Technology advances in spray drying of functional ingredients for automated beverage

Key external stakeholders:
Manufacturers of milk powders and dairy ingredients

Practical implications for stakeholders:
Technologies were developed to produce functional powders suitable for reconstitution/dispensing as either hot or cold beverages

- Installing an in-line high pressure gas/liquid injection system on the concentrate feed to the spray atomiser of a milk drier facilitated the production of dried ingredients with extensive foaming properties suitable for use in cappuccino-based beverage formulations.

- Development of foaming powder for hot beverage formulation and vending – a knowledge-base was established on the performance of different injection gases used and their interactions with concentrate formulation and process variables on powder characteristics

- Development of cold mixed smoothie-style beverages from textured dairy-fruits dry blends – ‘smoothie’ style powders containing fruit/dairy ingredient blends with desired physical characteristics e.g. texture, viscosity and phase stability were successfully developed for dispensing in prototype vending machines.

Main results:
The immediate effect of using either nitrogen gas or liquid CO\textsubscript{2} injection during atomisation was improved powder agglomeration and associated decline in bulk densities (from 0.56g/cc to 0.12g/cc) as well reduced moisture contents. This was also reflected in changes to the particle size distribution and particle density – the latter reduced from 1.2334g/cc to 0.599g/cc).

Interrelationships were established between drying parameters and powder properties (bulk density, particle size distribution, occluded air, interstitial air, particle density, wettability, foam height using a coffee dispenser at \( t=0 \) min, foam height after 5 min, and moisture content) specific to cappuccino beverages. Significant relationships, in particular, were established between powder bulk density and cappuccino foam stability using CO\textsubscript{2} (foam stability \( = 5.556-(5.532*\text{Bulk Density}) \)) and N\textsubscript{2} (foam stability \( = 5.017-4.573*\text{Bulk Density} \)) dosing.

Opportunity / Benefit:
Adding functionality and value to spray dried ingredients
This technology may be incorporated with some adaptation by ingredient drying manufacturers to prepare fat-filled base or fully formulated powders for supply to branded food companies with channel dominance in food service markets. Relevant pilot scale technologies at Moorepark may be availed of to support technology transfer initiatives.

Collaborating Institutions:
None

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1. Project background:
The concept of gas injection during spray atomisation was first explored during the 1960s by a team of researchers at the US Department of Agriculture. At the time these workers were motivated by the prospect of producing reconstituted milk with flavour profiles resembling fresh milk – an attribute that is absent in conventional spray dried milk powders. Although the innovation attracted little commercial attention at the time, a peripheral observation was an improvement in powder reconstitution properties and increased foaming tendency due to the effects of the injected gas. Thus, it was opportune to revisit this technology since foaming is now a desired property in functional ingredients that are designated for use in automated vending systems, particularly those which mix and dispense cappuccino-based drinks.

2. Questions addressed by the project:
An overall aim was to enhance spray drier functionality for the development of innovative ingredients for beverage applications. The project’s specific objective was to:

- Modify concentrate feed atomization conditions in order to influence physical properties of resulting powders especially those affecting reconstitution behavior e.g. tendency to foam.
- Update the technical specification of a prototype gas injection system by engineering a microprocessor-controlled precision dosing system.
- Apply modern analytical techniques and instrumentation to observe the effects of gas injection on resulting powder properties.

3. The experimental studies:
A high pressure in-line gas / liquid injection system was configured and installed on the concentrate feed line to the spray atomiser on the MTL Tall-form spray drier. This microprocessor-controlled unit was designed to meter precise low dose amounts of gaseous N₂, air, or liquid CO₂ under high pressure during spray drying. Initial technological hurdles faced included limitations e.g. injection nozzle sizing posed by operating at pilot rather than industrial scale. Secondly, a means of overcoming variability in gas dosing arising from declining pressures in supply storage cylinders had to be resolved.

An experimental matrix was designed to establish the interrelationships between coffee whitener formulation and process parameters during high pressure spray atomization and drying on physical properties, including foaming, of the resulting powders. An empirical foam test was set up by adapting a commercial automated cappuccino-dispensing machine in order to provide realistic foam generation volumes.

Hot beverage formulations centered around cappuccinos and latte’s were formulated in order to simulate the diversity of conditions by which such products may be vended and retailed e.g. vending using a single-sachet where all ingredients are pre-blended before mixing, or using dual sachets (separate coffee and creamer units) which are combined only at the point of mixing. Another scenario simulated a consumer application where retail packs of coffee/creamer pre-blends are prepared using manual (spoon) stirring.

The extensive foaming characteristics of powders achieved using the high pressure gas/liquid injection technology was also applied to the development of novel smoothie-style beverage concepts which could be reconstituted from functionalised blends of dried milk protein and fruits ingredients. Alternative ingredient texturisation approaches based on protein-hydrocolloid interactions were also explored in order to impart the desired sensory and textural properties in smoothie-style beverages.

4. Main results:
High pressure gas injection into the concentrate feed during spray is highly effective in promoting foamability of subsequent powders for use in hot beverages such as cappuccino.

The immediate effect of using either nitrogen gas (0.12 – 0.5% of feed) or liquid CO₂ dosage during atomisation was evident from the improved powder agglomeration and concomitant decline in bulk densities (from 0.56g/cc to 0.12g/cc) as well reduced moisture contents. This was also reflected in changes to the
particle size distribution and particle density (reduced from 1.2334g/cc to 0.599g/cc).

