Jun Howoong
ECE, Seoul National University

Clarifying Activated Sludge by using Ion Concentration Polarization

Howoong Jun
Department of Electrical and Computer Engineering, Seoul National University, KOREA

Abstract

The Micro Activated Sludge Clarifier (Micro ASC) using ion concentration polarization phenomenon is a micro size device that filters out activated sludge which is processed in the secondary clarifier. Main principle of the device is Ion Concentration Polarization (ICP). By applying proper voltage to the gates of the micro device, it can separate input solution which is sewage into purified water and other particles.

1. Introduction

Clarifying activated sludge is one of the most important parts among all the sewage purification process. There are some conventional methods to do this process such as Activated Sludge Process (ASP) and Membrane Bioreactor (MBR). [1] Recently, MBR is the most popular method because of its efficiency and quality. However, there are some problems about MBR. The most critical problem is fouling issue. [2] This is due to the deposition of activated sludge materials onto and into the membrane. [3] In order to clean this fouling, shooting the water backwards is the mostly used solution. Also, due to this fouling issue, it takes a lot of time to proceed the process. So, the new activated sludge clarifying process which is fast and does not make fouling problem is needed.

In order to meet these demands, the new activated sludge clarifier Micro Activated Sludge Clarifier (Micro ASC) is proposed. Micro ASC is a device which uses Ion Concentration Polarization (ICP) phenomenon. By using ICP phenomenon, it can divide sewage into purified water and concentrated water.

Table 2—Distribution of activated sludge flocs by different quantities.

Size, μm	Distributions			
	By number	By area	By volume	By mass
<2	30–80%	<2%	Negligible	2–8%
2–16	17–70%	1–8%	Negligible	5–28%
16–128	1–4%	20–70%	10–80%	50–80%
128–256	<1%	5–50%	10–70%	5–25%
>256	Negligible	0–50%	0–60%	0–30%

Figure 1 *Table of activated sludge flocs size distribution*

2. Backgrounds

2.1 MEMS/NEMS and Micro/Nanofluidics

Micro/Nano Electro Mechanical System (MEMS/ NEMS) is a micro/nano scale structure that is made by using semiconductor producing technology. The most well-known MEMS device is gyroscope. Especially, Micro/Nanofluidics is a micro/nano scale pipe structures. By applying liquid fluids into these pipe structures, the device can process the fluids. The key point of the micro/nanofluidics is that it is different from macro scale fluidics. For example, in micro/nano scale, shear stress and surface strength is dominant than other stresses, which is different from macro scale fluidics.

2.2 Ion Concentration Polarization (ICP)

ICP literally means an electrochemical transportation phenomenon that ion concentration becomes polarized. By applying voltage across the nano-junction, ICP phenomenon occurs. In macro scale junction, only the regions near the surfaces are negatively charged and other regions are neutral. However, because it is nano scale, there are no neutral regions between two surfaces due to the heavy influence of the surfaces. To conclude, nano-junction is negatively charged due to its scale. Because it is negatively charged, nano-junction absorbs cations and repulses anions. Only cations can cross the nano-junction and anions cannot reach the nano-junction. Because of this phenomenon, ion depletion region and ion enrichment region are formed. This is called ICP. [4]

Moreover, in desalination process, there are voltages and pressures applied to the channels so that anions can move

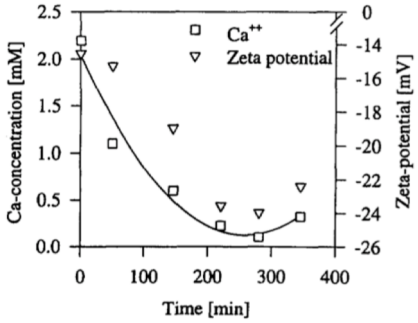

Figure 2 *Graph of ζ-potential of activated sludge*

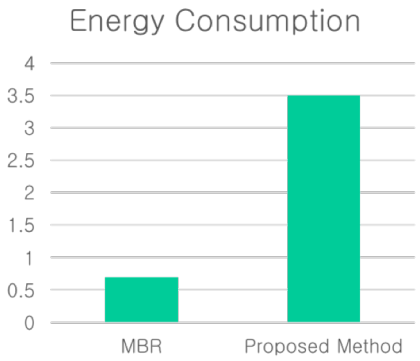

Figure 3 *Graph of Energy Consumption*

towards the channel and purified water which was in the ion depletion region can move towards to the other channel. Even more, not only anions but also other negatively charged particles, which have negative ζ-potential, can move towards the channels. To conclude, particles which have negative ζ-potential can be separated from purified water. By using this phenomenon, the device can separate input solution which is sewage into purified water and other particles. [4] [5]

3. Applications

3.1 Size

The proposed device is micro scale device so it is important that the input solution, which is activated sludge, should fit to the scale. The input channel of Micro ASC is designed to width of $500\mu m$ and depth of $100\mu m$. The bifurcated channels have width of $250\mu m$ and depth of $100\mu m$. In order to not blocking the channels, size of activated sludge should be less than the channels. Fortunately, there was a research about activated sludge size distribution on 1991 and it says almost all activated sludge flocs are sized under $16\mu m$ (Figure 1). [6] Even for the worst case, it is under $128\mu m$. By this data, it is clear that the size of Micro ASC is appropriate for controlling activated sludge.

