Reducing Energy Footprint of a Waste Water Treatment Plant by Increasing Harvesting Efficiency of Solids following Primary Clarification

A.R. Völkel, C.D. Lancaster, N. Chang, A. Kole, M. Stephenson

PARC, A Xerox Company, 3333 Coyote Hill Rd., Palo Alto, CA 94304, USA

ABSTRACT

This paper describes a novel hydrodynamic separation (HDS) technology that has the potential to reduce the energy footprint of a wastewater treatment plant (WWTP) by reducing the energy required for aeration and by increasing biogas production to offset plant energy demand. These goals are achieved by harvesting from primary effluent those organic solids, which are nearly neutrally buoyant and do not sediment out, before they enter the secondary treatment step. Biodegradable solids not removed in primary treatment translate into greater oxygen demand in the downstream biological processes. In addition, organic solids harvested in primary treatment have higher energy content than the biomass in the waste activated sludge. Therefore, improved primary treatment performance can yield energy benefits not only from the increased mass of organic solids for biogas production but also from reduced oxygen demand (aeration) in secondary treatment.

Keywords: Waste Water Treatment, Harvesting Efficiency, Particle Concentration, Particle Separation, Energy Reduction

1 INTRODUCTION

Waste Water Treatment Plants (WWTPs) in the US face tremendous amount of challenges in the 21st century, including but not limited to aging facilities and dwindling budgets. One particular area for improvements is the high energy demand for operating these plants: currently about 2-3% of the total energy used in the US is consumed by WWTPs. Facility operators and researchers around the country are examining every process to reduce energy consumption or explore new energy sources in a quest to become energy neutral. One specific target is to increase the harvesting of the organic solids in the waste water itself, which have significant energy content and can be accessed e.g. through bio gas production in an anaerobic digester. Current technologies such as gravity-based sedimendation, high rate clarification, hydro cyclones, or chemically enhanced primary treatment are limited in providing energy efficient solutions because the organic solids are almost neutrally buoyant, making it difficult to settle them out, or uneconomical when theddition of chemicals is required.

Using a novel hydrodynamic separation (HDS) technology developed at PARC [1] we have demonstrated particle harvesting efficiency of 50-70% in the laboratory using primary effluents from several municipal wastewater treatment plants in the San Francisco Bay Area. In particular we have shown that our technology is capable of concentrating small (20 to 100 μm) organic particles, which are neutrally buoyant and float in the waste water. The single-layer (1 channel) HDS prototype used for these tests has a flow rate of 0.25 L/min and requires about 11 psi of pressure head. Higher flow rates are achieved by stacking many layers in parallel into modules with a common inlet and common outlet manifolds. Particle concentration (or alternatively water recovery) is enhanced by connecting modules in series with the concentrate outlet of one stage providing the input for the next stage. A pilot system that can treat up to 30 liters per minute and has a 4-stage HDS system for the harvesting of solids from primary effluent has been built and is currently deployed at a waste water treatment plant in the San Francisco Bay Area.

In this paper we first present a quick summary on how HDS works and its benefits over other technologies. Then we will discuss separation results on primary effluent samples from different locations in the San Francisco Bay Area using single HDS channels in the laboratory. Finally we will discuss our pilot system that is targeted to achieve the solids harvesting goals needed to realize the estimated energy savings from the laboratory tests.

2 HYDRODYNAMIC SEPARATION

PARC has developed a novel hydrodynamic separation (HDS) technology for the concentration of suspended particles in fluids. By carefully controlling the flow conditions in a curved channel a transverse flow pattern containing a pair of Dean vortices is established. Suspended particles are pre-dominatly following the stream lines; but at select locations they are moved across streamlines through a combination of hydrodynamic forces (drag, shear, etc.) and collected at an equilibrium position near the outside wall (Figure 1).

By placing a flow splitter at the end of the channel a dilute stream and a concentrated particle stream are obtained (Figure 2). A single separator stage has a concentration factor of 2 to 5, but higher concentrations can be achieved by using multiple separator stages in series, where the concentrate output stream of one stage provides the input for the next stage.

