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HYDROCYCLONE OPTIMIZATION FOR THE REMOVAL OF IMPURITIES IN BIOWASTE CO-DIGESTION PROCESSES

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For solid-liquid separation hydrocyclones are widely accepted devices in several areas of process engineering. For the field of sludge processing in wastewater treatment and fermentation technology there is a demand for design criteria for hydrocyclones. The present paper shows a systematic approach for hydrocyclone optimization on the basis of viscosity measurements, empirical separation experiments, particle image velocimetry, computational fluid dynamics and field studies.

KEY WORDS: cyclone, solid-liquid-separation, sludge processing, inertial separation

1. INTRODUCTION

In order to improve the biogas output of existing municipal wastewater treatment plants (WWTP), anaerobic co-digestion of biological waste has gained importance within the last years (Bolzonella et al., 2006; Borowski, 2015). The biowaste often contains impurities such as sand, glass or metal particles which have effects on the plants operation economy in terms of particle deposition and enhanced attrition (Novarino and Zanetti, 2012; Agyeman and Tao, 2014; Romera-Güiza et al., 2014; Jank et al., 2016).

Hydrocyclones are widely used in chemical or mineral industry for solid-liquid-separation. Several studies in the past decades analysed the velocities inside the hydrocyclone in order to predict the separation efficiency and energy consumption. These investigations mainly focus on systems with water as a continuous fluid (Kelsall, 1952; Bradley and Pulling, 1959; Narashimha, 2005; Wang et al., 2015).

In the field of purification technology and sludge treatment the viscosity is different from water in terms of absolute value and dependence on shear forces (Baudez et al., 2011).

By now, comparatively few investigations on hydrocyclone applications in this field are available in literature (Mansour-Geoffrion et al., 2010; Bicalho et al., 2012; Bayo et al., 2015), although there is a need on behalf of the WWTP operators. This leads to optimization potential in designing hydrocyclones. A systemic approach for dealing with this task is the objective of this paper.

2. METHODS

Experiments on the rheology of sludge within a WWTP are the basis of the study. Feasibility assessments regarding the measurement systems (double-cylinder, stirrer; see Fig. 1) show that stirrer systems fulfill the requirements for measuring the viscosity of particle loaden sludges with best repetitious accuracy. This is in contrary to Moshage (2008) who suggests a cylindrical measurement system for the determination of viscosity in municipal WWTP sludge. To prevent the measurement system from damage by particle blocking, Moshage used a sieve for pre-treatment of the samples. This leads to a falsification of the results.

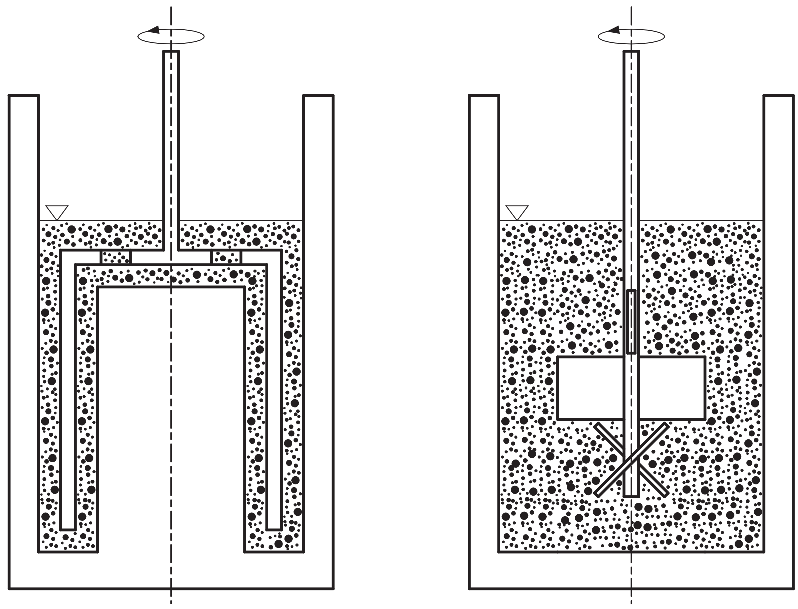

Fig. 1: Double-cylinder (left) and stirrer measurement system (right) for viscosity determination

With the stirrer system absolute values for the viscosity cannot be evaluated as the geometric parameters of the stirrer do not allow a calculation of the shear properties (Mezger, 2010). However, the torque which is applied to the sample consisting of anaerobic digested sludge (samples taken from WWTP Zirl, AUT) is measured. As a reference, different model substances such as glycerol, xanthan and pyrogenic silica (WACKER HDK®) are evaluated for qualification.

