[1]Mohd N. H. Musalim,*
[2]Mohd F. Hassan,
[1]Azeze Aziz,
[1]Mohd S. A. M. Yusoff,
[1]Mohamad E. M. Fazee,
[1]Suryani Abdullah

[1]Industrial Centre of Innovation for Industrial Design
SIRIM Industrial Research, SIRIM Berhad,
Lot 5285 Lebuhraya Sg Besi-Puchong
57000 Sungai Besi, Kuala Lumpur.

[2]Advanced Structural Integrity and Vibration Research (ASIVR), Faculty of Mechanical Engineering,
Universiti Malaysia Pahang, Pekan, Pahang.

nazrol@sirim.my

PULSE PRESSURE OSMOTIC DEHYDRATION (PPOD) METHOD FOR SALTED EGG MANUFACTURING USING 3D-PRINTED POLYMER PRESSURE CHAMBER

RINGKASAN: *Telur masin adalah makanan popular Asia yang berasal dari generasi purba negara China. Kaedah konvensional pada ketika ini adalah dengan menggunakan campuran tanah merah dan garam yang mengambil masa sehingga dua minggu untuk mencapai kadar kemasinan yang diterima pengguna. Kaedah penyelidikan baru menunjukkan, pengenalan Pulse Pressure Osmotic Dehydration (PPOD) mampu mempercepatkan proses ini. Tumpuan diberikan kepada penggunaan prototaip kebuk bertekanan udara yang dihasilkan menggunakan teknologi percetakan 3 dimensi. Menggunakan kombinasi yang berbeza antara komposisi NaCl-H_2O dan juga teknik denyutan, penyelidikan ini telah mengenal pasti masa yang diambil untuk mencapai nilai ambang penyerapan garam (berdasarkan telur masin yang boleh didapati secara komersial). Hasil kajian awal menunjukkan bahawa kaedah ini mampu menyingkatkan tempoh dehidrasi osmosis untuk proses pembuatan telur masin.*

ABSTRACT: Salted egg is a popular delicacy for Asian populace originated from ancient Chinese recipe. The current method of production is through preservation using red soil and brine coating which can take a minimum of 2 weeks before reaching the threshold of saltiness acceptation. Recent research shows that the introduction of Pulse Pressure Osmotic Dehydration (PPOD) method will be able to reduce the absorption time. This innovation is faster and more effective than the making of salted egg by using traditional salting. The focus is on the use of air pressure chamber prototype generated using 3-dimensional printing technology which was Selective Laser Sintering (SLS). The usage of 3D Printed air pressure chamber with different combination of NaCl-H_2O and pulse strategy to the egg specimen, identifies time taken in reaching the threshold value (based on commercially available salted eggs) of salt absorption. The preliminary result shows that this method is capable of shortening the osmotic dehydration time for egg salting.

Keywords: Salted egg, Additive Manufacturing, Selective Laser Sintering, Pulse Pressure Osmotic Dehydration.

INTRODUCTION

In the elder days, egg salting exercise is a preservation process with the aim of avoiding natural damage due to a long time keeping and to secure the egg quality. Over the years the saltiness has become the main feature of the egg, drawing interest from food lovers. There are several types of egg which are suitable for making salted egg, namely chicken, duck, and quail eggs. Traditional Chinese recipe prefers duck eggs rather than other eggs due to its high nutrition content and aesthetic. Although chicken based salted egg is also available in the market, too often being second choice after the duck eggs. There are many egg salting methods invented over the centuries such as salted charcoal, brining and osmosis technique. The osmosis method also has its own variation. Among the many method of osmosis are alkaline solution, salt, black tea and metal ions at the atmospheric temperature for 30 – 40 days (Tu *et al.*, 2013). Egg also can be coated with the mixture of red soil or salted charcoal and brine solution for 20 – 30 days at the ambient temperature around 27 °C (Chi & Tseng, 1998). Long-term period salting would additionally produce certain fermentation to create pure flavour of salted and to develop its original taste. Normally, salted egg is consumed as an additional condiment to other foods. The salted yolks are used as an “add-on” ingredient in some of Chinese foods for example moon cake, desserts and glutinous rice to give the extra nutrition and sensual quality of pastry (Kaewmanee *et al.*, 2009).

