PERSPECTIVE

Stainless Steel, the Forgotten Contributor to Healthy Food Processing: How Engineers Can Help Improve Snack and Convenience Foods

Clyde Don,[1] Paul Verbruggen,[2] and Ben Kop[2]

It is hard to imagine a world without snack and convenience foods. These foods have been key sales drivers in the food industry for decades and will probably be on our menus for many years to come (7). Furthermore, future trends indicate that eating on the go, replacing meals with snacks, and minimizing meal preparation times still top the list of consumer purchasing decisions. Although consumers in the United States, Europe, and elsewhere have become more aware of healthy versus unhealthy food choices, we cannot seem to resist purchasing snack and indulgence foods (8). Unfortunately, convenience and snacking are often associated with foods that are overprocessed, high in fat, and high in salt and that contain sugars and artificial ingredients and flavors. In short, they do not fit in a healthy lifestyle.

The vast realm of convenience and snack foods includes meat-based battered and breaded foods such as fried chicken, chicken nuggets, pork schnitzel, fish fingers, etc. On the positive side, the meat-base plays an integral role in meeting our protein nutritional needs, because meat and fish are good sources of proteins containing essential amino acids (3). The coatings, batters, and breadings used with these meat-based foods are largely made with wheat or other cereal flour (e.g., rice, corn) to give the products an appealing, crispy texture (Fig. 1). It is no wonder then that market forecasters such as Mintel (7,8) predict continued global growth for convenience and snack foods. When this dietary trend cannot be changed, food science and technology are challenged to improve the nutritional profiles of these food products to promote the health of consumers.

Food chemists tend to focus on the ingredient level. For example, it is known that adding fiber or using coating materials that do not absorb as much frying oil may move a product into a category that is perceived as healthier, but why not start at the beginning: the production process? A birds-eye view of a chicken nugget line is shown in Figure 2. In this example, the process steps are meat grinding/mixing → blender → former → battering and tempura/breading → frying → freezing → packaging.

In a chicken nugget line several food-processing operations take place that are also applicable to products such as fish fingers or pork schnitzels: meat paste forming, battering and breading, and deep-fat frying are the key operational steps. Machinery developers are constantly faced with equipment and food quality challenges. Current top-of-mind processing issues for health and sustainability include

- Lean-meat and low-salt recipe processing
- Optimizing batter/breading/tempura adhesion, structure, and texture
- Maintaining oil quality or preventing oil deterioration (e.g., cleaning, oxidation, burned particles)
- Preventing black or burned spots on baked or fried products
- Managing fat content during processing
- Minimizing rejected product and returns

Grinding, Mixing, Blending, and Forming Meat Products

Mechanical grinding, mixing, and blending turn raw meat into a malleable meat paste. In the case of high-quality nuggets fresh chicken breast is used as the meat base. In microbiology, salt is known for its food preservation properties. Additives like salt and phosphates also physically improve meat paste properties. It is common knowledge that 2.0–3.0% salt addition helps in solubilizing myofibrillar proteins. Today, the European Union and United States are demanding salt be reduced in food formulations by 30–40%, with low or no phosphate or additives. Processors, therefore, must find other ways to control the functional properties of their meat pastes and patties.

Although salt is viewed as indispensable for meat processing, the fact is that the extraction of muscle proteins during process-

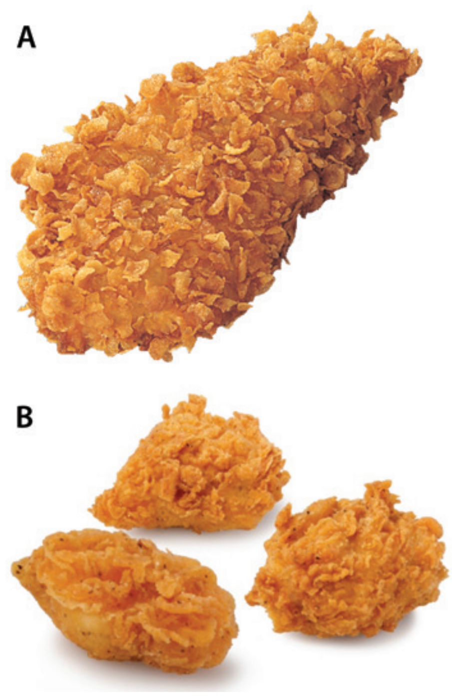

Fig. 1. A, Crispy schnitzel with corn-flake breading; and **B,** popcorn chicken with crispy coating. (Photo courtesy of GEA Food Solutions)

[1] CDC FoodPhysica Laboratory, Malden, The Netherlands.

