Design and Construction of a Batch Oven for Investigation of Industrial Continuous Baking Processes

Mette Stenby[a], Brian Nielsen[b], Jørgen Risum[a]
[a]*National Food Institute, Technical University of Denmark, Kgs. Lyngby, Denmark (metst@food.dtu.dk)*
[b]*Haas-Meincke A/S, Skovlunde, Denmark (Brian.Nielsen@haas-meincke.com).*

ABSTRACT
A new batch oven has been designed and build to model baking processes as seen in large scale tunnel ovens. In order to simulate the conditions found in tunnel ovens a number of critical parameters are controllable: The temperature, the humidity and the air velocity. The band movement is simulated by moving the two air ducts above and below the products; in this way it is possible to keep the baking tray steady for continuous measurements of the product weight. During baking the shape and colour of the product can be monitored visually through a window. The simultaneous measuring of mass and visual aspects is a unique feature of this batch oven. Initial experiments of reproducing tunnel oven baking in the batch oven have shown good results, based on comparisons of weight loss, dry matter content and surface colour. The measured quality parameters did not differ significantly. Even though a few adjustments are still needed in the batch oven set-up, it is clear that the batch oven, with its continuous data collection and high degree of process control will be a very valuable tool in the future work with modelling of baking process and products.

Keywords: Baking; Oven; Modelling; Food Processing; Process Control

INTRODUCTION
Many industrial bakeries depend highly on the experience and tacit knowledge of the operators. For oven manufactures, and large scale bakeries, there is a need to gain more knowledge on how the conditions in the oven affect the product quality during baking. This type of knowledge can be used, both for optimizing the processes, and to improve oven design.

The investigated types of tunnel ovens are comprised of different zones. In each zone the conditions such as temperature, air velocity, and humidity can be controlled independently. This is one of the major challenges when batch ovens are used to model tunnel ovens. Especially large decreases in temperature and humidity are difficult to obtain in batch ovens. In our design this has been taken into account by enabling rapid air exchange, using a fresh air inlet and a warm air exhaust controlled by the air humidity and temperature. It has to be noted that even though different zones in tunnel ovens have different settings, very fast temperature changes are generally not observed, as the hot air is dragged along the band through the oven chamber. However one of the goals for the new oven is not only to mimic existing processes, but also to investigate new possibilities and it must therefore be more flexible than standard tunnel ovens.

This is not the first batch oven designed to investigate continuous baking. Earlier important work has been done concerning this topic e.g. with the pilot plant oven described by Zareifard et al. [1]. This oven was designed to reproduce products and processes and validated against 15 continuous ovens. This oven has amongst other things been used to investigate heat flux and heating methods in baking procedures [2], and to investigate the air flow and heat transfer in ovens, assisted by computational fluid dynamics (CFD) [3]. CFD is generally used as an alternative to experimental testing, where this is either impossible or too laborious.

This paper is a description of the work behind the design and initial validation of our new batch oven. To the authors knowledge this oven differ from any previously described experimental ovens, by enabling of continuous measurements and observations of the product during baking. The work has been carried out as cooperation between an industrial tunnel oven manufacturer, Haas-Meincke A/S and the Food Production Engineering group at the Technical University of Denmark.

MATERIALS & METHODS
The batch oven

In a tunnel oven the product is moved through the oven chamber on a moving baking band. The speed of the band is set to fit the desired baking time. In the Haas-Meincke tunnel ovens the inlet air, used for convective heating, is introduced through 13mm holes made in heat ducts placed above and below the moving band. The pattern is a staggered holes design so that the product will encounter an even air stream when passing through the oven chamber. The same type of inlet is used in the batch oven and a schematic is shown in Figure 1; the hole pattern can be changed if needed. Contrary to the situation in a tunnel oven, the air ducts, not the product, are moving in the batch oven. This solution is chosen since the baking tray is placed on a scale measuring the weight continuously during baking. The distance from the air ducts to the product varies depending on the product height. Accordingly the batch oven has been constructed with the possibility to adjust the distances from air ducts to baking tray.