The novel and innovative feature of this system is the fact that the separation is predominantly driven by the particle size (i.e. particles above a “cut-off” size are efficiently concentrated), even though no physical barrier is involved. This makes the technology especially attractive for separating out organic substances (including most of the buoyant particles in waste water and activated sludge) which often have densities close to water and tend to foul on any mechanical barriers used to filter them. The cut-off size is mainly determined by the channel height and can be adjusted to be at a few tens of micrometers in “macrofluidic” down to a few micrometers in “microfluidic” channel geometries. The tradeoff is between throughput, energy needs, and cutoff size.

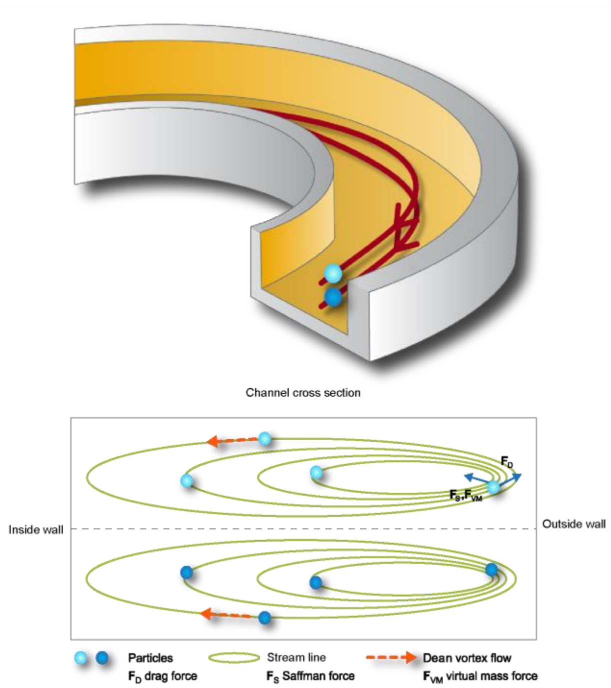

Figure 1: Schematic drawing of separator channel with relevant forces: Centrifugal force on the water creates a pair of Dean vortices in the transverse direction; a combination of drag and shear forces move the suspended particles to an equilibrium positions close to the channel outside wall.

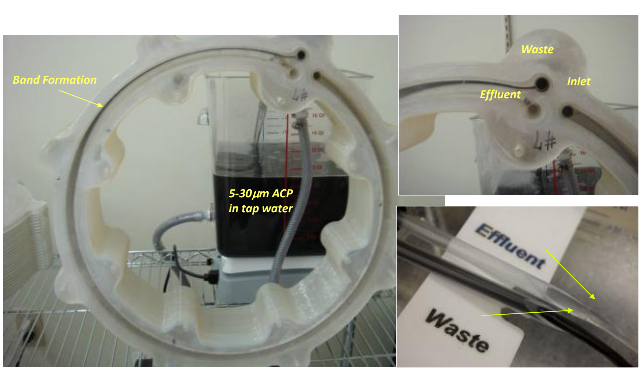

Figure 2: Picture of a HDS system in operation using a carbon bead suspension. Particles enter the separator at the one o’clock position. By the time they reach the ten o’clock position a tight band has formed that is separated off as concentrate (“waste”) stream by a flow splitter.

This technology has been tested on many raw water matrices, including seawater [2], produced water [3], and different types of algae [4] and particle concentrations of up to a few % by weight have been demonstrated with a single stage separator. Based on test results with our research prototypes and technical analyses conducted to date, the technology appears compelling on a number of dimensions:

- Highly effective with neutrally buoyant material, making it very suitable for removal of organic, in particular biological particles as well as for oil/water separation.
- Highly modular design allows for direct application in waste water treatment plants of any size.
- Direct concentration solids as small as ≈20 µm without the use of chemicals at reasonable energy consumption possible.

