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HYDRAULIC MIXING MODELLING IN REACTOR FOR BIOGAS PRODUCTION

Andrzej G. Chmielewski* [1,2], Aleksandra Berbeć[1], Michał Zalewski[2], Andrzej Dobrowolski[2]

[1]Warsaw University of Technology, Department of Chemical and Process Engineering, Waryńskiego 1, 00-645 Warsaw, Poland

[2]Institute of Nuclear Chemistry and Technology, Dorodna16, 03-195 Warsaw, Poland

Two-stage biogas production plant consists of two reactors: a hydrolyser and a fermentor. The bioreactor construction has to meet three requirements: low cost and simplicity of construction and good biomass mixing conditions with an application of appropriate method. This paper reports CFD modelling of hydraulic mixing in the tank to be applied in a two-stage industrial installation.

Keywords: biogas, biomass mixing, bioreactor, CFD modelling

1. INTRODUCTION

Different solutions are applied for biogas production. One of them is a two-stage system in which hydrolyse is separated from methanogenesis. Such a solution has been developed at a pilot plant constructed at Szewnia Wielka, Poland (Kryłowicz et al., 2008). High biogas productivity and high methane concentration in this product have been achieved (Kryłowiecz et al., 2011). Therefore industrial plants are being constructed. The best engineering solution for construction of a plant is reinforced concrete, which however requires simple casing board geometry and a horizontal rectangular cuboid seems to readily meet all the chemical and engineering requirements. Applied hydraulic mixing has to meet requirements of the process and therefore Computer Fluid Dynamics (CFD) has been applied to find a proper localisation of inlet – outlet biomass transportation pipes.

2. DESIGN OF THE BIOREACTOR

The analysed fermentor is a horizontal rectangular cuboid with the following dimensions:

- length - 10 m,
- height of liquid in a rectangular section – 3.75 m,
- width - 5 m,
- radius of curvature at the bottom – 0.25 m.

The biogas plant consists of two such tanks in series, therefore, the analyses are valid for both units – hydrolyser and fermentor. A semibatch process is applied and feed is delivered in regular time intervals. It is well known that performance of anaerobic digesters is affected primarily by the retention

*Corresponding author, e-mail: A.Chmielewski@ichtj.waw.pl

time of substrate in the reactor and the degree of contact between incoming substrate and a viable bacterial population (Karim et al., 2005).

In order to provide efficient mixing, a set of circulation pumps will be used. Cylindrical tubes with a diameter of 0.1 m will be used to provide inlet and outlet streams.

3. APPLIED CFD METHODOLOGY

To conduct the simulation, ANSYS FLUENT package was used, that refers to a finite volume method for numerical solutions of momentum balance equations. Calculations assume that the suspension is a homogeneous liquid with a density of water. The viscosity of the suspension was taken as 1.25 of the water viscosity (Rudniak, 2010). Fully developed turbulent flow was assumed and a modified k-ε turbulence model was used. The geometry of the fermentor was discretised using tetrahedron elements, the number of these was about 1.2 million for each case. Free surface of the liquid was modelled as a condition of symmetry (no normal component of the velocity vector and the derivative of the other components of the velocity vector in the normal direction is equal to zero). No slip on the walls of the fermentor was assumed. Based on these assumptions and boundary conditions, a numerical simulation of suspension flow in a fermentor was carried out. It consisted of a numerical solution of momentum balance equation and additional two equations for the model k-ε turbulence.

4. RESULTS

A hydraulic mixing system was analysed using the circulation in two dimensions: horizontal and vertical.

The first simulation - horizontal circulation - was to find a system that will provide the movement of the material throughout the length of the reactor and allow to recycle the biomass. Six different cases were examined. The location of the inlet pipe axis from the bioreactor bottom was variable, while the difference of 0.8 m between the inlet and outlet maintained the same for all the cases. Table 1. presents a summary of the analysed cases.

