ADM1 Simulation of the Mesophilic Anaerobic Digestion of Mixture of Primary and Secondary Sludge Treated by Effective Microorganisms

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Abstract

The main aim of this study is to investigate the ability of ADM1 to describe anaerobic digestion of mixed sludge treated by Effective Microorganisms (EM1®). In this paper the results obtained from previously experimental work by the author contains two semi-continuous digesters were used to extend the ADM1. The recorded data and digester performances were compared with the results of a modelling in ADM1. Practically, the ADM1 implementation as described by Rosen & Jeppsson is chosen as it effectively completes the mass balance for COD, carbon and nitrogen. The ADM1 model was able to reflect the trends that were observed in the experimental results for the COD, CODs. VFAs and pH value while the Biogas production rate of the experiment were lower than the predicted values for the control digester. The biochemical parameters values proposed by Rosen & Jeppsson (K_{dis} = 0.50, K_{hydch} = 10, K_{hydpr} = 10, K_{hydli} = 10, and K_{mac} = 8) for control mesophilic digester needed to be modified so after recalculating different combinations for disintegration and hydrolysis parameters the combination of (K_{dis} = 0.75, K_{hydch} = 15, K_{hydpr} = 15, K_{hydli} = 15, and K_{mac} =12) are considered to be the most optimal for the this study.

1. Introduction

Energy from biomass and waste is seen as one of the most promising future renewable energy sources, especially because a continuous power generation can be guaranteed, unlike other types such as solar and wind energy. Sewage sludge is a type of waste that can be used as a renewable energy source. Large amounts are produced during the treatment of wastewater. These amounts continue to increase due to more stringent legislation and more efficient/thorough wastewater purification. The handling and disposal of the vast amounts of waste sludge accounts up to 50 % of the total wastewater treatment costs [1]. Anaerobic digestion (AD) is a key factor in converting this waste into a renewable energy resource. It is a microbiological process that converts the organic fraction into an energy-rich biogas (55-70% CH_4), which can be valorised energetically. Other beneficial features include stabilization of the sludge, inactivation and reduction of pathogens, and improvement of the sludge dewaterability [2], which is very important for further handling after AD.

The Degradation of volatile suspended solids in the conventional mesophilic anaerobic process is about 40% at retention times between 30 an 40 days, So different strategies have been studied in order to enhance anaerobic digestion of sludge such as thermal pre-treatment, chemical pre-treatment, thermo-chemical pre-treatment, mechanical pre-treatment but these methods are costly and consumed a large amount of power [3], and co-digestion with food or agriculture wastes [4].

EM technology was primarily focused on improving productivity in agriculture but then came to prove to have important role to play in wastewater treatment processes. There has been major success on application of EM1 in septic tank systems, lagoons and activated sludge systems and UASB [5].

EM1 has effectively improved sludge digestion in mesophilic digesters receiving a mixture of primary and secondary sludge for batch digesters [6], and also for the semi-continuous digesters [7].

Over the years a range of models have been developed for modelling anaerobic digestion processes.

Early models were steady state and assumed a rate-limiting step [8]. However, the increasing complexity of the advanced digestion technologies requires more complex models that can represent the impacts of changing environments on chemical and microbial species. Based on reports in the literature there is evidence of a number of multi-species models that are based upon differing assumptions and have differing configurations [9]. Relatively recently there has been a move by the International Water Associations (IWA) Task Group for Mathematical Modelling of Anaerobic Digestion Processes to develop a common model that can be used by researchers and practitioners [10]. This model (ADM1) has a structure that is similar to the IWA activated sludge models that have received acceptance by practitioners over the last 10 years [11].

This research paper focuses on the simulation and modelling of the mesophilic anaerobic digesting of mixed sludge by the ADM1 and modifying and extension of the original ADM1 biochemical parameters in order to simulate the behaviour of mixed sludge treated by EM.

2. Model description

The ADM1 model is described in considerable detail in the report prepared by the IWA Task Group for Mathematical Modelling of Anaerobic Digestion Processes [10]. The following provides a brief overview of the model for the purposes of this discussion. The ADM1 model is a structured model that reflects the major processes that are involved in the conversion of complex organic substrates into methane and carbon dioxide and inert by-product In Fig. 1 an overview of the substrates and conversion processes that are addressed by the model is presented. From Fig. 1 it can be seen that the model includes disintegration of complex solids into inert substances, carbohydrates, proteins and fats. The products of disintegration are hydrolyzed to sugars, amino acids and long chain fatty acids (LCFA) respectively. Carbohydrates and proteins are fermented to produce volatile organic acids (acidogenesis) and molecular hydrogen. LCFA are oxidized anaerobically to produce acetate and molecular hydrogen. Propionate, butyrate and valerate are converted to acetate (acetogenesis) and molecular hydrogen. Methane is produced by both cleavage of acetate to methane (aceticlastic methanogenesis) and reduction of carbon dioxide by molecular hydrogen to produce methane (hydrogenotrophic methanogenesis).

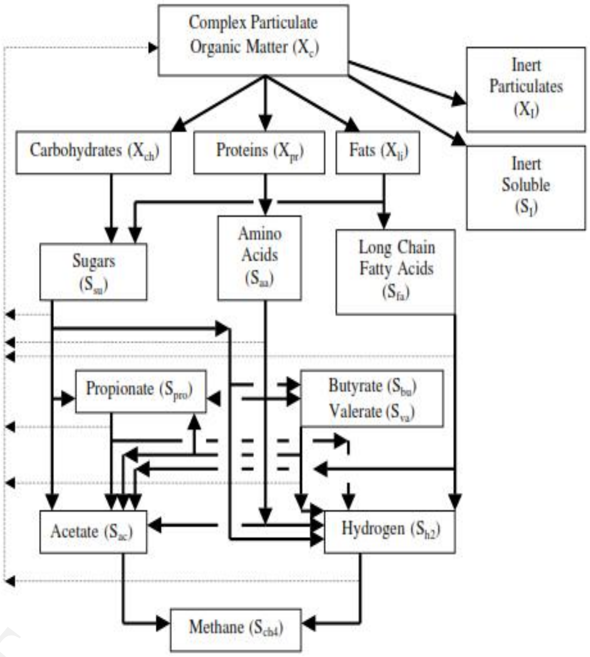


Fig.1 Conceptual model for ADM1 model

In ADM1 the input substrate is described through 28 variables. These are concentrations of 12 dissolved and 12 particulate substances, concentration of cations and anions, liquid flow speed and temperature. Three additional parameters are needed to describe the state of the reactor. These are concentrations of H_2, CH_4 and CO_2 in headspace [12].

Since its establishment, a lot of updates and extensions have been suggested for the model. A few of them, as well as some criticisms have been noted by Batstone et al. [13]. Rosen & Jeppson [14] discuss some issues concerning the materials balance of C and N in ADM1.

2.1 ADM1 Implementation

The model equations were implemented in the Matlab/Simulink platform version 7.8 according to the approach described in Rosen & Jeppsson [14]. All reactions, apart from the calculation of pH, are implemented as ordinary differential equations (ODE). As suggested by the same authors, the acid-base equilibrium is calculated using a nested routine in which the concentrations of acetate, butyrate, valerate, propionate, ammonium and hydronium are calculated. All kinetic and stoichiometric parameters used in the model, are listed in the original model proposed by Batstone. The ADM1 is a stiff model; a system is called stiff, when the range of the time constants is large. This means that some of the system states react quickly whereas some react sluggishly. The ADM1 is a very stiff system with time constants ranging from fractions of a second to months. This makes the simulation of such a system challenging and in order to avoid excessively long simulation times, one need to be somewhat creative when implementing the model. The best used solver for this model is the ODE 15s [15]. The ADM1 implementation in this paper were tested against the data published by Rosen & Jeppsson [14] as they give a complete influent and effluent parameters for their implementation, the tested implementation prove to be a accurate for all effluent parameters.

