

Review

A review of floc strength and breakage

P. Jarvis^a, B. Jefferson^a, J. Gregory^b, S.A. Parsons^{a,*}^a*School of Water Sciences, Cranfield University, Cranfield, Bedfordshire MK40 0AL, UK*^b*Department of Civil and Environmental Engineering, University College London, Gower Street, London WC1E 6BT, UK*

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Abstract

The main focus of the paper is to review current understanding of floc structure and strength. This has been done by reviewing current theoretical understanding of floc growth and breakage and an analysis of different techniques used for measuring floc strength. An overview has also been made of the general trends seen in floc strength analysis. The rate of floc formation is a balance between breakage and aggregation with flocs eventually reaching a steady-state size for a given shear rate. The steady-state floc size for a particular shear rate can, therefore, be a good indicator of floc strength. This has resulted in the development of a range of techniques to measure floc size at different applied shear levels using a combination of one or more of the following tools: light scattering and transmission; microscopy; photography; video and image analysis software. Floc strength may be simply quantified using the initial floc size for a given shear rate and the floc strength factor. More complex techniques have used theoretical modelling to determine whether flocs break by large-scale fragmentation or smaller-scale surface erosion effects, although this interpretation is open to debate. Impeller-based mixing, ultrasound and vibrating columns have all been used to provide a uniform, accurate and controllable dissipation of energy onto a floc suspension to determine floc strength. Other more recent techniques have used sensitive micromanipulators to measure the force required to break or compress individual flocs, although these techniques have been limited to the measurement of only a few hundred flocs. General trends emerge showing that smaller flocs tend to have greater strength than larger flocs, whilst the use of polymer seems to give increased strength to only some types of floc. Finally, a comparison of the strength of different types of floc (activated sludge flocs, organic matter flocs, sweep flocs and charge neutralised flocs) has been made highlighting differences in relative floc strength.

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*Corresponding author. Tel.: +44 1234 754841; fax: +44 1234 751671.

E-mail address: s.a.parsons@cranfield.ac.uk (S.A. Parsons).

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1. Introduction

Floc strength is a particularly important operational parameter in solid/liquid separation techniques for the efficient removal of aggregated particles. Unit processes at water treatment works (WTWs) are generally designed to minimise floc breakage, however in reality often this is not the case, with regions of high shear being prevalent (McCurdy et al., 2004). This may include regions around the impeller zone of flocculating tanks, processes such as dissolved air flotation (DAF) or transfer over weirs and ledges and through pumps. Flocs are, therefore, exposed to a range of stresses. Flocs must resist these stresses if they are to prevent being broken into smaller particles. In an operational sense, this is important because small particles generally have lower removal efficiencies (Boller and Blaser, 1998). Smaller particles will generally settle more slowly than larger particles of similar density. Flocs formed for removal in DAF that subsequently break up into many smaller parts may be captured less efficiently by air bubbles. In addition, flocs that are removed using membrane filtration will foul membranes if small pieces of floc break off and plug membrane pores.

Floc strength is dependent upon the inter-particle bonds between the components of the aggregate (Parker et al., 1972; Bache et al., 1997). This includes the strength and number of individual bonds within the floc. Therefore, a floc will break if the stress applied at its surface is larger than the bonding strength within the floc (Boller and Blaser, 1998). Increased floc compaction is considered to increase floc strength due to an increase in the number of bonds holding the aggregate together. Leentvaar and Rebhun (1983) also list the size and shape of floc microparticles as being an important consideration for floc strength.

However, the development of a satisfactory technique to quantify floc strength has proven to be difficult. This is partly due to the inherent complexity, fragility and variation in floc size, shape and composition and also due to a generally accepted view that there are two modes of floc rupture (Parker et al., 1972; Francois, 1987; Yeung and Pelton, 1996; Mikkelsen and Keiding, 2002). These have been classified as *surface erosion* and

large-scale fragmentation. Surface erosion is the removal of small particles from the floc surface resulting in an increase in the small particle size ranges. Large-scale fragmentation is the cleavage of flocs into pieces of a similar size without an increase in primary particle concentration. The problem of describing strength arises from the fact that these two rupture modes are thought to be caused by different stresses (Yeung and Pelton, 1996). Fragmentation is thought to occur from tensile stress acting normally across the whole floc, whilst erosion is due to the shearing stress acting tangentially to the floc surface (Fig. 1). In addition, there are complex interpretations of floc strength data arising from relative eddy size which will be discussed in later sections.

A review of the literature shows there to be no established standardised floc strength test, although a number of techniques have been evaluated. Floc strength may be broadly considered in terms of the energy required to break flocs under tension, compression or shear (Zhang et al., 1999). However, finding ways of quantifying the energy input for floc breakage has not been easy. There is, therefore, a need for a more thorough understanding of how floc strength can be measured and what information can be found from floc strength tests. This paper aims to review current knowledge on floc formation and breakage, the different techniques used to measure strength for a range of flocs including activated sludge flocs, inorganic metal flocs, natural organic matter (NOM) flocs and flocs formed from ionic salts. Particular emphasis has been placed on the applied shear rate, since most previous research has been concerned with this aspect of floc strength. Finally, the review looks at the interpretation of floc strength information.

2. Floc formation and breakage

Floc strength is directly related to floc structure and is, therefore, highly dependent upon the floc formation process. The combined processes of coagulation and flocculation aim to increase particle size for increased

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