POLLACK PERIODICA
An International Journal for Engineering and Information Sciences
DOI: 10.1556/606.2019.14.1.16
Vol. 14, No. 1, pp. 161–166 (2019)
www.akademiai.com

ANALYSIS OF A MECHANICAL MIXER PERFORMANCE IN ANOXIC REACTOR

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Received 17 December 2017; accepted 8 October 2018

Abstract: Denitrification is a key process in wastewater treatment since it is responsible for the effective nutrient removal. It requires anoxic conditions, where only chemically bound nitrogen is used as an oxygen source, and no aeration is applied. In suspended biomass systems the growth and homogenization of biomass is essential, high degree of mixing is required, which is achieved only by using mechanical mixers. Mechanical mixing performance relies on the mixing power determined by the equipment dimensions and rotational speed. In this paper the effect of three different rotational speed (rpm: 100, 400, 900 min^{-1}) on flow field and mixing conditions are evaluated. As a result of the simulations, the acceptable flow field was achieved at 400 rpm. The outcome of this research is that the high degree of energy transfer from mixers to fluid flow deteriorated mixing efficiency.

Keywords: Anoxic reactors, Mixing, Reactor hydrodynamics, Wastewater treatment

1. Introduction

Wastewater treatment requires biomass, which is a composition of microorganisms capable of decomposing organic matter and nutrient in sewage [1]. In the reactor the biomass can be suspended or in attached form. Suspended biomass consists of particles which are floating and well mixed in the entire reactor [2], whereas the attached biomass is bound to a carrier material. In a suspended growth system appropriate mixing is essential; therefore mechanical mixers are applied to keep the biomass suspended. Mixing is responsible for the control of biomass growth rate [3]. Some of

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HU ISSN 1788–1994

the treatment processes require the introduction of external oxygen (e.g. nitrification), which also helps in mixing, but there are processes, where denitrification takes place and nitrate as oxygen source is used. Even more emphasis is placed on mechanical stirring in the absence of aeration [4]-[6].

The purpose of mixing is to achieve uniform distribution of temperature, concentration of suspended solid in the entire volume of the stirred vessel. Mixing index is introduced to show the efficiency of mixing. Mixing index is a measure of the degree to which fluid flow promotes the dispersion of dissolved solutes or suspended materials in the fluid [7]. In ideal case this has a value of 1, but in actual situations it is somewhere between 0 and 1. Although perfect mixing cannot be achieved [8], but maximization of mixing performance is always a goal in process development or upgrading wastewater treatment plants.

Mixers and blenders are the most commonly used operating units in industry, but these are often part of a working technology, thus experimental information solely on the equipment is difficult to obtain; the operation of the device shall be investigated with its environment, and surrounding processes. Failure experiments can be a solution, but in these cases the scale-up could be an issue. Initially, scale-up equipment based on pilot scale experiments and with the application of dimensionless scaling factors data for the full scale process were determined. Dimensional analysis is a separate discipline and all of the physically relevant phenomena shall be taken into account, which is not always possible [9]. Nowadays simulation software is able to handle the full scale designs as much as the computational capacity allows it.

The power requirements of mixers can be described by similarity theory. Experiences show that the mixer power requirement depends on mixer and container dimensions, rotational speed of the mixer, material parameters of the fluid e.g. density, viscosity [10]. Power is in relation to the cube of the rotational speed. The goal of the research is to minimize the OPerational EXpenditures (OPEX) with the help of hydrodynamic analysis; by determination of the optimal location and operational parameters. Section 2 details the methodology applied, Section 3 summarizes the results and Section 4 describes the conclusions and future research need.

2. Methodology

Numerical simulation can be an effective tool for obtaining reliable, cost-effective solutions and compare different simulation alternatives [11]. The most important incentive for developing these tools was to develop a decision-supporting system based on predictive and deterministic models replacing physical measurements. Numerical analysis of fluid flow with rotating elements has also demonstrated the capability to simulate complex systems [12]. Fluid flow analysis solves the governing equations of the fluid flow for each simulation point. Finite volume method was used with Semi Implicit Method for Pressure Linked Equations (SIMPLE) algorithm [13]. The solution is based on Reynolds Averaged Navier-Stokes equation with k-epsilon turbulence closure [14]. Calibration of the turbulence model parameter is based on empirically data reported in the literature [15]. The turbulence parameters assumes isotropic grid turbulence, the values can be seen in *Table I*. As a result, a fully resolved flow field can be gained, where the appropriately stirred zones or hydraulic issues like short-circuiting or dead-zones could be predicted [16].

Table I

Turbulence model parameters

Model constant for dissipation transport eq. nr. 1 $C_{1\varepsilon}$	Model constant for dissipation transport eq. nr. 2 $C_{1\varepsilon}$	Model constant for eddy viscosity C_{μ}	Turbulent Prandtl number for k σ_k	Turbulent Prandtl number for ε σ_{ε}
1.44	1.92	0.09	1.0	1.3

In this research an anoxic reactor with two mixers at various rotational speed were analyzed. The basin has a length of 10 m, width of 2 m and height of 6 m. The two mixers were placed symmetrically, 3 m from the sides and at a height of 2 m (*Fig. 1*). For spatial discretization mesh size with 216 000 cells and 40 500 nodes were applied. The mesh does not change in time; an empirical relation is set between pressure rise and velocity. No-slip wall was set in the side of the basin, and zero-shear wall for the free surface. The modeling approach does not detail the flow between the blades, but it is acceptable in prediction of the amount of flow through the mixers. The flow rate calculated was used in model verification.