3 SINGLE-CHANNEL RESULTS

3.1 HDS Channel Fabrication

A single-channel laboratory-created prototype separator device consists of a 3-layer structure fabricated from laser-cut plastic sheets glued together to form the channel cavity. The layer that defines the channel is sandwiched between two support layers whereas the inlet and outlet manifolds are provided by connecting the opening via hose barbs to external tubing. Scale-up in throughput is achieved by stacking these sandwiched structures, with the bottom support layer of the first (top) channel becoming the top support layer of next channel, etc. The 1 inlet and 2 outlets of each channel are all connected and only one inlet and two outlet manifolds are needed per stack (Figure 2 shows a 20-layer stack). Typical channel geometries have an arc length from 180 deg (“half-turn”) to 345 deg (“full-turn”) with a radius of curvature of 20 cm, channel widths ranging from 5 to 15 mm and channel heights extending from a few hundred to over one thousand micrometers. Depending on the concentration of particles in the source water and, consequently, the width of the resulting concentrate band, we have fabricated channels with flow splits between the clean and concentrate streams ranging from 80:20 to 50:50. For this study we used a channel with a cut-off size of about 20 µm that is operated at about 11 psi (half-turn) or 21 psi (full-turn) and has a 80:20 flow split.

3.2 Sample Preparation

Primary effluent samples were collected from different waste water treatment plants within the San Francisco Bay area. Before the start of the experiments the samples were stirred with a glass rod to re-suspend any sediment. Most experiments were done the same day the samples were collected to reduce aging effects as much as possible. During the tests samples were collected at the inlet and two outlets for particle size distribution (PSD) and total suspended solids (TSS) measurements. From the TSS data the harvesting efficiency η_H=(total mass in concentrate stream)/(total mass in input stream), which provides a measure of how much of the original suspended solids mass is contained in the concentrate stream, was calculated.

3.3 Analytical Techniques

Particle size distribution (PSD) - A Horiba LA-950 laser-scattering based particle size analyzer was used for all PSD measurements. For the primary effluent samples a flow cell was used to achieve sample mixing prior to measurements.

Total suspended solids (TSS) - TSS assays were performed confirming to the gravimetric method approved in "Method 2540D, Total Suspended Solids" by Standard Methods Committee in 1997. Sufficient amount of each sample was carefully filtered through 1.5 µm glass fiber filter with house vacuum and the filter was baked at 105°C for at least one hour or until the weight change was negligible. The net dry weight of the solids retained was divided by the volume of liquid filtered to calculate the TSS, in mg/L or ppm.

3.4 Solids Harvesting

The collected primary effluent samples have gone through primary clarification and contain mostly difficult-to-settle solids due to their small size and buoyancy. Figure 3 shows a typical particle size distribution for primary clarifier effluents with the peak of particle sizes between 40-50 µm and 83% of all particles larger than 15 µm.

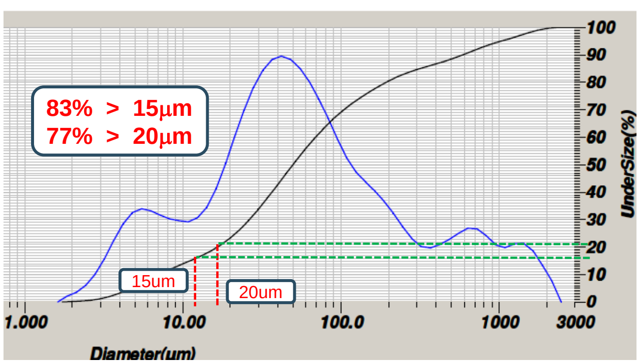

Figure 3: Typical particle size distribution in the effluent of the primary treatment stage of a WWTP (EBMUD in Oakland, CA).

