Innovation in milk powder technology

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Global trade in preserved milks is on the increase as new markets open up in regions of the world that have not been traditionally associated with milk consumption. Equally, a rise in world milk production is forecasted to continue, and the indications are that significant quantities of the extra milk produced will be converted to commodity products such as butter and powders. Consequently, on-going investment in new spray drying capability is likely to track geographical shifts in milk production. Successful application of advanced process control to the operation of large scale drying plant is both a priority and a challenge.

Meanwhile, opportunities for the exploitation of milk as a source of functional ingredients are being availed of by the dairy industry as it continues to achieve added value and unique key selling points. Recent research on the role of spray drying, along with other processes in the development of dairy ingredients for applications in chocolate and the preparation of microencapsulated powders, is reviewed.

Keywords: Competitiveness, Free fat, Microencapsulation, Milk chocolate spray dried ingredients.

DRIVERS OF CHANGE IN MILK SPRAY DRYING

Spray drying in the dairy industry has evolved in recent years along two separate lines: an intensification of scale and efficiency in the drying of commodity milk products, e.g. skim milk and whole milk powders; and the adaptation of spray-drying processes for the production of functional dairy ingredients in dried form. Following the adoption of the Common Agricultural Policy (CAP) in the European Union (EU) in the late 1960s, commodity milk spray drying provided flexible processing capacity for the dairy industry at times when the supply of milk for the manufacture of consumer products exceeded demand. Very quickly, however, the CAP’s market support system, i.e. intervention, triggered considerable expansion in milk production across the EU, with the result that increasing amounts of surplus milk production required more and more processing capacity investment in the form of bigger spray driers. Eventually, the EU succeeded in curbing milk production expansion with the introduction of a quota system in the early 1990s. The resulting static-looking annual milk production pattern across EU-15 since then has seen continued investment in milk-drying plant for commodity products taper off. In milk-producing countries such as New Zealand, however, where annual growth has been virtually unrestricted due to favourable production conditions, continuing investment in milk-drying capacity over the years has led to the emergence of a new generation of super spray dryers, the largest of which is capable of producing 25 tonnes per hour of skim milk powder. A major challenge when working at this scale, of course, is to ensure adherence to food safety and quality issues. With competitive market conditions leading to the operation of such plants for extended running periods in between cleaning interruptions, appropriate precautionary measures need to be taken in order to limit the risk of microbial growth, e.g. thermophilic spore-forming bacteria, in the process. Environmental issues have also emerged as priority considerations as most national agencies charged with responsibility to reduce pollution loadings demand that at least all new spray drying installations are now fitted with secondary milk powder recovery systems capable of reducing the amount of particulate emissions to very low levels. A particular aspect of this concerns the emission of very fine particles of less than 10 µm known as PM10s. Particles of this nature are regarded as a respiratory burden, especially for those whose breathing is impaired by illness.

GROWTH IN WORLD MILK PRODUCTION

An Organization for Economic Cooperation and Development (OECD) forecast to 2013 predicts that world milk production is set to increase by 121 million tonnes from its current base of approximately 470 million tonnes. OECD member countries are expected to contribute about 25 million tonnes of this anticipated expansion in production. Hence, the
bulk of the expansion is going to take place outside OECD member states, and the spotlight is focused on countries such as China and Argentina as major individual contributors. In line with past trends, growth in milk production is already being accompanied by increased manufacture of commodity dairy products such as butter and skim milk powder (Figure 1).

Milk powder production has increased substantially on a global scale in recent years. Although the output of the EU-15 has levelled off and is now going into a slight decline, most of the expansion has come in recent years from Oceania countries (New Zealand and Australia) with other nations such as Brazil now emerging as very significant producers of milk powders. From a very small base in milk production, China has rapidly increased its total annual production of milk powder to 800 000 tonnes, equivalent to the output of the then EU-15 countries (IDF 2004) (Figure 2).