3. Materials and methods

3.1 Reactor set-up and sampling

In this research, two digesters were operated in the semi-continuous mode (SRTs = 20d) as the feeding was once daily, each digester had a total volume of approximately 32L and had an effective volume of 24 L figure (2) shows a schematic diagram of the used model, This study was held at the environmental engineering department laboratory at the faculty of engineering; Zagazig; Egypt.

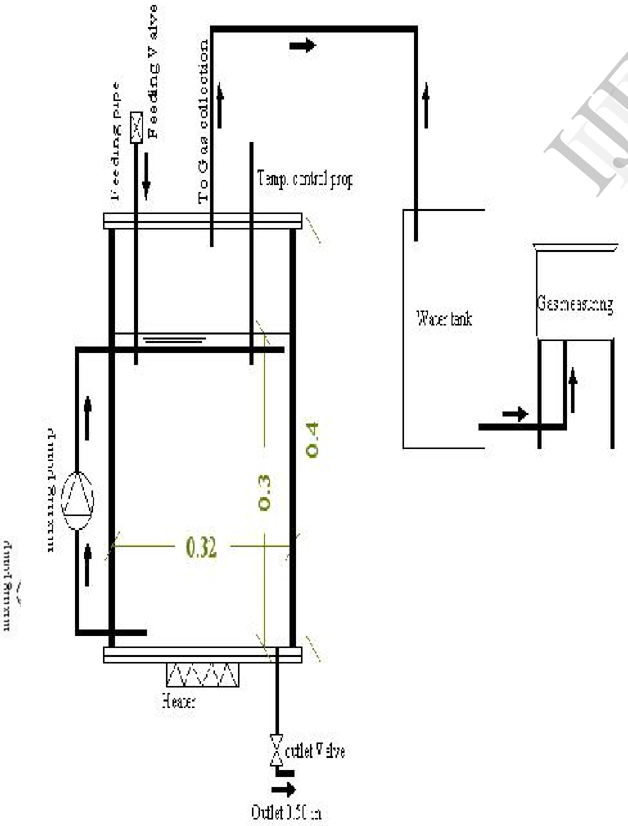


Figure 2 schematic diagram of the model

For more details about the reactors start up, operation and sampling refer to [7].

3.2 Parameter estimation

A basic parameter search routine was implemented in which different parameter combinations were tested. The first-order dissociation kinetic and hydrolysis constants were optimized, both for the untreated and EM1 treated sludge. As criterion, the sum of squared errors was used between the predicted and measured values of the biogas production.

4. Results and discussion

4.1 Control digester model

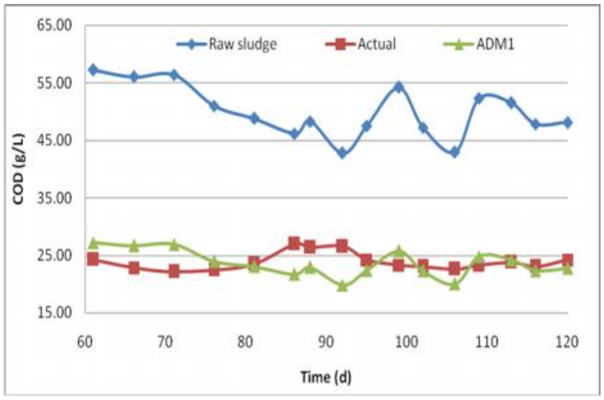
Despite the inclusion of specific components in the model, application of ADM1 exhibits some uncertainty. This is, however, due to the incomplete characterization of the substrate or digestion mixture. No reports have been made of a complete characterization of all specific components included in the model. Because of the inclusion of 7 microbial groups, which can be considered as undefined selections of microorganisms, a complete characterization is in effect almost unfeasible. As a result, some assumptions are required to cope with these and other issues [2].

