CONTRIBUTIONS ON BIOLOGICAL REACTORS FLOW OPTIMIZATION

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Abstract

In order for the biological processes in wastewater treatment systems to develop optimally a good contact between the microorganisms and the substrate has to be realized. The reactors homogeneity can be achieved by applying intensive mixing systems that have high energy consumption. This paper has the aim of determining the optimal system that can assure the close contact while maintaining the energy need as low as possible.

1. Introduction

During the evolution of the wastewater treatment processes, the solids and the organic matter are removed from wastewater. The sludge that results from wastewater treatment plants is derived from primary, secondary and/or tertiary treatment processes. Most often, the produced sludge has a high biodegradable load that can be turned in usable derivates. Primary sludge is the result of primary treatment, usually being sedimentation. Anaerobic digestion is a common process for stabilizing and reducing the biological sludge from wastewater treatment plants [1].

Secondary sludge is generated from the biological treatment stage; stage that usually has the purpose of decomposing the organic matter through biological methods. Most often, the activated sludge process is used, a stage where wastewater is aerated in an aeration basin in which micro-organisms metabolize the organic matter. At the end of the process, the treated water has to go through a clarifier in order to be separated from the activated sludge. A part of the separated sludge returns to the biological stage in order to renew the microbiological background in the activated sludge stage tank. The rest of the sludge, not necessary for the optimal development of the biological processes is surplus activated sludge that goes to the sludge treatment stage.

In the sludge treatment stage of the wastewater treatment plant, the primary and secondary sludge described above are usually mixed together generating a type of sludge referred to as mixed sludge. This sludge has to pass through additional treatments, in order to reduce its water content, stabilize its organic matter and reduce the generation of odors, reduce its pathogen germs load, reduce its volume and global mass. Several treatments can be applied to sludge to achieve this.

After the stabilization process, the sludge is usually referred to as "digested sludge". This so-called digestion process is the one that represents the subject of this paper.

Anaerobic digestion is a series of processes in which multiple types of microorganisms break down biodegradable matter in the absence of oxygen. The process is used in wastewater treatment plants with the main purpose of destruction of organic substances and pathogen reduction. The overall conversion process of complex organic matter into methane and carbon dioxide can be divided into four steps: hydrolysis, acidification, acetogenesis and methanogenesis.

When compared to the aerobic sludge stabilization the principal advantages of anaerobic treatment are the reduced consumption of energy, methane production and smaller reactor volume required. Amongst the disadvantages, the long necessary start-up time and increased potential for production of odors and corrosive gases are the most often mentioned. Also, must be mentioned that the anaerobic digestion process can be less stable after 'toxic shock' (eg after upsets due to toxic substances in the feed).

Anaerobic digestion is a biochemical degradation process that converts complex organic material, such as animal manure, into methane and other byproducts [2]. Over the past 25 years, anaerobic digestion processes have been applied to a wide array of industrial and agricultural wastes [3].

The biogas that results from anaerobic digestion can be used in cogeneration units to obtain the thermal energy needed for the anaerobic digestion and a part of the electrical energy consumed in the wastewater treatment processes. The only drawback is the hydrogen sulphide content of biogas, a gas that in contact with oxygen develops sulphuric acid, a strong mineral acid, which can damage the engines. At this moment, there is more than one solution that can eliminate this inconvenience.

Anaerobic digestion processes are influenced by many factors of which we mention: temperature, mixing – in order to keep the solids in the digester form forming deposits in the bottom side and to realize a good homogenization of the tank's content, hydraulic retention time – is decisive in the percent of stabilized organic matter; solids concentration in the influent; inhibitors.

When heating of the anaerobic digester is applied, the produced methane is usually used as a fuel. Internal or external heat exchangers may be used. The decision as to whether heating of the digester is attractive depends predominantly on the minimum environmental temperature. If it has a low value, a considerable increase in sludge activity can be expected when heating is applied and consequently the required digester volume will be much smaller. On the other hand, the equipment required to maintain a high and constant temperature is expensive and skilled labor is required to operate the digester. Hence heating is only attractive at low temperatures if proper performance without it is impossible.