The second factor that impacts on demand for spray-drying capability is the availability of cheese whey and its derivative products. Trends in world cheese production have a significant impact in terms of the amount of whey produced and subsequently processed into ingredients. The growth in global cheese production is currently averaging 2–3% and total whey available for processing is in the order of 145 million tonnes. The most dynamic growth is occurring in countries such as New Zealand (7%) and more significantly in the USA, where a 30% increase over a 10-year period is anticipated. The amount of permeate available alone from this period of expansion in the USA would amount to 3.5 million tonnes. With an ever-increasing focus on the extraction of natural ingredients from whey in order to meet new market opportunities for health-enhancing products, whey, once a by-product of the dairy industry, has evolved to become the value-added driver of integrated cheese and whey-processing operations. Some examples of branded whey and whey-based ingredients embracing whole proteins, fractionated whey protein, milk minerals and carbohydrate derivatives are available in dried form (Figure 3).

PHYSICOCHEMICAL AND OTHER FUNCTIONAL CHARACTERISTICS OF MILK POWDERS

Typical market specifications for milk powders embrace headings such as composition, physicochemical characteristics, quality and food safety criteria, e.g. residues and contaminants as well as microbiological aspects. Although the milk powder industry has adopted international quality management standards and HACCP procedures in recent years, constant alert is demanded at all times in order to satisfy strict customer audit requirements. Furthermore, as the industry targets and extracts more specific components for use as functional health ingredients, the more exacting the demands in relation to microbiological criteria become. In particular, the emergence of a recent pathogen such as Enterobacter sakazakii is of concern to the infant formula sector in particular.

An international collaboration project involving Ireland and Australia is currently addressing the issue of protein standardization and its effects on skim milk powder quality. In recent years, Codex Alimentarius adapted its standards for milk powders and other preserved milks to permit standardization of milk protein to a minimum level of 34% in nonfat dry matter using permitted ingredients. The driving force behind this original change hinged around the acceptability of fat standardization as a routine processing option within the dairy industry; and the assumption that there was no real reason why similar rules should not apply in the case of protein now that the technology for doing so is available. Much of the relevant background
research at the time was, however, confined to the effects on sensory and other changes to liquid milk. Meanwhile, it was felt that a knowledge gap existed in relation to possible effects on skim milk powder drying, and that a research study should be undertaken to investigate the protein standardization of skim milk to 34% protein prior to evaporation and spray drying. Thus, the collaborative project involving Moorepark Food Research Centre, Food Science Australia (FSA), and Dairy Ingredients Group of Australia (DIGA) is examining the effects of the individual permitted ingredient options such as milk ultrafiltrate (permeate), lactose and a 50:50 combination of both. In addition, two preheating regimes are applied aimed at the production of low- and high-heat powders. Experimental preparation and drying of the milk powders undertaken at Moorepark is supported by additional analyses and functionality evaluation for use in recombined milks (recombined evaporated milk and yogurt) at FSA and DIGA.