A hydrocyclone test rig is developed to model the problem in the laboratory (see Fig. 2). Separation experiments lead to optimized geometrical and operational parameters for a small scale hydrocyclone with a cylindrical diameter of 100 mm and a length of 500 mm.

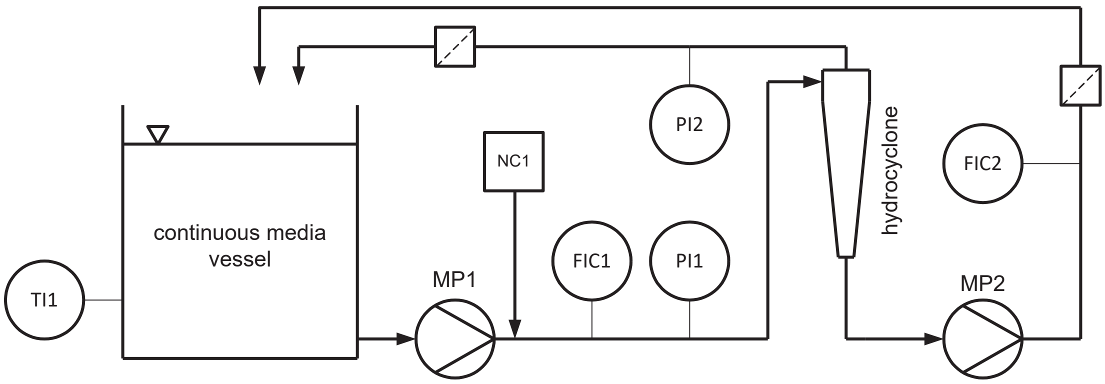

Fig. 2: Hydrocyclone laboratory test rig with pumps (MP1+2), particle feeder (NC1) and sensors (PI…pressure, TI…temperature, FIC…flow rate)

The geometric proportions of the hydrocyclone are designed according to Rietema (1961). The separation efficiency is determined on a gravimetrical basis by measuring the particle mass in the feed, underflow and overflow of the hydrocyclone.

Additionally, velocity profiles in the hydrocyclone are investigated with 2D/2C-Particle Image Velocimetry (PIV). In a validation step the measurements are compared with Computational Fluid Dynamics (CFD) simulations. Subsequently, CFD data is used for further parametric studies on the hydrocyclone to identify more optimization potential. After systematic development in the laboratory, subsequent field studies located at a WWTP shall prove the optimization effects.

3. PRELIMINARY RESULTS

In conclusion of the viscosity studies a mixture of glycerol and water in a 1:1 ratio represents acceptable similarity in the rheological characteristics (see Fig. 3, left) for modelling anaerobic digested sludge. As the composition of the anaerobic digested sludge varies on a daily and weekly basis, sampling is done 10 times in a period of 2 months. In addition, the viscosity measurement for every sample is repeated 10 times in order to compensate variations in sample splitting. The particle size distribution of the test dust for the experiments is given in Fig. 3. The median diameter of the particles is 70 µm and the density is 2500 kg/m³.

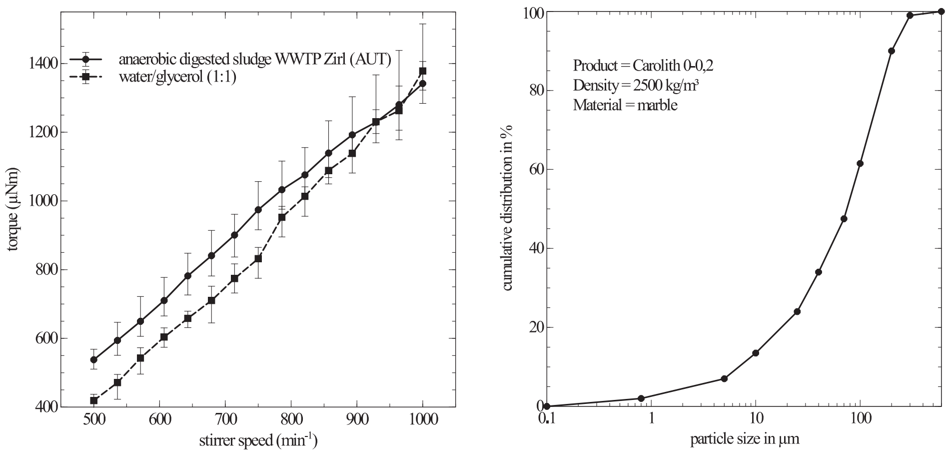

Fig. 3: Rheological characterization of anaerobic digested sludge and water/glycerol (left) and particle size distribution of particular impurities used as test dust (right)

For the laboratory hydrocyclone the dimensions for inlet diameter and vortex finder geometry are investigated according to Fig. 4. With respect to the operational parameters the feed flow rate (2.5-7.5 m³/h) and the underflow ratio (2-6%) is investigated for a most effective separation.

