Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 123 (2017) 235–242

Energy Procedia

www.elsevier.com/locate/procedia

1st International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF 2017, 19-20 April 2017, Berkshire, UK

Reducing energy consumption in spray drying by monodisperse droplet generation: modelling and simulation

James C. Atuonwu[a,b]*, Andrew G. F. Stapley[a]

[a]*Department of Chemical Engineering, Loughborough University, Loughborough LE11 3TU United Kingdom*
[b]*Brunel University London, Institute of Energy Futures, Center for Sustainable Energy Use in Food Chains, Uxbridge, Middlesex UB8 3PH, UK*

Abstract

The possibilities of reducing energy consumption in spray drying by monodisperse droplet generation have been explored. From heat/mass balances and droplet travel dynamics in a single-stream spray dryer, correlations have been established for the drying gas temperatures that satisfy given outlet product moisture contents for droplet streams of different diameters–with skimmed milk as a case study. The results suggest that energy consumption can be reduced by up to 90%, compared to what obtains in a conventional system that produces droplet sizes up to 10 times the desired size. An experimental single-stream monodisperse droplet dryer, based on piezoelectric atomisation has been constructed, with an imaging system for future validation studies.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.

Keywords: *Spray drying; monodisperse droplet; energy savings; mathematical model; food processing*

1. Introduction

Drying is a widely-applied energy-intensive process, accounting for 10-25% of overall industrial energy consumption in the developed world [1]. Spray drying, the primary method for producing dry powders from liquid feeds is a significant energy sink in for instance, milk production plants [2]. With the increasing strain on the fast-

* Corresponding author. Tel.: +441895268975;
E-mail address: james.atuonwu@brunel.ac.uk

1876-6102
Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.
10.1016/j.egypro.2017.07.251

Nomenclature

C_D	Drag coefficient
C_p	Specific heat capacity (J/kg K)
D	Droplet diameter (m)
f	Droplet generation frequency (Hz)
G	Drying gas mass flowrate (kg/s)
g	Gravitational acceleration (9.81 m/s^2)
h	Heat transfer coefficient (W/m^2 K)
h_{fg}	Specific latent heat of vaporisation (kJ/kg)
M	Mass (kg)
q	Volumetric flowrate (m^3/s)
Q	Heat energy rate (J/s)
$S_{\%}$	Percentage energy savings
T	Temperature (°C)
U_{loss}	Dryer body heat loss coefficient (W/m^2 K)
U_p	Droplet velocity (m/s)
X	Moisture content dry basis (kg/kg)
Y	Drying gas absolute humidity dry basis (kg/kg)
z	Droplet/particle travel distance dimension (m)

Greek letters

$\alpha, \beta, \gamma, \lambda, \varphi, \omega$	Model fit parameters
ρ	Density (kg/m^3)

Subscripts

amb	Ambient
cr	Critical
d	Dry matter (milk)
D	Dryer
EQ	Equilibrium
G	Drying gas
in	Inlet, input
or	Orifice
p	Droplet/particle
ref	Reference
v	Water vapour
w	Liquid water

depleting global energy resources, stringent environmental regulations and high energy costs, innovative steps are needed to reduce spray drying energy consumption. Atomization has been regarded as the heart of the spray drying process [3] as it is inextricably linked to not only the drying kinetics and quality of the final product, but also to the energy efficiency of the process. Conventional spray dryers suffer from wide droplet size distributions of the atomised sprays. As droplet drying rate is proportional to its area per-unit volume, larger-diameter droplets imply lower drying rates per volume. Droplet falling speed also rises tremendously with diameter. A ten-fold increase for instance, in droplet diameter would lead to a 1000-fold increase in its initial velocity and approximately a ten-fold increase in its terminal velocity (neglecting diameter reductions due to drying). Hence, for the same feed and process/equipment design conditions, a higher inlet air temperature is required to bring larger-sized droplets to desired outlet particle moisture contents. This leads to over-drying of smaller droplets; lower powder production rates and hence profit levels as the plant operates well-below the maximum permissible product moisture content;