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Description of development step of Mofi measurement environment

CLEEN
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Abstract

The novel equipment to characterize activated sludge floc morphology has been developed. With current equipment imaging of flocs is fast and simple and only required pre-treatment is dilution. Current equipment is suitable for laboratory analysis but also the requirements of in situ processes have been noticed.

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1 Introduction

This report presents development steps of Mofi measurement environment which is part of the project of Measurement, Monitoring and Environmental Assessment (MMEA) - programme conducted by The Energy and Environment Strategic Centre (CLEEN).

1.1 Participants

Name	Organization	E-Mail
Elisa Koivuranta	University of Oulu	elisa.koivuranta@oulu.fi
Jukka Keskitalo	University of Oulu	jukka.keskitalo@oulu.fi
Esko Juuso	University of Oulu	esko.juuso@oulu.fi
Tuomas Stoor	University of Oulu	tuomas.stoor@oulu.fi
Heli Karaila	Metso Automation Oy	heli.karaila@metso.com
Matti Saren	Metso Automation Oy	matti.saren@metso.com
Marjatta Piironen	Kemira	marjatta.piironen@kemira.com
Ilkka Laakso	Stora Enso	ilkka.laakso@storaenso.com

1.2 Background

The activated sludge treatment is one of the most typical processes in municipal and industrial wastewater treatment plants. It consists of two stages, a biological stage (aeration tank) and physical stage (secondary clarifier). The main role of the process is the development of micro-organisms that consume the organic matter in the wastewater. Micro-organisms flocculate in aeration tank and are removed in secondary clarifier. Effective settling of flocs in the secondary clarifier is necessary as the effluent is normally discharged to a natural water system.

A common problem in activated sludge process is the excessive growth of filamentous bacteria i.e. bulking sludge, which reduces the settling speed of the flocs. Despite much effort on the fundamental reasons of the formation of bulking sludge, it still seems to be continuous problem in most activated sludge treatment plants. To guarantee the minimum organic load from the activated sludge process to water systems, effective operation of the floc forming is critical. Nowadays, the main problem in monitoring and controlling the activated sludge treatment process is the lack of on-line measurement of floc characteristics.

Also dewatering of biosludge produced in secondary clarifier is difficult due to its gelatinous nature. Several studies have shown, that dewaterability of biosludge is related to floc structure. Through image-analysis of activated sludge flocs, it could also be possible to control and understand dewatering process.

Image analysis of activated sludge flocs can offer a possibility for fast and reliable way to control activated sludge process, thus better effluent quality and better dewatering can be achieved.

1.3 Objective

Aim of the project is to develop floc measurement equipment to characterize activate sludge flocs. The developed method can be used e.g. in control of chemical dosing. Through on-line-measurement better control of activated sludge plant is possible and environmental impacts of wastewater treatment can be diminished.

2 Development step of Mofi measurement environment

The aim of the project is to develop a floc measurement environment for activated sludge plants. The steps include development of a measurement unit and an image analysis system. So far, the developed floc measurement environment has only been tested in laboratory, but the further aim is to develop measurement environment to in situ processes.

2.1 Literary survey

Several studies made during the past decades have shown that bulking sludge is a common problem in most activated sludge plants and it reduces the quality of effluent. Despite the extensive amount of research that has been done, a comprehensive solution does not seem to be available. [1] There are several reasons for bulking sludge such as formation of small flocs, particle size and density, floc morphology, dominance by filaments and surface chemistry [1-6]. Many of these factors are difficult or impossible to measure in full-scale processes.

Typically microscopy analysis has been used to analyze activated sludge floc morphology and size by many researchers. Results are not uniform. [3-7] Main problem in studies is the use of microscopy which is time consuming. Recommendation is that at least 625 individual particle per sample should be analyzed [8]. In most microscopy studies this recommendation was not achieved, so the results are not statistically reliable. Also the problem in microscopy analysis is sample preparation and proper transferring of the flocs into microscopy.

Many researchers have developed automated image analysis systems to speed up the microscopy analysis [3, 4, 7, 9]. Even so, it is still difficult to make in-situ microscopy measurements as it needs sample preparation prior the actual analysis. [8]

Also, a light scattering method has been used in analyzing floc size. It is easy to use and also possible to measure in situ, but the limitation is that it only gives information about particle size distribution, not floc morphology. It's is impossible to measure e.g. amount of filaments in sludge through a light scattering method. [8]

Results of the literary survey indicate that there is a need for new floc measurement equipment, which is fast, easy to use and possible to use in situ. The need to measure in-situ floc size distribution and morphological characteristics has long been noticed in both chemical and biological wastewater treatment, but still the usable equipment is lacking.