Using our laboratory HDS prototype, we have demonstrated successful separation of 50-70 % of the suspended solids for the different primary effluent samples. Figure 4 shows separation results for primary effluent from Sunnyvale, CA, WWTP: Most of the large particles were collected in the concentrate stream, while the dilute stream only contained small (<20 µm particles). Further concentration of these solids beyond 1 % (dry weight) to reach a sludge concentration similar to that of a primary clarifier can be achieved by connecting several HDS modules in series with the concentrate output of one stage providing the input for the next stream. Assuming a starting concentration between 100 to 200 ppm and a harvesting efficiency of at least 70% per stage a 4-stage HDS system will be required to achieve a final solids concentration in excess of 1 % wt. Figure 5 lays out such an implementation where the last stage contains a single channel, and earlier stages are designed to provide the flow needed to ensure continuous operation of subsequent stages.

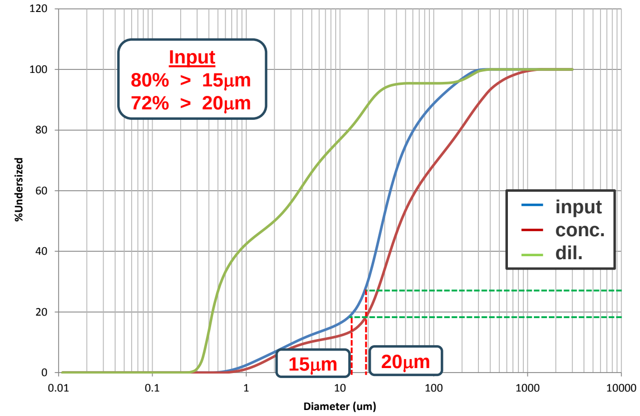

Figure 4: Accumulative particle size distribution of source water (primary effluent from Sunnyvale, CA) and clean and concentrate streams after HDS. The concentrate stream contains most of the particles exceeding 20 µm as expected.

Assuming a 50% overall harvesting efficiency for the system of four stages shown in Figure 5 it is estimated that aeration demand for carbon oxidation is reduced by 20% and biogas output from anaerobic digesters is increased by 20%. Pumping requirements are estimated at 160 kWH/mgd. The impact of the HDS separation stage on the WWTP's energy balance depends on the amount of solids removed, and generates more value for treatment plants with higher solids loading and/or with larger particle sizes that allow for overall higher harvesting efficiencies.

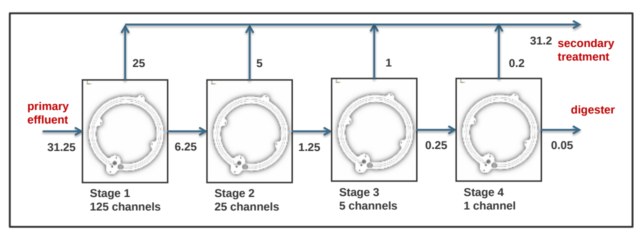

Figure 5: Schematic diagram of a 4 stage HDS system. Because of the 80:20 flow split each subsequent stage has to treat only 1/5th of the flow of the upstream stage. All flow rates are in liters per minute (lpm).

4 PILOT SYSTEM

In order to demonstrate primary effluent solids harvesting at a WWTP and to verify our estimates on the energy savings we have designed and built a 10000 gallon per day pilot system that is currently deployed in Sunnyvale, CA. Figure 6 shows a schematic flow diagram of the primary treatment stage with the HDS system following traditional primary treatment. Input water for the HDS system is taken after primary clarification and before the water enters the secondary process.

Figure 7 shows a picture of the complete pilot system in operation. Each one of the 4 HDS stages has its own pump and the all outlets are at atmospheric pressure to simplify flow control through the system. A 200 µm strainer at the entrance of the pilot protects the HDS channels from large particles that exceed the channel height. For fouling and plugging prevention, a "cleaning-in-place" (or CIP) system is integrated into the pilot, which allows for both routine maintenance cleaning and clog remediation by infrequent but periodic flushing of the channels with clean effluent.

