Poland. The survey has been done between October 2006 and March 2007. The design of the questionnaire included several aspects such as practices of purchases and consumption, psychological representation of bread, interest and importance of nutrition, interest about gluten free bread, interest in the energy needed to produce bread (environmental concern), degree of importance of the shelf life of bread, degree of acceptance of “innovation” in bread …. A detailed report is available in [87]. Among the key results, quite different point of view was observed between Northern Europe (Poland, Belgium-Flemish) and France. French consumers were attracted by freshly baked crispy rolls, whereas schematically, the consumers from northern Europe were rather considering sandwich bread and viennoisierie. Two main groups were identified. The “crust consumers group” represented around 62 % of the sample, whereas the “crumb consumers group” made 38%. The “crust group” gathered frequent customers (at least on bread purchase per day), who were more interested in the hedonic perception and who have a minimal interest in the shelf life. The crumb group represented non frequent customers. This group was more interested by nutrition issues and by shelf life, and also by energy demand of the process. This kind of result is of importance. Indeed, the making of a bread crust demands a long baking at high temperature and therefore is energy demanding. The convenience is also an important aspect. Some consumer can support to buy bread once a week. For these consumers, shelf life, labelling (i.e. nutrition facts, …) and eventually information on the environmental impact of the product (i.e. CO_2 tags) appeared as important parameters that may condition the will of purchase. On the opposite, customers belonging to the “crust group” were paying little attention to the shelf life. Another interesting and quite striking issue was the attitude of consumers toward gluten free products. For some consumers, who know what gluten is, gluten free products may be interesting to experience. Beside, some consumers who were less informed about what gluten is were suspicious about such a labelling. The lack of information about gluten make that a “gluten free” labelling may be considered in two opposite directions: either as a chemical that is withdrawn (positive image) or as a natural compound that has been withdrawn to a conventional recipe (negative image).

Innovations in bread making such as those that could arise form the EU-FRESHBAKE project are rather of interest for urban and young consumers. Beside, distrust towards food industries was detected for ¾ of the sample, who considered that food products produced by the industry are less good and less tasty and around 60% of the sample consider that they are less good for health. This point highlights the fact that a lot of efforts is done nowadays in the decoration and ambiance that is created in the vending shops using BOT products (baking stations, affiliated bakers, …) to obtain a warm and cosy ambiance that gives trust to the consumer.

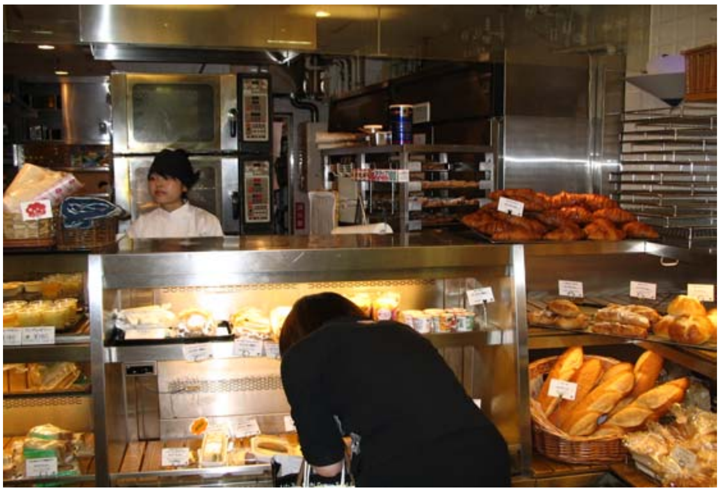


Figure 45

A Baking station in Tokyo (Japan)

ANNEXE 3

ENTHALPY FUNCTION OF BREAD DOUGH

The enthalpy function of dough has been evaluated using the flour and recipe used during the EU-FRESHBAKE project. Details on a recipe for direct-conventional baking process are given in Table 9. The amount of freezable water (g water/ g dry mater) per g of dry matter of the dough is plotted in Figure 46 is and the freezable water (g water/g dough – wb) in function of the amount of water added to 100 g of flour (Moulins SOUFFLET – France) in Figure 47.