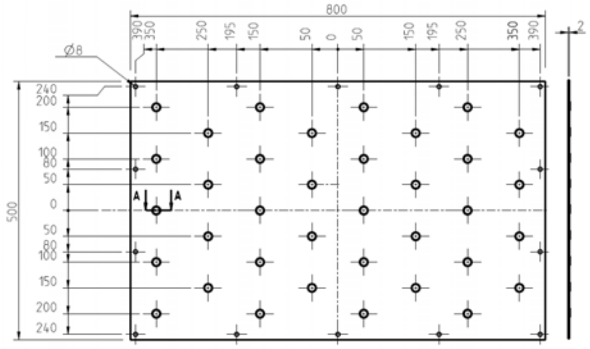

Figure 1. Dimensions of the inlet part of the air ducts, distances given in mm. The upper air duct has outlet suction along the two 800mm sides.

Heating system

In order to simulate the widest possible range of tunnel ovens both a convective and a radiative heating system has been installed in the batch oven. The radiative system consists of two KMIN 9.24 meters heating cables with a diameter of 3.6 mm and a 200W/m power capacity from SAN Electro Heat (Denmark). They are placed on the heat ducts between the inlet air holes above and below the baking tray. The ratio of heat supplied from each element can be controlled. The convective heat system is more complex as the air requires an external heating system. The piping is shown schematically in Figure 2. After leaving the baking chamber (A) the air passes the humidity sensor (B), hereafter the fresh air intake (C) can supply dry and cool air. This is followed by the ventilator (D), the air outlet (E) and the heating unit (F). Before entering the baking chamber the air is divided into the top and bottom air duct channels (G). The exhaust in the baking chamber is placed above the baking tray, at the front and back sides of the upper air duct.

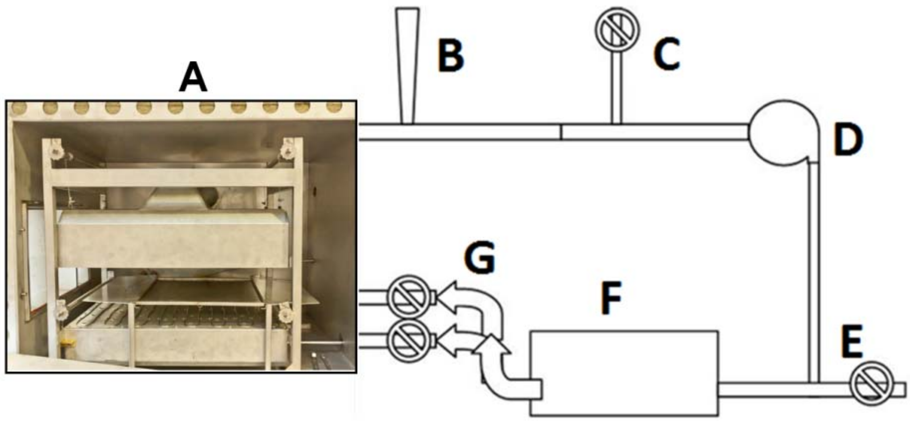

Figure 2. Schematic of the air heating system. A - the oven chamber, B - humidity sensor, C - air intake, D - ventilator, E - air out, F – heating unit, G - separation into top/bottom heat ducts.

