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Quantitative monitoring of batch sedimentation based on fractional density changes

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ABSTRACT

The paper proposes a methodology for rapid estimation of the mass of suspended solids in the batch settler based on the phenomenon of fractional density changes. The methodology is intended for use in industrial processes and requires no human interaction. It requires the measurement of hydrostatic pressures at two different levels inside the settler and enables: (1) estimation of the total mass of suspended solids before the sedimentation process is finished with accuracy of about 10%, (2) monitoring of the percentage of mass that is still above the height of one of the measurements (separation index), (3) indication of sedimentation finalization at a certain level in the settler and also (4) observation of the compaction of sludge at the bottom of the settler. The separation index can be used to quantitatively specify the separation progress and also as a guide in applications requiring specified increase of the suspended solids concentration e.g. thickening to a specified concentration be settling.

Used symbols

indices 1,2 correspond to the pressure sensors mounted on different heights. Sensor 1 is higher than sensor 2.

Values constant throughout the whole settling process

- H true level of medium in the settler,
- H_1, H_2 heights at which pressure sensors are mounted,
- M_T total mass of solid particles in the settler,
- A cross section area of the settler,
- ρ_L, ρ_S density of the liquid phase and the solid phase respectively,
- $\Delta\rho = 1 - \frac{\rho_L}{\rho_S}$ a term accounting for the fact that the increase of pressure due to solids present in the liquid results from the difference between the density of solids and the density of the liquid [21].

Values changing throughout the settling process

- M_1, M_2 mass of solid particles above the corresponding heights at which pressures are measured,
- H_{P1}, H_{P2} levels of the liquid/solids mixture as measured by pressure transducers mounted at the corresponding heights.
- H_{est} estimation of true level of liquid in the settler
- ΔH_1, ΔH_2 increase of the measured level values for the corresponding sensors, caused by the presence of solid particles above the corresponding height.
- I_{sep} – separation index defined as the percentage of mass of solids still above the level H_1.

1. Introduction

Sedimentation is one of the most widely used processes for separation of suspended solids from a liquid. The process can be divided into two major categories: continuous sedimentation with constant inflow of suspended solids into the settler (see for example [1–3]), and batch sedimentation in which no inflow or outflow occurs during the settling process. This paper deals with batch sedimentation.

The majority of sedimentation models are directly or indirectly based on a theory proposed by Kynch [4], in which the velocity of solid particles depends only on the local suspended solids concentration. This theory has been extensively used and a number of modifications exist [5], for example extending the model to reflect the compression behavior ([6–8]). Increase in computational power enabled the development and the effective application of two-dimensional sedimentation models (for example [9,10]). The applicability of one-dimensional theories for the design and operation of settlers has therefore been assessed (for example [11]) and experimental validation of mathematical models has been presented for example in [12].

2. Motivation

Batch sedimentation is widely used in the industry and in many cases automation is desirable in order to decrease operation costs and increase effectiveness. In order to control the process of batch

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sedimentation, measurements that indicate the progress of the process are needed. A number of techniques exist for measuring the sedimentation progress and for the identification of sedimentation model parameters. Usually, settling velocities and settling flux functions are estimated using batch settling curves [13,14]. On-line quantification of settling properties in the application to activated sludge characterization has been presented and practically evaluated [15]. Different optical methods for characterization of stability of dispersed systems have been compared in [16]. Sensors based on image analysis for the estimation of the activated sludge settling properties have also been presented (for example [17–19]). Photometric measurements, namely turbidity sensors, are available and may be used to indicate whether the liquid is clear enough at a certain level, thus enabling control of decantation in a batch settler [20]. Methods that are based on optic measurements however are not always suitable, especially in situations when the clarified liquid contains a non-settling fraction of solid particles.

The mentioned methods enable precise quantification of batch sedimentation parameters and the measurement of mass of suspended solids in laboratory conditions. The aim of this paper is to propose a method to be applied in industrial applications. The presented methodology aims at estimating the progress of batch sedimentation from a purely mass-based view. Therefore, only the bulk mass of suspended solids is observed. Small and slowly settling particles are not observed. The presented methodology requires no human interaction, no drawing of samples from the settler and can be used for on-line monitoring of settlers involved in industrial processes.

The phenomenon of fractional density changes [21] can be used to automate the operation of the batch sedimentation process and to quantify the progress of this process. The method is based on comparatively inexpensive measurements of hydrostatic pressures at different levels in the settler (Fig. 1). Because two measurements are used, it is possible to calculate the total mass of suspended solids in the settler at the beginning of the settling process. It is therefore possible to continuously calculate a sedimentation progress index, defined as a percentage of the total mass in the settler that is still above the higher level at which the pressure is measured (H_1 level in Fig. 1).