Table 9
EU-FRESHBAKE recipe for conventional baking process

DOUGH RECIPE	
FLOUR	100 g
FLOUR MOISTURE	14%
WATER	58 g
COMPRESSED YEAST	3 g
IMPROVER	1 g
SALT	2 g

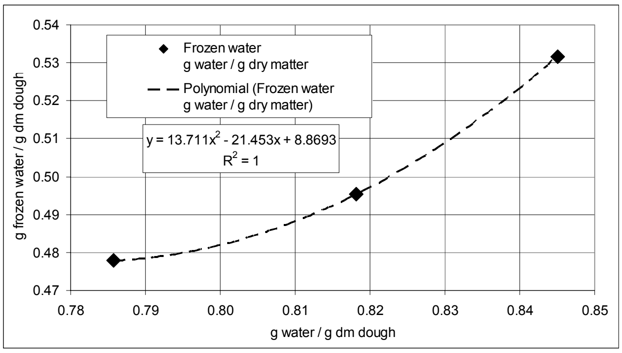


Figure 46
Amount of freezable water (g water/ g dry mater) per g of dry matter of the dough. EU-FRESHBAKE recipe and flour (Moulins SOUFFLET – France)

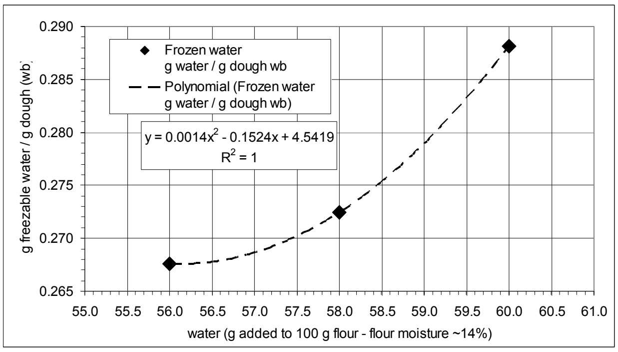


Figure 47
Amount of freezable water (g water / g dough – wb) as a function of the amount of water added on 100 g of flour. EU-FRESHBAKE recipe and flour
(Moulins SOUFFLET – France)

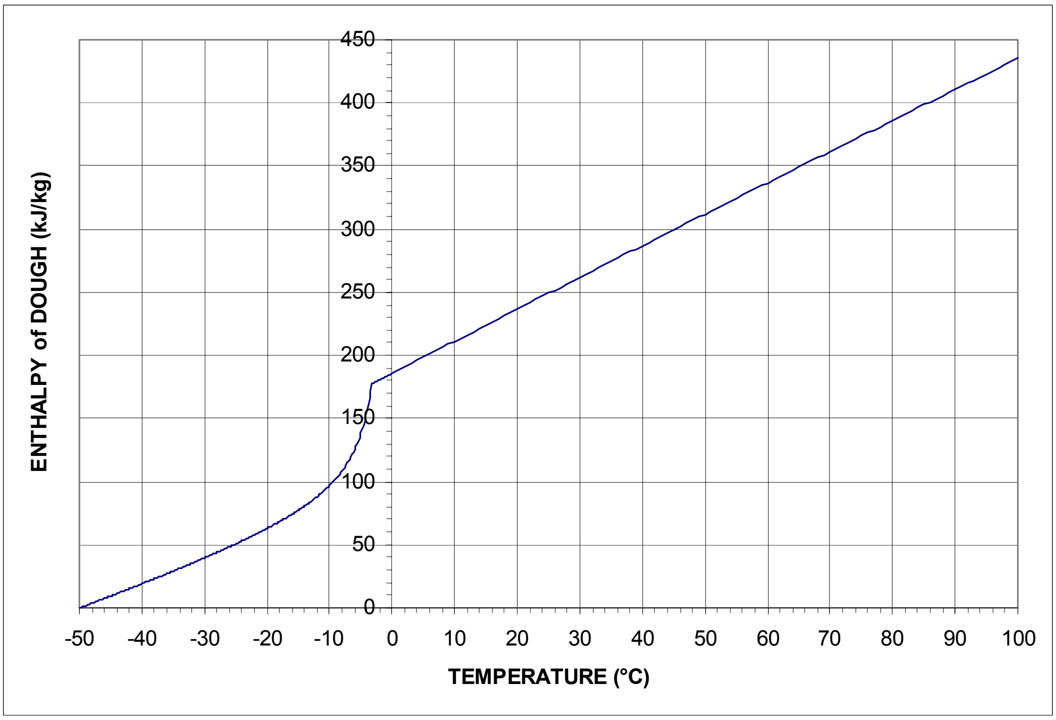


Figure 48

Enthalpy function of bread dough made with 58 g water / 100 g flour.

