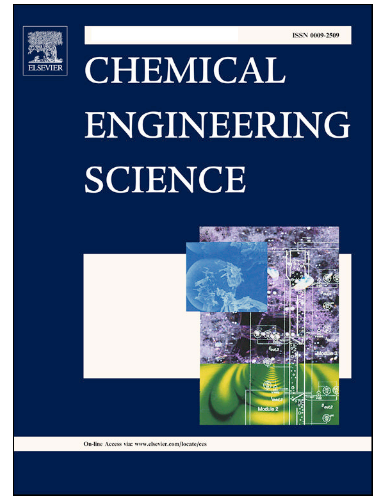

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PII: S0009-2509(17)30575-4
DOI: http://dx.doi.org/10.1016/j.ces.2017.09.021
Reference: CES 13798

To appear in: *Chemical Engineering Science*

Received Date: 31 May 2017
Revised Date: 18 August 2017
Accepted Date: 12 September 2017

Please cite this article as: C. Christodoulou, E. Sorensen, S. García-Muñoz, L. Mazzei, Mathematical Modelling of Water Absorption and Evaporation in a Pharmaceutical Tablet during Film Coating, *Chemical Engineering Science* (2017), doi: http://dx.doi.org/10.1016/j.ces.2017.09.021

Mathematical Modelling of Water Absorption and Evaporation in a Pharmaceutical Tablet during Film Coating

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Abstract

It is well understood that during the pharmaceutical aqueous film coating process the amount of liquid water that interacts with the porous tablet core can affect the quality of the final product. Therefore, understanding and simulating the mechanisms of water droplet spreading, absorption and evaporation is crucial for controlling the process and optimising the shelf-life of the tablets. The purpose of the work presented in this paper is to define and describe the spreading, absorption and evaporation phenomena after droplet impingement on a tablet. We divided the droplet behaviour into three phases of different dynamics and duration: the kinematic, capillary and evaporation phases. To model the kinematic phase, we combined and modified 1-D spreading models from the literature which solve the kinetic energy balance equation for the first milliseconds of spreading. For the capillary phase, we simplified and solved the continuity and Navier-Stokes equations using the lubrication approximation theory. Finally, for the evaporation phase, we adopted a modelling approach for the second drying stage of slurry droplets inside a spray dryer. During this stage, one can no longer describe the droplet as a liquid system containing solids, having to regard it as a wet particle with a dry crust and a wet core. In our work, we represented in a novel way the crust as the dry surface of the tablet and the wet core as the wetted area inside the porous matrix. We implemented the mathematical model presented in this work in gPROMS, employing the Modelbuilder platform. Our numerical results (droplet height and spreading, wetting, evaporation front profiles) are in good agreement with recent experimental data that we found in the literature.

1. Introduction

Aqueous film coating is a crucial step in the manufacture of solid-dosage drugs in the pharmaceutical industry. It is well understood that the shelf life of pharmaceutical tablets depends on the amount of humidity to which they are exposed during the coating process, the handling of the intermediate coated product and the packaging (Amidon, 1999). Understanding and being able to predict the mechanisms of water absorption onto and into tablets, is therefore important to avoid accelerating the degradation mechanisms caused by high water content.

During tablet coating a liquid solution is sprayed onto the solid tablet surface. Several researchers have investigated the impact of a droplet on an impermeable substrate, mainly for inkjet printing applications. Park et al. (2003) developed a mathematical model to estimate the maximum spreading factor at low impact velocity. They defined the spreading factor as the ratio of the cyclical wetted area diameter at time t to the initial droplet diameter of the spherical droplet just before impact. Attane et al. (2007) developed an analytical 1-D model based upon the energy equation. By assuming the shape of a droplet (either spherical cap or cylindrical), Attane et al. (2007) reduced the unknown variables in the energy balance equation. They compared their model with others from the literature (Kim and Chun, 2001; Bechtel et al, 1981), achieving better predictions of the maximum spreading factor. The main limitation of their model is its inability to simulate the first milliseconds after impact and predict the droplet rebounding when the equilibrium contact angle has a high value. Recently, Lee et al. (2016) have also used the 1-D model approach to describe the impact of a water droplet on porous stones. Their numerical results were in close agreement with the experimental ones.

In terms of pharmaceutical tablet coating, Shaari (2007) investigated both experimentally and numerically the impact and spreading of a pure liquid water droplet on pharmaceutical tablets. He divided the process into two sub-processes: short-term and long-term. The former involved the first milliseconds after impact when inertial forces are significant and spreading, splashing and rebounding occurs, whereas the latter included penetration and/or wetting. He conducted a series of experiments to investigate the impact behaviour of a droplet on tablet surfaces with different roughness. Using a Volume-Of-Fluid (VOF) CFD model, he described quantitatively the short-term phenomena, but he did not develop any numerical model to describe the long-term phenomena, in particular, absorption.