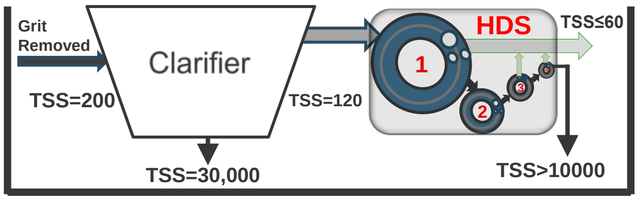

Figure 6: Schematic diagram of primary clarifier with HDS harvesting system. Input concentration for the HDS system is about 120 ppm and a total of 4 stages are needed to achieve a concentrate in excess of 1 % by weight.

Figure 7: Pilot System at Sunnyvale WWTP.

To allow for the assembly of large channel stacks and long term operation of the pilot system a more robust fabrication method for the channel stacks is needed beyond the laser-cutting and hand-gluing approach used for the laboratory prototypes. Currently, we use injection molded layers made from clear ABS that are glued together with a UV curable glue using a tongue and groove method. Stacks up to 72 channels high are combined into modules with a common inlet manifold and two common outlet manifolds (Figure 8).

Initial test show harvesting efficiencies similar to the lab tests for the last two stages (single channel and 5-channel modules). However, the observed harvesting efficiency of the first two stages is less than the expected 60 to 70%. This has been traced back to deviations in the channel cross-section due to fabrication tolerances that are increasing with the stack size. We are currently working on a new mold design that is more forgiving about the fabrication tolerances and will allow the assembly of large channels stacks without while maintaining the internal channel geometry.

5 SUMMARY

This paper describes a novel approach for increasing harvesting efficiency of solids for energy generation following the primary clarification process in waste water treatment plants. This is achieved using a novel hydrodynamic separator invented at PARC. Using purely hydrodynamic forces this technology efficiently removes suspensions by concentrating them into a narrow band that is subsequently split off the main stream without the need for physical filtration. Solids concentration (or alternatively water recycling) is increased by connecting several separator stages in series. We have demonstrated harvesting efficiencies of more than 60 % of solids after primary clarification using single channel lab prototypes and estimated that four HDS stages in series could increase solids concentrations from the values typical for primary effluent to above 1 % by weight. A 4-stage pilot system for treating up to 30 liter per minute of primary effluent has been built ans is undergoing testing at a local waste water treatment plant. The HDS channels for this prototype are injection molded and glued together into modules of up to 150 channels.

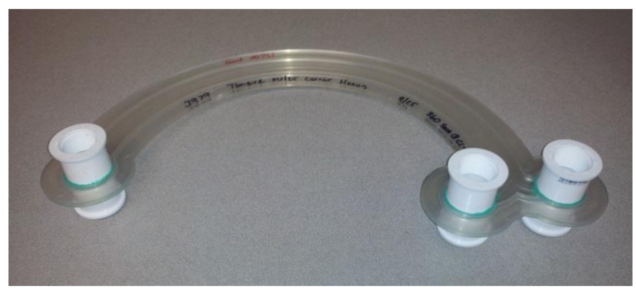

Figure 8: Example of channel stack using clear injection molded channel parts and UV curable glue.

REFERENCES

[1] Hsieh, H.B., Völkel, A.R., Chang, N.E., Kole, A., Melde, K., Torres, F., *Water Sci. & Technol.: Water Supply* **13**, 524-530, 2013.

[2] Lean, M.H.; Seo, J.; Kole, A.; Völkel, A.R.; Chang, N.E.; Hsieh, H.B.; Melde, K., Proceedings of International Water Convention, Singapore, 2010.

[3] Lean, M.H.; Seo, J.; Kole, Völkel, A.R., A.; Chang, N.E.; Hsieh, H.B., Melde, K., Proceedings of FilTech Conference, Wiesbaden, 2011.

[4] Völkel, A.R.; Hsieh, H.B., Chang, N.E.; Melde, K., Kole, A.; Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA., 2012.