3. Estimation of mass in the settler

The model of fractional density changes in a batch settler is presented in detail in [21,22]. A comparison between experimental results and the Kynch theory is presented in [21]. In principle, the hydrostatic pressure at any given level is dependent on the height of the medium column and on the density of the medium above the level at which the pressure is measured. The pressure transducer used to measure the level of the medium in the settler is calibrated for clear water. Therefore, when solid particles are present in the liquid, the measurement is biased, giving slightly higher values of the level. This is due to the slightly higher overall medium density as compared to clear water.

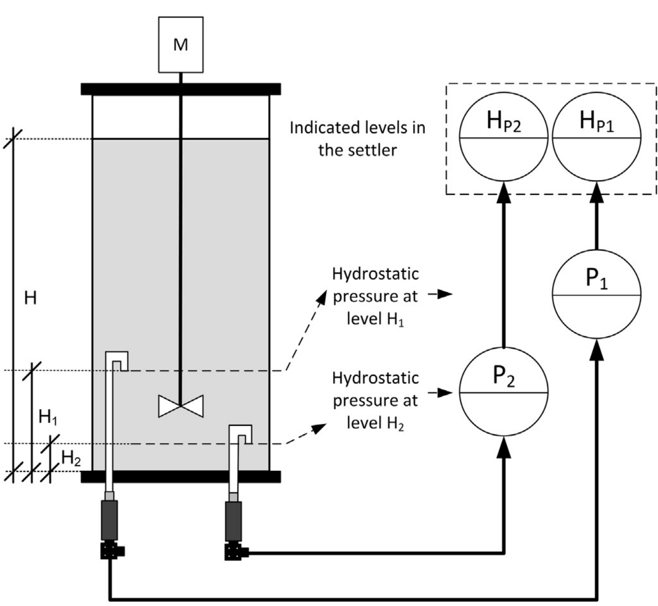

Fig. 1. Measurements of hydrostatic pressure in a batch settler under consideration.

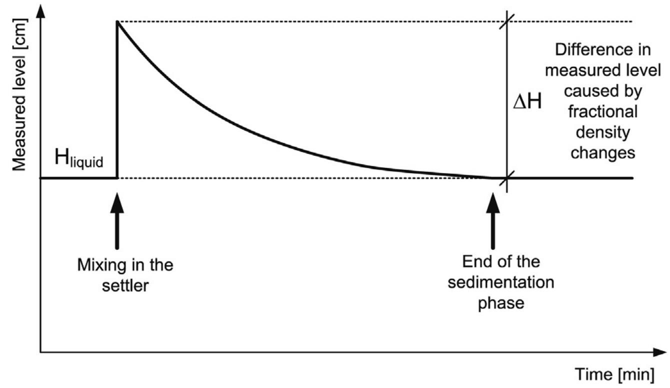

Fig. 2. The effect of fractional density changes on the level measurement taken by the pressure sensor mounted above the bottom of the settler.

For example, with solid particles present in the settler, the indicated level H_{P1} (Fig. 1) will be higher than the real level H because pressure P_1 is biased due to the solid particles present. With time, as the solid particles settle due to gravity, the bias will decrease until all the solid particles settle below the level H_1 (Fig. 2). At that time, the measured level is equal to the real level in the settler.

The mass of solid particles above the H_1 and H_2 levels respectively can be expressed by the following equations [22]:

$$M_1 = \frac{\Delta H_1 \cdot A \cdot \rho_L}{\Delta \rho} \tag{1}$$

$$M_2 = \frac{\Delta H_2 \cdot A \cdot \rho_L}{\Delta \rho} \tag{2}$$

where:

$$\Delta H_1 = H_{P1} - H. \tag{3}$$

$$\Delta H_2 = H_{P2} - H. \tag{4}$$

If the content of the settler is perfectly mixed, the distribution of solid particles is uniform and the total mass of solids present in the settler can be calculated from the following equation:

$$M = M_1 \frac{H}{H - H_1} = M_2 \frac{H}{H - H_2}. \tag{5}$$

Therefore, the total mass M can be calculated based on the analysis of level measurement from only one pressure sensor assuming, that the real level of liquid/solids mixture in the settler is known, as demonstrated in [22].

In this paper however, it is assumed that the real level of medium H in the settler is not known a priori. This is a reasonable assumption, since the pressure sensors are primarily used to indicate the level of medium in the settler. It is also assumed, that an independent measurement of the real level is not available for reference. Instead, having two pressure sensors at different heights, it is possible to calculate the real level in the settler using Eqs. (1)–(5).