The advancement of additive manufacturing has spurred an opportunity to explore air pressure chamber application, expectantly it is able to expedite and improve salted egg production time. Among many additive manufacturing methods, selective Laser Sintering was chosen throughout the research. Selective Laser Sintering (SLS) is a powder-based Additive Manufacturing (AM) process used to fabricate complex or non-complex shaped parts without using preforms or moulds. A roller or scraper system is conventionally used to deposit successive powder layers. A laser beam is used as a heating source for selectively sintering each powder layer according to predetermined geometries. The SLS process that is vastly studied for polymeric and metallic materials, and different polymer and metal powders are commercially developed to produce fully functional parts (Kruth *et al.*, 2007).

Salted egg is produced by immersing eggs in the brine solution, or by coating the eggs in damp, salted ash or charcoal. Traditionally, these methods take about 20-30 days at around 27 °C (Chi & Tseng, 1998). The salted eggs are commonly made from duck eggs due to its more desirable aesthetic. The most effective and easiest method for the production of salted egg is by using immersing method (Wang *et al.*, 2013). Therefore, in this study the design criteria of pressure chamber adopted the preferred immersing method.

With increasing demand of salted eggs in the oriental food chain, the production is in need of improvement. The current time to market is very dependent to the osmosis process, unless the absorption time is shortened, manufacturers struggle to meet the market demand. However, the quality of salted egg must be maintained at the current standard of which the key parameter for such standard is the salt content of post processed egg. The proposed solution in this paper identified a benchmark target of salt content as qualifying method for adoption by an establishment of digital salt meter.

MATERIALS AND METHOD

The design of the pressure chamber, preparation of different solution concentration of sodium chloride and the processes of making salted egg are described in this section. The study will evaluate the usage of 3D-printed salted egg pressure chamber by applying the Pulse Pressure Osmotic Dehydration (PPOD) process.

Design of pressure chamber

The pressure chamber was designed by using Solidwork CAD software and later printed by Formiga P110 Selective Laser Sintering (SLS) machine. Nylon Polyamide White (PA 2200) was selected for pressure chamber material due to its relatively high stiffness and strength in comparison to other available materials. The mechanical properties of PA2200 was shown in Tables 1 and 2. In addition, its chemical resistance and outstanding long-term stability characteristic are suitable for chemical used for the empirical model. It consists of two parts of printing i.e. (i) pressurised tank and (ii) tank lid with O-ring embedded (Figure 1).

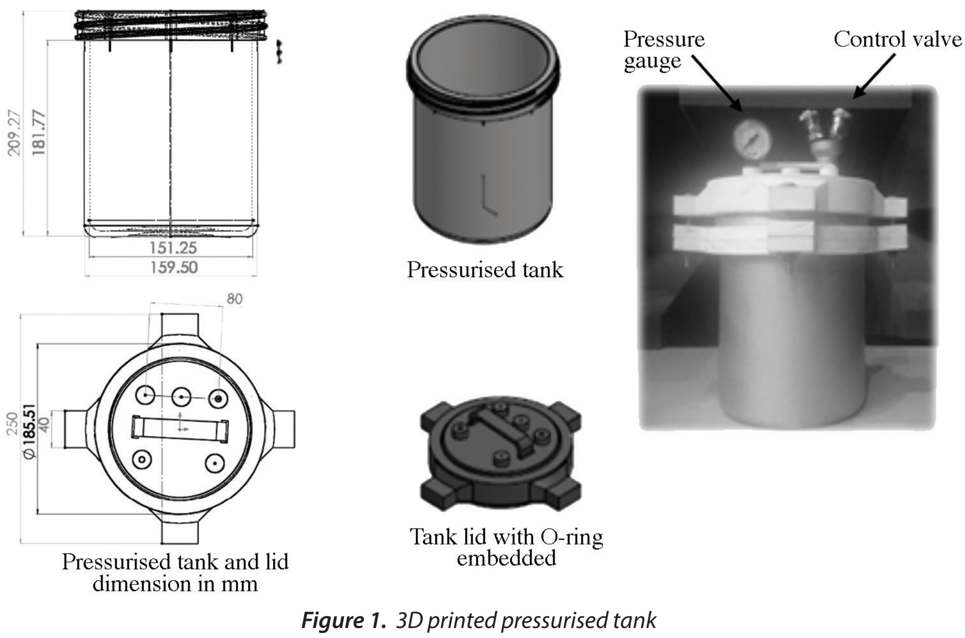

Figure 1. *3D printed pressurised tank*

Table 1. General properties of additive manufacturing strategy.