2.2 Mofi measurement environment

2.2.1 Description of Mofi

Mofi measurement environment is presented in Figure 1.

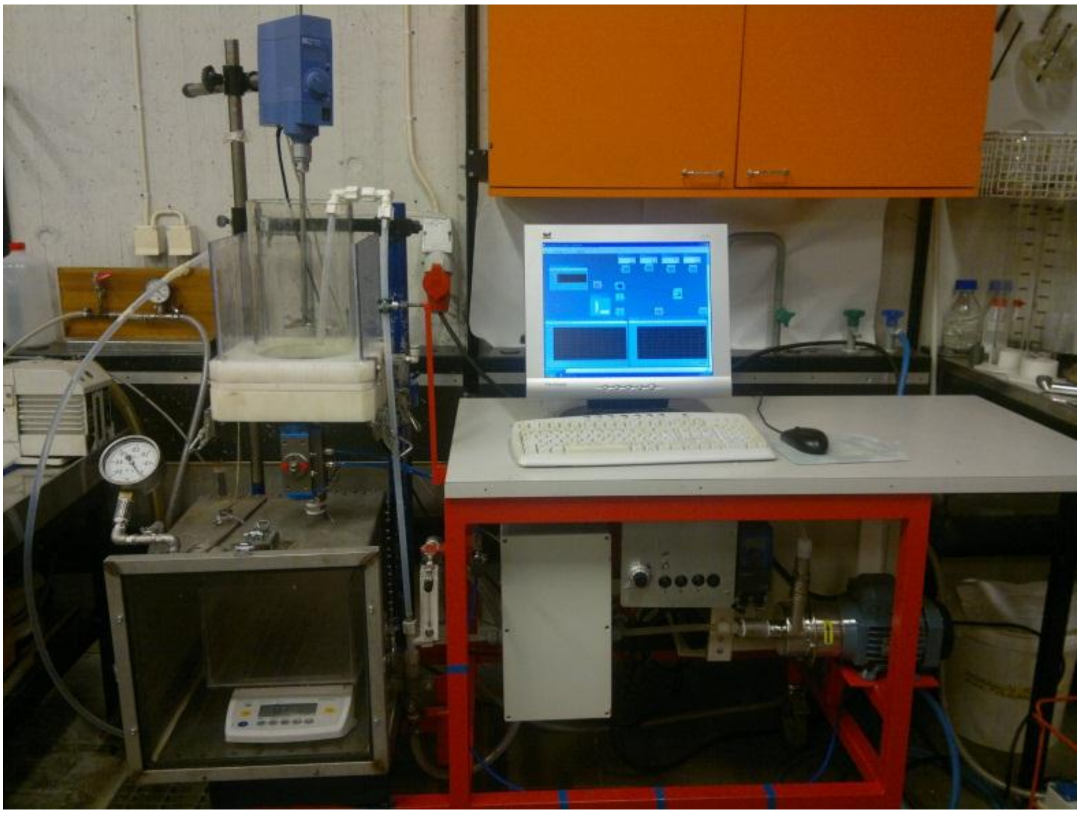

Figure 1. Mofi measurement environment.

Mofi has two units: a filtration unit and an imaging unit. With the filtration unit it is possible to filtrate samples through different types of wires. Computer records the filtration speed automatically. It is also possible to filtrate with over or under pressure. The equipment included an adjustable mixer. In the imaging unit samples are photographed with a CCD- camera. The image size is currently 5.01 x 3.74 mm and resolution is 3.6 μm x 3.6 μm.

2.2.2 Development of imaging unit

In the beginning of the study, Mofi was tested with different wastewater samples to see its application area. It was observed that original image resolution wasn´t sufficient to quantify activated sludge flocs without polymer addition (figure 2).