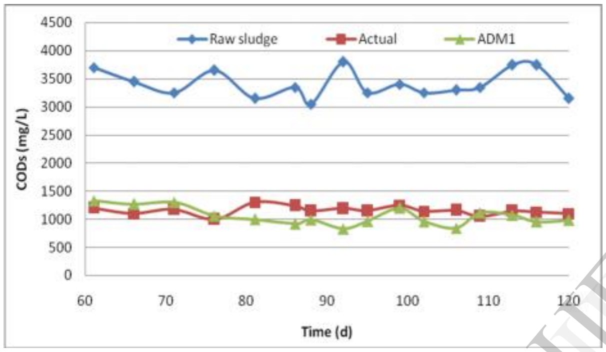
Firstly, the initial biomass concentrations are estimated by simulating ADM1 through several HRTs with an average feed composition and using the default parameters given by Rosen & Jeppsson [14]. The final biomass concentrations are taken as starting points for the simulation of the runs.

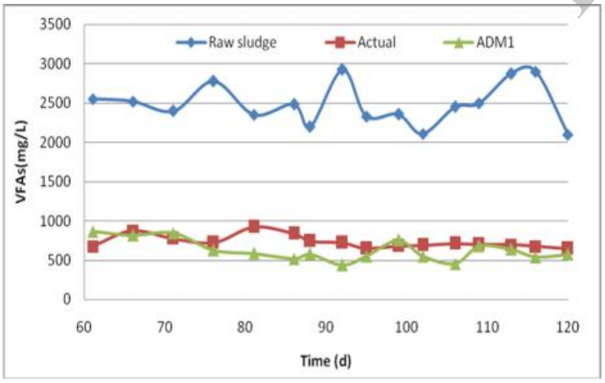
The comparison of the model predictions for effluent COD, CODs, VFAs, pH and gas production for the control digester is summarized in Fig. 3. It can be seen that the model was able to predict the effluent COD, CODs, VFAs and pH with considerable accuracy.

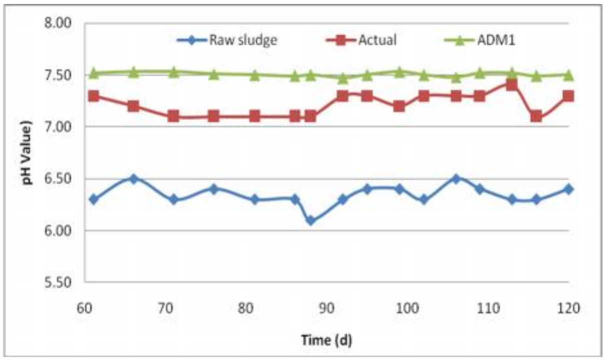
The actual effluent COD ranged between 22.17(g/L) and 26.96(g/L) while the COD predicted by the ADM1 ranged between 19.81(g/L) and 27.20(g/L), the actual effluent CODs ranged between 1000(mg/L) and 1300(mg/L) while the CODs predicted by the ADM1 ranged between 830(mg/L) and 1330(mg/L), the actual effluent VFAs ranged between 650(mg/L) and 925(mg/L) while the VFAs predicted by the ADM1 ranged between 439(mg/L) and 865(mg/L), the actual pH value ranged between 7.1 and 7.40 while the pH value ADM1 prediction ranged between 7.47 and 7.53. These results consist with the results of (Parker 2005, and Appels et al 2010) and shows that the assumed biochemical parameters and percent composition of the total COD is acceptable.

On the other hand the actual gas production was lower than the predicted values by the ADM1 this was mainly due to the short time of the experiment and also may be there was a leakage in the collected gas.