Continuous or semi-continuous introduction of the excess sludge favors the stable performance of the digester. Intermittent feeding with a frequency of once per day or less leads to large fluctuations in the composition and concentration of the substrate and may result in disturbing the process.

The metabolic activity of the bacteria in the anaerobic digestion process increases up to the optimal temperature of 35 to 37°C. When heating of the anaerobic digester is applied, the produced methane is usually used as a fuel. Internal or external heat exchangers may be used.

There are basically two different types of anaerobic digesters, one is a standard-rate and another is a high-rate. In a standard-rate digester, the sludge breakdown process is usually left on its own to take place without using heat or mixer and the retention period can be anywhere between 30 to 60 days. For high-rate digester, the slurry is well mixed and then heated up and the whole process will require less time. Today, advancement in technologies for wastewater treatment plants manipulate both processes combined together to form a single two-stage process for better conversion of organic matter.

2. Mixing of sludge in anaerobic digestiers

Mixing can be accomplished by mechanical mixers, biogas recirculation, or by slurry recirculation. Mechanical mixers are reported to be most efficient in terms of power consumed per gallon mixed [4]. However, the internal fittings and equipment are not accessible for maintenance during digester operation, and long term reliability of operation is of paramount importance. In general, such reliability can be more readily attained with biogas or liquor recirculation systems, where there are no moving parts within the digester [5]. Interestingly, in other literature sources it has been reported that biogas recirculation is the most efficient mode of mixing for anaerobic digesters [6].

Mechanical mixers are reported to be most efficient in terms of power consumed per mixed volume [4]. Interior mixing aims for: a) homogenization the anaerobic digesters contents by bringing fresh sludge in contact with microorganisms, b) breaking of the crust that may form at the surface of the sludge, c) releasing the gas bubbles that form in the sludge mass d) reducing temperature and concentration gradients of the mass of mud. Exterior circulation of mud aims at getting the sludge to the optimal temperature for the anaerobic digestion process; this process also represents a mass mixing process but it develops more slowly than the interior mechanical mixing.

Mixers are mechanical devices with axial rotors, which are directly coupled to the electric motor shaft. The mixer works intubated in a cylinder of 450 ... 600 mm diameter designed to ensure the circulation of sludge in the anaerobic digester. The upper end of the draft tube has a wavy edge and is located below the free surface of the sludge. During the mixing process, the rotor draws the liquid sludge to the bottom side of the anaerobic digester, this way managing to break the surface crust and foam, and pushes them down the draft tube ensuring a movement throughout the tank. The rotor movement is achieved by direct coupling to electric motor's shaft.

The anaerobic digesters vertical draft tube is centered by rods mounted in the upper side and supported on resistance elements resting on the foundation. The rotor and it's speed are hydrodynamic sized to circulate the tank volume of about 2 ... 4 times a day. A reduced speed or a undersized rotor can lead to solid deposits in the foundation, while a increased speed can lead to the destruction of microorganisms and inhibition of the anaerobic digestion process.

3. Experimental setup and simulation results

Since the wastewater treatment plant anaerobic sludge digester is completely closed, it is very difficult to assess the nature and intensity of movements generated and induced by the mixer in the sludge mass. Generally, engineers use the experience gained when it comes to the anaerobic digesters design. The design of the anaerobic digesters walls and bottom aims to prevent the formation of deposits on the foundation and maintain a homogeneous environment inside the tank.

The experimental research were held in Politehnica University's Poliphasic Fluid Flow and Wastewater Treatment Laboratory. In the center of an existing tank an four blade mixer was installed inside a cylindrical tube. The aim of the experimental setup was to determine the fluid velocity induced by the moving rotor. The blades tilt angle was modified between 30^o and 45^o and the shaft speed was varied between 150 and 800 rpm.

Fig. 1. Experimental setup

The fluid velocity was determined with a velocimeter. The results for the 30^o and 45^o tilt angle and different shaft speeds are shown in the following table.