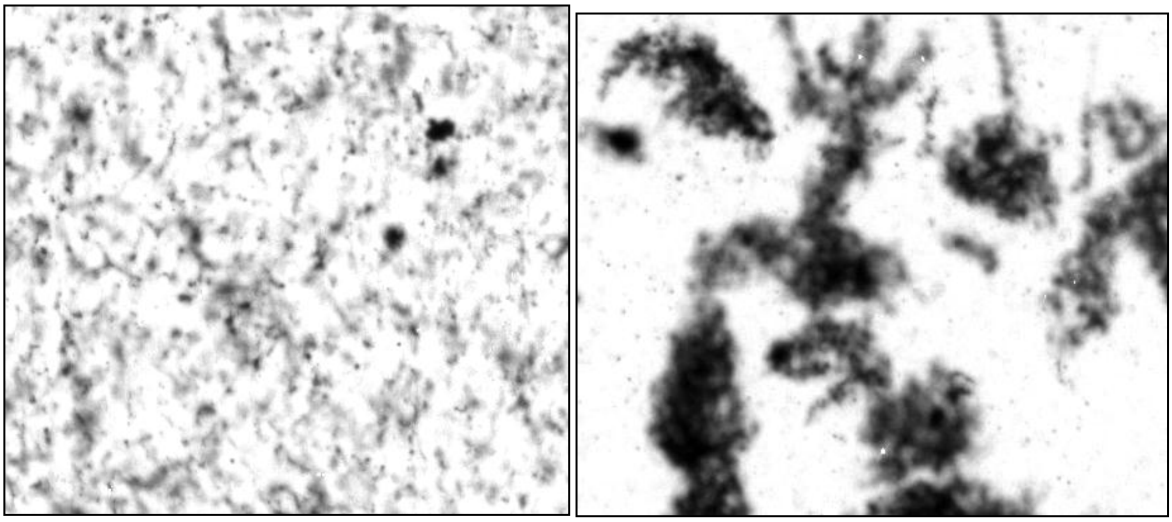

Figure 2. Original image of activated sludge floc (left) and conditioned activated sludge flocs (right).

New camera with better resolution was installed in February 2011. With the current camera, Mofi is suited for survey of both chemical and biological flocs. Better resolution enables imaging activate sludge flocs without any chemical pretreatment (Figure 3).

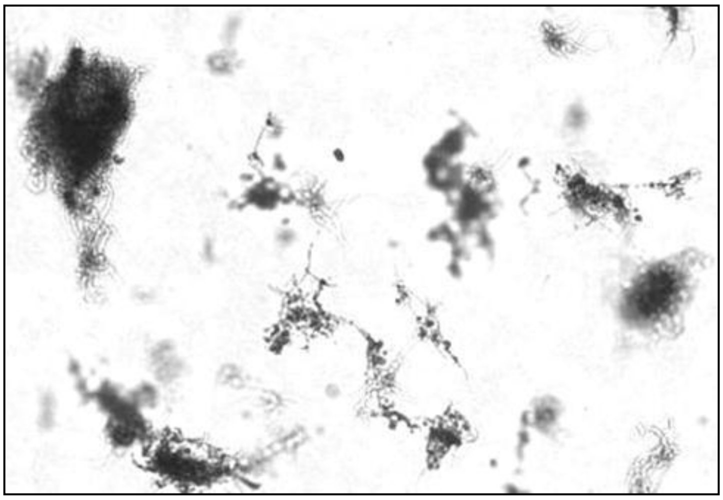

Figure 3. Activated sludge flocs with current camera.

2.2.3 Adjustment of parameters

Parameters such as dilution, volume size and rotation speed of pump have to be tested and adjusted. It was noticed, that activated sludge samples require dilution of 1:200. With a sample of 10 ml, it is possible to take about 400-500 images which include over 60 000 individual flocs. The high quantity of images obtained from the samples offer statistically reliable information about floc morphology.

2.3 Image analysis

Image analysis program has been developed for automated analysis of images obtained with the Mofi. The developed is done in Matlab environment but it can be compiled also as a standalone program for users without Matlab. Image analysis consists of preprocessing of images and calculation of floc shape and size parameters.

2.3.1 Processing of images

2.3.1.1 Preprocessing

The Mofi equipment stores images in Jpeg format with the dimension of 1392 x 1040 pixels and color depth of 8 bits per pixel. The images are stored in a container format developed by Metso Automation. Therefore the first step in preprocessing is unpacking of images obtained from a single sample. Background is removed from images by division with background image. Binary image is then obtained by simple thresholding operation with a user supplied threshold value. So far there has been no need to alter the threshold value for processing images from different samples.