WHOLE MILK POWDER BASED INGREDIENTS FOR CHOCOLATE APPLICATIONS

The chocolate manufacturing industry has been a significant user of milk and milk ingredients over the years. In particular, mainland European producers use whole-milk powder-based formulations when manufacturing milk chocolate (Figure 4) as distinct from the chocolate crumb-based industry, which is more prevalent in the UK and Ireland. Apart from sensory properties, the role fulfilled by whole milk powder in chocolate manufacture is to contribute (a) particles to the actually molten suspension and (b) fat to the continuous phase. Roller-dried whole-milk powder has been traditionally preferred for this purpose, largely because of its high free fat content. As roller drying is now an outdated process there is considerable interest in the adaptation of spray-dried whole milk in order to recreate physical properties similar to that achieved by roller drying. Spray drying, however, does the very opposite of roller drying in that it gives powders with a very low free fat content—an attribute desired for the most part for all uses other than chocolate manufacture. In order to reverse this capability, it is necessary to feed the spray atomizer during drying with a sufficiently high fat content medium so that it is unable to encapsulate the fat adequately during droplet formation. This can be carried out in either of two ways: (a) feed high fat milk concentrate to the spray dryer, or (b) use a...
In recent years we have conducted research at Moorepark in Ireland and it is observed that the viscosity value measured in terms of Casson Yield is kept low, i.e. < 4%. Hence, by incorporating microencapsulation in conjunction with spray drying it is possible to push this protective capability to the limit where the exposure of a targeted component on the surface of the powder particles is minimized. The idea therefore is to use other components within the concentrate medium to fulfill the role of a protective wall on the surface. When working with milk concentrates, one is limited by the natural levels of its ingredient components, namely protein and lactose content. When focused on optimizing microencapsulation, however, it is feasible to select and blend proteins and carbohydrates in a manner appropriate to give the desired level of protection to the targeted component (Rosenberg and Young 1993). An additional factor concerning formulation is the extent to which it lends itself to the formation of stable very fine particle emulsions (Young et al. 1993a). Ideally, concentrate particles smaller than those obtained under standard homogenization conditions should be produced. Multiple pass homogenization may be used to get down to lower particle sizes, but ideally newer technologies such as microfluidization offers much better prospects of achieving this characteristic in a single pass. Finally, having formed stable emulsions, the next step is to carry these properties through to the final powder form where an additional property arises, namely porosity. Our understanding of the role of carbohydrate in the wall material of microencapsulated whey protein/lactose systems is increasing as a result of research undertaken over the adapted process as described earlier for producing high free fat powders.

**MICROENCAPSULATION**

Spray drying is being increasingly considered as a means of protecting particular components in the feedstock during processing, product storage and for specific end use such as intestinal delivery. Spray-dried powder particles by their very nature tend to provide some degree of protection for their inner constituents. For example, as has been just discussed in the case of powders for chocolate, the level of free fat resulting from spray drying is usually quite low, i.e. < 4%. Hence, by incorporating microencapsulation in conjunction with spray drying it is possible to push this protective capability to the limit where the exposure of a targeted component on the surface of the powder particles is minimized. The idea therefore is to use other components within the concentrate medium to fulfill the role of a protective wall on the surface. When working with milk concentrates, one is limited by the natural levels of its ingredient components, namely protein and lactose content. When focused on optimizing microencapsulation, however, it is feasible to select and blend proteins and carbohydrates in a manner appropriate to give the desired level of protection to the targeted component (Rosenberg and Young 1993). An additional factor concerning formulation is the extent to which it lends itself to the formation of stable very fine particle emulsions (Young et al. 1993a). Ideally, concentrate particles smaller than those obtained under standard homogenization conditions should be produced. Multiple pass homogenization may be used to get down to lower particle sizes, but ideally newer technologies such as microfluidization offers much better prospects of achieving this characteristic in a single pass. Finally, having formed stable emulsions, the next step is to carry these properties through to the final powder form where an additional property arises, namely porosity. Our understanding of the role of carbohydrate in the wall material of microencapsulated whey protein/lactose systems is increasing as a result of research undertaken over the adapted process as described earlier for producing high free fat powders.
the past number of years. Lactose in its amorphous form has been shown to be a good hydrophilic filler, whereas crystalline lactose creates a more coarse wall material and may give rise to greater solvent diffusion (Young et al. 1993b). An additional challenge is posed by the amount of shrinkage that takes place during dehydration, and it is believed that lactose may fulfil a role in protecting the emulsion interfacial film from excessive shrinkage.