Measuring and control equipment

The frame supporting the 40x40cm baking tray is placed on a scale outside the oven chamber in order to record the product weight loss during baking. The scale is a Signum Suprime level 1, 35 kg (±0.1g) from Sartorius (Germany). As seen the upper limit for the scale is 35kg, this high capacity is chosen so that different materials can be used for baking trays. Not all products are baked on metal sheets. For some products a stone surface is needed, which will increase the total weight significantly. For humidity control a Yokogawa High Temperature Humidity Analyzers type ZR22G-040 (Japan) has been installed, measuring the humidity in the outlet air. The temperature in the oven chamber is measured in the inlet air, the outlet air and close to the baking tray using temperature sensors (±1°C). These measurements are used to control the air exchange with regard to needed air humidity and temperature. Additional sensors can be installed if needed. At the side of the baking chamber a window enables visual observations and on-line monitoring of the products during baking. This will be used as input for dynamic modelling of the baking processes. Further features of the oven, which are not yet in place, include pitot-tubes for flow measurements and a steam injector.

The batch oven is designed so that it can reproduce conditions as found in tunnel ovens, but also enable validation and modelling outside the prevailing settings. It should be possible to test settings and combinations of temperature, air velocity and humidity which are not necessarily used industrially today.

Initial experiment

So far only few baking procedures have been carried out. The purpose has been to validate if it is possible to 1) bake evenly in the batch oven, and 2) for the batch oven to reproduce a product baked in the tunnel oven (colour, weight loss and dry matter), under the same operating conditions as found in a tunnel oven.

The tested procedure

Cookies were used for the initial baking experiments; the dough composition is shown in Table 1. The tunnel oven used for validation was a 10 meter indirectly heated convection oven divided into 2 zones. The settings were the same for both zones. It was set to 180°C and with a 50/50 top and bottom distribution of the inlet air. The inlet air temperature was measured to 177°C (average of 30 seconds using a T-type thermocouple and measuring each second). The cookies were baked for 8minutes. The air velocities were measured half way through the tunnel oven, on the air entering through the air ducts' inlet holes, using an anemometer from Testo AG (Argentina) with a vane/temperature probe, Ø 16 mm. For the tunnel oven the maximum measured velocities were 3.5 m/s (top) and 2.3 m/s (bottom).

Table 1. Composition and mixing procedure for cookie dough, based on 25kg flour [6].

Ingredients	**Amount (kg)**	**Mixing procedure continued…**	**Amount (kg)**
Margarine	15	Leavening agents	0.67
Icing Sugar	6.5	Vanilla sugar	0.05
Granulated sugar	6.5	Butter flavour	0.005
Mixing speed: *Mixing time (min):*	*Fast* *3*	*Mixing speed:* *Mixing time (min):*	*Fast* *3*
Skimmed milk powder	0.5	Flour, wheat	25
Glucose sugar	0.5	*Mixing speed:*	*Slow*
Whole eggs	3.0	*Mixing time (min):*	*2*
Salt	0.1	**Total dough prepared**	**57.8**

The conditions in the batch oven were set as close as possible to the tunnel oven. The air temperature was 178°C measured just above the baking tray. The air velocities were maximum 3.6 m/s (top) and 2.1 m/s (bottom), when measured at the inlet holes. Two features of the batch oven were not possible to adjust in the initial experiments. The speed of the ducts' movement and the height of the baking chamber were not exactly the same. The heights were measured to 154 mm (top) and 82 mm (bottom) in the tunnel oven, and 130 mm (top) and 100 mm (bottom) in the batch oven. As mentioned, both the height of the baking chamber and the duct velocity can be adjusted in the batch oven, and the effect of these parameters on the product quality will be investigated in future work.

The cookies were formed by shaping the dough into spheres which were flattened to approximately 1 cm high circular shapes. Two groups were baked in each oven. One group of smaller cookies app. 15g dough, and a group of larger cookies app. 21g dough each. The groups consisted of 6 cookies, giving a total of 24 cookies.

The colour of the top and bottom surfaces was measured using a Minolta CR200 colorimeter (Japan). A CIE-Lab representation of the colour was chosen, and the lightness, L*, was used in the comparison of the tunnel and batch ovens. The use of L* values as an indicator for the degree of browning during baking has been used for bakery products in works such as [4, 5]. Furthermore the weight loss during baking and the final dry matter content were measured and compared.