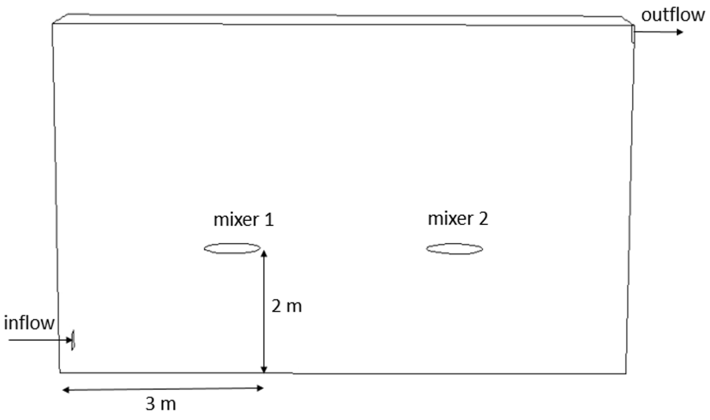

Fig. 1. Simplified geometry of the simulated basin

Scenarios with rpm of 100, 400, 900 min^{-1} were calculated and the results were compared, which included the determination of flow field and integral averaged velocities in the basin.

3. Results and discussion

Steady-state simulations were performed at various rotational speed of the mixer as Section 2 describes. Convergence criteria for the iterative calculation were the following:

i) iteration residuals of continuity, momentum and turbulence closure equations shall be under 10-3; and

ii) the flow rate through the mixer shall be constant over the time.

As a result of the simulation well-resolved pressure and velocity fields could have been gained. For better representation of the flow, streamlines are drawn from the mixer (see *Fig. 2* and *Fig. 3*). Fluid particles basically show vertical flow dominance. As the flow reaches the water surface it reverts and the movement becomes downward closing the circulatory pattern. In the center of this circulation flow the detention time is above the average residence time, stagnant zones could appear. Flow pattern is similar if 100 or 400 min^{-1} rotational speed is applied. The difference between the two cases is the average velocities in the basin induced by mixing.

Fig. 2. Streamlines starting from mixer plane (rpm:100 and 400 min^{-1})

Fig. 3 shows the streamlines if 900 min^{-1} rotational speed is applied. It is clearly seen that the two mixers work together causing deterioration of mixing efficiency. In the midst of the reactor there is a high speed zone, which could damage the flock particles due to shearing. At the right and left bottom corner stagnant zones appear which may provoke undesirable settling.

Table II summarizes the integral averaged velocities in each scenario. It demonstrates that momentum induced by mechanical mixing at high rotational speed is two times higher than in the case of 400 rpm.

For verification of the model the calculated flow rate through each mixer were 96, 180 and 338 l/s, whereas the actual (catalogue-based) values were 100, 190 and 340 l/s were respectively.

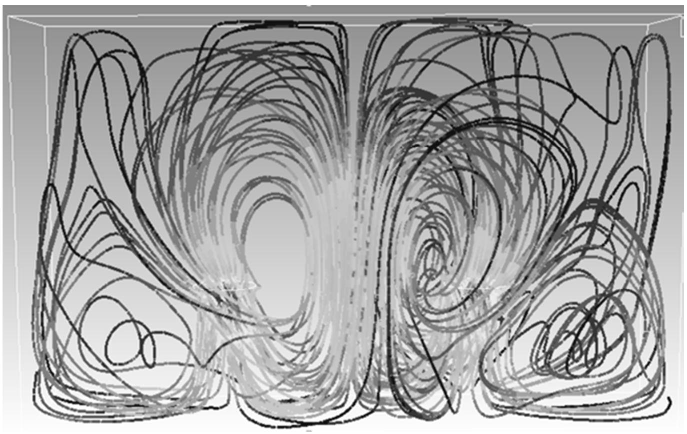

Fig. 3. Streamlines starting from mixer plane (rpm:900 min^{-1})

Table II

Average velocities and flow at various rotational speed of the mixers

Rotational speed (1/min)	Integral averaged velocity of mixed fluid (m/s)	Modeled flow rate through the mixer (l/s)
100	0.037	96
400	0.054	180
900	0.109	338

4. Conclusion

Mixing is a decisive operational parameter responsible for homogenization and control of biomass. Mechanical mixer operation applying various rotational speeds in wastewater treatment was analysed in this study. The prime outcome of this research is that the high degree of energy transfer from mixers to fluid flow does not evidently mean better flow pattern and mixing efficiency. If rotational speed exceeds a certain limit, the flow field becomes unstable, having high-shearing zones and regions supporting undesirable sedimentation. In future work the simulations will be extended to find the optimum location and dimensions of the mixers.

Acknowledgements

This work has been undertaken as a part of a project founded by the EFOP-3.6.1-16-2016-00025 institutional development of water management in tertiary education aiming at intelligent specialization

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