In Collaboration with the Royal Netherlands Institute for Sea Research

Journal of Sea Research 58 (2007) 167 – 188

JOURNAL OF SEA RESEARCH

www.elsevier.com/locate/seares

InSiPID: A new low-cost instrument for in situ particle size measurements in estuarine and coastal waters

T. Benson [1], J.R. French *

Coastal and Estuarine Research Unit, University College London, Department of Geography, Pearson Building, Gower Street, London WC1E 6BT, UK

Received 4 December 2006; accepted 2 April 2007
Available online 13 May 2007

Abstract

In estuaries dominated by cohesive sediments, tidal variation in the size distribution of suspended particulates has important implications for automated suspended sediment monitoring, since instrument calibration must typically take account of both sediment concentration and particle size. Particle size variation at tidal time-scales also directly affects the parameterisation of numerical sediment transport models through its effect on the settling velocity. In situ measurements of particle size are preferred, since the behaviour of complex particle aggregates (flocs) is strongly influenced by turbulence intensity. A variety of in situ particle size measurements systems have been developed, mostly based upon either direct photographic or video imaging, or the analysis of optical or acoustic scattering. However, existing systems are expensive and/or unsuited to small-boat deployment.

This paper describes a new low-cost particle sizing system that can easily be deployed within shallow estuarine and coastal waters. The **In** **s**itu **P**article **I**maging **D**evice (InSiPID) combines twin CCD video cameras with fully automated digital image acquisition and processing algorithms for the extraction of size and shape statistics. The system has a useful imaging range of approximately 4 to 3000 μm. It has been tested in concentrations in the range 5 to 400 mg l^{-1}, and provides near real-time analysis of image ensembles using a compact portable computer. The image processing algorithms are specifically designed for the analysis of flocculated particles, and perform well against manual analysis of laboratory standards. A trial deployment within a small UK estuary reveals a clear bimodality in particle size, with the proportion of suspended material contained within these distinct micro- and macro-floc modes varying both within and between spring and neap tides. InSiPID is considerably cheaper than alternative systems. It is also more flexible in that additional functionality can be implemented in software without any major alteration to the underlying hardware.

Keywords: Estuaries; Suspended particulate matter; In situ particle size; Flocculation; Imaging techniques; UK; Suffolk; Blyth estuary

1. Introduction

In estuaries characterised by cohesive sediments, flocculation and break-up of the suspended particles throughout the tidal cycle results in temporal and spatial variability in the particle size distribution (Edzwald et al., 1975; Krone, 1978; McCave, 1984; Eisma, 1991). This has implications for both the monitoring of

* Corresponding author. Fax: +44 20 7679 0580.
E-mail addresses: t.benson@hrwallingford.co.uk (T. Benson), j.french@ucl.ac.uk (J.R. French).
[1] Present address: HR Wallingford Ltd, Howbery Park, Wallingford, Oxon, OX10 8BA, UK. Fax: +44 1491 832233.

1385-1101/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.seares.2007.04.003

suspended sediment concentration (SSC) and the parameterisation of numerical sediment transport models. Monitoring of SSC using in situ optical instruments (McCave, 1983; Baker and Lavelle, 1984; Finlayson, 1985; Sternberg et al., 1986; Moody et al., 1987; Wiberg et al., 1994; Clifford et al., 1995) or acoustic backscatter systems (Young et al., 1982; Varadan et al., 1985; Hanes et al., 1988; Libicki et al., 1989; Lynch et al., 1991; Thorne et al., 1991; Dworski and Jackson, 1994; Reichel and Nachtnebel, 1994; Lane et al., 1997; Land and Bray, 1998; Holdaway et al., 1999) is thus problematic, since the calibration of such instruments must take account of both SSC and particle size. Numerical models of sediment transport are heavily reliant upon SSC data for their calibration and validation, and particle size variation also directly affects model parameterisation through its effect on the settling velocity (Spearman and Roberts, 2002).

In energetic estuarine flows, flocculation is predominantly controlled by the turbulent shear intensity and SSC (Manning and Dyer, 1999; Winterwerp, 2002). An increase in SSC reduces the distance between individual particles, thus increasing the chance of collisions and hence enhancing the rate of flocculation. An increase in turbulence will also increase the probability of particle collisions. At low turbulent shear intensities this will enhance flocculation. However, naturally occurring flocs tend to form in a fractal manner (Kranenburg, 1994; Gregory, 1997). This results in large, porous, and fragile structures that are easily broken up when the turbulent shear exceeds the strength of the floc bonds.

The dependence of floc size on turbulence intensity means that laboratory determination of particle size using samples taken from the field are of dubious value (Swift et al., 1972; Gibbs, 1982). As a consequence, various methods have been adopted for measuring in situ particle size. These fall into the following three categories:

- settling velocity derived measurements
- imaging systems
- optical or acoustic techniques

Early investigations of estuarine flocs concentrated mainly on the measurement of in situ settling velocity because of its importance in the parameterisation of sediment transport models. Such work was initiated through the use of Field Settling Tubes, such as the Owen tube (Owen, 1971) or variants thereof (Zaneveld et al., 1982; Bartz et al., 1985; Van Rijn and Nienhuis, 1985; Pejrup, 1988; Kineke et al., 1989; Jones and Jago, 1996; Murray et al., 1996; Puls and Kühl, 1996; Van Leussen, 1996). These measure the mass of sediment that has settled through a trapped cylinder of water at timed intervals. Particle size distribution data can then be derived from the settling velocity spectra by means of Stokes Law (Stokes, 1851). Results from such instruments suggested an increase in settling velocity (and hence particle size) with increasing SSC but failed to fully quantify the dependence on turbulence (Owen, 1971). This is because this technique requires that the particles be trapped in a settling chamber, thus removing them from the turbulent estuarine environment. Consequently, the measurement is not truly in situ (Jones and Jago, 1996).

A method of obtaining settling velocity that does not require the use of settling columns is *model-dependent inversion* (Lynch and Agrawal, 1991). If it is assumed that the SSC depth-profile follows a simple model, such as the Rouse profile (Rouse, 1937), the mean settling velocity may be indirectly estimated from the measured SSC. However, the Rouse equation is only applicable in steady state conditions. This makes its use questionable at slack water when settling is most important. Deviations from the Rouse profile also occur due to flow stratification and the presence of fluid mud (Ross and Mehta, 1989).

The advent of in situ photography, with instruments such as the Benthos Plankton Camera (Kranck and Milligan, 1980; Eisma et al., 1980; Edgerton et al., 1981), meant that truly in situ size measurements could be obtained. Such measurements revealed maximum floc sizes in excess of those previously envisaged, with diameters ranging from just a few microns up to several millimetres. Inherent limitations of image resolution and restricted field of view mean that single camera systems cannot measure this full size range. To address this problem, a photographic system with multiple cameras was designed at the Netherlands Institute of Sea Research (Eisma et al., 1990). This system could measure particles from as small as 3.5 µm up to several millimetres. This was soon followed by the Floc Camera Assembly (FCA; Heffler et al., 1991), which also included a stilling chamber, thus allowing settling velocity measurements to be obtained (although this had a more modest minimum resolution of 50 µm). These systems are large and difficult to deploy, though smaller instruments have subsequently been developed. These include the photographic In situ Aggregate Analysis Camera (ISAAC) (Knowles and Wells, 1996), as well as video (Thomsen et al., 1996) and digital camera systems (Maldiney and Mouchel, 1995; Pfeiffer, 1996). However, all these systems incorporate only a single camera and, hence, have a restricted size detection range.