On-line Dynamic Fluid Velocity Profiling in Secondary Clarifiers

B. De Clercq, D.J. Kinnear and P.A. Vanrolleghem

Biomath, Ghent University, Coupure Links 653, B-9000 Belgium
(E-mail: *bob.declercq@biomath.rug.ac.be*; *dkinnear@msn.com; peter.vanrolleghem@.rug.ac.be)*

Abstract
Optimization of the sludge removal performance of a clarifier requires, in part, a complete understanding of the tank hydraulics. This paper presents velocity profiles obtained by utilizing an acoustic doppler current profiler (ADCP). The latter provides the necessary temporal and spatial scale to understand and analyze in a detailed way density-driven flows in wastewater clarifiers. Velocity profiles were measured in a circular clarifier with sloped floor. The ADCP revealed that sloped clarifiers provide significant sludge transport towards the central sump. From this, the velocity measurements suggest that the analysis of the removal mechanism should be considered from a fluid mechanical perspective. The paper has to be seen as a first attempt to apply this measurement technology in wastewater treatment.

Keywords
ADCP, fluid velocity, secondary clarifier

INTRODUCTION

In wastewater treatment clarifiers fulfill an important task, i.e. the solids removal from the cleaned water by gravitation. If this process does not work properly, suspended solids are flushed out of the tank into the receiving water. Many factors influence this removal efficiency; amongst them the tank hydraulics are of primordial importance.

Attempts to measure the flow field with drogues (Anderson, 1945; Brescher *et al*., 1992; Ueberl and Hager, 1997) and ultrasonic flow meters (Larsen, 1977) can be found in literature. Unfortunately, practical problems are encountered such as low adequacy to measure low velocities and the ability to measure only in one dimension. But the major drawback is the invasiveness of the mentioned flow meters, i.e. the local flow field is altered. In ocean and estuary research, non-invasive acoustic doppler current profilers (ADCP) have been used widely (Lohrman *et al*., 1990; Stacey *et al*., 1999a, b). The device is based on the principles of doppler shift of a wave reflected from particles suspended in the fluid stream. A typical ADCP (Figure 1) transmits and receives signals via four transducers arrayed in the so-called Janus configuration; they are positioned around a horizontal circle every 90 degrees, and are directed outwards at a certain angle to the vertical. The device listens to and processes the echoes coming from successive volumes, i.e. bins, along the beam to determine how much the signal has changed. From this change the 3D-velocity vector is calculated.
Unwanted hydraulics in clarifiers can be detrimental for the solids removal performance. Hence, design retrofitting might be desired and is aimed at by computational fluid dynamics (Krebs *et al*., 1995; Brouckaert and Buckley, 1999). Model validation and calibration are crucial. In this respect, the ADCP technique provides an improved method for measuring on-site average velocities profiles in clarifiers.
The aim of this paper is to demonstrate the capabilities of the ADCP in wastewater treatment industry; more specifically its application on the secondary clarifier. Important features in the flow field will be highlighted.

METHOD

Measurements were conducted at the WWTP of Central Davis County Sewer District, located near Salt Lake City, Utah, USA. The considered circular clarifier (Figure 2) had a sloped floor and was equipped with a spiral scraper to transport the sludge to the central sump where it is withdrawn.

At three different radial distances the Workhorse Monitor ADCP Direct-Reading 1200 kHz (RD Instruments, San Diego, USA) was deployed downwards from approximately mid-depth in the clarifier while velocities near the surface were measured upwards from the same location. The depth of measurement was limited in favor of measurement resolution; eighty bins of 5-centimeter depth were preferred. Sampling was done on a 1-second time interval at a 1 mm s^{-1} accuracy. Because the averages and standard deviations did not differ, a 2-minute time-average was used for velocity averaging.

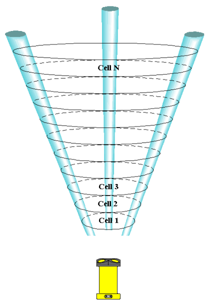

Figure 1 Principle of ADCP

Figure 2 Picture of the (empty) Central Davies clarifier

During the experiments the sludge removal mechanism was turned off for two reasons. Firstly, the attached scum skimmer arm would interfere with the ADCP support mechanism. Secondly, a particular objective of this study was to measure to what extent the sludge is removed hydraulically (and not mechanically).

RESULTS AND DISCUSSION

An overview of the velocity measurements is given in Figure 3. For three radial distances two vertical velocity profiles are given. The profiles correspond with the downward and upward deployment of the sensor. Since the ADCP truly measures the velocity of the particles entrained in the fluid, only the measurements at the bottom part of the clarifier are corresponding to fluid velocities; fluid velocities are high and interparticle contact exists. As a consequence, particle and fluid velocities coincide. Near the surface fluid velocities are too low to entrain the particles completely, hence, they settle as can be seen in the vertical component of the velocities. It is clear that in this region the ability to accurately measure fluid velocities is restricted. Further discussion will therefore focus on the bottom velocities.