General Material Properties			
Average Grain Size	ISO 13320-11 Laser diffraction	56 2.20	µm mil
Bulk Density	EN ISO 60	0.45	g/cm³
Density of Laser-sintered part	ESO method	0.93 58	g/cm³ lb/ft³

Source: Extracted from EOSP MATERIAL DATA SHEET PA 2200 2017.

Table 2. Mechanical properties of additive manufacturing material.

Mechanical Properties			
Tensile Modulus	EN ISO 527 ASTM D638	1700 247	MPa ksi
Tensile Strength	EN ISO 527 ASTM D638	48 6962	MPa psi
Elongation at break Elongation at break	EN ISO 527 ASTM D638	24 24	% %
Flexural modulus	EN ISO 178 ASTM D790	1500 217	MPa ksi
Flexural strength	EN ISO 178 ASTM D790	58 8412	MPa psi
Charpy - Impact strength Charpy - Notched impact strength	EN ISO 179 EN ISO 179	53 4.8	kJ/m² kJ/m²
Izod – Impact strength	EN ISO 180	32.8	kJ/m²
Izod – Notched impact strength	EN ISO 180	4.4	kJ/m²
Ball indentation hardness Shore D - hardness	EN ISO 2039 ISO 868 ASTM D2240	78 75 75	N/mm² - -

Source: Extracted from EOSP MATERIAL DATA SHEET PA 2200 2017.

Preparation of Different Solution Concentration of Sodium Chloride

Three different NaCl concentrations were used to investigate the optimized concentration needed for the shorten time of pickling of egg. The concentration of NaCl solution follows the ratio of 3:5 (w/w) NaCl to water solution and the NaCl must be greater than or equal to 25 % (w/w). The ratio of NaCl concentration used was 10:90, 25:75 and 40:60 NaCl to water (w/w), (Wang *et al.*, 2013).

Pulse Pressure Osmotic Dehydration Process

The main objective of the experiment is using Pulse Pressure Osmotic Dehydration (PPOD) to replace the existing method of egg salting procedure. Six pre-washed duck eggs were used in every cycle of the experiment. The eggs were immersed in the pre-prepared NaCl solution in the pressure chamber and then the pressure chamber lid was closed to ensure there is no air leakages. The pressure chamber was set to the intermittent pressure as shown in Figure 2. In this phase, the tank was pressurized to 200 kPa and the condition was kept for 10 minutes. The air pressure was then released to the value of 100 kPa and kept stagnant for another 10 minutes. The cycle is repeated for 60 minutes. This process was continued for 6 days with only a single egg sample unloaded every morning, however the unloading of every eggs was only done when the tank pressure was reduced to atmospheric pressure via control valve. The tank pressure adjustment was done in the morning prior to unloading process. This to monitor the daily egg salting progression and maintain the reference initial pressure during sample unloading.

Once all the eggs were collected, they were boiled imitating the typical dish preparation and the salt content in the egg white and egg yolk was tested using Digital Salt-Meter.