[2] GEA Food Solutions BV, Bakel, The Netherlands.

https://doi.org/10.1094/ CFW-63-4-0143

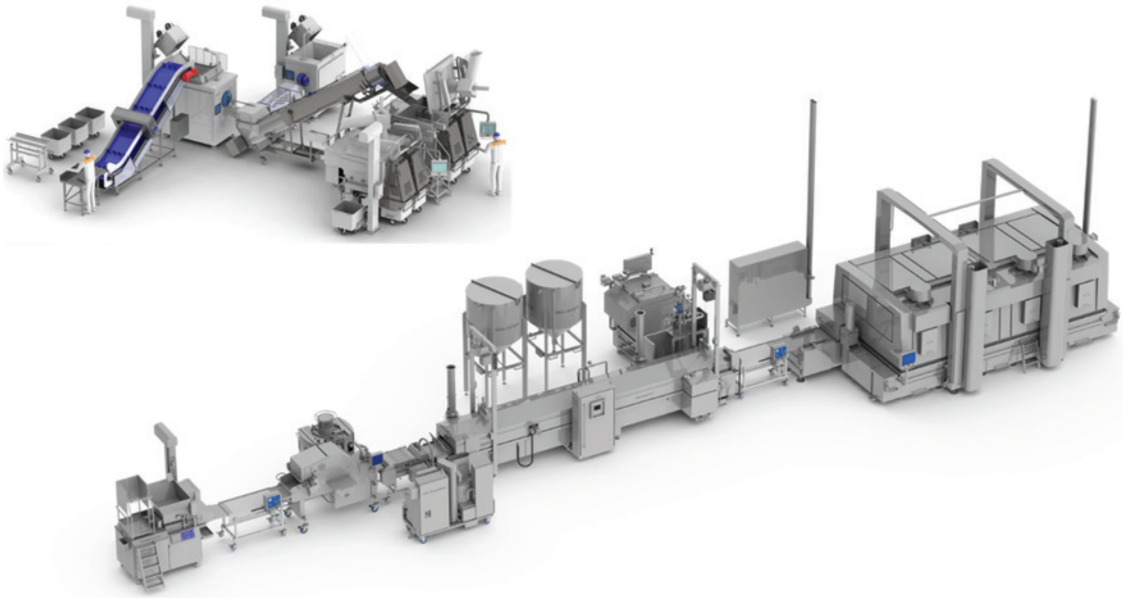

Fig. 2. Birds-eye view of processing lines for meat-based convenience foods such as chicken nuggets and other snack foods. (Photo courtesy of GEA Food Solutions)

Fig. 3. Crispy chicken filet. (Photo courtesy of GEA Food Solutions)

Fig. 4. Application of batter on fish sticks. (Photo courtesy of GEA Food Solutions)

ing involves an interplay between salt concentration and mechanical energy input (11). Theno et al. (12,13) suggest that mechanical treatment, massaging, grinding, mixing, and/or tumbling may play a more dominant role than salt concentration in extracting myosin from meat. Furthermore, especially for poultry, it is possible to prepare meat pastes that exhibit similar Bingham rheological behavior when using 1.25% versus 2.50% salt; Barbut and Mittal (1) also note that poultry meat paste containing 1.25% NaCl had the highest heat-induced gel rigidity modulus (1). As a plausible explanation for some of the counterintuitive findings, Barbut and Mittal (1) state, that they were probably due to protein (myosin) extraction during the vigorous chopping process. Hence, functional myofibrillar proteins can be physicomechanically liberated at lower salt levels. Processors, therefore, can rely on their mixing machinery to help extract and solubilize myofibrillar proteins at lower salt levels to create a cohesive malleable meat paste or patty. Cohesion is important for enabling shaping or molding of the meat mass into typical nugget shapes on the former (e.g., ball, bell, bowtie, boot). Attaining a suitable rheology at which the meat paste does not flow at low stress and heat-set gelling of the meat paste is optimal is not only a matter of salt concentration. An appropriately engineered meat grinding and mixing process enables the production of chicken nugget cores that are leaner and lower in salt, while still delivering a desirable meaty texture (Fig. 3).

Batters and Breadings

The next process step is enrobing the meat, first with a "light batter" that contains wheat flour or starch as a main constituent. In this step, adhesion is a major quality issue—the batter must stick to the meat surface—as are coating thickness, viscosity, and stability. Many ingredient suppliers have their own ingredient-based solutions, such as hydrocolloids, emulsifiers, and/or pregelled starches. However, it is important not to underestimate what the machinery can do to optimize these technical requirements. Batter mixing speed and flow rate, operation of the curtain "nip," and/or the dipping processing can also help in adjusting coating thickness and stability (Fig. 4).

