Automation of sedimentation test

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ABSTRACT

This paper reports on the development of an automated method to perform sedimentation tests on a suspension, to study the settling and sedimentation behaviour of particle suspension. The standard method for measuring sedimentation rate is the jar test, but this is burdened with some errors: the possibility of misinterpretation of the interface or subjective readings by technicians. In order to overcome these problems, there are many different methods that exclude subjective mistakes. The proposed solution automatically detects the phase separation boundary and, by use of a moving camera, plots the real-time sedimentation curve. The good agreement of settling curves between the manual method, another CCD image processing method and the current technique demonstrates the reliability of the system. This system can be used for testing different types of suspensions. The article presents a comparison of the commonly used method of image analysis and the proposed solution with a tracking camera, based on the example of a coal suspension.

Key words | automation, image processing, sedimentation test

INTRODUCTION

The sedimentation process is one of the most widely used processes for the separation of suspended solids from liquid (Nocon´ 2016). Sedimentation is widely used in wastewater treatment processes, and in the chemical, food and mineral processing industries (Kowalski et al. 2001). The energy demand for is very low for sedimentation itself (though energy must be supplied to accompanying processes, e.g. pumping of generated sediment). The progress and speed of the sedimentation process depend on many factors, such as the type of suspension, particle size distribution, suspension concentration, chemical composition, particle and fluid density difference, fluid viscosity, etc. (Kowalski 2004). Although sedimentation is beneficial for energy reasons (Banaś et al. 2014), the biggest drawback is its very low speed, therefore there is a need to use various techniques to intensify the sedimentation process, including coagulation, flocculation, multiflux fillings, even autocoagulation (Banaś 2004). The addition of flocculant causes the fine particles of the suspension to combine into larger agglomerates, and agglomerates settle much faster than the fine particles.

Due to the complexity of the process of settling particles in a suspension of relatively high concentration, it is necessary to experimentally determine the parameters of the sedimentation process. For this purpose, a static sedimentation test of the suspension is performed, resulting in plot of the sedimentation curve of the investigated suspension. The standard test for measuring sedimentation process parameters is the so-called jar test (clear liquid-solid interface as a function of time). The position of the boundary phase separation (interface) allows the determination of the size of the designed settler, and the maximum attainable degree of compression or concentration of suspension (Bandrowski et al. 2001).

The jar test method is quite simple and direct, but it has significant disadvantages: the possible misinterpretation of the interface or a subjective reading (using the naked eye) of the interface by different technicians (Yang et al. 2017). The problem associated with performing a sedimentation test is, for example, the duration of the test. Manual reading is very monotonous and tedious, especially when settling lasts for dozens of hours or even days. On the other hand,
when a flocculent (or coagulant) solution is added to enhance the settling process, at higher dosages, the settling time is very short (Singh et al. 2014). Due to the widespread use of the sedimentation process in many branches of the industry, despite awareness of the imperfection of the jar method, there is a need to carry out sedimentation tests to determine the operating parameters of the settlers (thickeners or clarifiers) or to adjust the dose of chemical addition (coagulant or flocculant).

In order to eliminate these types of errors and to optimize work time for sedimentation tests, there are a number of other methods that have been used for measuring particle settling, which include electrical capacitance (Guerin & Seaman 2004) or conductance (Vergouw et al. 1997), ultrasonic methods (Hunter et al. 2011), γ-ray radiation (Kaushal & Tomita 2007), light sensor (Hoffman et al. 2012), numerical methods (Kolodziejczyk 2016a), magnetic resonance imaging (Acosta-Cabronero & Hall 2009) or CCD video analysis (Zhu et al. 2000; Hubner et al. 2001). Some of these methods are either expensive or require specialized equipment, with the exception of the method using image analysis proposed by Zhu et al. A video recording is most commonly used for this purpose, followed by a posteriori analysis of recorded film, carried out by a technician. The CCD video analysis system (Figure 1) is based on recording of the intensity of the light penetrating the test sample, then image analysis (detection of the phase separation boundary), and the depiction of the position of the phase separation point in time. The amount of light depends on the color and concentration of the suspension to be tested – the intensity of light is high with a low concentration of the suspension (clarified part). This method is mainly used for suspensions, of which color varies the level of light intensity penetrating the test sample. Based on the obtained images, the concentration of the tested suspension can be determined (Hernando et al. 2014); for this purpose, the value of the light intensity of the tested sample should be compared with the values of light intensity for samples with known concentrations.

Due to the low cost and simplicity of this method, it was decided to carry out sediment tests using the CCD method. At the same time, manual measurements and image analysis were carried out. After comparing several measurement series, it was noticed that the results for both tests coincide around the optical axis of the camera, and with increasing distance from the optical axis, the differences increase. It could be caused by availability of only one setting for the recording camera, a parallax error occurs, increasing with the distance of the camera axis (especially when the level of the phase separation is below the optical axis of the camera).