Objects which touch image border are very unlikely to be completely within the image. Including these objects in the analysis would give unrealistic shape parameters. Therefore an option has been added to remove objects touching image border.

Air leaks in the measuring equipment cause air bubbles to appear occasionally in images. Air bubbles can be separated from flocs as air bubbles are almost completely round while flocs have highly irregular shape. An option has been added to remove air bubbles based on their roundness value. The user can set a roundness threshold value above which objects are removed. However, this procedure for bubble removal is not yet perfect as bubbles which overlap with other objects will not be detected.

Some of the objects in each image appear to be out of focus while others have very sharp contour. With white background the objects out of focus also have lighter color. Some of the shape parameters are calculated from the measurement of object perimeter. Therefore objects which are out of focus have their shape parameters calculated separately from objects with sharp contour. Out-of-focus objects are detected based on their mean color intensity. The user can supply an intensity threshold value above which objects are categorized as out-of-focus.

The final step in preprocessing is removal of small debris. The size of objects is measured as the number of pixels. Objects with fewer pixels than a user defined threshold value are excluded from the analysis.

Image preprocessing step is illustrated in Figure 4. Boundaries of objects touching image border are colored in cyan, out-of-focus objects in green, small debris in red, air bubbles in magenta and accepted objects in blue.

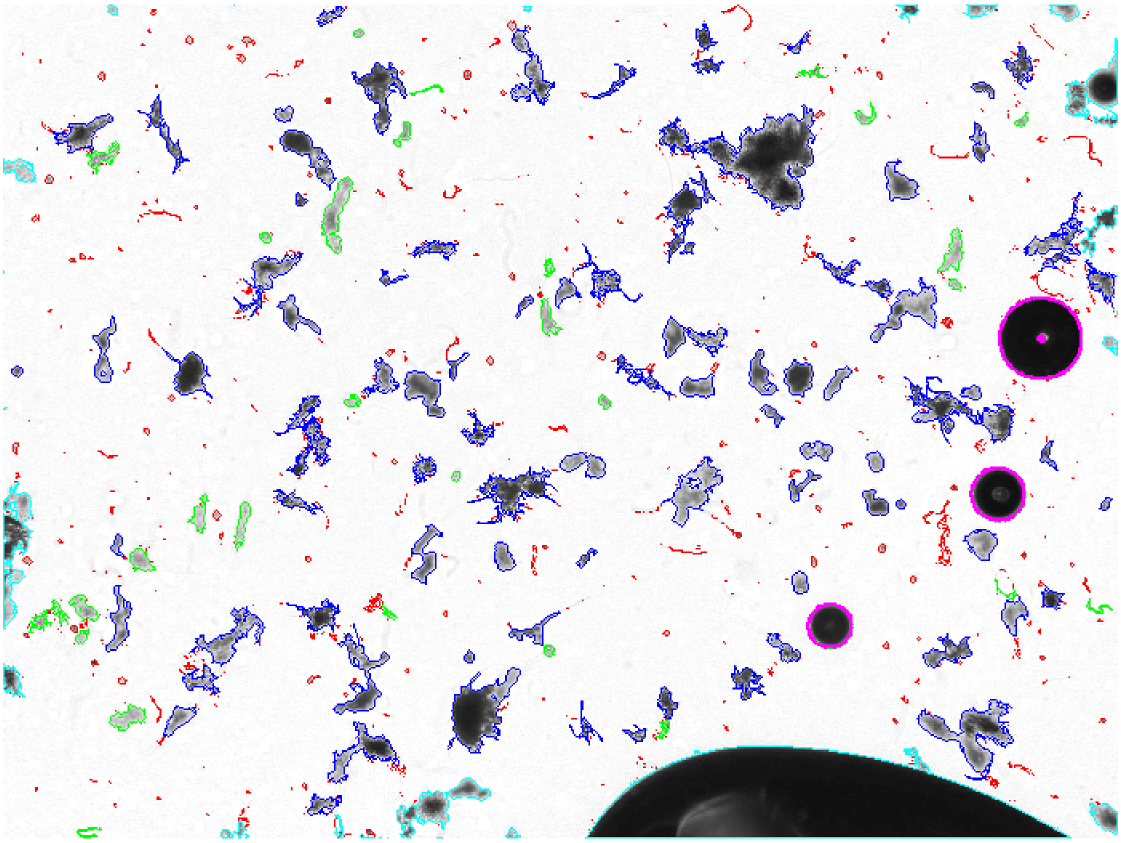

Figure 4. An example of object classification in image preprocessing. Boundaries of objects touching image border are colored in cyan, out-of-focus objects in green, small debris in red, air bubbles in magenta and accepted objects in blue.