ANNEXE 4

ENTHALPY FUNCTION OF BREAD

The enthalpy function of bread has been evaluated using the flour and recipe used during the EU-FRESHBAKE project. Details on a recipe for direct-conventional baking process are given in Table 9. In the case of bread, different crust crumb ratio may be obtained. It is worth mentioning here that the crust crumb ratio (equation (11) refers to the ratio of mass of crust and of crumb (on a wet basis). The mass of crust and of crumb on basis of the bread is given by equations (12) and (13) respectively. For example a crust crumb ratio of 1 means that there is 50 % of crust and 50 % of crumb. The enthalpy function is given in **Figure 49**.

$$X_{CRUST/CRUMB} = A \quad (11)$$

$$X_{CRUST/BREAD} = A / (1+A) \quad (12)$$

$$X_{CRUMB/BREAD} = 1/(1+A) \quad (13)$$

As an example, bread with a 0.2 crust crumb ratio has been used. The data related to the initial freezing point, the moisture and the freezable water are presented in

Table **10**. The graph of the freezable water for the crust, for the crumb and for the bread is shown in **Figure 50**. The temperature that can be considered as the final freezing temperature is the temperature for which 80% of the freezable water is frozen. In our case, considering only the crumb, the final freezing temperature was considered to be -15°C as shown in the graph.

Table 10

Data related to the bread used for the enthalpy function presented in Figure 49.

	CRUMB	CRUST
CRUST CRUMB RATIO g crust wb / g crumb wb	0.2	
Dry Matter g DM / g product wb	0.545	0.727
Bound water - g water / g product wb	0.1726	0.245
Initial freezing temperature (°C)	-5	-10

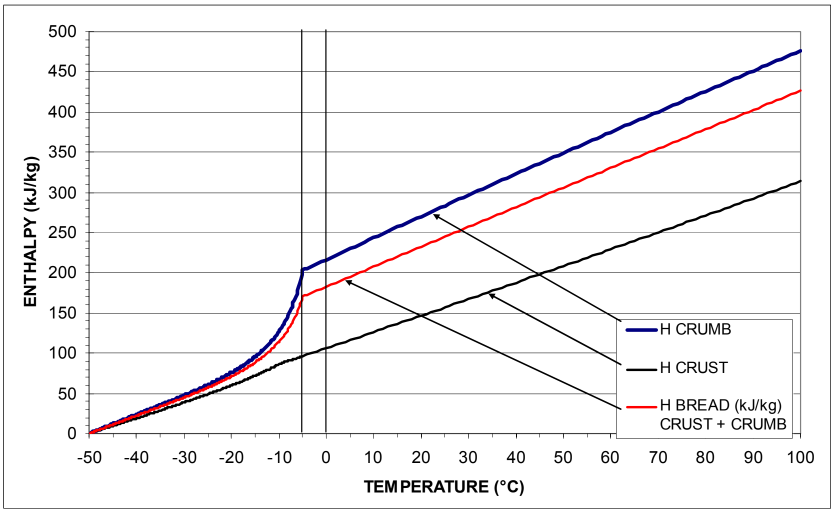


Figure 49

Enthalpy function of bread dough made with 58 g water / 100 g flour

Crust crumb ratio 0.2 wb (wet basis)

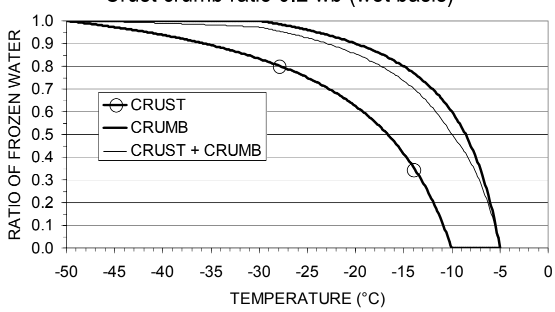


Figure 50

Evolution of the ratio of frozen water (based on the freezable water) for a bread according to recipe of **Table 9.** 80% of frozen water was obtained at around -15°C for the crumb and was considered as the final freezing temperature.