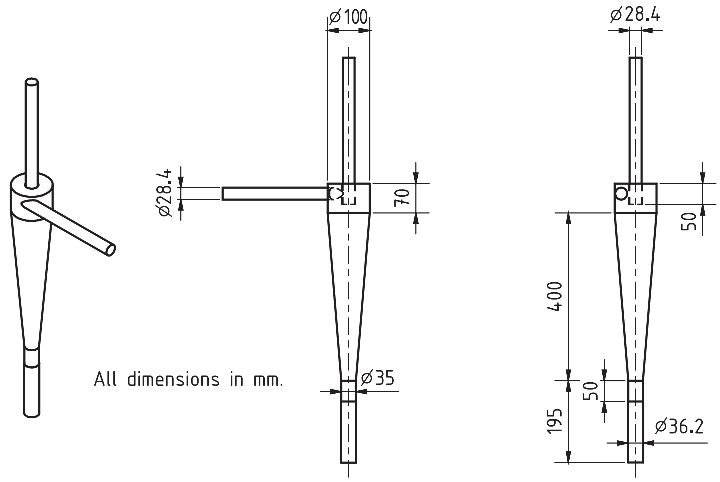

Fig. 4: Hydrocyclone dimensions

PIV measurements offer information on the velocity profiles in different axial positions of the hydrocyclone (Fig. 5). For tracing the streamlines in the hydrocyclone nearly monodisperse polyamide powder (Evonik VESTOSINT®) with a mean diameter of 5 µm and a density of 1060 kg/m³ is appropriate. A Nd:YAG-Laser (532 nm) is used for illumination of the tracer particles. Optical data acquisition is implemented with a special camera (sCMOS pco.edge 5.5) and a pulse rate of 80 µs.

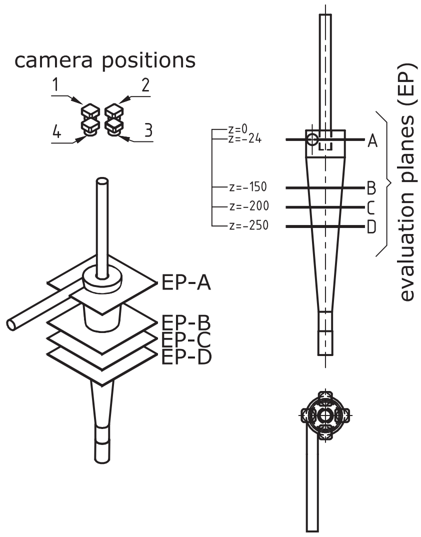

Fig. 5: Setup for PIV measurements and positions of evaluation planes

Simulations are carried out with the Finite Volume Method (FVM – ANSYS FLUENT®) including turbulence model RSM (Reynolds Stress Model) and 2nd order accuracy. The comparison of a selected evaluation line of PIV measurements and CFD simulations (see Fig. 6) show a maximum difference of 20 %.

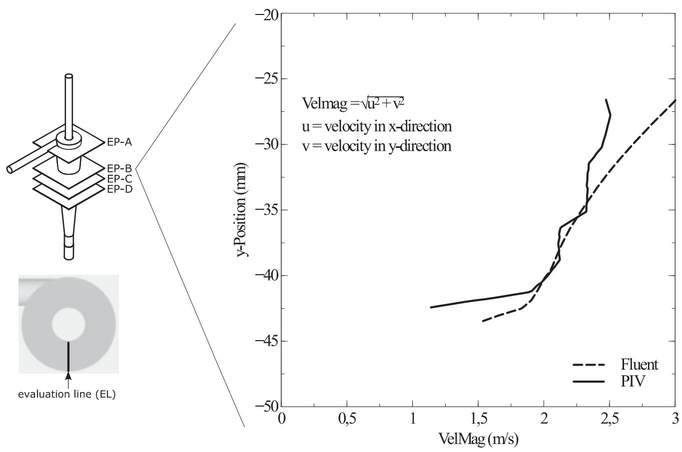

Fig. 6: Setup for PIV measurements and positions of evaluation planes

The objective of the present paper is not the presentation of the optimized hydrocyclone for applications in sludge processing. However, the systematic approach for dealing with the problem is described. Accordingly, the hydrocyclone optimization will be the focus of the ongoing year.

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