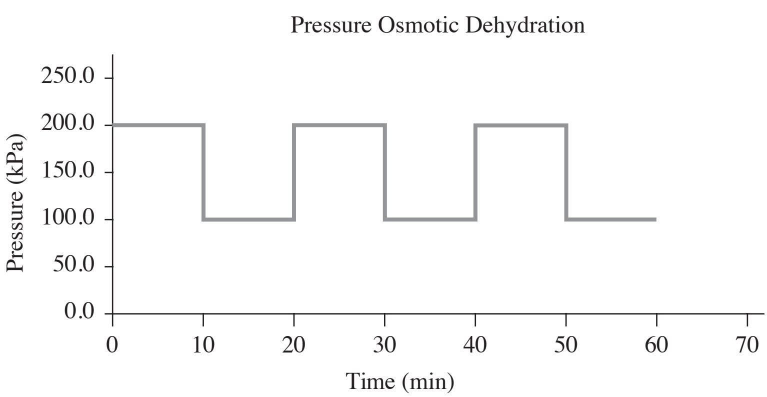

Figure 2. *Pressure pulse design for experiment*

RESULTS AND DISCUSSION

The pulsed pressure osmotic dehydration (PPOD) technology used pulsed pressure of osmotic solution to increase the pickling efficiency. From Figures 3, 4 and 5 it was observed that the salinity of pickled egg increased as the pressure for the PPOD increased. As the pressure increased from 1 bar, 1.5 bar and 2.0 bar, the time taken for the egg samples to reach desirable internal appearance was shortened. Mass transfer between NaCl solution and the egg samples was driven by force created via gradient in the pressurized chamber system potential. The driving force for transport over phase boundaries is generated by a deviation from equilibrium over such an egg shell plus thin membrane boundary. Additional driving forces contribute to a drift velocity, such as the forces created by intermittent pressure adopting the PPOD approach. However, this effect was only apparent for egg white rather than the yolk part of it. This characteristic can be explained by the natural position of the two compositions as the egg white boundary layer being closer to the shell.

Figure 6 showed the comparative analysis for the egg white with and without PPOD implementation. By setting the same threshold of saltiness being the commercially available off the shelf salted egg, the osmosis period was presented for different PPOD conditions. The salted egg was cut into two sections to inspect the internal appearance of the white egg as well as the yolk (Figure 7).

The waiting time for salted egg to reach the desired saltiness similar to the conventional method was reduced to less than 50 % using all the three different PPOD strategies. Maximum pressure for the pressurised tank was limited to 2 bar due to design capabilities of the embedded silicone O-ring insert, located between bottom chamber and its top cover.