ANNEXE 5

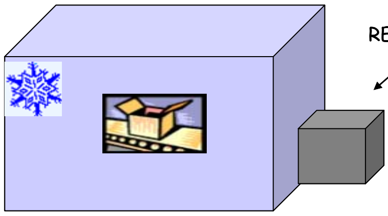
ENERGY AND BAKING – DATA FROM LITERATURE FOR DIFFERENT OVENS [88]

Authors	Type of baking	Energy Consumption (MJ/kg)
[82]	General Value	0.45-0.6
[89]	Bread (35000 kg / day)	7.26
[90]	3 bread bakeries	6.99
[91]	Bakery No.1: 250000 kg/y (batch)	13.96
	Bakery No. 2: 3500000 kg/y (continuous)	4.88
[85]	Bread baking (1700 kg /h)	0.86
	Multizone oven in USA	
[92]	12 Finish bakeries	6.5
	(1000000 bread/y)	
Bera et al. (1991)	USA : 35000 kg bread/day	7.26
	India: 1404 kg bread/day	31.82
[93]	9 gas fired ovens	6.17
	14 electrical ovens	5.34

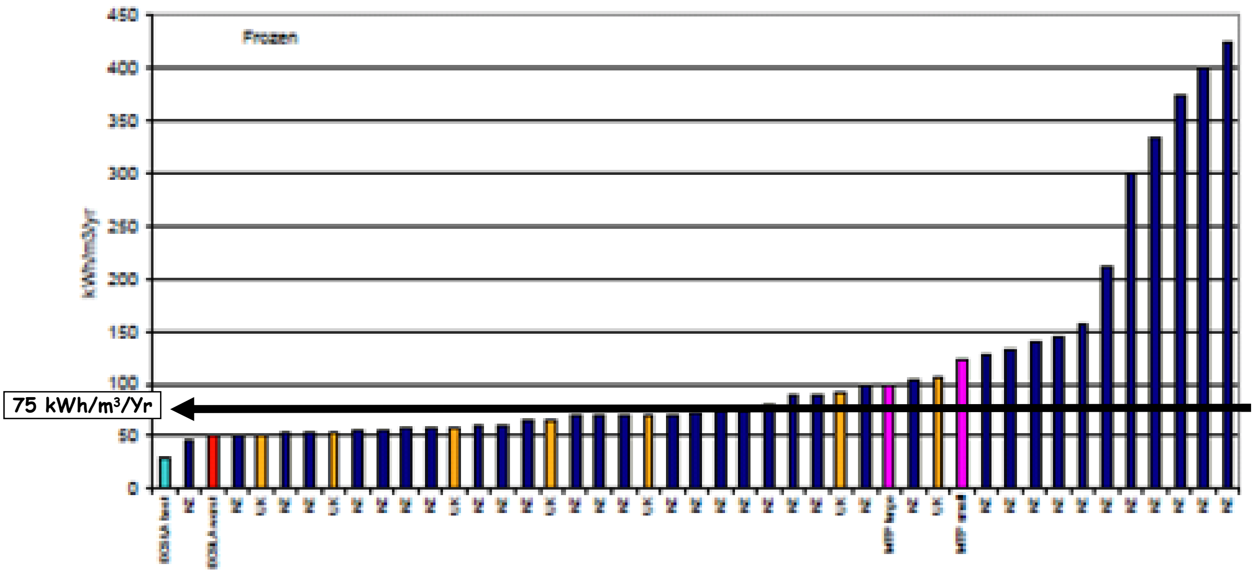
ENERGY AND BAKING – DATA FROM LITERATURE FOR DIFFERENT OVENS [81]