Table 1. Summary – horizontal circulation

Case No.	Inlet pipe axis height from bottom [m]	Outlet pipe axis height from bottom [m]	Mass flow [kg/s]	Stream range [m]	Fraction of height affected by stream
1	0.2	1.0	11.07	7	1/3
2	0.4	1.2	11.07	5	2/3
3	0.6	1.4	11.07	4	1
4	0,8	1.6	11.07	2	1
5	1.0	1.8	11.07	1	1
6	2 x 0.4	2 x 1.2	2 x 11.07	10	1

The inlet stream impact range was evaluated on the basis of the flow charts presenting velocity as a function of the distance from the inlet (Fig. 1., Fig. 3., Fig. 5., Fig. 7., Fig. 9., Fig. 11.). It was observed that the range of the stream impact increased with a decreasing height of the installation of the inlet tube from the bottom of the reactor. In addition, due to the flow structure charts (Fig. 2., Fig. 4., Fig. 6.,

Fig. 8., Fig. 10., Fig. 12.), the movement of the liquid in the entire height of the fermentor was analysed. It was observed that a fraction of liquid height affected by the stream increased while increasing the height of the inlet tube installation from the bottom of the vessel. The results showed that in order to ensure horizontal circulation two inlet streams located at the same height of 0.4 m distance from the bottom should be applied (case 6). Moreover, to mix the entire volume it is required to use an additional vertical circulation loop.

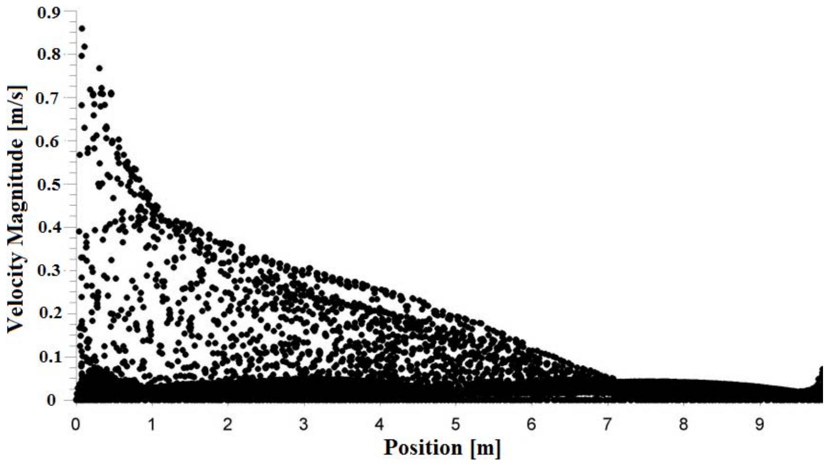

Fig. 1. Flow chart – Case 1

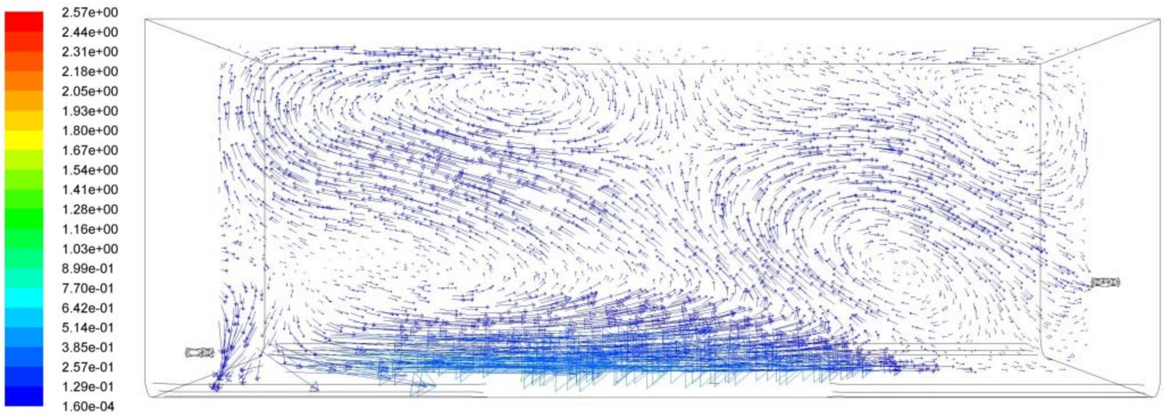

Fig. 2. Flow structure chart – Case 1

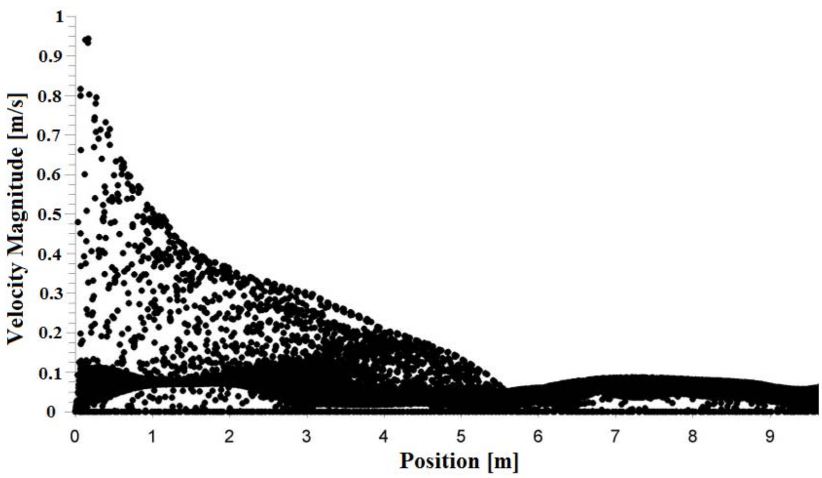

Fig. 3. Flow chart – Case 2

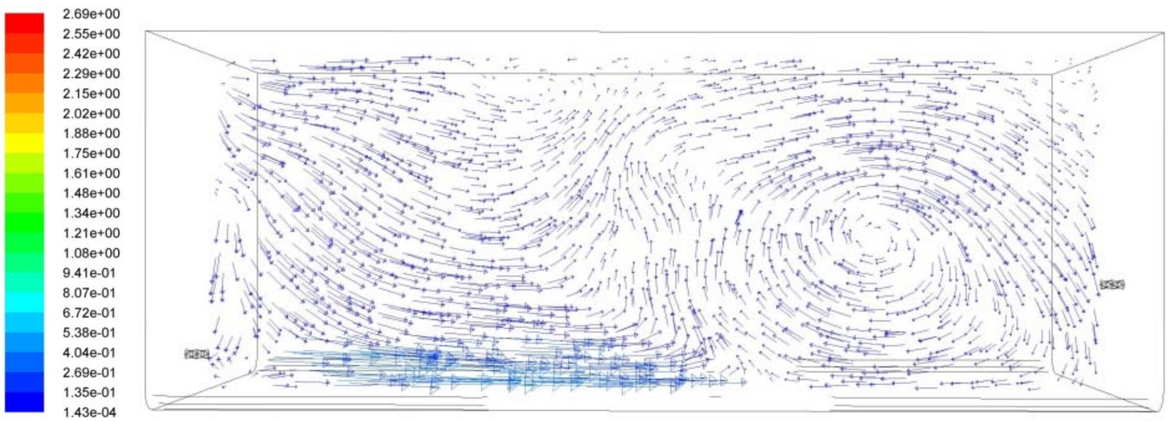

Fig. 4. Flow structure chart – Case 2

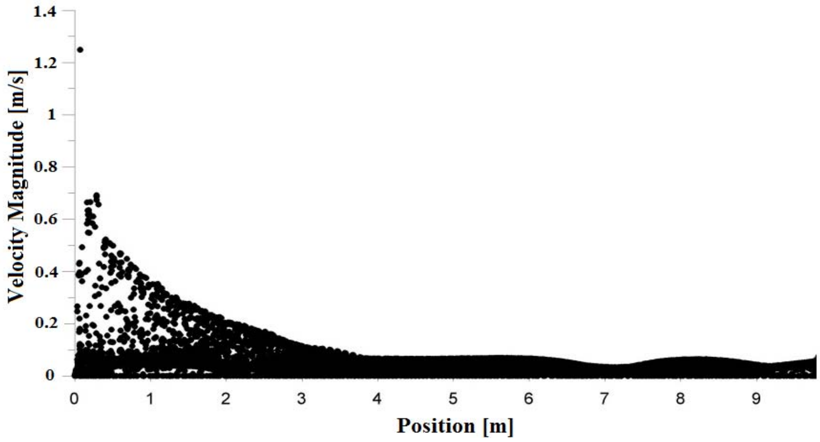

Fig. 5. Flow chart – Case 3

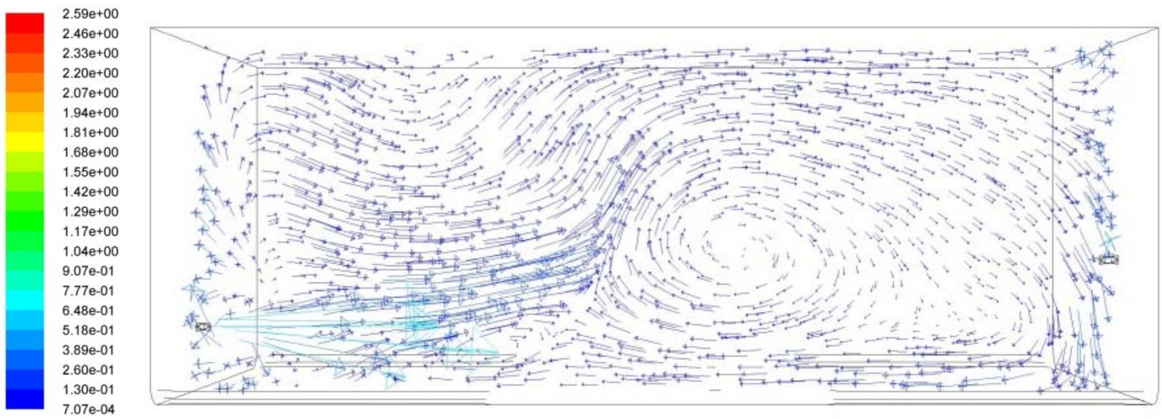

Fig. 6. Flow structure chart – Case 3

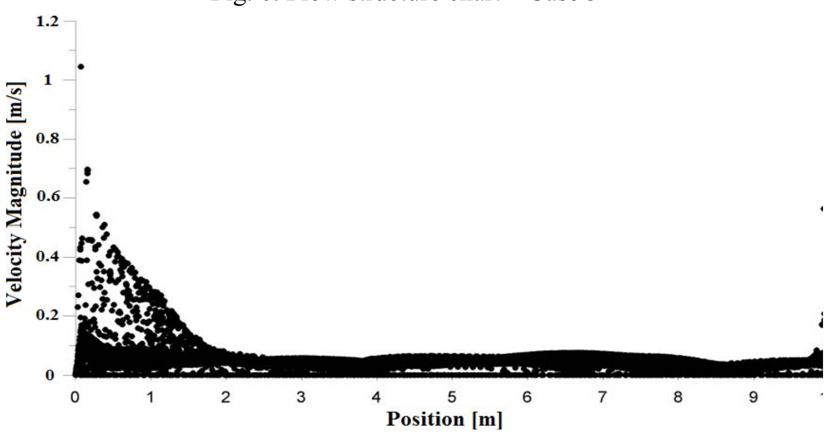

Fig. 7. Flow chart – Case 4

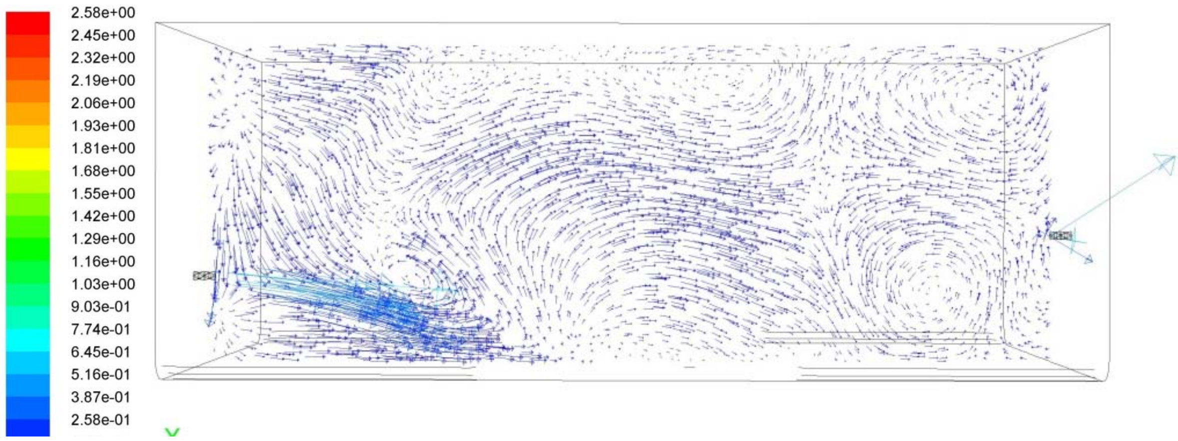

Fig. 8. Flow structure chart – Case 4

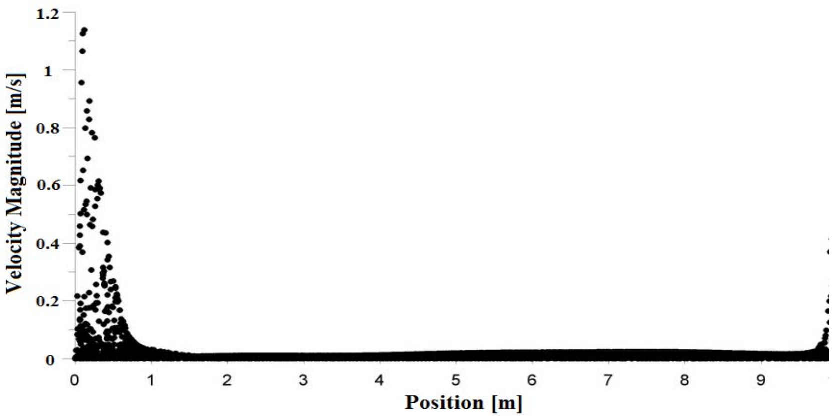

Fig. 9. Flow chart – Case 5

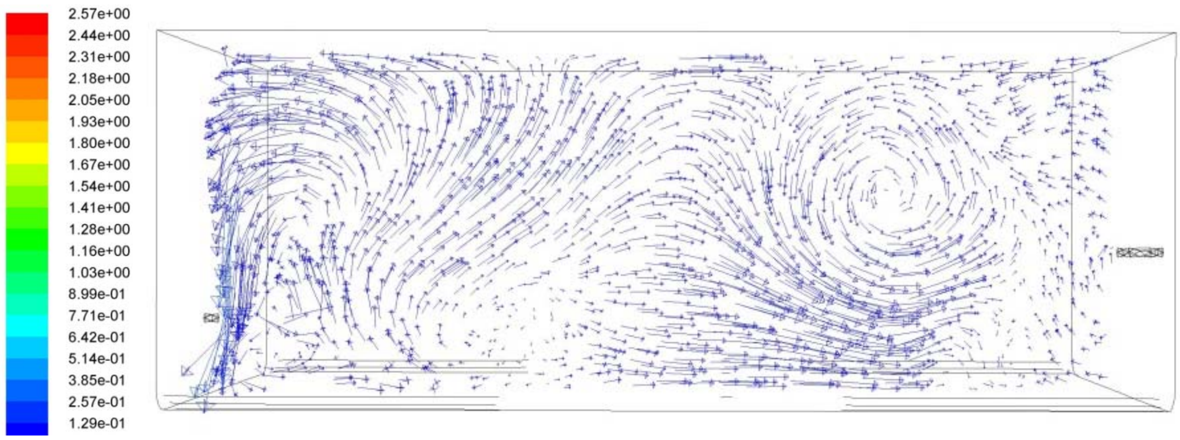

Fig. 10. Flow structure chart – Case 5

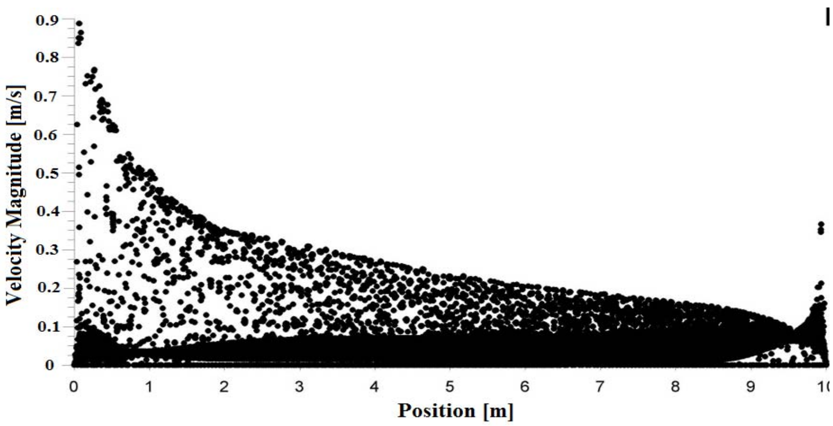