2.3.1.2 Morphological parameters

At this stage it is uncertain which morphological parameters will prove to be significant in determining sludge quality as measured by variables such as settleability and dewaterability. Therefore a broad range of morphological parameters from image analysis literature have been included in the image analysis program. Morphological parameters are calculated for all floc objects that are accepted after preprocessing.

Form factor (FF) is affected by irregularity or roughness of object boundary. It is 1.0 for a perfect circle and below 1.0 for any other shape. Objects with more irregular boundaries have more perimeter per surface area and therefore smaller form factors. Form factor is calculated as [10]

$$FF = \frac{4\pi \times area}{perimeter^2}.$$

Roundness (RO) is also 1.0 for a perfect circle. However, it has different definition than form factor. Roundness is defined as the ratio between area of an object and area of a circle with a diameter equal to the object's length [10]

$$RO = \frac{4 \times area}{\pi \times length^2}.$$

Aspect ratio (AR) describes how elongated the object is [10]. It is calculated as

$$AR = \frac{length}{width}.$$

Fractal dimension can also be used to describe particle structure. Box counting method can be used to calculate fractal dimensions from floc images. In the box counting method, the image is covered with squares of a certain size using the minimum number of squares to completely cover the object in image. Then the square size is reduced and the process is repeated. Fractal dimension is obtained as the slope of a curve from a plot of the logarithm of size of squares against the logarithm of number of squares [11].

In addition to the parameters describing object shape, also parameters related to the object size are calculated. Mean, median and standard deviation of size are calculated separately for objects of all size and for objects above the user defined minimum size. Another size parameter is the equivalent diameter, which is the diameter of a circle with an area equal to the object's area [10].

2.3.2 User interface

The image analysis of floc videos from the Mofi equipment can be performed from a graphical user interface. The user interface allows opening a video file, starting, stopping and pausing of image analysis and changing of settings. Settings which can be changed are the threshold value for minimum acceptable floc size, enabling calculation of fractal dimension, enabling calculation of fractal dimension for floc perimeter instead of filled floc area, enabling plotting of results, enabling removal of flocs touching image border, enabling removal of air bubbles, threshold value for roundness of objects above which objects are removed as air bubbles, maximum mean intensity for objects above which they are removed for being out of focus and intensity threshold in creating binary image. Screenshot of the user interface is shown in Figure 5. In the user interface there is three figures. The figure on the upper left is the original image that is being processed. The figure on the upper right is binary image from which air bubbles and flocs touching image border have been removed. The figure on the lower right has also had the small debris removed.

