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HYDRODYNAMIC FACTORS IN AN ANAEROBIC DIGESTER

Buta Singh[1], Zoltán Szamosi[2], Zoltán Siménfalvi[3]
[1] MSc, doctorate student, [2] PhD, assistant professor, [3] PhD, associate professor
Institute of Energy Engineering and Chemical Machinery, University of Miskolc

INTRODUCTION

Higher solid content feed to digester have potential to increase the efficiency of conversion of organic waste material to biogas. But the higher total solid content can cause reduction in mass and heat transfer between bacteria, enzymes and substrate in the digester. Hydrodynamics is a major factor that contributes in formation, mass transfer, structure and metabolism of microbial community in an anaerobic digestion process [1]. Agitation of anaerobic slurry is important to achieve firstly the supply of uniformly distributed substrate, secondly to keep continuous contact between the microorganisms and sludge, thirdly the concentration of end product and prohibited biological intermediates have to be maintained at minimum levels [2]. Mixing can enhance the homogeneous distribution of nutrients and micro-organisms and can avoid formation of surface crust and sedimentation [3]. It has been revealed by Gerardi [4] that close contact between acetogens and methanogens can lead to effective methanogenesis which can achieved by smooth and adequate mixing. Negative impacts of inadequate mixing are observed as abortive methane yield, defective stabilization of raw slurry, loss of digester volume and increasing the operation expenses [5]. Most of the studies agree that the excessive mixing in an anaerobic digester can lead to decline in methane production while moderate mixing can show positive impact. The negative effect of excessive mixing is observed due to fact that the high shear forces disrupt the microbial flocs and syntrophic relationships between methanogens and bacteria [6].

1. TYPES OF MIXERS

Many studies have been published dealing with impact of mixing on biogas production in last years using different designs, positions and configurations of impellers along with shape of digesters. Digesters can be equipped with one or more impellers having same or different design. Usually both radial and axial impellers are used. For the small scale digesters coaxial impellers are used whereas in large equipments eccentric or inclined agitators can be used [7]. Many researchers compared various types of impellers corresponding to the mixing time and biogas production. In a study by Lebranchu et al [8] double helical ribbon (Fig. 1) and Rushton turbine (Fig. 2) was compared in mixing of cattle manure at different mixing intensities

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continuously. Helical ribbon produced 50% more biogas as compared to Rushton turbine. Three different mixing modes i.e. biogas circulation, impeller mixing and slurry recirculation were used producing 29%, 22%, 15% more biogas than unmixed digester at 10% manure slurry [9]. However, in-vessel slurry velocities are of course, not necessarily indicators of the degree of mixing. The sludge may be moving at a particular speed, but if all sludge in the immediate vicinity is moving at the same speed and in the same direction, then mixing is not occurring, rather the sludge is simply being moved within the vessel [10]. It was noted that ideal behavior of tank mixing may deviate due to variety of reasons associated with placement of inlets, outlets, stratification, and tank geometry. The presence of even a slight amount of density difference between the mixed fluids strongly influence the progression of mixing [11].

In the study by F. Battista [12] the high viscosity olive pomace (OP) and olive mill wastewaters (OMW) were used for methane production. Four different types of impellers were tested to know the mixing effect on this high viscosity fluid. The impellers were a marine impeller (Fig. 3) with three blades, an anchor impeller (Fig. 4), a Rushton impeller with 45^o inclined blades and Pelton impeller (Fig. 5). After the comparison it was observed that the marine impeller possess good homogenization in the digester due to both axial and radial moments given to fluid. The 6-blade Rushton impeller with blade inclination of 45^o performed much better than traditional Rushton impeller resulting in increase in biogas production containing methane content of 82v/v% (volume per volume percentage). The process efficiency of almost 17% was attained due to the effect to changing impeller motion from radial to axial and hence boosted the mixing efficiency. Further Marine impeller performs better than 6-blade turbine producing 15.34 NL/L (Nanolitre per Litre) biogas and methane content of 84 v/v%. Best performance was noted in anchor impeller with biogas production of 22.6 NL/L, and methane content of 84.4 v/v% [12]. A stronger tangential flow is generated by Anchor impeller as compared to other impellers which makes it suitable for mixing viscous fluids [13].

Flow pattern of slurry strongly depends on the off bottom and inter impeller clearance, the size and type of lower impeller. Z. Trad et al. [14] studied the flow pattern of slurry by combining different types of impellers. An elephant ear turbine (Fig. 6) was on the top of vessel and the lower impellers in different configuration were a four blade Rushton turbine, a six blade Rushton turbine and a marine impeller. Effect of different off bottom and inter impeller distances was studied. When the off bottom clearance was decreased it restricted the circulation below the lower impeller and make it difficult to get the sludge being suspended. With the usage of the 6RT70 (6 blade

Rushton turbine) and 3MP77 (3 blade marine impeller) impellers one can reach faster homogeneous distribution.