The light batter is followed by application of a thicker tempura (or breading) layer, which completes the enrobing process. Because many aspects of texture and structure depend on the tempura, this is the stage at which product developers prefer to manipulate structural features, such as appearance, color, coarseness, and crispiness. The structural features of the tempura will interact with the mechanics and formulation, and their interplay must be taken into account. Keeping things

Fig. 5. Example of deep-fat fried chicken nuggets. (Photo courtesy of GEA Food Solutions)

simple is an engineer's adage: viscosity, structure, and thickness are controllable and do not require complicated adjustments to the tempura formulation. By keeping the process as simple as possible the producer can save money and avoid having to add components that may be under discussion or suspicion, now or in the future, as is exemplified by the continuing discussions in the popular media on the safety of well-studied food additives (5) with an E number in the EU region (9).

Deep-Fat Frying

Deep-fat frying is still the operation of choice for transforming the raw chicken nugget into a finished or semifinished product that is ready for packaging. Seasonings can be added after frying or by the final user or consumer at will. There are several reasons deep-fat frying is still very popular: one of the major benefits is the overall crispy texture and uniform color that can be achieved using deep-fat frying (Fig. 5). Oils and fats are generally considered to be unhealthy, but as scientific research reveals more information about animal fat and plant-based oils and fats, it appears that when consumed in moderation some oils and fats provide nutritional benefits, including fat-soluble vitamins, polyunsaturated oils, and fatty acids.

Controlling oil uptake during frying is challenging because the structure, porosity, and surface properties of the product play major roles in its oil absorption capacity. Changing the existing shape and structure of familiar snack and convenience foods is difficult, but over time much has been learned about the factors that affect the oil content of fried foods. Oil temperature and frying time are important factors in oil absorption—the longer a product is fried, the deeper the oil may penetrate (10). Comparing 160°C and 180°C for frying a 14 mm potato fry, the initial oil uptake was lower for the higher frying temperature (14). Faster steam and surface-coating formation may reduce initial oil uptake, suggesting a higher initial frying temperature provides a head-start for reducing oil uptake compared with lower temperatures (≤160°C). However, further oil absorption during prolonged frying (4 min) is slower at 160°C (10). Initial moisture content is also a factor, because moisture evaporates, leaving voids that the oil will likely fill, which increases oil uptake. An optimized initial moisture content, therefore, may also be important. Although higher moisture produces more voids and results in more oil absorption, low moisture may lead to less steam that can force oil out during frying. As a result, the formation of the surface coating will enable faster frying with an optimal moisture-content tempura in initially hot frying oil. Finally, there is Blumenthal and Stier's theory (2) on the formation of oil degradation products that are surface active, which suggests they act as soaps/emulsifiers that help oil to transfer into the product. After frying, upon product cooling internal pressure drops, resulting in suction of oil into the product. Using modeling, Wu et al. (15) estimate that in potato crisp frying 78% of the absorbed oil enters the product post-frying. Not everything in this complex set of factors that affect oil uptake can be fully controlled for an individual nugget or in a process-line, but temperature, time, oil degradation, maintenance of oil quality, moisture in the tempura, and post-frying conditions are technologically manageable factors. Even if these factors can only be partially improved, a 30% reduction in oil-uptake should be feasible.

During deep-frying operations, oil is oxidized further, fissioned, browned, hydrolyzed, and polymerized (4), producing compounds that contribute to health problems. Therefore, frying equipment is finely tuned to maintain oil quality at the highest specifications. Monitoring of temperature and oil quality and filtering and refreshing the oil keeps harmful reaction products out of snack or convenience foods. Debris and particles are separated by "cold well and sifting" technology (6). In general deep-fat fryers have a heated upper section, in which the food is actually fried in oil, and an elongated, unheated cold well portion that depends from the frying section and is designed to receive and retain particles that inevitably fall from the food product. The relatively cooler temperature of the cooking fluid in the cold well prevents severe burning of fallen food particles that need to be filtered out, prolonging optimal oil quality. Avoiding hot spots and creating a uniform temperature distribution in the frying section assures an evenly fried product with a minimal amount of product rejected or returned due to black spots or overfrying.

