Filter media expansion during backwash: The effect of biological activity

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Abstract

Close observation at a number of South African water treatment plants has shown that media losses during backwashing are excessive – much higher than anticipated. The only likely reasons for this phenomenon are either that insufficient freeboard was provided by the designer or that the mechanical behaviour of the media gradually changes after being placed in the filters. A number of media tests confirmed that the biological fraction of the specific deposit on the filter media (after backwashing) is relatively high – about 50% of the total specific deposit. This led to the hypothesis that the combination of high nutrient concentrations in surface waters, coupled with elevated water temperatures, stimulate biofilm formation on the media grains. These films, in turn, somehow affect the mechanical behaviour of the media bed expansion and backwash. This paper reviews the Dharmarajah bed expansion model (as the most advanced model for media expansion to date) and presents evidence that it predicts the expansion of clean, oven-dried media reasonably well. It further shows that media from filters which have been in operation for a while, expand significantly more than predicted by the Dharmarajah model. This finding has major implications for filter design, and suggestions are made on how to adapt design procedures for what is now believed to be the formation of biofilm on media grains.

Introduction

Designers of water filtration plants need to accurately predict the expansion of filter media when the filters will be backwashed. The expansion determines the minimum freeboard between the top of the media and the lip of the backwash overflow weir to prevent the large-scale washout of filter media during the backwash cycle. The best design practice at present is to either conduct experimental tests on the media selected for the plant or, more commonly, to use the grading analysis of an oven-dried sample in conjunction with a theoretical bed expansion model.

Over a number of years, observations at numerous treatment plants suggested that these approaches are possibly flawed. Media losses are almost consistently more than anticipated, as evidenced by a media surface level well below the originally specified media level. The trapping of underfloor air is a well known reason for media loss – when the air bubbles are inadvertently released during the "water only" backwash phase, a cloud of media is suspended in the water above the media and dropped over the overflow weir before it can settle again. But even where this problem was eliminated, a problem with excessive media loss was evident. This eventually led to a study to systematically investigate other possible reasons for what was observed.

This paper reports on the following parts of the investigation:

- A review of mathematical granular bed expansion models
- The results of a treatment plant survey where the expansion of filter media in actual use was measured, followed by identical tests after drying the same media sample in an oven
- A discussion of the implications for filter design

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A review of mathematical bed expansion models

The widely cited correlation by Richardson and Zaki (1954) applies to spherical particles and relies on the backwash velocity, the media porosity and some empirical relationships using the Reynolds number of the particles when settling:

$$\frac{V_a}{V_i} = \varepsilon^n \qquad [1]$$

$$\text{for } 1 < R_s < 200 \quad n = (4.45 + 18d/D)\, R_s^{-0.1} \qquad [2]$$

Cleasby and Fan (1981) extended this approach to allow for non-spherical particles by adapting the 'n' in the Richardson-Zaki model by using the dynamic shape factor DSF as a measure of particle sphericity. The following expression was solved for the exponent 'α', which would satisfy the expression for each media and size:

$$n_{(actual)} = n_{(spherical)} DSF^{\alpha} \qquad [3]$$

The DSF is measured by

$$DSF = \left(\frac{V_s}{V_n}\right)^2 \qquad [4]$$

Other models by Sholji and Johnson (1987) and Quaye (1987) attempted to introduce a measure of the particle sphericity by using the particle settling velocity as one of the variables, but still required additional variables to obtain a reasonable fit. A recent model by Dabrowski et al. (2002) reverts to an empirical approach, which requires a newly calibrated equation for every new media sample.

The most comprehensive model to date is that of Dharmarajah and Cleasby (1986). Dharmarajah developed a correlation to predict the velocity-voidage relationship using Blake's modified Reynolds number (Re_B) and a voidage function that is dependent on the Galileo number and the porosity of the bed. A fluidized system is considered to be fully defined by the following parameters: