

SIMULATION OF MECHANICAL MIXING IN ANAEROBIC DIGESTERS

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Procesul de degradare anaerobă este influențat esențial de amestecarea nămolului din metantanc. În scopul identificării valorilor optime ale parametrilor procesului de amestecare, autorii au realizat simulări numerice tridimensionale considerând forma și dimensiunile unui metantanc dintr-o stație de epurare funcțională. Valorile simulate au fost comparate cu cele măsurate pe un model funcțional al metantancului. Astfel a fost stabilită geometria optimă și turația nominală pentru amestecătorul central din bazinul de fermentare anaerobă.

The anaerobic digestion process is essentially influenced by sludge mixing. In order to determine the optimum parameter values for the mixing process, the authors developed three-dimensional numerical simulations, considering the shape and size of a wastewater treatment plant anaerobic digester. The simulated values were compared to the ones measured on a lab-scale anaerobic digester. Thus, the optimum geometry and nominal shaft speed were established for the anaerobic digester central mixer.

Key words: mixing, anaerobic digestion, sludge, wastewater

1. Introduction

Anaerobic digestion is a method of processing the resulted sludge from wastewater treatment plants during which methane-producing bacteria break down the organic matter. Anaerobic digestion tanks may be rectangular, cylindrical, or egg-shaped [1].

Effective anaerobic digestion is highly dependent on the efficient mixing. Basically, there are three types of mixing systems that include gas mixing, mechanical mixing and pumped recirculation. The most efficient mixing device in terms of power consumed per mixed volume is the mechanical mixer.

Research on mechanical mixing can be made directly, experimentally, by building a geometric model similar to the real one or by mathematical modeling and simulation. Due to the fact that the anaerobic digester is completely closed, it

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is very difficult to evaluate the intensity and type of movement induced by the impeller in a full-scale anaerobic digester.

Computational fluid dynamics (CFD) can help in studying mixing through numerical simulation of fluid flow [2]. CFD can allow determining the flow characteristics of sludge with a much lower cost than experimentations. Its advantages are even greater in applications where it is difficult to experimentally detect the mixing parameters, as it is in the case of wastewater treatment plant's anaerobic digester.

The application of CFD in anaerobic digesters is still limited. In [3] mechanical mixing of low solids content sludge in a digester was simulated. The digester domain was reduced to one-third of the vessel volume and the fluid property was regarded as Newtonian.

In the case of a total solids content greater than 5% in sludge, many experiments have been performed to identify the rheological properties and behavior of these media.

The rheological properties of sludge that do not influence the impeller design and the flow in the central draft tube were usually neglected. This led to the appearance of sludge deposits in the lower area of the digester, deposits that were noticed during the inspection and repairs periods.

The purpose of this study is to determine the flow directions and to choose the optimum mixer shape and shaft speed for a known geometry of the anaerobic digester.

2. Mathematical modeling of the sludge flow in anaerobic digesters

The modeling of multiphase fluid flow through the anaerobic digester is particularly difficult using the specific equations. In this case, to avoid the integration difficulties, the system modeling is performed by Navier-Stokes equations - valid for the homogeneous fluid flow. The use of this equations system simplifies the flow modeling. In this paper, is to be considered the partial differential equations system which reflects the flow of multiphase mixtures with low concentrations (less than 6%) in the equivalent polyphasic fluid hypothesis.

The fluid inside the anaerobic digester was considered to be sludge, with the solids concentration of 5%, as it is in the studied wastewater treatment plant. For this concentration, it was necessary to determine the values for density and dynamic viscosity, by considering the equivalent polyphasic fluid hypothesis. This led to a density of 1125 kg/m^3 and a value of $1.195 \cdot 10^{-3} \text{ P}$ for the dynamic viscosity, considering the expression given by H. Einstein (1).

$$\eta_n = \eta_f (1 + \varphi C) \quad (1)$$

For the modelling of the sludge flow the equivalent model vectorial equations for incompressible homogenous fluids are considered.

$$\frac{d\vec{v}_n}{dt} = \vec{f}_{mn} - \frac{1}{\rho_n} \nabla p_n + \nu_n \Delta \vec{v}_n \quad (2)$$

where: \vec{v}_n is the motion vector with three components (v_{nr} , $v_{n\theta}$, v_{nz}) for cylindrical coordinate system; \vec{f}_{mn} is the unitary mass force, ρ_n is the mixtures density, p is the mixtures pressure and ν_n is the mixtures kinematic viscosity.

For the compatibility of the system, the continuity equation has to be added:

$$\frac{\partial(\rho_n v_{nr})}{\partial r} + \frac{\partial(\rho_n v_{nz})}{\partial z} = 0 \quad (3)$$

3. Simulation of the mixer generated motion in the anaerobic digester

Simulations were realized for the sludge flow in the geometry shown in Fig. 1. The purpose of these simulations was to observe the flow fields inside the anaerobic digester and to choose the optimum shaft speed in order to obtain the optimum recirculation ratio inside the anaerobic digester.

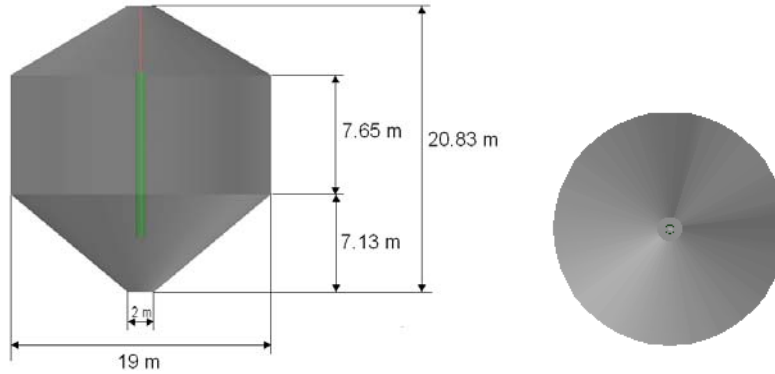


Fig. 1. The geometry of the anaerobic digesters - side view and respectively top view

A sludge height of 19 meters is considered inside the anaerobic digester. The anaerobic digester's central tube inner diameter is 0.66 m. The outer diameter of the impeller used for mixing the sludge is 0.5 m. The impeller is located 13 m from the ground level of the anaerobic digester.

The most often recommended axial mixers for anaerobic digesters are those having four or six blades, with a tilt angle between 15° and 45° . Considering these recommendations, simulations of axial flow were realized for four and for six blade rotors with a tilt angle of 30° and of 45° and shaft speeds of 100 and 800 rpm, as it can be seen in table (1).

The propeller mixing was studied using the multiple reference frame approach. The equations for the rotating zone were solved using a rotating

reference frame while the equations for the stationary zone were solved using a stationary reference frame.

The solution was coupled at the interface between those two zones via velocity transformation from one frame to the other. The boundary conditions were specified such that there are zero normal gradients of all variables at the liquid surface and no velocity slip exists at the solid walls. The domain was meshed into an unstructured array of tetrahedral mesh elements ranged between 111060 and 125392. Mixsim software was used for simulations.

Table 1

Simulation cases			
Case no.	Number of blades	Tilt angle [°]	Shaft speed [rpm]
1.	4	30	100
2.	4	30	800
3.	4	45	100
4.	4	45	800
5.	6	30	100
6.	6	30	800
7.	6	45	100
8.	6	45	800

The impeller mesh is presented in figure (2), for all four cases, as follows:

- 2.a four-blade impeller, 30° tilt angle;
- 2.b four-blade impeller, 45° tilt angle;
- 2.c six-blade impeller, 30° tilt angle;
- 2.d six-blade impeller, 45° tilt angle;

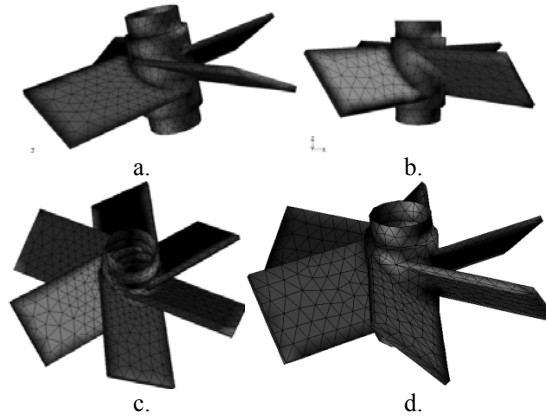


Fig. 2. The rotor mesh

The fluid flow inside the anaerobic digester is generated by the mixer rotational movement. The velocity profiles for the four-blade, 30° tilt angle mixer are displayed in the following figures.