Conclusions

As consumers continue to aspire to better health and healthier eating patterns, snack products that can close the gap between nutrition and indulgence will have a global role to play. When attempting to improve such products, do not forget to look for input from a mechanical engineer as well. Food machinery design and operation may take a major "gulp of unhealthiness" out of your snack product, without requiring a food chemist to open a Pandora's box of ingredients.

References

1. Barbut, S., and Mittal, G. S. Effects of salt reduction on the rheological and gelation properties of beef, pork and poultry meat batters. Meat Sci. 26:177, 1989.
2. Blumenthal, M. M., and Stier, R. F. Optimization of deep-fat frying operations. Trends Food Sci. Technol. 2:144, 1991.
3. Boye, J., Wijesinha-Bettoni, R., and Burlingame, B. Protein quality evaluation twenty years after the introduction of the protein digestibility corrected amino acid score method. Br. J. Nutr. 108(Suppl. 2): S183, 2012.
4. Choe, E., and Min, D. B. Chemistry of deep-fat frying oils. J. Food Sci. 72(5):R77, 2007.
5. European Food Safety Authority. Food additives. Published online at www.efsa.europa.eu/en/topics/topic/food-additives. EFSA, Parma, Italy, 2018.
6. Grob, J. T., and Kinch, J. M. Deep fat frying apparatus with improved under-fryer cooking liquid pumping and filtration system. U.S. patent 4,974,501, 1990.
7. Mintel. Snacking motivations and attitudes – US – April 2015. Published online at https://store.mintel.com/snacking-motivations-and-attitudes-us-april-2015. Mintel Group Ltd., London, 2015.
8. Mintel. Snacking motivations and attitudes – US – May 2017. Pub-

lished online at https://store.mintel.com/snacking-motivations-and-attitudes-us-may-2017. Mintel Group Ltd., London, 2017.

9. Newcombe, R. Top E numbers to avoid. Published online at www.exploreenumbers.co.uk/top-10-e-numbers-try-avoid.html. Explore-ENumbers, www.exploreenumbers.co.uk, 2018.
10. Sahin, S., and Sumnu, S. G. *Advances in Deep-Fat Frying of Foods*, 1st ed. CRC Press, Boca Raton, FL, 2008.
11. Schmidt, G. R. Processing effects on meat product microstructure. J. Food Struct. 3(1):33, 1984.
12. Theno, D. M., Siegel, D. G., and Schmidt, G. R. Meat massaging technique. Page 53 in: Abstr. Proc.13th Meat Ind. Res. Conf. American Meat Science Association and American Meat Institute Foundation, Chicago, 1977.
13. Theno, D. M., Siegel, D. G., and Schmidt, G. R. Meat massaging: Effects of salt and phosphate on the microstructural composition of the muscle exudate. J. Food Sci. 43:483, 1978.
14. van Koerten, K. N. Deep frying: From mechanisms to product quality. Ph.D. thesis. Wageningen University & Research, Wageningen, Netherlands, 2016.
15. Wu, H., Karayiannis, T. G., and Tassou, S. A. A two-dimensional frying model for the investigation and optimisation of continuous industrial frying systems. Appl. Therm. Eng. 51:926, 2013.

Clyde Don studied chemical engineering in The Hague/Delft (B.S. degree) and chemistry at the University of Amsterdam (M.S. degree). He obtained his Ph.D. degree in food chemistry from Wageningen University. He has worked in applied research and technology (e.g., TNO) and analytical service labs in various leadership functions. As an active member of AACCI he has chaired scientific initiatives and divisions, cochaired courses, conducted workshops, and led technical committees and working groups. For IFT he is the cofounder and leadership team member of the IFT Protein Division (2015). Clyde is also currently a member of the AOAC Expert Review Panel on gluten methods. Since 2009 he has been the managing director of Clyde Don Consultancy FoodPhysica and, since 2016, director of the FoodPhysica R&D Laboratory, providing consulting and contract R&D services in sustainable food science and technology, bio-based products, processing and interactions, food machinery and NPD, protein functionality and applications, analytical chemistry, and food safety and quality. Clyde can be reached at clyde.don@foodphysica.com.

Paul Verbruggen has a bachelor's degree (HTS) in mechanical engineering and more than 25 years of experience in technical development, support, and technical sales for various companies. Since 2000 he as been the head of product management and processing at GEA Food Solutions in The Netherlands.

Ben Kop has a bachelor's degree in food technology from HAS Den Bosch University of Applied Sciences and a master's degree in food science and technology from Wageningen University. He currently is manager of the Technology Centre at GEA Food Solutions in The Netherlands.