Surface Composition of Industrial Spray-Dried Dairy Powders and Its Formation Mechanisms

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Abstract

Spray-dried dairy powders are common ingredients in many food and dairy products. Some of the properties of these powders that are important in their storage, handling and final application are expected to be determined by the surface composition of the powder. Therefore, an understanding of the mechanism behind the formation of the surface composition of the powder and the ability to control the surface composition will be very useful in the improvement of product quality and the development of new products.

The aim of this thesis was to understand the mechanism behind the formation of the surface composition of industrial spray-dried dairy powders. To achieve this, a comprehensive research on the surface composition of industrial spray-dried dairy powders was undertaken, using electron spectroscopy for chemical analysis (ESCA, also known as X-ray photoelectron spectroscopy (XPS)). This involved the investigation of the effects of the composition of the concentrate before drying, manufacturing processes, processing conditions and storage on the surface composition of the powder. The distribution of milk components (including triglycerides in milk fat) within the powder particles was also investigated to obtain further insight in the processes occurring within the particles during powder production.

It was found that the surface composition of industrial spray-dried dairy powders (skim milk powder, whole milk powder, cream powder and whey protein concentrate) is significantly different from the bulk composition. Particularly pronounced was the accumulation of fat on the powder surface, deteriorating several powder properties

(flowability, wettability and oxidative stability). The fat content of the powder appeared to be the critical factor in determining the surface composition of the powder.

Results showed that there is redistribution of components within the particles during the spray-drying process. A kind of solid/solute segregation seems to occur. Fat and proteins are preferentially accumulated near the surface of the particles whereas lactose in the interior of the particles. It was also observed that there is some fractionation among the different milk fat present in the powders, with the accumulating of high melting triglycerides in the free-fat and even more at the surface of the powders. The redistribution of components was found to be affected to a large extent by the spray-drying conditions employed (feed solids content, drying temperatures and degree of homogenization).

The subsequent fluidized bed drying and handling processes appeared to have little effect on the surface composition of the powders. However, during long-term storage, there was a release of encapsulated low-melting triglycerides towards the surface of powder, thereby lowering the melting points of the surface free-fat and the inner free-fat.

Based on the findings in this work and theoretical considerations, possible mechanisms behind the formation of the surface composition of industrial spray-dried dairy powders, from powder production, through storage, to its final application, were suggested.

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List of Publications

This thesis is based on the following publications.

1. Kim E. H.-J., Chen X. D., and Pearce D. (2002) “Surface characterization of four industrial spray-dried dairy powders in relation to chemical composition, structure and wetting property”, *Colloids and Surfaces B : Biointerfaces*, **26**(3), 197-212.

2. Kim E. H.-J., Chen X. D., and Pearce D. (2003) “On the mechanism of surface formation and the surface compositions of industrial milk powders”, *Drying Technology*, **21**(2), 265-278.

3. Kim E. H.-J., Chen X. D., and Pearce D. (2005) “Melting characteristics of fat present on the surface of industrial spray-dried dairy powders”, *Colloids and Surfaces B : Biointerfaces,* **42**, 1-8.

4. Kim E. H.-J., Chen X. D., and Pearce D. (2005) “Effect of surface composition on the flowability of industrial spray-dried dairy powders”, *Colloids and Surfaces B : Biointerfaces*, **46**, 182-187.

5. Kim E. H.-J., Chen X. D., and Pearce D. “Surface composition of industrial spray-dried milk powders. 1. Development of surface composition during manufacture”, *Journal of Food Engineering*, **Submitted**.

6. Kim E. H.-J., Chen X. D., and Pearce D. “Surface composition of industrial spray-dried milk powders. 2. Effects of spray-drying conditions on the surface composition”, *Journal of Food Engineering*, **Submitted**.

7. Kim E. H.-J., Chen X. D., and Pearce D. “Surface composition of industrial spray-dried milk powders. 3. Changes in surface composition during long-term storage”, *Journal of Food Engineering*, **Submitted**.

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Abbreviations and Symbols

AMF	anhydrous milk fat
CLSM	confocal laser scanning microscopy
CP	cream powder
D	diffusion coefficient
E_b	binding energy
E_k	kinetic energy
ESCA	electron spectroscopy for chemical analysis
eV	electron volt
hυ	photon energy (eV)
I_o	intensity of emitted electrons at z = 0
I_z	intensity of emitted electrons at a distance z from the surface
K_B	Boltzmann's constant (1.38 x 10^{-23} J/K)
LM	light microscopy
m_{ext}	mass of the extracted surface free-fat per 1 g powder (g)
$m_{particles}$	mass of the powder sample (g)
$n_{particles}$	number of particles in 1 g of powder
r	radius of particles (µm)
R_0	solute radius
RH	relative humidity (%)
SEM	scanning electron microscopy
SFC	solid fat content (%)
SMP	skim milk powder
T	temperature (^oC)
TEM	transmission electron microscopy

V	volume of particles (m^3)
V_{ext}	volume of extracted surface free-fat (m^3)
WMP	whole milk powder
WPC	whey protein concentrate
XPS	X-ray photoelectron spectroscopy
z	distance from the surface of the material
Φ	spectrometer work function
γ	relative surface coverage
δ	average thickness of the extracted surface free-fat layer (μm)
θ	analyzed take-off angle
λ	inelastic mean free path
μ	solvent viscosity (MPa)
ρ_{fat}	true density of fat (kg/m^3)
$\rho_{particles}$	particle density (kg/m^3)