Table 1. Experimental results

Nr.crt.	n [rpm]	v [m/s] (30^o)	v [m/s] (45^o)
1	150	0.43	0.45
2	210	0.61	0.59
3	300	0.79	0.77
4	350	0.82	1.02
5	400	0.94	1.09
6	460	1.02	1.33
7	500	1.12	1.41
8	580	1.24	1.66
9	640	1.36	1.80
10	700	1.50	1.99
11	750	1.62	2.12
12	800	1.69	2.25

Theoretical researches in wastewater treatment are usually focused on aspects of biological degradation, biochemical and retention of colloidal particles through physical and chemical mechanisms. The purpose of this paper is to evaluate a optimal speed for mixing in anaerobic digesters, in order to obtain all the necessary conditions for the processes to develop optimally. The evolution of organic matter was not taken into account at this stage, nor was the sludge heating through outside circulation.

One of the major problems associated with the anaerobic digestion process is its poor record with respect to process stability. Dynamic modeling and simulation are useful tools for investigating process stability and can be used to quantify operation and improve design [7].

Simulations were made for the sludge flow geometry shown in the figure 2, the dimensions of which comply with the geometry of a wastewater treatment plant anaerobic digester. The purpose of these simulations was the observation of flow directions and choosing the optimal stirrer speed mixer, respectively.

A volume of 4000 m^3 was considered for the anaerobic digestion tank, a mesophilic domain fermentation at a temperature of 36^oC.

The velocity vector profiles were studied in the mixer and the central tube area, at the draft tube's entrance and exit. The values of the velocity module, axial velocity, tangential velocity and radial velocity were represented (fig. 4-7).

For simulations was used MixSim program contained in the Fluent package.

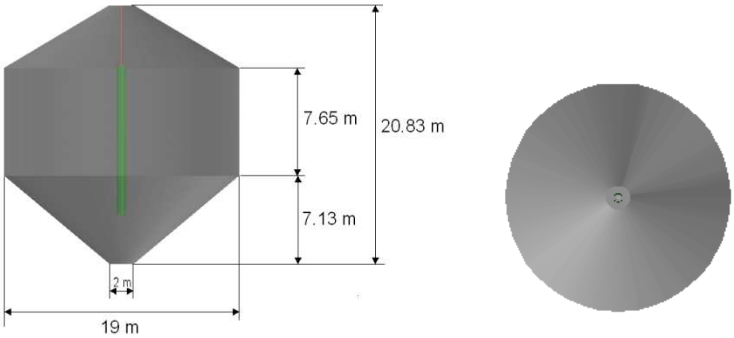

Fig. 2. The anaerobic digesters size, side and top view

A sludge height of 19 meters is considered in the anaerobic digester. Inner central inner draft tube's diameter is 0.66 m and the outer rotors diameter is 0.5 m. The rotor is located at a 13 m height from the foundation of the anaerobic sludge digester.

The geometry is simplified when compared to the real anaerobic digesters by not taking into account the sludge inlet and outlet, the draft tube's support elements and the outside circulation.

Simulations were realized considering an inclined four paddle stirrer at 30^0 for shaft speeds of 100 rpm and 800 rpm (fig. 3).