The presence of these errors is disadvantageous especially when the most important part of the research is the initial phase of the sedimentation process (e.g. when the suspension sediments very quickly or in determining the maximum concentration of thickened suspension/compression ratio).

For these reasons, it was necessary to develop a method that would alleviate these errors, while maintaining a low cost of measurements (minimizing operator input and low price of equipment).

**METHODS**

In order to exclude such errors, the concept of a stand for automated sedimentation testing is proposed. This stand is equipped with a digital camera located on a trolley that moves along a guide parallel to the test cylinder. The camera image is continuously processed through the image analysis module. The output of this module is the height of the phase separation point on the recorded frame. The use of mathematical calculations (the difference between the position of the boundary and the center of the image transferred from the camera) allows the signal to be sent to the camera.
position control module. The signal received enables the camera to be positioned in such a way that the center of the recorded image is exactly at the level of the interface. In case of a moving camera test, the position of the phase separation point is processed by the positioning system of the trolley with the camera. If the phase separation boundary is in a different position from the center of the image (captured by the camera), correction of the position of the trolley is necessary. The trolley moving system determines the new position of the trolley: the center of the image recorded by the camera is at the same height as the phase separation boundary.

The first step in the measurement process is to identify the liquid level of the suspension to be tested. In the case of suspensions without a clear phase separation at the initial stage of the sedimentation test, calibration can be performed based on a previously performed sedimentation test of the suspension to be tested (either a specific intensity level constituting the boundary) or based on the intensity difference between the clarified suspension and the concentrated part. The built-in camera uses a commonly available camera Logitech C920 Webcam with Full HD recording (1080p). The control of the camera position (height) is done with the NI myRIO 1900 and the SSK B02-4A. The image analysis software (and thus the positioning of the camera trolley) is written in the LabView graphical environment using the Vision Acquisition, Vision Development and LV Real Time modules. The distance of the camera from the measuring cylinder can be arbitrarily set by the operator. For this reason it allows the recording of the smallest particles or change a jar/cylinder.

This method is innovative due to the fact that the methods proposed so far are based on one camera setting (burdened with parallax errors) or several stationary cameras (complex image analysis required). The proposed method excludes these errors. Tracking of the interface allows the observation of the phenomena of settling particles near the interface in high-resolution imaging, which allows the observation the smallest particles and the study of suspensions with a ‘close-to-transparent’ color.

A coal suspension was used to verify the correctness of the proposed position. The suspension for the research came from the process of coal enrichment in one of the processing plants. The sample was taken from the treatment system of the duct leading the suspension to the settlers, just before the flocculants dosing point. The concentration of the sampled suspension was in the range of $45 \pm 2$ kg/m$^3$, therefore this suspension can be classified as a high-concentration suspension (Kołodziejczyk 2016b). FLOPAM AN 923 SHU was used for the sedimentation test with addition of flocculant.

A sedimentation test of coal suspension was carried out on a laboratory stand proposed by the author: moving automated settling test – MAST (Figure 2). For comparative purposes, a classical sedimentation test using the CCD analysis method and manual test were carried out simultaneously (Figure 1) – the height of the stationary camera was 0.8 m.

Sedimentation curves for coal suspension were plotted for suspension without flocculant (raw suspension) and with various doses of flocculant. In addition, the effect of flocculant on the concentration of the suspension in the clarified liquid was determined. The sedimentation rate of the sedimentation process was determined for different doses of flocculant. The distance of the measuring cylinder from the camera was 1,000 mm in both cases. The duration of a single sedimentation test was about 6 hours. Defining the boundary separation criteria for both methods was established on the basis of a previously conducted sedimentation test.

RESULTS AND DISCUSSION

The sedimentation curves for the coal suspensions were plotted using two methods: a sedimentation test based on video analysis (automated sedimentation test – AST) and by using an automated sedimentation test proposed by the author of the article (MAST). Manual (classical) sedimentation tests were also performed in reference to the results of the automated tests.

Based on the color intensity of the test suspension (Figure 3(a)), the presence of several zones of different concentrations can be observed. In the first phase of the sedimentation test, there is no clear phase separation. After image processing all artifacts are removed and a clear phase separation boundary is obtained (Figure 3(b)). In the final phase of sedimentation there is a clear interface (Figure 4).

Sedimentation tests of raw suspension

It is noted that in the case of AST and MAST the results obtained (Figure 5) are almost identical in the range from 930 mm suspension to 800 mm (that is the position of the optical axis of the stationary camera). The relative error between manual tests and automated tests in this range is
less than about 0.5%. The results of both automated methods are convergent with the results from manual reading of interface (no parallax effect).