RESULTS & DISCUSSION

Initial experiments

Due to the design of the tunnel oven it was necessary to adjust the baking time in the batch oven, to obtain comparable baking conditions. After passing through the 10 meter oven, the band is covered for another 2 meters. During this time (50-100 seconds) the cookies are still on the heated band and in warm but gradually colder air. To approach this extra baking time, 30 seconds were added to the 8 minutes baking time in the batch oven.

The measured results are shown in Table 2. No difference between the tunnel and batch oven is seen for the weight loss and dry matter contents. The top surface colour does not differ within one standard deviation of each other. The bottom surfaces differ more, with the batch oven producing the lighter cookies. In Figure 3 examples of the cookies are shown, both top and bottom surfaces are shown.

Table 2. Overview of results from the initial baking experiments, average values and standard deviations are given for each group of cookies.

	Tunnel		Batch	
	Small	Large	Small	Large
Initial dough weight (g)[1]	15 ±0.9	22 ±0.7	14 ±0.7	21 ±0.5
Baking loss (%)[1]	13 ±0.5	12 ± 0.4	13 ±0.4	12 ±0.4
Final dry matter content after cooling (%)[2]	97 ± 0.0	96 ± 0.5	97 ± 0.0	96 ± 0.1
Lightness (L*) top surface[3]	58 ±1.3	59 ±1.4	61 ±3.2	59 ±2.2
Lightness (L*) bottom surface[4]	39 ±2.2	41 ±1.1	45 ±0.8	48 ±3.1

[1)] All cookies were measured (n = 6), [2)] 2 cookies from each group were measured (n = 2), [3)] Three measurements were made on each cookie, all measurements were used for the average values (n = 18), [4)] One measurement was made on each cookie (n = 6).

The standard deviation for the top surface colour of the cookies baked in the batch oven is slightly higher than that for the tunnel oven. This larger variation when using the batch oven compared to the tunnel oven is possibly related to the positioning of the cookies. The cookies baked in the batch oven were placed on a 40x40cm baking tray. Partly browned cookies, which are not included in the data, clearly showed limitations for the baking area on the baking tray. They were placed near the front edge of the tray, below the air outlet, and were only browning on the inner half of the top surface. Approximately the centre 35x35cm of the baking tray was used for the measured cookies and these showed no systematic colour variations. The exact baking area in the batch oven will be mapped in the next step of the oven validation. Compared to the cookies baked in the tested tunnel oven, larger variations in the local baking condition may still have arisen in the batch oven. Ideally the cookies baked in the tunnel oven, would have been positioned across the baking band, maximizing the possible differences in baking conditions. However this was not possible for the current experiment and the measured cookies were baked in an almost straight line through the tunnel oven. This might have resulted in unrealistically small baking condition variations. Overall the differences in standard deviations are not very large. Compared with the visual inspections of the cookies baked in the batch oven there is a clear indication that evenly coloured products can be produced with the used convective heating system.

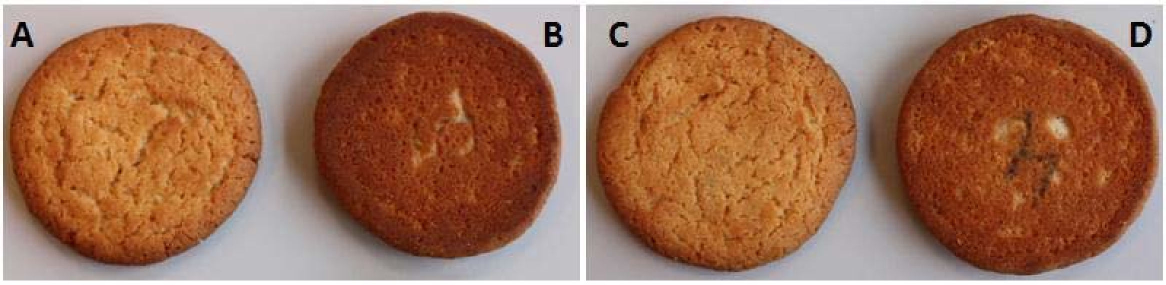

Figure 3. Pictures of the top and bottom surfaces of cookies baked in the tunnel oven (A+B) and the batch oven (C+D).