By creating too low a bulk density, there was a risk of generating foams that were too voluminous so that powder dispersibility and sinkability were restricted during reconstitution.

Formulation effects
Targeted bulk densities were achieved more readily using WPC- instead of SMP-based based formulations e.g. 0.19 g/cc and 0.35 g/cc for WPC and SMP, respectively at 0.12% N₂ dosage

Powder agglomeration effects with/with gas injection
Since high pressure gas injection contributed to the formation of powder agglomerates, it was necessary to isolate its additional contribution from the powder agglomeration process settings already configured on the spray drier. With the drier configured in regular (control) drying mode i.e. without gas injection, powder bulk density was 0.68 g/cc compared to typical values of 0.5 g/cc for agglomerated control powders. With gas injection during the regular (conventional non-agglomerated) mode of drying, bulk density was 0.2g/cc compared to 0.15 g/cc for agglomerated powders. Particle density for the control was 1.194g/cc compared to ~ 0.4 g/cc for the gas-injected agglomerated powder. On the otherhand, gas injecting without the agglomerated mode function could only yield a particle density of 0.651 g/cc. However, irrespective of the evident differences in bulk densities and particle densities, foaming capacity and stability from a cappuccino perspective were similar to those values obtained in earlier trials.

Development of powder foaming test
A commercial automated powder-based cappuccino dispensing machine (Flavia) was successfully adapted as a standardised method of generating data on foaming tendency that would be more realistic for testing the performance of the experimentally produced powders (Figure 1). The instrument generated a pressurised jet of hot water at 70°C to create turbulence in the cupholder containing the test powder. The cupholder was also mounted on a rotating platform

Interrelationships between process parameters and powder foaming
Correlation coefficients were established for drying parameters and powder properties (Bulk density, Particle size distribution, Occluded air, Interstitial air, Particle density, Wettability, Foam height using the adapted Flavia™ coffee dispenser at t=0 min, Foam height after 5 min, moisture content) specific to cappuccino beverages using Sigma Plot analysis. For example, significant relationships between bulk density and cappuccino foam stability using CO₂ (foam stability = 5.556-(5.532*Bulk Density) and N₂ (foam stability = 5.017-4.573*Bulk Density) dosing were statistically established.

Development of an automated smoothie-based beverage dispensing system
Smoothie powders containing fruit/dairy ingredient blends (88/12 and 76/24, respectively) suitable for vending dispensers were successfully developed having regard to key physical characteristics e.g. texture, viscosity and phase stability. The role of pectin supplementation (fruit-based hydrocolloid) proved particularly effective as a texture enhancer in selected formulations e.g. strawberry rather than apple. During this study, an experimentally-developed whey protein-based ingredient was superior to other forms of added dairy ingredients and represented a significant innovative achievement in terms of developing a tailored functional ingredient formulation for smoothie dispensing.

5. Opportunity/Benefit:
Growing food service opportunities are the result of how well the food industry is able to respond with novel concepts to consumer needs for high quality and healthy beverages ‘on the go’ e.g. market growth in smoothie-based beverages. The individualised and personalised nature of smoothie and juice bar beverage service has been primarily responsible for its market growth. However, such a service is self-limiting by virtue of the dependency on location (usually shopping malls, central stations etc), labour intensity, and
availability during the ‘working day’. In this regard, the proposed automated dispensing system provides consumers not only a quality beverage but a refreshing drink experience that is superior to that encountered with retailed bottled smoothies. It is with this context in mind that these ideas have been promoted to interested food companies.

This research project generated knowledge and expertise at three levels which are continuing to be exploited

(i) Elaboration of research infrastructure at large pilot scale spray drying with ‘bolt-on’ innovative gas injection technology to extend the functionality of spray dried ingredients – these facilities are now accessed by national and international food companies.

(ii) Development of competence and skills in powder technology and increased scientific understanding of its effects on powder properties – a knowledge base that is attracting active engagement by national and international food companies.

(iii) Functional ingredient concepts such as foaming powders for hot beverage use (cappuccino), as well as texture enhancement of cold beverages (smoothies) reconstituted during powder dispensing at vending points.

6. Dissemination:
Non-disclosure agreements were signed with a number of companies in the course of discussing the notion of an automated smoothie-beverage dispenser. An SME engineering company constructed a basic (manually operated) prototype dispenser (tentatively called ‘Smoothex’) to demonstrate the concept.

The success of the gas injection technology has been brought to the attention of the dairy and ingredient manufacturers, and in a number of instances the technology has been exploited for other ingredient functionality purposes.

Main publications:

Popular publications:

Invited keynote address: Whey permeate drying: a review. J. Kelly, P.M. Kelly, D.O’Callaghan & S.A. Hogan presented to 4th International Conference on Spray Drying of Milk Products, Melbourne, Australia,

High pressure N2 gas or Liquid CO2 injection during spray atomisation – powder functionality and ingredient innovation, J. Kelly in RELAY Workshop on An Insight into Current Milk Powder Research and Innovation, Moorepark, 18th April 2007.

New ideas for dairy-based beverages, P.M. Kelly in RELAY Workshop on Commercial opportunities for developing new beverage concepts, UCC 16th September 2009


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