When the phase separation boundary is below 0.8 m, there is a noticeable difference in the results achieved using automated methods (the interface is located at the level of the optical axis of the constrained camera). In results the position of the liquid-solid interface is higher in the case of a stationary camera test. The relative error between AST and the manual method is less than 3%. The relative error value between the MAST and the manual test is less than 1.5%. The results obtained by the AST method are influenced by the increasing effect of parallax. The error values for the fixed camera increase as the interface level moves away from the camera's optical axis. If the tested suspension was fast-sedimenting it would have a big influence on the obtained results. The error values for both methods are satisfactory and show a good selection of methods to facilitate the determination of the phase separation interface (raw coal suspension settling slowly). The calibration curve (determination of the binarization threshold) used for image analysis (filtration or binarization) can also affect the error value for these methods. Performing measurements for...
several binarization thresholds could affect the minimization of measurement error. Further research will be carried in this direction. The MAST method has no effect of parallax on the results of measurements. Due to the achievement of convergent results by the MAST method, subsequent tests were carried out using only this method.

Sedimentation tests of suspension with addition doses of flocculant

From the results it is clear that depending on the dose of flocculant a different sedimentation curve is obtained (Figure 6). As the flocculant dose increases (flocculant

![Figure 5](https://iwaponline.com/wst/article-pdf/77/7/1960/214431/wst077071960.pdf)

**Figure 5** | Comparison of settling curves between AST and MAST (without addition of flocculant).

![Figure 6](https://iwaponline.com/wst/article-pdf/77/7/1960/214431/wst077071960.pdf)

**Figure 6** | Settling curves with different doses of flocculant obtained from MAST.
doses in the range of 50 ÷ 200 ppm), the clarity of the suspension increases – higher number of smaller particles are bound to large particles.

For the sedimentation test with addition of flocculant, the maximum relative error is less than 2% for a dose of 50 ppm and less than 3% for a dose of 200 ppm. The value of these errors is within an acceptable range (and confirms the applicability of this method for fast-sedimenting suspensions). These errors may occur due to the problem of interpretation of the position of the phase separation boundary (different behaviour of the flocculated particles) and the rapidly changing position of the phase separation boundary (in manual measurement it is difficult to register the solid-liquid interface at higher flocculant doses).

In order to determine the effect of flocculant application on the clarity of the suspension, turbidity measurements of the liquid were carried out. Samples were taken from the clarified part. Turbidity (in case of increasing flocculant dose) is several times lower than in the case of raw suspension (without any dose of flocculant). Using the dependence of concentration on turbidity (Banaś 2016) it can be clearly stated that the resulting solid phase particle concentration in the suspension is significantly lower with addition of flocculant than pure suspension.

These results were confirmed using the color saturation analysis of the clarified liquid image obtained from the MAST method.

**Sedimentation rate**

For all of the tests the sedimentation rate of suspension is calculated (Figure 7) based on Equation (1) where \( \Delta h \) is the increment of height (descending layer separation) and \( \Delta t \) is the time interval in which this increase occurred. The sedimentation rate determined for the initial straight section of the sedimentation curve is a rate of sedimentation of the suspension from its initial concentration.

\[
v_r = \frac{\Delta h}{\Delta t}
\]  

(1)

Based on these calculations, it can be seen that the sedimentation rate for a sample with the addition of 200 ppm of flocculant is several hundred times greater than that of sedimentation without a flocculant. This confirms the necessity of using flocculant.

Due to the high sedimentation rate, and thus a rapid change in the position of the phase separation boundary, there is a need for automated methods that are not subject to large measurement errors.

The method proposed by the author fully meets the requirements for carrying out sedimentation tests, even with the addition of high doses of flocculant.

**CONCLUSIONS**

An automated technique was developed to measure the settling velocity of suspension particles. The system consists of a moving CCD camera, image processing software, control unit of the position of the trolley and data acquisition. The verification of the correctness of the construction and the effectiveness of the algorithms used in this device was carried out using several doses of flocculant.

Examples of sedimentation tests carried out using this stand are provided in the article. An analysis of the difficulties encountered during the design and operation of the device was carried out and an assessment of the possibility of using the automated sedimentation tester in a wide spectrum of suspensions is assessed. The measurements verified positively the suitability of the proposed laboratory stand. The use of the automated sedimentation test has eliminated errors in the subjective assessment of phase separation (the classical sedimentation test) and the parallax effect (CCD image processing). This method is low-budget and minimizes the operator’s work, with satisfactory accuracy of results.

The proposed method can be a very good alternative to other methods that have been used for measuring particle settling.

**REFERENCES**


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