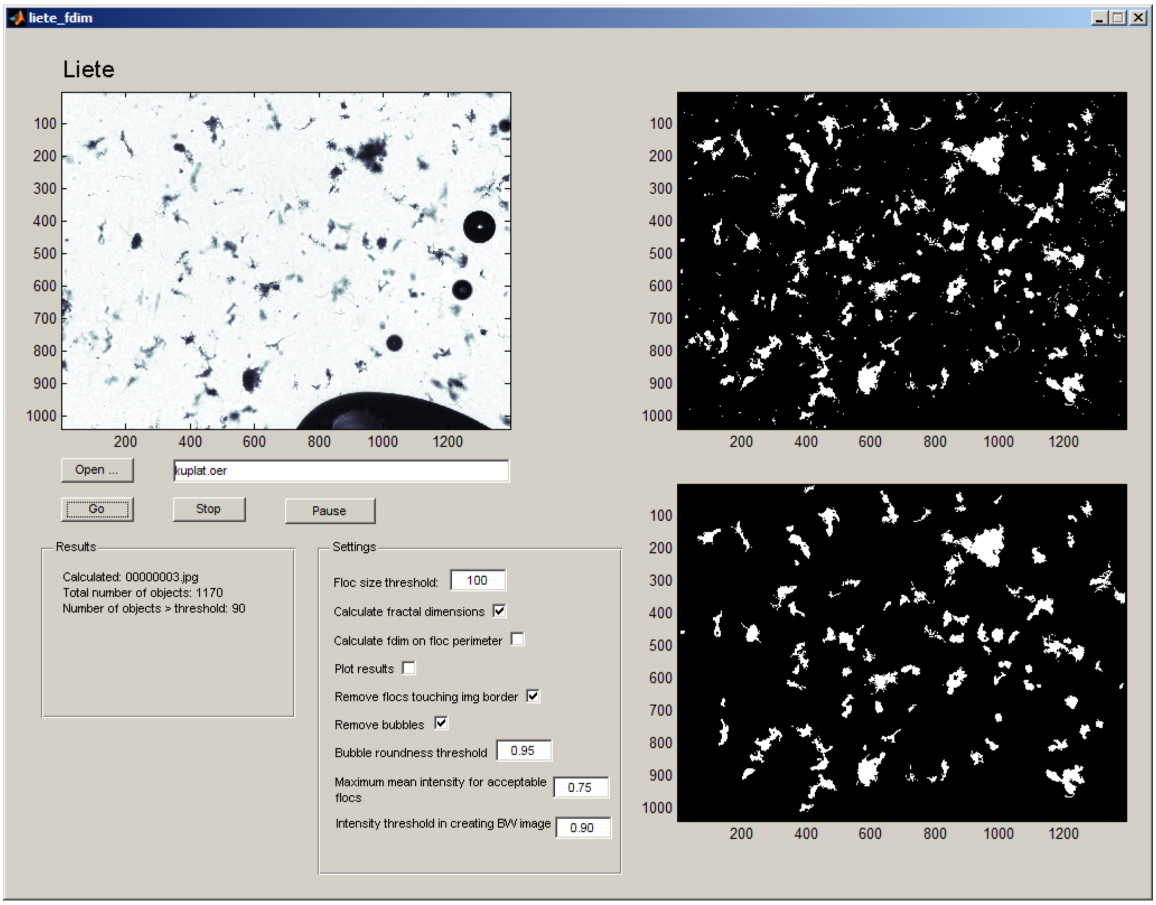

Figure 5. Graphical user interface for image analysis.

Results from the image analysis are stored in csv-files for further analysis. Morphological parameters stored for each image are the mean values and standard deviations of the parameters for individual objects.

2.4 Testing of Mofi and image analysis

To ensure proper results, lots of testing had to be made during the development. It was observed that dilution of activated sludge flocs affected on floc size but not shape factors (Table 1). It is important to use same dilution in future research. Volume size didn't have any significant role on the measurement accuracy.

Dilution	Fracatal dimension	Form factor	Roundness	Aspect ratio	Equivalent diam.	Mean area of all	Mean area of flocs
1:100	1,52	0,36	0,42	2,05	25,29	103,29	692,41
1:200	1,51	0,38	0,43	2,09	23,14	92,47	543,91

Table 1. Effect of dilution to results.

Also, repeatability and standard deviations was surveyed. It was noticed, that repeatability was major and standard deviations were minor (Table 2).

	Fracatal dimension	Form factor	Roundness	Aspect ratio	Equivalent diam.	Mean area of all	Mean area of flocs
Mean value	1,52	0,38	0,43	2,09	23,14	92,47	543,91
Stand. Dev.	0,01	0,02	0,02	0,08	0,95	8,77	67,01

Table 2. Standard deviations of image analysis.

2.5 Further development steps

Aim of the project is to develop floc measurement environment to in situ processes. Further development steps include the development of an imaging unit with an automatic sample dilution system so that the equipment is suitable to in situ operation.

As image quality increases with the ongoing development of the Mofi, more useful parameters can be calculated from the images. In further development of image analysis, filament objects and floc objects will be detected and processed separately.

The requirements of in situ operation have to be considered also in the processing and analysis of images. The current image analysis program is computationally too heavy, as it has been designed for offline use. Further development will reveal which of the calculated shape and size parameters are the most significant in estimating sludge quality.

3 Conclusion

With the current imaging unit, Mofi offers a novel method to quantify floc morphology. Its advantages are fastness, ease of use and the ability to provide statistically relevant information. Mofi has already been proven feasible in laboratory scale studies, but with further development it is also possible to transfer to in situ process in the future.

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