Fei Shen et al. [15]studied the mixing performance if various impellers in digester containing rice straw as substrate by using CFD simulations and experiments. Three different blades including the High efficiency blade (HEB) (Fig. 7), pitched blade (PB) (Fig. 8), disc mounted flat blade (DFB) were investigated at stirring rate between 20 RPM to 160 RPM. It was noted that at stirring rate of 80 RPM complete mixing of rice straw in vertical column was achieved by PB and HEB blades. In further experiments, number of impellers were increased which resulted in generation of strong axial recirculation loop along with change in flow pattern which improved mixing performance.

In study by Binxin Wu [16] the computational fluid dynamic model of mixing by mechanical draft tube in egg shaped anaerobic digester was developed. The direction of rotation and position of propeller were observed to identify the optimum position and primary pumping mode of propeller fixed in the tube. Two mixing methods i.e. mechanical draft tube mixing and external pumped circulation were compared. In case of mechanical draft tube both upward and down ward pumping modes were implied using an axial pump at rotating speed of 580 RPM. In up mixing mode two symmetrical vortexes were observed and two strong flow streams spread from top splash disc to side wall and on other hand in down pumping opposite flow paths were observed. It was concluded that up pumping is more effective as compared to down pumping. More over mechanical draft tube is more effective as compared to external pump circulation in terms of power consumption. Optimum position of impeller for slurry was determined as 0.914 m below the liquid surface.

In study by Hopfner Sixt et al. [17] in Austria showed paddle mixers were maximum used in biogas plants. According to study by Wu et al [18] digester shape have significant influence on the mixing of slurry. In this research the flow pattern of Egg shaped digester was tested by Computation Fluid Dynamics. It was observed that mixing in Egg Shaped digester is more uniform which leads to reduction in power consumption and energy demand to maintain the homogeneity of digester and more over amount of foam formation is also reduced. This geometry of digester is more effective to process upsets and removal of dead zones which helps to reduce the maintenance and operational needs.