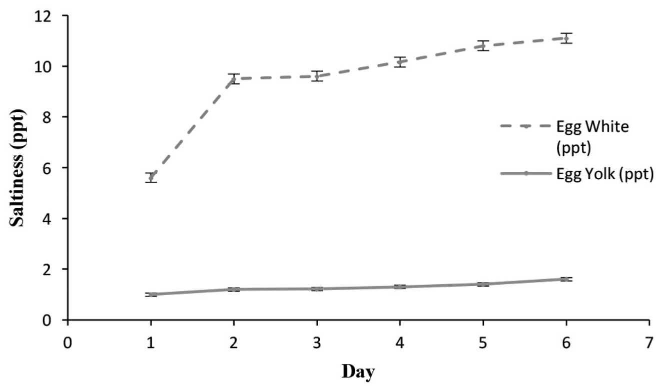

Figure 3. *Saltiness response for 1 bar pressure PPOD.*

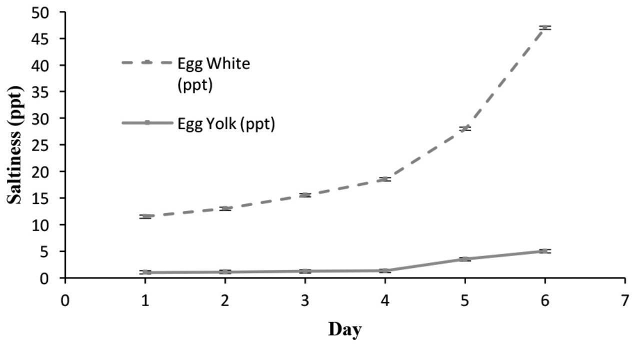

Figure 4. *Saltiness response for 1.5 bar pressure PPOD.*

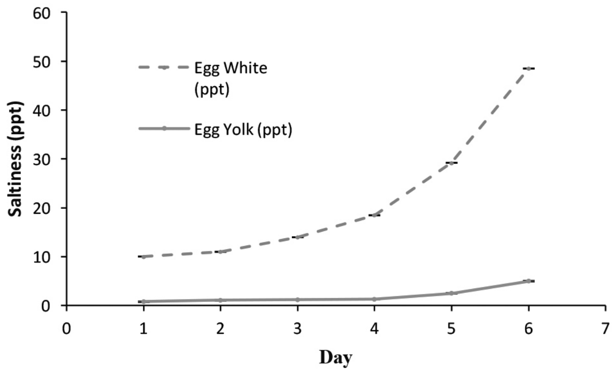

Figure 5. *Saltiness response for 2.0 bar pressure PPOD*

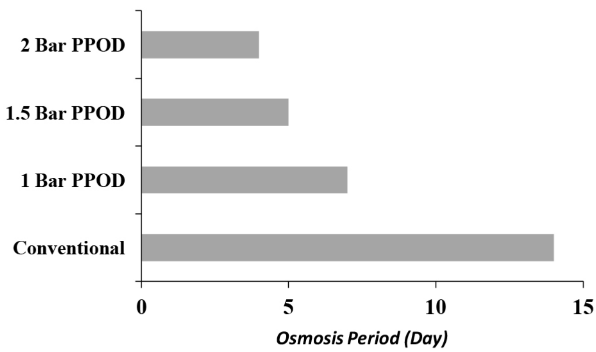

Figure 6. *Comparative analysis of conventional vs PPOD method osmosis period for reaching desired internal appearance.*

Figure 7. *The internal appearance after having the salting process(conventional).*

The additive manufacturing approach of building pressurised chamber using Selective Laser Sintering(SLS) method is a potential solution to the PPOD system. It can be an economical substitute for pressurised metal chamber where it will require researcher to produce metal mould which is very costly. The effect of higher operating pressure for the PPOD was not established, due to the limitation of pressure to 2 bars on the current design. Beyond this pressure value, the pressure chamber will start having an air leakage. This limitation opens up a new opportunity to work on the design of container using different method of 3D printing to obtain better chamber rigidity. Additionally, more suitable material for the silicone O-ring can be explored further. A rather automated data acquisition shall be introduced to the method in reducing the manpower for data collection and PPOD execution.

CONCLUSION

The method of PPOD had reduced the traditional salt pickling process of duck egg. The typical 14 days waiting time can be reduced significantly by allowing the osmosis process to happen in a pressure chamber. However, the limitation of this method requires an improvement as the response of PPOD is only apparent for egg white without significant improvement to the yolk. Further study using computational fluid dynamics can be explored to obtain optimal pressure and brining time for effective salt penetration into the yolk.

ACKNOWLEDGMENT

The author would like to thank Adil Anuar, Hazley Sham Othman Dagang, and Norazman Satiman for their contribution in accomplishing this study.

REFERENCES

Chi, S., & Tseng, K. (1998). Physicochemical Properties of Salted Pickled Yolks from Duck and Chicken Eggs, 63(1), 27–30.

EOS GmbH – Electro Optical System. (2012). FORMIGA P 110 - Training Manual, 11.12 , 7 – 8.

EOSP MATERIAL DATA SHEET PA 2200 2017.

Formiga, P. (2017). Material data sheet PA 2200. EOS-Plastic - PA2200 Material Data Sheet, 49, 1–2.

J.-P. Kruth, G. Levy, F. Klocke, T.H.C. Childs (2007). Consolidation phenomena in laser and powder-bed based layered manufacturing CIRP Annals–Manufacturing Technology, 56, 730-759.

Kaewmanee, T., Benjakul, S., & Visessanguan, W. (2009). Effect of salting processes on chemical composition, textural properties and microstructure of duck egg. Journal of the Science of Food and Agriculture, 89(4), 625–633.

Tu, Y. gang, Zhao, Y., Xu, M. sheng, Li, X., & Du, H. ying. (2013). Simultaneous Determination of 20 Inorganic Elements in Preserved Egg Prepared with Different Metal Ions by ICP-AES. Food Analytical Methods, 6(2), 667–676.

Wang, X., Gao, Z., Xiao, H., Wang, Y., & Bai, J. (2013). Enhanced mass transfer of osmotic dehydration and changes in microstructure of pickled salted egg under pulsed pressure. Journal of Food Engineering, 117(1), 141–150.