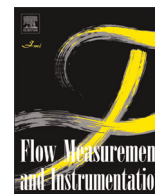




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The influence of grain size on the performance of conductivity concentration meters

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ABSTRACT

The use of conductivity as a means to determine the volume fraction of solids in a suspension of poorly conductive solids in water combines the benefits of high sampling rates and ease of use at the cost of a high sensitivity to salinity and fluid temperature. In this paper we investigate a custom built CCM, to which a third parameter was found to be of much influence: the grain size of the suspended phase. This paper describes a calibration experiment with which the influence of grain size on the CCM output has been investigated. The data give rise to an alternative calibration curve which is different from the regular effective media theories.

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1. Introduction

The electrical conductivity of a fluid containing suspended particles depends on the conductivity of the fluid and the volume fraction of the suspended particles. The larger the volume fraction of the suspended particles, the more the conductivity of the mixture is affected. In the research reported here the electrical conductivity of the suspended particles is very small compared to the conductivity of the fluid. Adding such particles to fluid (water) in a measuring volume forces the measured conductance to a lower value as long as the particles remain well distributed over the entire volume.

By measuring the electric conductance or electric resistance of a mixture, it is thus possible to get information about the volume fraction of the different individual phases in the mixture. There is a wide range of application for this technique, for instance in well-bore logging in the oil and gas industry or the measurement of the volume fraction of suspended solids in a mixture of water and solids. The latter application has been mainly concerned with suspensions or slurries with fine material.

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Nasr-El-Din et al. [10] describe an intrusive conductivity probe that is tested with spherical glass beads and irregularly shaped particles. Although the conductivity measurement was expected to be dependent on the flow velocity, their results were not sensitive to velocity changes. The electrodes in the probe have a spacing of 1 mm, and for particles with $d > 1$ mm it proved that the Maxwell model is not valid. MacTaggart et al. [9] describe an improved version of the intrusive probe of Nasr-El-Din et al. [10] and use it for measuring the volume fraction of solids with $d < 1$ mm in a mixing tank. It proved again that the results were independent of the rotational speed of the stirrer, and it proved that monitoring the background conductivity (i.e. carrier fluid conductivity) is preferred to improve the results.

Holdich and Sinclair [8] use a different approach by mounting two electrodes opposite of a pipe. Multiple pairs were placed along the length of a $D=65$ mm pipe, which was used for a sedimentation experiment. This method is non-intrusive so it will not affect the experiment, but the electric field of the electrodes was found to be influenced by the pipe wall, which gave poor reproducibility of the results. A similar setup was used in Glasserman et al. [6] to measure the volume fraction of solids (the maximum d/D being 1/17) in a fluidized bed setup with $D=50$ mm. The electrodes were curved stainless steel plates placed opposite of each other on the fluidization column. No influence of the pipe wall is reported, and the volume fraction of solids based on the conductivity measurement agreed very well with reference

Nomenclature

A	cross section area (m ²)
c_v	volume fraction of solids (-)
d	particle diameter (m)
d_{50}	median particle diameter (m)
D	pipeline diameter (m)
h	bed height (m)
k_f	fluid conductivity (S/m)
k_m	mixture conductivity (S/m)
m	mass (kg)

m_i	mass inserted in the test setup (kg)
m_m	mass measured (kg)
T	temperature (°C)
T_0	reference temperature (°C)
v_s	solid's bulk velocity (m/s)
α	constant of proportionality (-)
ρ_s	solid's density (kg/m ³)
ξ	exponent in Archie's equation (-)
ζ	exponent in the data fit equation (-)
CCM	conductivity concentration meter

measurements based on the inserted mass of solids. The work of Holdich and Sinclair [8] was continued in Richardson and Holdich [11] by designing an intrusive probe which could simultaneously measure the mixture conductivity and the background conductivity, thus solving the problem of MacTaggart et al. [9] as well. The use of intrusive conductivity probes is a common practice in the field of mineral processing for monitoring the bed height in thickeners [14,17,1].

Although many industrial applications are concerned with mixtures of fine material in a carrier liquid, there are exceptions to this case. Since 1960s deep sea mining is being considered as a viable alternative for terrestrial mining, and laboratory research and technology development in this field are still progressing [5]. In deep sea mining, the vertical hydraulic transport of the excavated material from seafloor to sea surface over a distance of hundreds to thousands of meters is a key operation. The excavated deposits are large, with d/D up to 1/5, hence laboratory experiments in this field are concerned with relatively large particles as well [18,19,16].