#	MJ/kg	kg	m²	kg/m²	Occ ratio	Reference	Remarks
1	0.45	NA	NA	NA	NA	Fellows, P.J. 1996. Food Processing Technology Principles and Practice. Woodhead Publishing Series in Food Science and Technology, Cambridge: Chap. 1:54-58, Chap. 15:314-327.	general values
2	0.60	NA	NA	NA	NA	Fellows, P.J. 1996. Food Processing Technology Principles and Practice. Woodhead Publishing Series in Food Science and Technology, Cambridge: Chap. 1:54-58, Chap. 15:314-327.	general values
3	0.86	NA	54.00	NA	NA	Christensen, A. and Singh R. P. 1984. Energy consumption in the baking industry. In Engineering and Food, Vol. 2, Processing Applications, B. M. Mckenna (Ed.), Elsevier Applied Science Publishers, London: 965-973	Bread baking (1700 kg /h) Multizone oven in USA - 1680 kg bread per hour - effective baking surface was 54 m^2
4	1.30	3.5	0.96	3.65	NA	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume partial baking 190 °C - 200 mL steam Energy includes the reheating before 2nd baking
5	1.80	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 281	Sole oven / mobile - Forced convection - no heat exchanger
6	1.90	3.96	0.96	4.13	1.00	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume baking 230°C - 500 mL steam 20 min with 16 min key open
7	2.00	2.3	0.96	2.40	NA	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume partial baking 190 °C - 200 mL steam Energy includes the reheating before 2nd baking
8	2.11	2.4	0.48	5.00	NA	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.2 m3 volume Exp design 220 - 250 °C steam 510-850 mL holding time 0 - 60 min 2 to 2.8 Kg dough
9	2.76	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 277	Sole oven - steam heating
10	3.09	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 279	Sole oven/fixed - Forced convection - no heat exchanger
11	3.10	2.36	0.96	2.46	0.66	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume baking 230°C - 500 mL steam 20 min with 16 min key open
12	3.37	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 280	Sole oven / mobile - Forced convection - with heat exchanger
13	3.54	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 278	Sole oven / fixed - Forced convection with heat exchanger
14	3.83	NA	NA	NA	1.00	Les Pains Français, Ph Roussel, H. Chiron, MAE-ERTI Editeurs, ISBN 2-84601-693-3 Page 276	Conventional oven - concrete construction
15	4.00	1.07	0.96	1.11	NA	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume partial baking 190 °C - 200 mL steam Energy includes the reheating before 2nd baking
16	4.88	NA	NA	NA	NA	Tragardh, C. 1980. Lebensm.-Wiss. u. - Technol., 14: 213-217	3 500 000 kg of bread per year.
17	5.34	NA	NA	NA	NA	Roosen, H.P. 1993. Getreide,-Mehl-und-Brot. 47(3):36-38	14 electrical ovens
18	5.40	1	0.96	1.04	0.50	EU-FRESHBAKE Data (06-09) - Confidential	Stone oven 0.4 m3 volume baking 230°C - 500 mL steam 20 min with 16 min key open
19	6.17	NA	NA	NA	NA	Roosen, H.P. 1993. Getreide,-Mehl-und-Brot. 47(3):36-38	9 gas fired ovens
20	6.50	NA	NA	NA	NA	Laukkanen, M. 1984. Improving energy use in Finnish bakeries. In Engineering and Food, Vol. 2, Processing Applications, B. M. Mckenna (Ed.), Elsevier Applied Science Publishers, London: 917-926.	12 Finish bakeries (1000000 bread/y)
21	6.99	NA	NA	NA	NA	Beech, G.A 1980. J. Food Sci. 13:(3): 289-294	3 bread bakeries
22	7.26	NA	NA	NA	NA	Johnson, L.A. and Hoover, W.J. 1977. Bakers Dig. 51-58	Bakery 35 000 kg of bread per day - USA
23	7.26	NA	NA	NA	NA	**Bera et al. (1991)**	USA : 35000 kg bread/day

ANNEXE 6
ENERGY for FROZEN STORAGE



ENERGY FOR FROZEN STORAGE : FRPERC SURVEY (UK-NZ): kWh/m3/Y
AVERAGE VALUE : 75 kWh/m3/Y



OCCUPANCY RATIO OF CARDBOARD IN FROZEN STORAGE : 0.7 m^3 CARBOARD/m^3 STORAGE
OCCUPANCY RATIO OF PART BAKED BREAD IN CARDBOARD : 120 kg/m^3 CARDBOARD
EFFECTIVE OCCUPANCY RATION IN STORAGE (per m³ of storage) : 84 kg/m^3 STORAGE
ENERGY in kWh/m^3 STORAGE/kg : 75 kWh/m^3 STORAGE/Yr = 270 MJ/m^3/Yr (1 Wh = 3600 J)

ENERGY = 270 MJ/m^3 STORAGE/Yr or

22.5 MJ/m^3 STORAGE/Month or 0.268 MJ/kg/Month

References :

Ref : Energy savings in cold storage – J EVANS –
http://www.frperc.bris.ac.uk/defraenergy/index.html
http://www.frperc.bris.ac.uk/defraenergy/storage.html