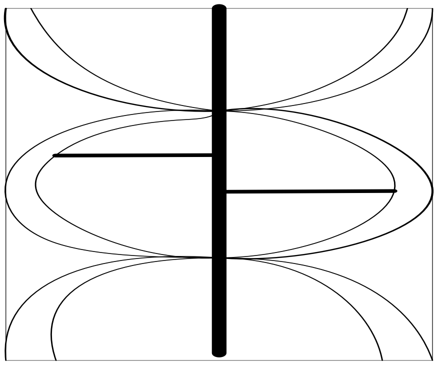

Figure 1
Hellical Ribbon Impeller

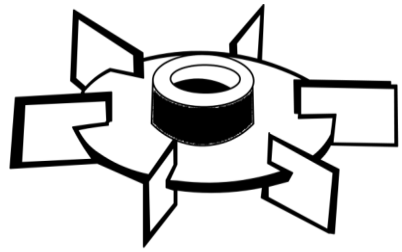

Figure 2
Rushton Impeller

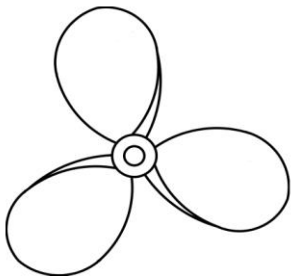

Figure 3
Marine Impeller

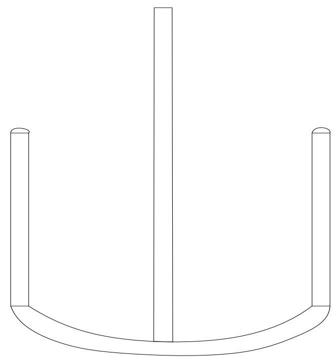

Figure 4
Anchor Impeller

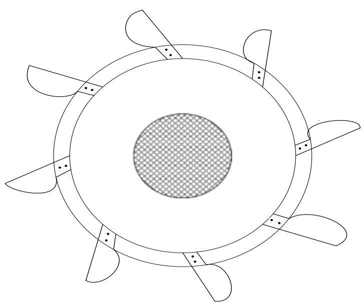

Figure 5
Pelton Impeller

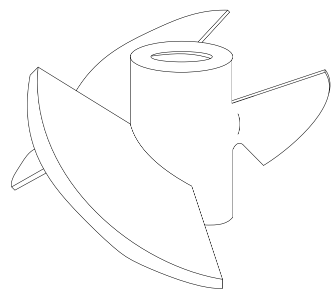

Figure 6
Elephant Ear Impeller

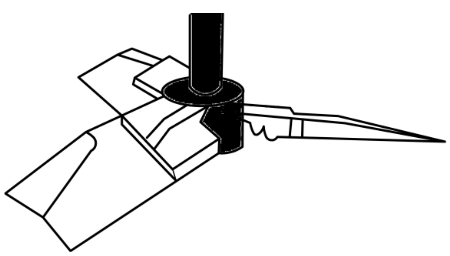

Figure 7
High Efficiency Blade Impeller

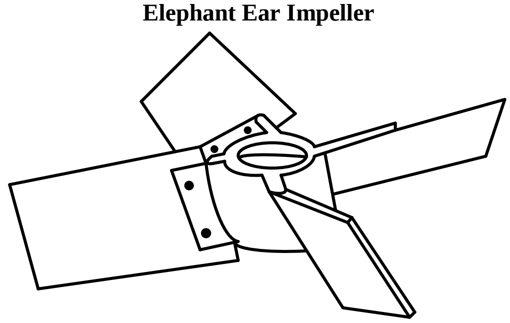

Figure 8
Pitched Blade Impeller

2. EFFECT OF MIXING INTERVALS AND MIXING SPEED

Two important parameters of mixing in anaerobic digester which can be examined are: intensity of mixing and mixing duration [9]. According to the literature research, excessive mixing can enhance rate of hydrolysis and fermentation, but on other hand syntrophic bacterial and methanogens association won't be able to convert these fermentation products at the rate which they are formed due to inhibitory effect of the fermentation products which degrades the digestion performance [6]. After continuous pre run from 0-19 days different mixing modes were analyzed which resulted that minimal mixing (mixing for 10 min prior to extraction/feeding) yielded highest methane as compared to intermittent (withholding mixing for 2 h prior to extraction/feeding) and continuous mixing in digester. Whereas higher levels of Volatile fatty acids were noted in intermittent mixing. The methane production was improved in intermittent mixing by 12.5% and 14.6 % in lab scale and pilot scale digesters respectively as compared to continuous mixing [6]. It was noted that methane yield of maize stover at low mixing intensity (20 rpm) was higher as compared to intensive mixing (70 rpm). Intensive mixing blurred the boundaries of upper and lower phases resulting in Volatile Fatty Acids accumulation and loss of methanogens [20]. Floating layers of solids form due to insufficient mixing so increased mixing level is preferred. Low mixing can result in stable performance of anaerobic digester and further help to generate good contact between the substrate and microorganisms resulting in increasing the specific Gas production [24]. According to study by Schink (1992) [21] kinetic effectiveness is reduced by lack of mixing because the single cells are surrounded by their own progeniture due to their growth. Moreover it was observed that the occasional mixing is necessary for newly formed cells. Whitmore et al. [22] observed that by high mixing syntrophic relationships in between the microorganisms are disturbed due to disruption of structural flocs in completely mixed reactor. In study by Peter G. Stroot et al. [20] the results obtained suggested that continuous and vigorous mixing may restrict the digester to perform well. Minimal mixing was employed which helped distribute the feed adequately and allowed formation of new spatial associations. Mixing also played important role in turnover of propionate due to destruction of syntrophic interactions. Further explaining the reasons for improved performance of digester at minimal mixing corresponds to difference in feed distribution. Minimal mixing resulted in slower hydrolysis and fermentation which helped syntrophs and methanogens to gobble the fermentation products without building of new compounds. In study by Elnekave et al. [23] it was observed that interrupted mixing can lead to hydraulic dead zones which results in decreasing effective hydraulic retention time and further have negative impact on reaction kinetics. This is true for case only where total dissolved solid is less than 2.5 % because here mixing efficiency is maximum and dead volume is minimum. According to S. Ghanimeth et al. [24] the digester with slow mixing at 100 rpm performed better than the unmixed digester and it was more stable in terms of lower α ratio, lower propionate level and reduced volatile fatty acids. Slow mixing also increased the system stability, digester capacity and startup process. In the research by R. Dauge et al. [25] the effect of mixing on solid separation and biological flocculation was studied. In the initial stage the digester was mixed continuously for 150 days and gas production was noted as 1240 ml/day. After 150 days mixing strategy was changed from continuous to intermittent as mixing was done only for 2 minutes every hour. It was observed that the biogas production increased to 1950 ml/day on day 156 due to reason that the concentration of effluent volatile solids decreased from 2026 g/l to 1.1 g/l in days 140 to 155 respectively. Low and high mixing also have significant effect on foam formation. Poor mixing can result in solid/liquid phase separation and poor degradation due to which surface active substances can accumulate at air/liquid interface and it enhances surface activity and potentially foaming [18].

3. SUMMARY

Although the importance of mixing to enhance performance in anaerobic digestion is noted by many researchers but the optimum mixing method is still debatable subject. Mixing is mainly associated with various costs like equipment, maintenance cost and operation cost. Mixing mostly depends on the type of mixer (radial or axial), shape, inter impeller space, bottom clearance and position of agitator in vessel. Further design of mixer and time of mixing determines the power consumption. Intermittent mixing was prominent among continuous and unmixing as continuous mixing has negative effect on biogas production during startup process along with higher power demand. Moreover by shifting to intermittent mixing both maintenance and operation costs can be reduced. In this review it is concluded that the intermittent mixing is superior to continuous and un-mixing in terms of biogas yield and energy point of view.

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