Optimising Coffee Extraction Using a Multiscale Approach

ROMAN CORROCHANO Borja [ab], MELROSE, John[a], FRYER, Peter [b], BAKALIS, Serafim[b]

a - Mondelēz International , Global Coffee Technology Centre Ruscote Avenue, Banbury - OX16 2QU, UK.

b - Centre for Formulation Engineering, Department of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.

Introduction

Despite the significance of coffee extraction as a substantial part of a business worth $32Bn per year, it has not been yet systematically approached from an engineering point of view. The most successful combination of variables (temperature, grind size, flow rate) to obtain a certain sensory profile has been traditionally determined with the aid of practical experience and subsequent statistical data treatment of compiled chemical and sensory data (Andueza, Maeztu et al. 2003; Caprioli, Cortese et al. 2012). This approach regards the coffee bed as a "black box" and neglects any kind of understanding of the physical mechanisms driving the process, leading to inaccuracy in yield, strength, and flavour predictions as well as some misconceptions and myths surrounding coffee technology. The current technological challenges originated with the double-digit growth of the on-demand coffee business (proportioned coffee capsules brewed in small automatic machines) stresses the necessity of coming up with physical predictive models to optimise the operation. The starting point to achieve this challenging objective is to formulate the problem as a sequence of complex transport phenomena in porous media: convection at the bed scale (~cm) and diffusion at the particle scale (~µm). Particularly, this work is concerned with the study of hydrodynamics at the bed scale.

Materials and Methods

A new method to measure the permeability (K) of roast and ground coffee in steady-state was developed using a custom pressure rig and the fundamental principles of fluid flow in packed beds. A range of bed densities (360-480 kg/m^3) and particle size distributions provided experimental flow rate - pressure drop data, which was fitted to Darcy's equation (Bear 1988) to calculate the permeability (figure 1). It was observed that the height of the coffee bed varied with time as a result of the applied axial compression exerted by the fluid and thus an independent experiment was performed to analyse this behaviour. The porosity of the beds (ε_{bed}) was also estimated following two different approaches: fitting experimental data to Kozeny-Carman equation (figure 2) and direct calculation based on the measurement of the density and porosity of individual particles with Hg porosimetry and He pycnometry, correcting the measurements with the compression of the bed. The estimated permeability values were used to simulate the total drink volume as a function of time during an espresso preparation, assuming it was a steady-state process and typical operation conditions.

Results

Typical permeability and porosity values were found to be in the range of 10^{13} -10^{-14} m^2 and 0.09 and 0.19 respectively. The fitted and calculated porosity compared well except for the case of high bed densities (e.g: 480 kg/m^3), probably due to deformation of the particles as the applied axial force to obtain such densities is higher when compared to densities in the range of 360 kg/m^3. It was also found that the height of the bed can be reduced up to 35% and that most part of this process takes place during the first 30-60 seconds. The simulation of the drink volume showed very promising results and compared well to the typical 25-30 ml extracted in 10-15 seconds.

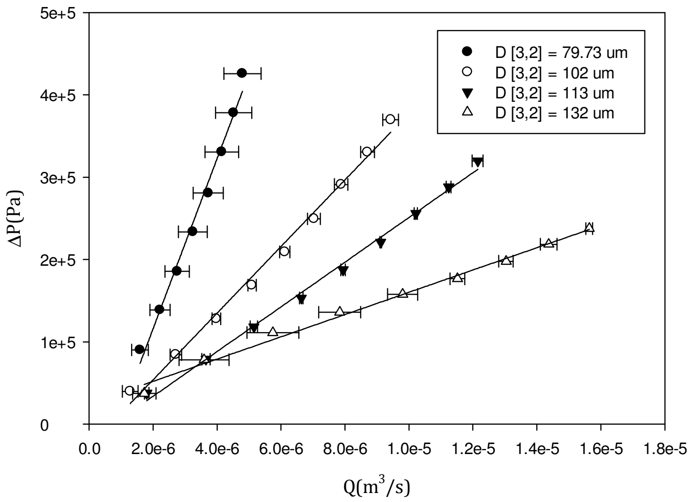

Figure 1: Fitting to Darcy´s equation

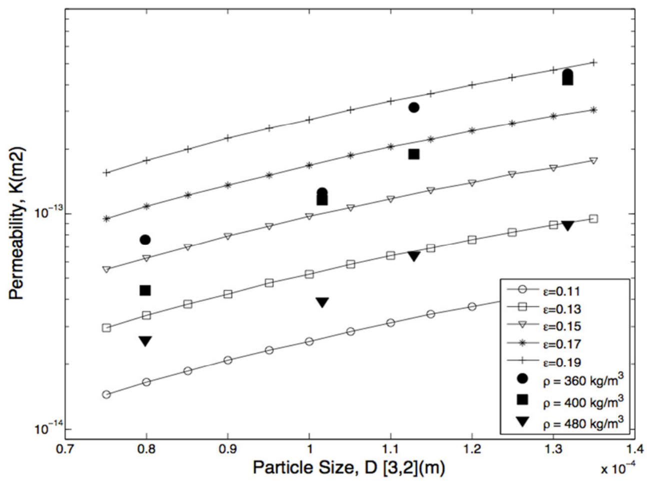

Figure 2: Porosity Vs. Particle size

Conclusions

The work reports the first systematic study of the permeability of coffee packed to predict drink volumes as a function of operation conditions and time. Future stages of the project will involve use the collected data of the non-steady state to derive a hydrodynamic model for the first stages of the process and a coupled study of mass transfer.

References

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