Fig. 11. Flow chart – Case 6

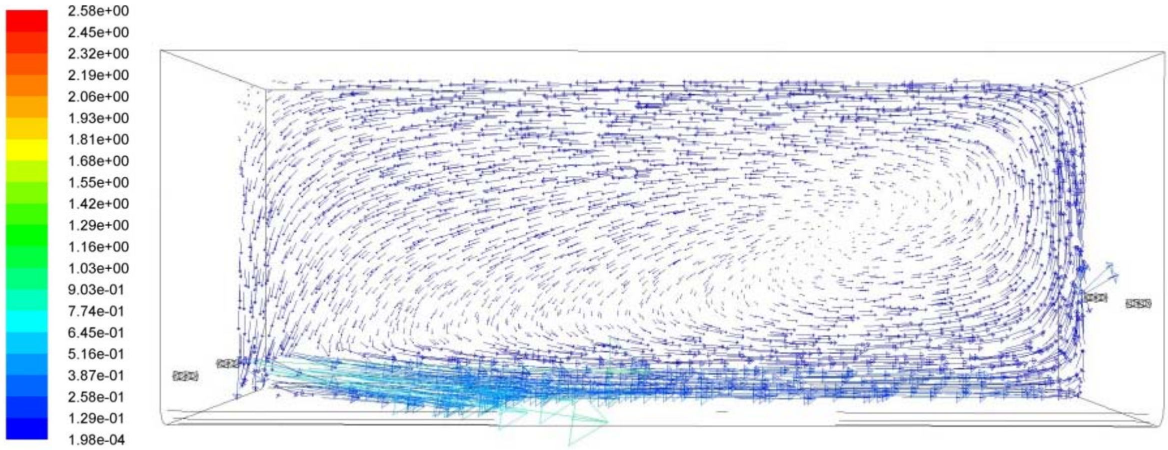

Fig. 12. Flow structure chart – Case 6

The second simulation – vertical circulation - was to find a system proving efficient mixing in the entire volume of the fermentor. The analysis started from one-loop circulation, and then it was developed with other loops, until a complete mixing was achieved in the analysed fermentor. An analysis of the impact range from one-loop case (Fig. 13.) showed that the solution does not accomplish the task of obtaining the forced movement of the suspension in the entire volume of the fermentor. The two - loop case (Fig. 14.) increased the area of mixed fluid, but only the use of three - loop model proved to be a solution ensuring the suspension movement in the entire volume of the analysed reactor (Fig. 15).

