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Numerical Analysis of the Computational Fluid Dynamics of Co-Digestion in a Large-Scale Continuous Stirred Tank Reactor

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Abstract : Co-digestion in anaerobic biodigesters is a technology improving hydrolysis by increasing methane generation. In the present study, the dimensional computational fluid dynamics (CFD) is numerically analyzed using Ansys Fluent software for agitation in a full-scale Continuous Stirred Tank Reactor (CSTR) biodigester during the co-digestion process. For this, a rheological study of the substrate is carried out, establishing rotation speeds of the stirrers depending on the microbial activity and energy ranges. The substrate is organic waste from industrial sources of sanitary water, butcher, fishmonger, and dairy. Once the rheological behavior curves have been obtained, it is obtained that it is a non-Newtonian fluid of the pseudoplastic type, with a solids rate of 12%. In the simulation, the rheological results of the fluid are considered, and the full-scale CSTR biodigester is modeled. It was coupling the second-order continuity differential equations, the three-dimensional Navier Stokes, the power-law model for non-Newtonian fluids, and three turbulence models: k-ε RNG, k-ε Realizable, and RMS (Reynolds Stress Model), for a 45° tilt vane impeller. It is simulated for three minutes since it is desired to study an intermittent mixture with a saving benefit of energy consumed. The results show that the absolute errors of the power number associated with the k-ε RNG, k-ε Realizable, and RMS models were 7.62%, 1.85%, and 5.05%, respectively, the numbers of power obtained from the analytical-experimental equation of Nagata. The results of the generalized Reynolds number show that the fluid dynamics have a transition-turbulent flow regime. Concerning the Froude number, the result indicates there is no need to implement baffles in the biodigester design, and the power number provides a steady trend close to 1.5. It is observed that the levels of design speeds within the biodigester are approximately 0.1 m/s, which are speeds suitable for the microbial community, where they can coexist and feed on the substrate in co-digestion. It is concluded that the model that more accurately predicts the behavior of fluid dynamics within the reactor is the k-ε Realizable model. The flow paths obtained are consistent with what is stated in the referenced literature, where the 45° inclination PBT impeller is the right type of agitator to keep particles in suspension and, in turn, increase the dispersion of gas in the liquid phase. If a 24/7 complete mix is considered under stirred agitation, with a plant factor of 80%, 51,840 kWh/year are estimated. On the contrary, if intermittent agitations of 3 min every 15 min are used under the same design conditions, reduce almost 80% of energy costs. It is a feasible solution to predict the energy expenditure of an anaerobic biodigester CSTR. It is recommended to use high mixing intensities, at the beginning and end of the joint phase acetogenesis/methanogenesis. This high intensity of mixing, in the beginning, produces the activation of the bacteria, and once reaching the end of the Hydraulic Retention Time period, it produces another increase in the mixing agitations, favoring the final dispersion of the biogas that may be trapped in the biodigester bottom.

Keywords : anaerobic co-digestion, computational fluid dynamics, CFD, net power, organic waste
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