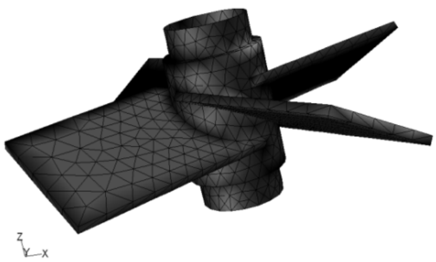

Fig. 3. The inclined paddle stirrer

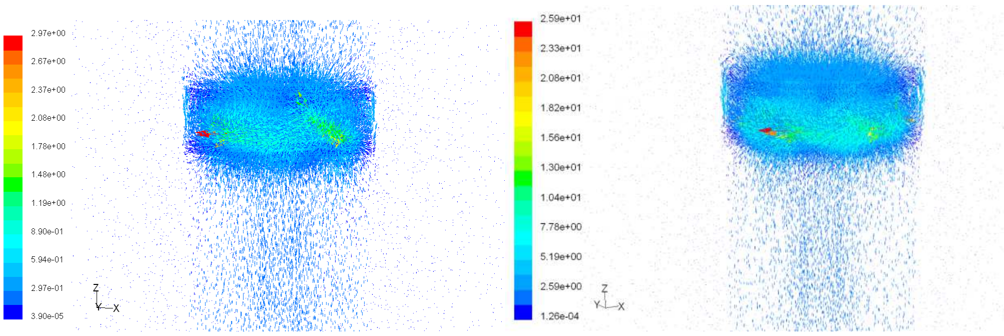

Fig. 4. Velocity vector representation in the mixer area. Representation by color code depending on the velocity module

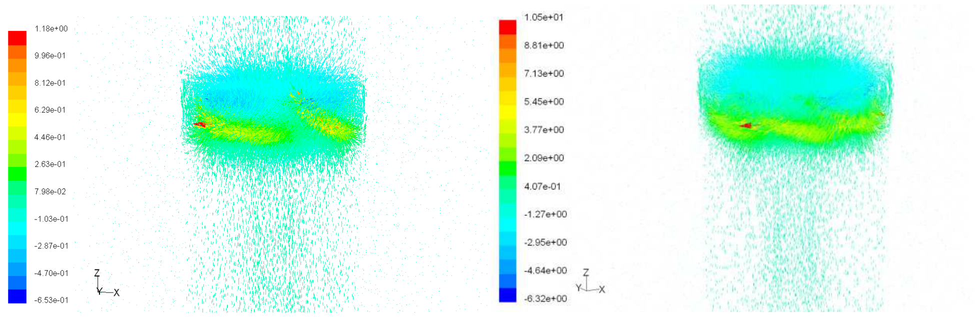

Fig. 5. Velocity vector representation in the mixer area. Representation by color code depending on the radial velocity value

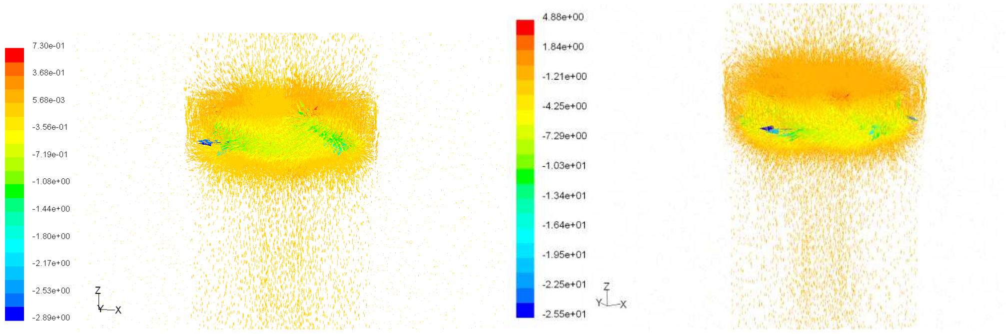

Fig. 6. Velocity vector representation in the mixer area. Representation by color code depending on the tangential velocity value

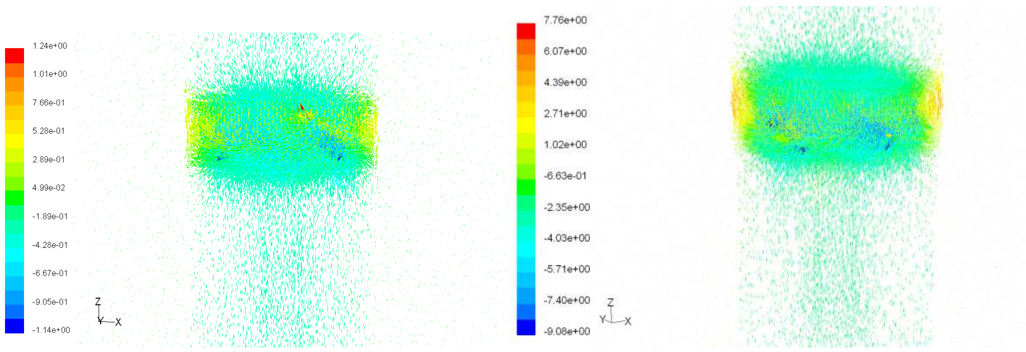

Fig. 7. Velocity vector representation in the mixer area. Representation by color code depending on the axial velocity value