Figure 3 shows the presence of a strong bottom current. At every radial distance, a radial-outward density current develops in the vicinity of the sludge blanket, i.e. at equal density (Lakehal *et al.*, 1999; Armbruster *et al.*, 2001). From a hydraulic point of view this density effect has a greater impact on the sludge removal efficiency than the settling process. Indeed, ambient water is entrained by the particles and thus the flow rate of this bottom current is increasing. From Figure 3 it is also seen that this density current is translocated downwards while moving radially outwards. This is due to the momentum transfer at the interface of the sludge blanket; sludge layers below are entrained because of the high shear. As a consequence of the short circuit from the inlet to the outlet, a reverse top current is induced. The upward looking ADCP does not record this since the particles move independently of the liquid. Immediately above the density current the vertical velocities are still (mostly) downwards. Again, this is due to settling; sludge concentration is fairly low and does not restrict settling.

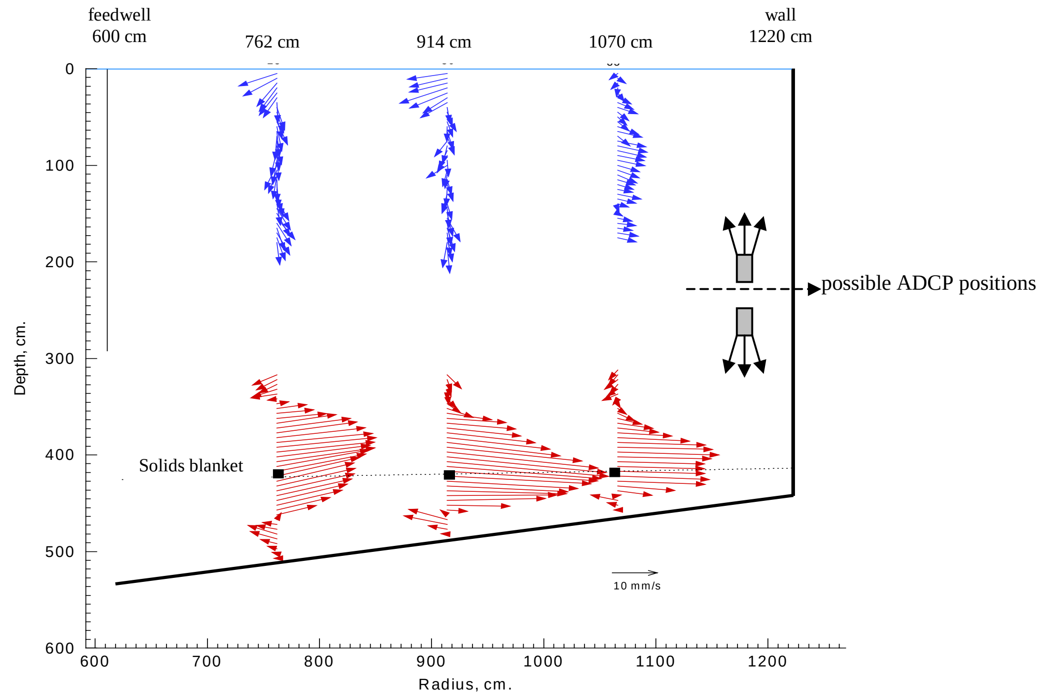

Figure 3 Overview of the velocity measurements at Central Davis clarifier

It can be noted that the radial velocity becomes negative right above the density current. Since the ADCP was located at half-depth, it is not known if the velocity becomes again positive when moving to the surface. Further, the radial velocity above the density current is alternating negative-positive-negative along the radius of the tank. This suggests that at least two recirculation zones exist above the sludge blanket. Otherwise, this sequence of negative and positive radial velocities can never be retained. This likely explanation is supported by simulations (Lakehal *et al*., 1999) and measurements (Krebs *et al*., 1998) from literature.

In the velocity profiles the no-slip velocity boundary condition at the floor can be clearly seen. Further, a density-driven radial-inward flow developed below the radial-outward flow. This flow originates from the sloped floor and is driven by gravitational forces. This demonstrates that hydraulic phenomena play a significant role in sludge transport towards the central sump since no sludge removal occurred. Lakehal *et al*. (1999) concluded from simulations that the scraper's function is to overcome the slurry's yield stress and to make it flow. It does not induce the transport to the center as such. Instead, Narayanan *et al*. (2000) and Albertson (1992) stated that mechanical transport dominates. The ADCP data does not suggest that the clarifier would operate succesfully without any sludge removal mechanism. Due to the no-slip condition at the bottom, a region of low velocities near the floor must exist, which limits proper sludge transport.