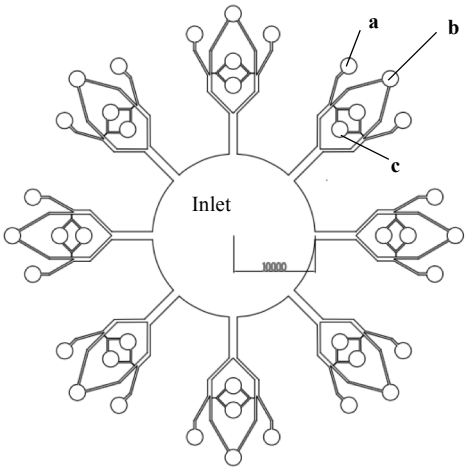

Figure 4 *Schematic Design of Suggesting Device (Top View)*

3.2 ζ-Potential

To apply ICP to the Micro ASC, it is important that the activated sludge should have negative ζ-potential. Fortunately, there is a research about ionic composition of activated sludge in 1996. [7] The research is about the relation between activated sludge and Ca^{2+} concentration of bulk water. In the research, the researchers measured the ζ-potential of activated sludge and it is graphed on the Figure 2. In conclusion, activated sludge has negative ζ-potential so it can be separated by ICP.

3.3 Strength

A. No Fouling

In MBR process, which is a conventional method of processing activated sludge, the most fatal weakness is fouling problem. Fouling is formed due to the deposition of activated sludge materials onto and into the membrane. This can result serious problem such as lowering pressure and quality of water. However, the proposed method uses micro scale device so activated sludge materials cannot be deposited. Also, even for the membrane, which is nano-junction in the device, only cations can reach to it so it will not be fouled.

B. Time

The most time-consuming process in MBR is cleaning the membrane. There is no clear solution for cleaning it yet. The most common way to clean MBR is shooting water in the backwards. This method needs hands and it consumes the most of the time of process. However, the proposed method does not have fouling problem so it does not need cleaning membrane process.

3.4 Weakness

Even though the proposed method has strong advantages, it has weakness. The most critical weakness is energy efficiency. In MBR process, energy is consumed mostly in the cleaning the membrane process. However, the proposed method uses electric energy so it consumes much

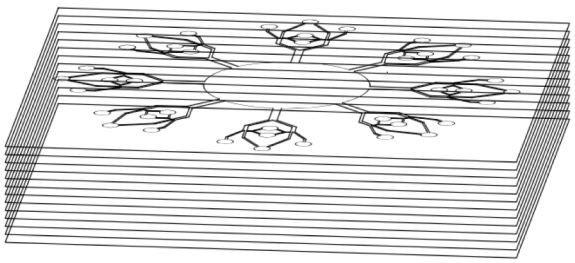

Figure 5 *Schematic Design of Suggesting Device (Front View)*

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ECE, Seoul National University

energy than MBR. In Figure 3, MBR consumes only 0.5 ~ 0.7 kWh/m^3, whereas Micro ASC consumes 3.5kWh/m^3. [4] [8]

4. Suggesting Device

A design of the proposed device is displayed on the Figure 4 and Figure 5. The design is drawn by using 'Autodesk Auto CAD 2016' program which is used to make a mask of MEMS device. Figure 4 indicates the top view of the device and Figure 5 indicates front view of the device. By using circular shape, the device can have an optimized size. Inlet is in the middle of the design, which is a big circle of radius 2mm. Outlets are small circles which is tagged in Figure 4 a, b and c. Figure 4a is outlet for concentrated water and Figure 4b is for purified water. Figure 4c is for cation and it has ground electrical potential. Figure 4a and 4b has non-zero electrical potential. By applying proper voltage to Figure 4a and 4b, the device can filter out the activated sludge. Also, by stacking each channel like Figure 5, it can process the input solution, which is sewage, in parallel. This stacking structure can integrate all the inlets and outlets. By connecting the inlets and outlets, it becomes easy to apply voltages to each hole.

5. Conclusion

In this paper, new method of clarifying activated sludge named Micro Activated Sludge Clarifier (Micro ASC) is proposed. Due to two features of activated sludge, the proposed device can be justified. First, the size of most activated sludge is less than 16μm so that it can cross the micro scaled device. Second, particles of activated sludge have negative ζ-potential which indicates that ICP can be applied to the solution. Also, the process has great advantages that it does not form fouling so it needs less time and unwanted process. However, the proposed method has weakness. Energy consumption of the proposed method is almost 5~7 times higher than the conventional method, MBR. If the process can reduce the energy consumption, it can be the perfect replacement for the MBR process.

Based on the theoretical backgrounds, the proposed device is being designed. For drawing the schematic design, Autodesk Auto CAD 2016 is used. The design has circular shape, which can have optimized size and stacked structure that makes the process parallel. The design needs realization and experiments but the concept and basic idea cannot be changed. Even though it has some weakness aspect, it can be the perfect solution for clarifying activated sludge.

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