The authors are concerned with laboratory scale vertical hydraulic transport experiments of large particles, in which the determination of the in situ volume fraction of solids (up to $c_v \approx 0.6$) at cross sections along the riser is the most important aspect. Conductivity concentration meters are well suited considering the operational range of c_v and the high sampling rates, but their use in combination with relatively large particles (in terms of d/D) has to be investigated in more depth.

2. The conductivity concentration meter

Individual particles will not be noticed when the particles are small relative to the size of the measuring volume and the electrodes used to measure the conductance, so the mixture will act electrically homogeneously. If the particles and the electrodes have dimensions of the same order of magnitude, then the measured conductivity will also vary with the position of the particles relative to the electrodes. In that case the measured conductivity will not only depend on the concentration of the suspended matter but also on the ever changing positions of the particles, in particular those close to the electrodes.

The electrical conductance between two electrodes depends on to what extent the current can spatially develop between the electrodes. Would the current be confined to a narrow corridor between the electrodes, then a smaller conductance will be observed than in the case the current can fully spread between the electrodes. When used inside a pipe, the current is confined to some extent, hence the observed conductance will not reach the maximum level.

The Conductivity Concentration Meter used in this research is designed and built by Deltares, The Netherlands. It is based on

their standard devices for measurement of the volume fraction of sand particles in different laboratory and commercial applications. The current design has been proposed for the use in vertical hydraulic transport experiments with relatively large particles. The device consists of four pairs of platinum electrodes, placed opposite of each other in the cross section of a pipe section with internal diameter $D=99.4$ mm. The PVC pipe is non-conducting so the pipe wall limits the spatial extent of the electrical current. The sensor electrodes are mounted flush with the inside of the pipe wall. The electrodes are manufactured of 4 mm diameter platinum rod. Platinum is chosen for the electrical stability of its metal-water interface.

As mentioned, the measured conductance not only depends on the volume fraction of suspended particles but also on the particle size in relation to the electrode size. The design particle size for this device is $d=15$ mm, but in the calibration experiments this range is extended. To limit the influence of particle size, the electrode surface area exposed to the fluid was increased by combining the electrodes in sets of four. This approach also reduces the effect of the spatial distribution of the particles. After all, a particle close to an electrode cannot be close to any of the other electrodes. The configuration is depicted in Fig. 1. The configuration thus obtained effectively consists of two electrodes.

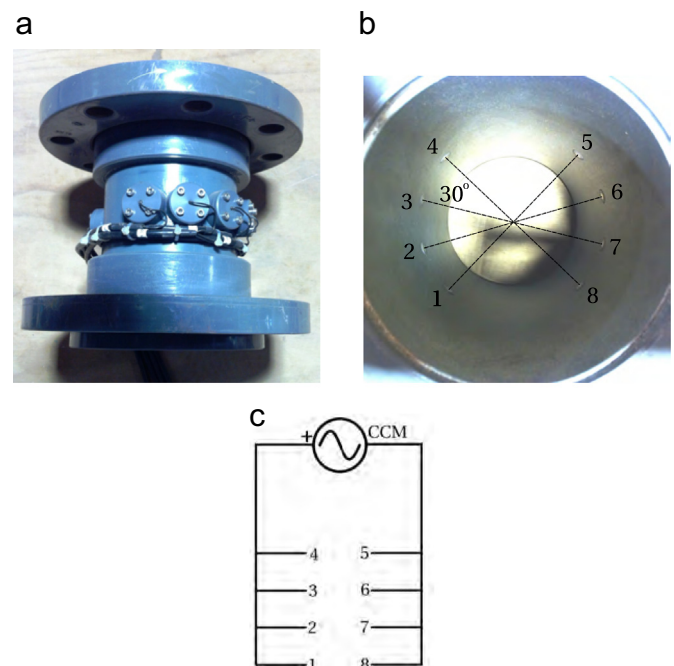


Fig. 1. The Conductivity Concentration Meter as used in the experiments: (a) exterior view of the CCM; (b) interior view of the CCM; and (c) electric scheme of the CCM.

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