When multiphase flow is simulated by solving a single set of equations for the whole flow field, it is necessary to account for differences in the material properties of the different fluids [8].

Considering a solid matter concentration of 5% in water for the sludge, the density and dynamic viscosity were determined in the equivalent polyphasic fluid hypothesis.

The predominant velocity component is the axial velocity, as resulted from the simulation results.

The resulted velocity profiles were as expected. The velocity values lead to the conclusion that the optimal shaft speed is around the value of 100 rpm, because in this case the sludge volume would be transferred through the draft tube 4 times a day.

4. Conclusions

Anaerobic digestion of organic sludge is widely used in wastewater treatment plants mainly due to the technical and economical advantages it holds. During the development of anaerobic digestion processes biogas is obtained. It is most often used for energy production. Wastewater treatment plants are power consumers and any king of method to reduce this cost is always taken into account.

Although, the importance of mixing is clear from many studies [9],[10] its effect on the performance of anaerobic digesters is still confusing.

Anaerobic digestion is a complex process that can be easily slowed and it's necessary to maintain constant values for the input parameters so that the process to develop smoothly. Any kind of disturbance reflects rapidly on the biogas production, and restarting the process takes time and resources. The most often used mixing method in wastewater treatment plants anaerobic digesters is the one approached in the present paper, due to the fact that it's very reliable.

References

[1]. *M. Terashimaa, R. Goelb, K. Komatsua, H. Yasuic, H.Takahashid, Y.Y. Lie and T. Noikef* "CFD simulation of mixing in anaerobic digesters", in Bioresource Technology, Volume 100, Issue 7, April 2009, Pages 2228-2233.

[2]. *M. H. Gerardi* "The microbiology of anaerobic digesters", Ed. Wiley-IEEE, 2003 – 177

[3]. *S. Ghosh*, " Anaerobic digestion for renewable energy and environmental restoration" in The 8th International Conference on Anaerobic Digestion, 1997.

[4]. C.E. Brade and G.P. Noone, Anaerobic digestion—need it be expensive?, *Water Pollut. Control.* **80** (1981), pp. 70–76.

[5]. *T.J. Casey*, "Requirements and methods for mixing in anaerobic digesters. Anaerobic Digestion of Sewage Sludge and Organic Agricultural Wastes. " Elsevier App. Sci. Pub., 1986, pp. 90–103.

[6]. *S.R. Lee, N.K. Cho, W.J. Maeng*. "Using the pressure of biogas created during anaerobic digestion as the source of mixing power." J. Ferment. Bioengng. 80 (4), 1995 pp. 415–417.

[7]. J*.F. Andrews, S. P. Graef* "Dynamic Modeling and Simulation of the Anaerobic Digestion Process", in *Advances in Chemistry*, Vol. 105, June 1971.

[8]. *Andrea Prosperetti, J. V. Satrape*. "Stability of two-phase flow models" in D. D. Joseph and D. G. Schaeffer, editors, *Two Phase Flows and Waves*, pages 98–117, Springer, 1998.

[9]. *M. Elnekave, N. Tufekci, S. Kimchie and G. Shelef*, "Tracing the mixing efficiency of a primary mesophilic anaerobic digester in a municipal wastewater treatment plant", Fresen. Environ. Bull. 15 (9B) (2006), pp. 1098–1105.

[10]. *K. Karim, R. Varma, M. Vesvikar and M.H. Al-Dahhan*, "Flow pattern visualization of a simulated digester", Water Res. 38 (1–2) (2004), pp. 3659–3670.