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

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Engineering

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2008
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.
Acknowledgements

First and foremost, I give my greatest thanks to God for giving me this great learning opportunity. All glory to God who has given me the wisdom, ability, health and endurance to complete this degree.

I would like to express my sincere gratitude to my supervisor Professor Xiao Dong Chen for his encouragement, ever-lasting support, guidance and supervision of this thesis. It was a privilege to have him as my supervisor.

I would like to thank specially Dr. David Pearce of Fonterra Research Centre for his valuable advice and support throughout the course of this research. I also gratefully acknowledge the Fonterra Research Centre for financial support.

I would also like to thank all staff and my postgraduate colleagues at the Department of Chemical and Materials Engineering, former and present, for their help and friendship. Especially Jin-Ah Yoo for her friendship, who made my postgraduate years memorable.

Last but most, I would like to thank my family. I would like to thank my sisters and brother, Nam-Hee, Hyun-Joo and Woo-Sung, for their loving support. Thanks to my husband, Hyung-Suk. This thesis was completed with his love and support. My highest tribute must go to my parents who give me unconditional love and support. None of this would be possible without their support and encouragement. 아버지, 어머니 감사합니다! (Thank you, Mum and Dad!)
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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
$\hbar \nu$  photon energy (eV)
$I_0$  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 ($1.38 \times 10^{-23}$ J/K)
LM  light microscopy
$m_{\text{ext}}$  mass of the extracted surface free-fat per 1 g powder (g)
$m_{\text{particles}}$  mass of the powder sample (g)
$n_{\text{particles}}$  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 (°C)
TEM  transmission electron microscopy
\( V \) volume of particles (m\(^3\))
\( V_{\text{ext}} \) volume of extracted surface free-fat (m\(^3\))
\( \text{WMP} \) whole milk powder
\( \text{WPC} \) whey protein concentrate
\( \text{XPS} \) X-ray photoelectron spectroscopy
\( z \) distance from the surface of the material
\( \Phi \) spectrometer work function
\( \gamma \) relative surface coverage
\( \delta \) average thickness of the extracted surface free-fat layer (\( \mu \)m)
\( \theta \) analyzed take-off angle
\( \lambda \) inelastic mean free path
\( \mu \) solvent viscosity (MPa)
\( \rho_{\text{fat}} \) true density of fat (kg/m\(^3\))
\( \rho_{\text{particles}} \) particle density (kg/m\(^3\))