The development of a spray-dried microencapsulated fish-oil powder was undertaken as part of an EU FAIR contact (CT 95-0085). The objective of this study was to establish a delivery system for fish oil in powdered form so that there would be a degree of protection from oxidation during storage, containment of fishy odour/flavour as far as possible, and finally to try to achieve the highest oil content possible in the dry matter. Deodorized sand-eel oil stabilized with natural antioxidants was used as a fish oil source that was formulated in an emulsion system incorporating oil : protein : lactose : water in a 10:10:10:70 ratio, respectively. Both processing variables (homogenization pressure and number of passes, and spray-drying effects) and packaging (vacuum vs nitrogen flushing) were studied. Emulsion stability was monitored by particle size analysis (Dv, 0.9) µm index. The effectiveness of fish oil protection in powder particles was monitored using free fat, surface fat (Electron Spectroscopy for Chemical Analysis—ESCA) and confocal laser microscopy techniques. Based on physical indicators, it was concluded that homogenization pressure and protein source (sodium caseinate, calcium caseinate, skim milk powder) influenced free fat and surface fat contents. Skim milk powder as a protein source, however, gave better sensory scores when used in the formulation of the microencapsulated fish oil emulsion (Keogh et al. 2000). Although skim milk powder usage was associated with higher surface fat, it would appear that its lower vacuole volume content may be one of the main beneficial contributions. The resulting microencapsulated fish oil powder had very good sensory properties and was stable for up to 6 months provided it was stored under chilled conditions. This falls short of the ideal storage properties that food processors would prefer, i.e. storage under ambient conditions for a minimum period of 12 months.

2ND INTERNATIONAL SYMPOSIUM ON SPRAY DRYING OF MILK PRODUCTS

The second international symposium of spray drying of milk products was held in Cork during October 2004. A session on advanced process control (APC) considered the needs of the milk powder industry today in terms of the process control strategies necessary to operate such large-scale drying plant. Several speakers addressed the topic of model predictive control as a means of operating plant to closer process tolerances. The application of APC to evaporation is advancing at a significant rate. Spray drying imposes, however, extra challenges because of the difficulties encountered with modelling all aspects of the dehydration process and the need for more in-process data between drier inputs and outputs (Figure 6). The European-funded EDECAD project (www.edecad.com) has gone a long way toward building up models on different aspects of spray drying, namely atomization, droplet drying, particle collision and agglomeration. One remaining challenge is to build up a sufficient picture of the stickiness behaviour and properties of droplets and powders in the drying process. Ultimately, advanced process control should assist with the operation of high-capacity spray dryers more efficiently, support rapid change-over in a multiproduct manufacturing environment, and reduce the amount of product downgrade.

Glass transition (Tg) behaviour is increasingly impacting on the thinking of those engaged in the spray drying of new dairy ingredients. The term glass transition is a reflection of the physical state that a particular product undergoes during the advanced stages of drying. Technologically, this has implications for the design of dryers and their particular operation. The most practical manifestation occurs when a product is prone to becoming sticky. There is every likelihood that partially dried product will adhere to the walls of the dryer and make continued drying very difficult. For dairy ingredients, Tg is determined by the relationship between water absorption behaviour of lactose and water activity (Aw) for a particular ingredient. Latest research findings presented at the spray drying
symposium focused on combining additional thermodynamic information generated by differential scanning calorimetry (DSC) with Tg. With the aid of DSC, it is now possible to observe certain biochemical changes taking place during glass transition. In particular, model studies are proving useful in identifying interaction between β-lactoglobulin and lactose, and also show how β-lactoglobulin slows lactose crystallization from the amorphous state.

CONCLUSIONS
A combination of newly developing markets for dairy products, particularly in South-East Asia, the emergence of new entrant countries with rapidly expanding milk production and in some instances milk powder outputs along with globalization, is changing the dynamics of the world dairy industry. With a projected increase in world milk production for the foreseeable future, it is to be expected that milk drying will continue to play an important role at processing level and in facilitating trade of milk solids on an international scale.

Spray drying along with other existing and novel technologies will continue to be an important contributor to ingredient innovation. The adoption of an increasing amount of intellectual property protection covering novel dried ingredients and processes will be used by companies both for defensive purposes, and also to exploit commercial opportunities on international markets.

REFERENCES