The darker colour seen on the bottom surface of the cookies baked in the tunnel oven is likely due to the use of a preheated baking band. The exact temperature of the steel band was not measurable, but the temperature was higher than that for the batch oven baking tray (room temperature), as the steel band does not have time to cool between leaving and re-entering the tunnel oven. Additionally the heat transfer after the product leaves the oven and before it can be removed will mainly be from the hot band to the bottom surface, adding more energy for colouring of the bottom surface.

The air temperature in the batch oven was measured during baking. Before the door was opened and the product inserted, the air temperature in the oven chamber was 178°C. The development after closing the door is seen in Figure 4. It was not possible to make a comparable temperature measurement of the air near the cookies during baking in the tunnel. But it is assumed that the air temperature is more stable in the tunnel oven as the inlet and outlet areas are small compared to the size of the oven.

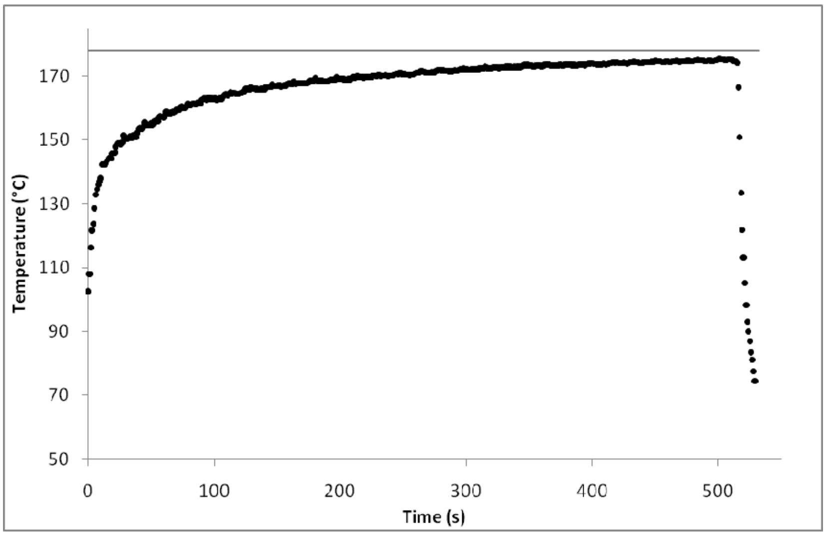

Figure 4. The black dots show the air temperature in the batch oven near the products, during the 8.5 min baking. The grey line indicates the initial oven temperature of 178°C.

The inability to reach the original air temperature after placing the product is a clear difference between the batch and tunnel ovens. It was seen immediately when the batch oven was switched on that the installed 5 kW heating element was insufficient. The slow reheating was thus to be expected for the present baking experiment. A 20kW element will be installed in the next phase of the project. Furthermore the possibility to switch off the air flow when the oven door is opened and restarted when it is closed is being pursued. This will reduce the heat loss due to emission of warm air, when product is inserted.

CONCLUSION

A new unique batch oven has been constructed. The oven is capable of following both the baking products during baking and modelling baking procedures, as seen in continuous tunnel ovens. The initial experiments showed that it is possible to reproduce products made in a tunnel oven and that the convective heating system in the batch oven, produces an even baking over the main area of the baking tray. From the experiments it was further seen that the present heating capacity of the batch oven is insufficient and that the baking trays might need to be preheated to better match the tunnel oven conditions. The next step of the project will be a more in-depth validation of the new batch oven. Hereafter it can be used as a tool for modelling baking procedures with emphasis on heat and mass transfer during baking.

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