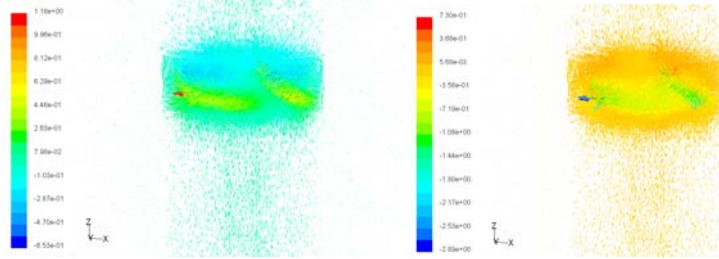


Fig. 3. Velocity profiles in the rotor area, colored by radial velocity and tangential velocity

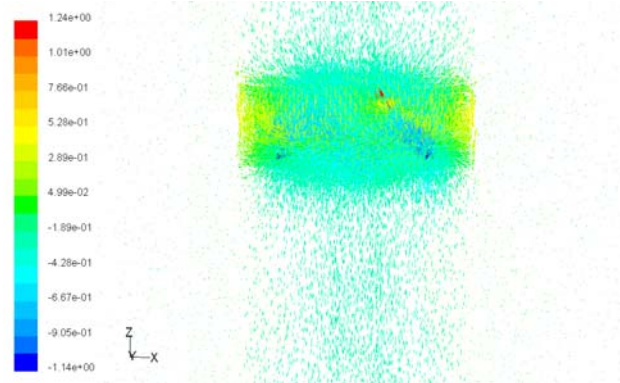


Fig. 4. Velocity vectors in the rotor area, colored by axial velocity. The negative sign on the scale represents the fact that the flow is in the opposite direction to the „Oz” axis.

The main purposes of sludge mixing is to homogenize the anaerobic digester's content and to avoid the sludge deposits in the bottom area. The entire volume of sludge has to be recirculated through the central draft tube 2-5 times every day. In order to determine the sludge flow through the central draft tube, the velocity has to be evaluated in the draft tube admission and the output area [4].

The results are displayed in the following figures.

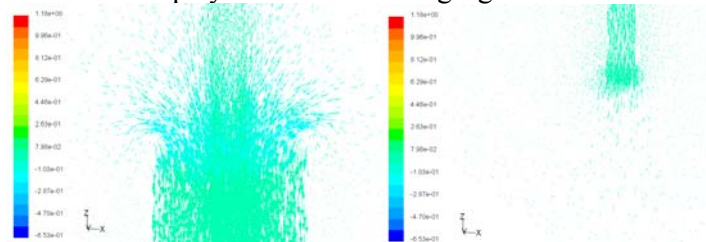


Fig. 5. Velocity vectors profile in the entry area and in the straight draft tube outlet area, colored by the values of radial velocity

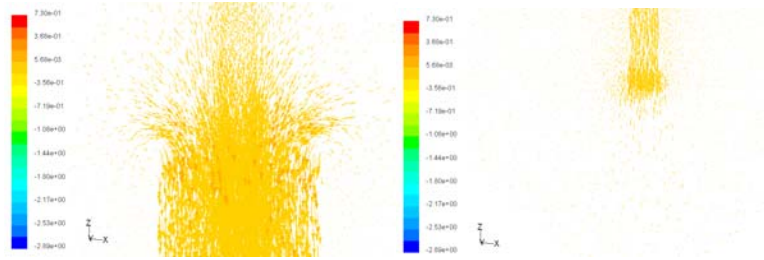


Fig. 6. Velocity vectors profile in the entry area and in the straight draft tube outlet area, colored by the values of tangential velocity

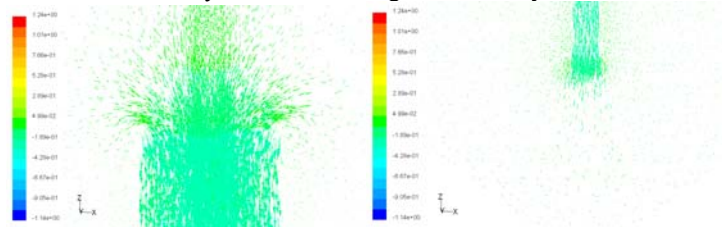


Fig. 7. Velocity vectors profile in the entry area and in the straight draft tube outlet area, colored by the values of axial velocity

The values for the flow through the central draft tube are represented in Fig. 8.