To avoid rising sludge due to nitrogen bubbles, it is crucial that the sludge residence time inside the blanket is short. To ensure this for all sludge, plug flow conditions inside the blanket are favored. From Figure 3 it is clear that this is not the case; velocities are not constant in the blanket. The scraper has to overcome the yield stress, mix the sludge and has to move it from the low to the high velocity region where it is transported to the sump.

CONCLUSIONS

In the past, drogues and ultrasonic flow meters have been used to measure the local flow field in clarifiers. Due to their invasiveness and other drawbacks, new techniques had to be looked for. The ADCP offers the possibility to measure the flow velocity in a non-invasive way. However, it should be reminded that low flow velocities in secondary clarifiers cannot be measured accurately. This is due to the (liquid) flow dependent particle movement. It opens opportunities to study particle transport phenomena though. Nevertheless, this research demonstrated clearly that the ADCP is able to reveal important currents near the bottom floor. This information can be used for system evaluation, and model validation and calibration. This study has to be seen as a first attempt to apply the technique on secondary clarifiers. Proper use still requires a lot of future work.

ACKNOWLEDGEMENT

This research is financially supported by the Fund for Scientific Research - Flanders (F.W.O.) and the Ghent University Research Fund. The first author is F.W.O. Research Assistant.

REFERENCES

Albertson, O.E. (1992). *Clarifier Design. Design and Retrofit of Wastewater Treatment Plant for Biological Nutrient Removal*, eds. Randall, C.W., Barnard, J.L. & Stensel, H.D., Technomic Publishing Company, Lancaster, PA.

Anderson, N.E. (1945). Design of Final Settling Tanks for Activated Sludge. *Sewage Works Journal,* **17**, pp. 50-65.

Armbruster, M., Krebs, P. and Rodi, W. (2001). Numerical Modelling of Dynamic Sludge Blanket Behaviour in Secondary Clarifiers, *Water Science and Technology*, **43(11)**, pp. 173-180.

Brescher, U., Krebs, P. and Hager, W.H. (1992). Improvement of Flow in Final Settling Tanks. *Journal of Environmental Engineering*, **188**, pp. 307-321.

Brouckaert C.J. and Buckley C.A. (1999). The use of computational dynamics for improving the design and operation of water and wastewater treatment plants. *Water Science and Technology*, **40**(4-5), 81-89.

Krebs, P., Armbruster, M. and Rodi, W. (1998). Laboratory Experiments of Buoyancy-influenced Flow in Clarifiers. *Journal of Hydraulic Research*, **36(5)**, pp. 831-851.

Krebs P., Vischer D. and Gujer W. (1995). Inlet-structure design for final clarifiers. *Journal of Environmental Engineering*, **121**(8), 558-565.

Lakehal, D., Krebs, P., Krijgsman, J. and Rodi, W. (1999). Computing Shear Flow and Sludge Blanket in Secondary Clarifiers. *Journal of Hydraulic Engineering*, **125(3)**, pp. 253-262.

Larsen, P. (1977). *On the Hydraulics of Rectangular Settling Basins, Experimental and Theoretical Studies*. Report No. 1001, Department of Water Resources Engineering, Lund Institute of Technology, Lund University, Lund, Sweden.

Lohrmann, A., Hackett, B. and Roed, L.P. (1990). High Resolution Measurement of Turbulence, Velocity and Stress using a Pulse-to-Pulse Coherent Sonar. *Journal of Atmospheric and Oceanic Technology*, **166**, pp. 3-21.

Narayanan, B., Buhr, H.O., Leveque, E.G., Lee, M.C. and Dielman, D. (2000). Could your Secondary Clarifier Removal Mechanism be a Process Bottleneck? *Proc. of the 2000 Water Environ. Fed. Conf. and Exposition*, Anaheim, CA.

Stacey, M.T., Monismith, S.G. and Burau, J.R. (1999a). Observations of Turbulence in a Partially Stratified Estuary. *Journal of Physical Oceanography,* **29**, pp. 1950-1970.

Stacey, M.T., Monismith, S.G. and Burau, J.R. (1999b). Measurements of Reynolds Stress Profiles in Tidal Flows. *Journal of Geophysical Research*, **104**, pp. 10933-10949.

Ueberl, J. and Hager, W.H. (1997). Improved Design of Final Settling Tanks. *Journal of Environmental Engineering*, **123**, pp. 259-268.