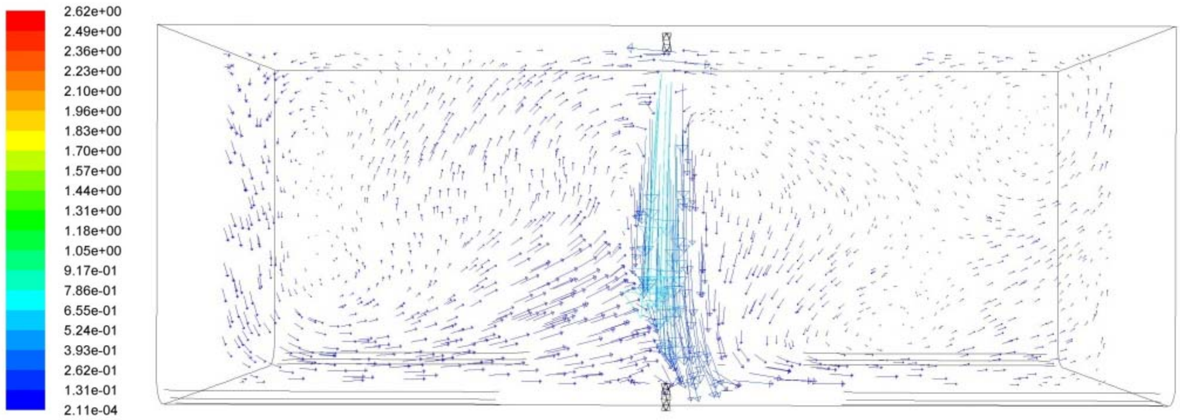

Fig. 13. Flow chart – one-loop circulation

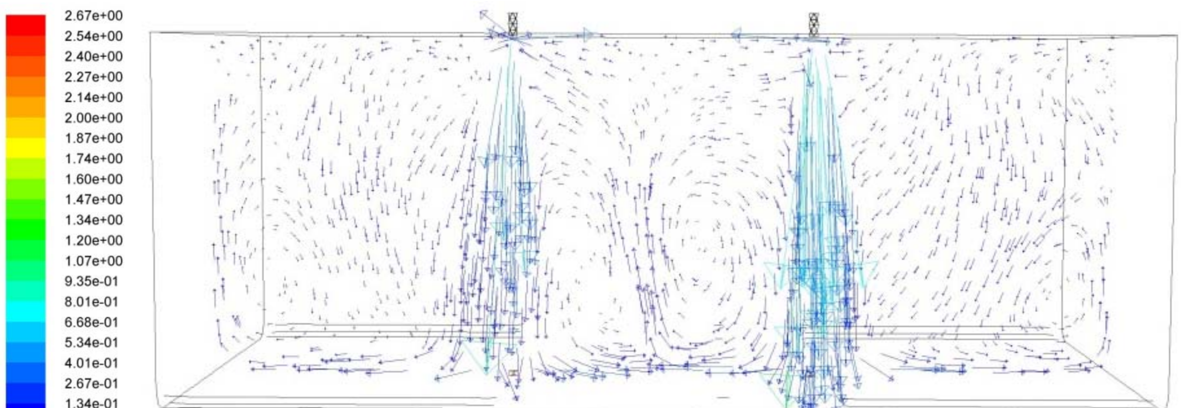

Fig. 14. Flow chart – two-loop circulation

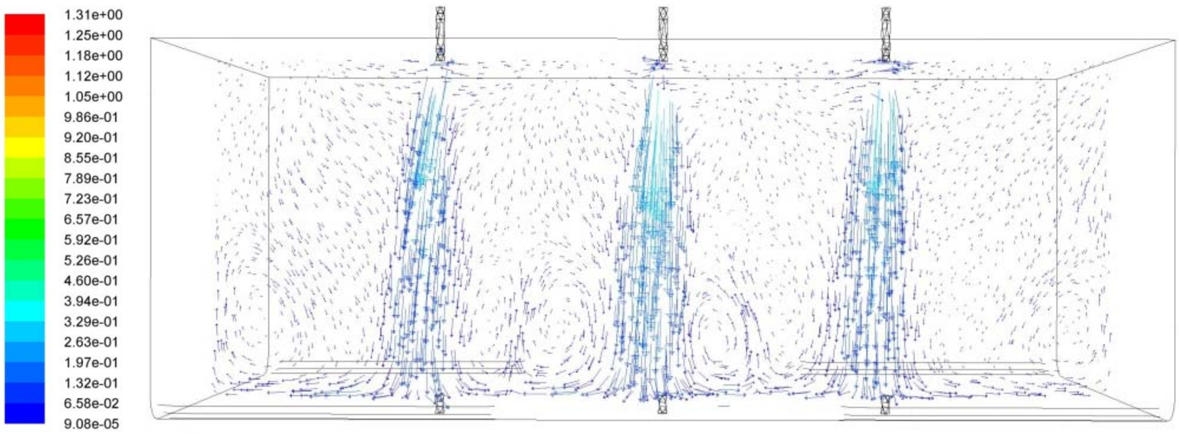

Fig. 15. Flow chart – three-loop circulation

These streams play a very important role regarding foaming reduction and forced submergance of floating part of biomass. A schematic structure of mixing in the fermentor is shown in Fig. 16.

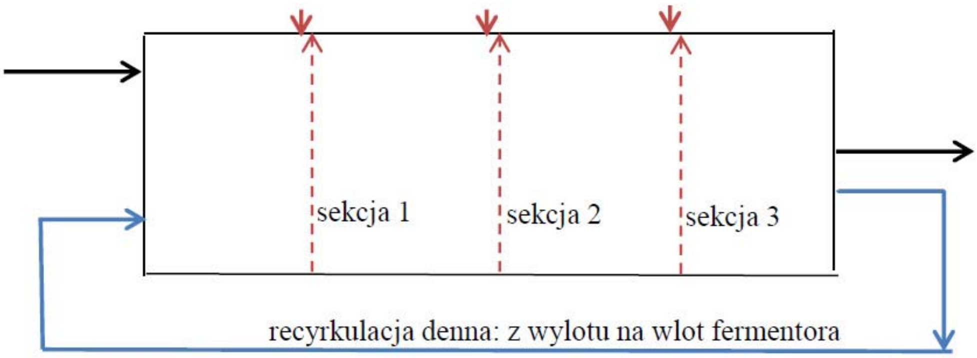

Fig. 16. Schematic structure of the mixing process in the fermentor

This solution is a new advanced solution in comparison to previously used systems, including plug flow reactors (Jagadish et al., 1998) or batch mode system in mixed biofermentors (Raposo et al., 2011). The proposed mixing system assures effective mixing and a good contact between biomass flocks and the substrate.

5. CONCLUSIONS

The study on hydraulic mixing leads to the following conclusions:

- Horizontal circulation allows to recycle the leachate with the respective cultures of bacteria to the anaerobic digestion process. For this purpose, two inlet streams located symmetrically at the same height at a distance of 0.4 m from the bottom of the tank should be applied in the fermentor.
- Sections of vertical circulation are designed to mix the material in the entire volume of the reactor. In the presented reactor, it is advised to use three recirculation loops spaced at equal intervals of 2.5 m.
- A course of the mixing cycle in the analysed fermentor consists of the following stages: activation of the recirculating pump, deactivation of the recirculating pump, activation of the first section of the mixing for a certain time, deactivation of the first section, activation of the second mixing section for a limited time, deactivation of the second section, activation of the third section of mixing for a certain time, deactivation of the third section.

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