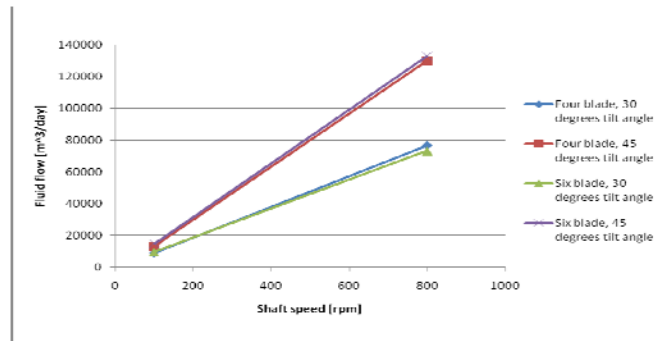


Fig. 8. Fluid flow for the four mixer geometries

As it can be seen in the figure above, the number of blades tube does not modify considerably the fluid flow through the straight draft. The important parameters are the shaft speed and tilt angle. Considering this observation, there is no reason to recommend as optimum a six-blade mixer, which implies increased material costs.

Considering these flow values in the straight draft tube the optimum number of daily recirculation times resulted for a shaft speed of 150 rpm for the four-blade mixer with a 30° tilt angle and of a 120 rpm shaft speed for a 45° tilt angle.

An experimental stand, equipped with an axial mixer was developed. The impeller diameter/draft tube diameter ratio was maintained, as well as the tank walls. The pumping capacity was directly determined by measuring the axial flow of the wastewater treatment sludge, using a velocimeter with a 0.1 FPS accuracy. The tank walls are at sufficient distance in order to have no influence on the velocity profiles. The impeller that was used has four blades and a 30° tilt angle. The results are listed in the following table.

Table 2.

The measured velocity and flow values

Shaft speed [rot/min]	Velocity [m/s]	Fluid flow [m ³ /day]
100	0.32	9454.123
200	0.627	18528.39
300	0.934	27602.66
400	1.241	36676.93
500	1.549	45751.2
600	1.856	54825.47
700	2.163	63899.74
800	2.47	72974.01
900	2.78	82132.69
1000	3.09	91291.38
1100	3.4	100450.1
1200	3.71	109608.7

The next step was to compare the flow values determined from the simulation results with the ones resulted considering the measured velocity values.

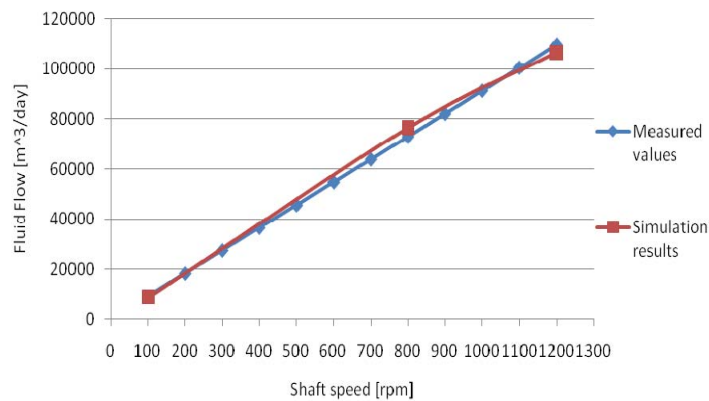


Fig. 9. Comparison between the simulated and measured figures

As it can be seen from Fig. 9, a good correlation was obtained between the simulated and the measured values.

4. Conclusions

Knowing the solid matter concentration in the wastewater treatment sludge, the density and kinematic viscosity were determined. The velocity profiles in the straight draft tube were determined; the velocity components (axial, radial and tangential) were represented.

Although the optimal flow was obtained for both four blades and six blades rotors, there is no reason to justify the increased materials cost for the six blade mixers.

The optimum shape and speed for the mixer were determined. The simulated flow values were found in good agreement to the measured ones.

Based on the results obtained through modeling and simulation, the authors became able to match the capacity of the central recirculation mixer to the needs of the anaerobic digestion process in order to increase the resulted biogas flow - the main purpose of the anaerobic digester.

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