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Accurate prediction of liquid-solid fluidized bed porosity in drinking water treatment processes using empirical data-driven genetic programming models

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Abstract

For an accurate prediction of the porosity of a liquid-solid homogenous fluidized bed, various empirical prediction models have been developed. Symbolic regression machine learning techniques are suitable for analyzing experimental fluidization data to produce empirical expressions for porosity as a function not only of fluid velocity and viscosity but also of particle size and shape. On the basis of this porosity, it becomes possible to calculate the specific surface area for reactions for seeded crystallization in a fluidized bed.

Introduction

Multiphase flows frequently occur in drinking water treatment processes, liquid-solid fluidization for instance, is a commonly used process for high-quality drinking water softening. In this process and for sustainability reasons, water companies want to reduce the use of chemicals and energy and also re-use waste materials as raw materials.

Efficient pellets softening (Graveland 1983) is based on the dosage of caustic soda in fluidized bed reactors with a high available specific surface area. The water is softened through the crystallization of calcium carbonate on pellet grains. Because the pellets grow in size, the larger ones are continuously extracted from reactors. The more or less spherical pellets are crushed and re-used as a seeding material (Schetters (2015). These crushed particles are irregularly shaped, and this deserves careful consideration: for optimal process conditions, fluidized bed porosity is important because it determines the effective specific surface area.

In the literature, many porosity prediction models have been derived for particles that are perfectly spherical (Kramer 2018). The prediction accuracy for irregularly shaped particles, however, is rather low, particularly in reactors with an emergent particle size profile over the bed height.

A commonly used laboratory technique to quantify particle diameter is sieve analysis. This technique, however, is not suitable for determining the morphological properties of irregularly shaped crushed particles from the pellet softening processes.

Materials and Methods

Genetic programming is a random-based technique (Koza 1992) for automatically learning computer programs through artificial evolution. It has been successfully applied in many applications (Barati 2014, Whiten 2015). The advantage of genetic programming is that there is no need to define the structure of a model *a priori*. It randomly generates a population of several mathematical operators.

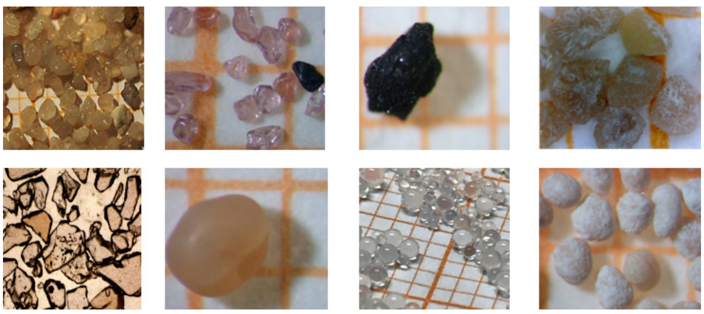

Figure 1: Examples of irregularly shaped natural particles applied in drinking water treatment processes.

Expansion experiments were carried out for several materials (Figure 1) in Waternet's Weesperkarspel drinking water pilot plant located in Amsterdam, the Netherlands. Fluidized bed expansion was obtained by varying the water flow rate at different water temperatures. The physical particle properties were determined using 2D image analysis recognition techniques (ImageJ). The data consist of superficial velocity, kinematic viscosity, particle density, grain sieve size, and several morphological particle properties.

Results and Discussion

The experimental data set consists of porosity measurements for 25 ascending superficial velocities at 4 different temperatures and involving 10 different calcium carbonate pellets with a diameter in the range of 0.5-2.0 mm. ImageJ software provided us with particle morphological properties such as the ellipsoid aspect ratio and sphericity.

Symbolic regression software was used to analyze the data set, and this yielded several empirical models to estimate the porosity. An example of a porosity plot is given in Figure 2.

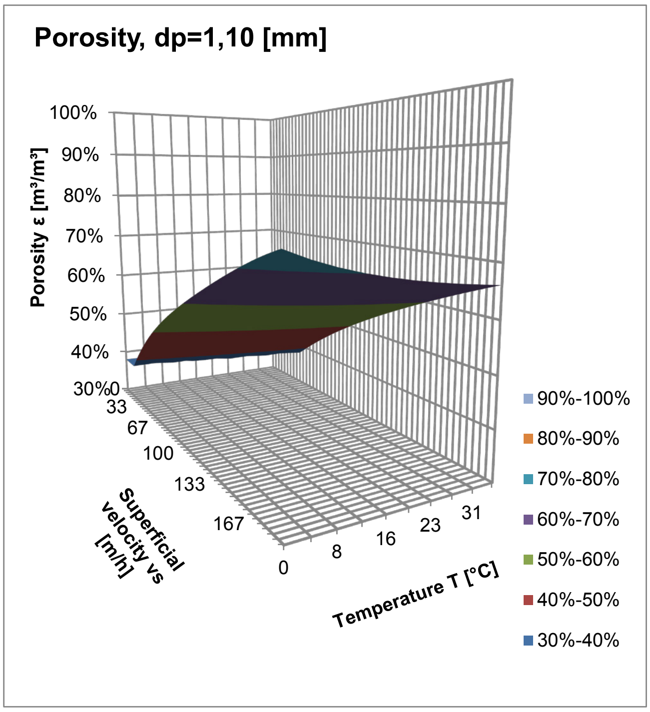

Figure 2: Example of the predicted porosity as a function of superficial water velocity and water temperature.

Conclusions

Reliable empirical prediction models can easily be acquired using symbolic regression machine learning techniques based on sufficient and accurate experimental data.

Pellets softening processes can be improved by using these models in which the liquid-solid fluidized bed porosity is estimated as a function of fluid velocity and viscosity as well as particle size and shape.

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