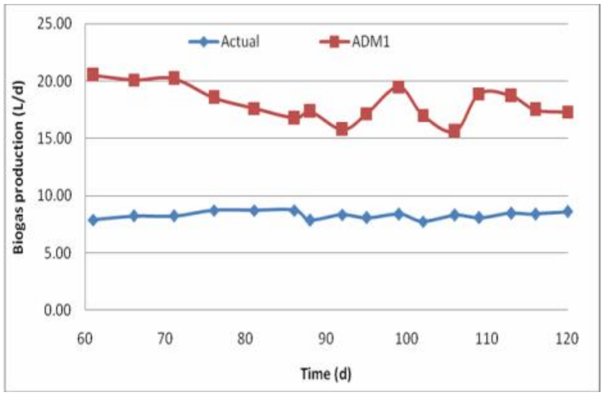


Figure 3 Actual and ADM1 prediction for COD, CODs, VFAs, pH and gas production for the control digester

4.2. EM treated sludge digester model

In order to extend the ADM1 model for the prediction of EM treatment the same characteristics and percent composition of the raw sludge were used as inputs for the model, Batstone in the original model order the sensitivity parameters of the model and consider the most sensitive parameter to be disintegration, hydrolysis and acetate uptake rate parameters with a variability varies within 300%. So after recalculating different combinations for disintegration and hydrolysis parameters the combinations presented in Table 1 are considered to be the most optimal for this study.

Table 1. Estimated parameters values for the untreated sludge (US) and EM treated sludge (EM)

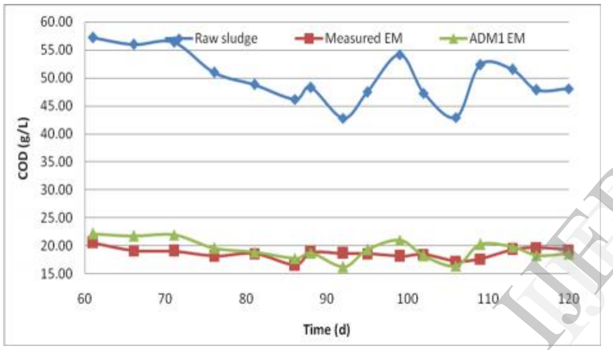
Parameters	Values (d^{-1})	
	US	MW 1
K_{dis}	0.50	0.75
K_{hydch}	10	15
K_{hydpr}	10	15
K_{hydli}	10	15
K_{mac}	8	12

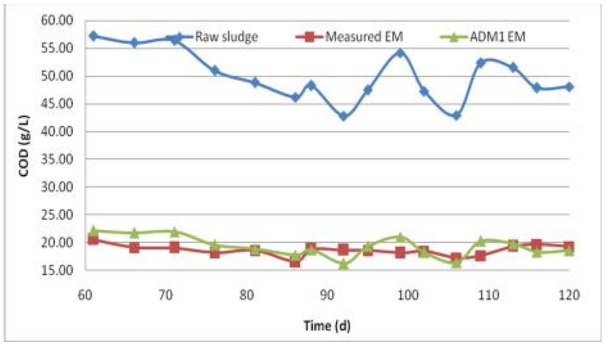
The comparison of the model predictions for effluent COD, CODs, VFAs, pH and gas production for the EM digester is summarized in Fig. 4. It can be seen that the model was able to predict the effluent COD, CODs, VFAs and pH with considerable accuracy.

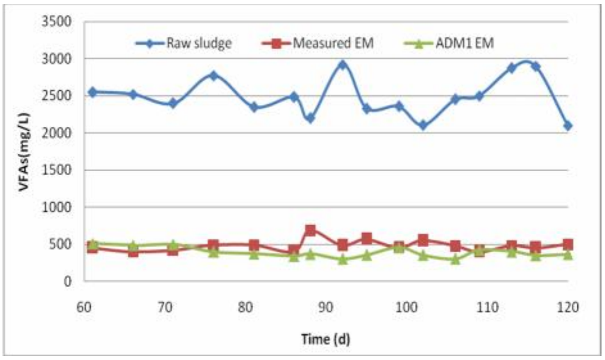
The actual effluent COD ranged between 16.56(g/L) and 20.57(g/L) while the COD predicted by the extended ADM1 (ADM1 EM) ranged between

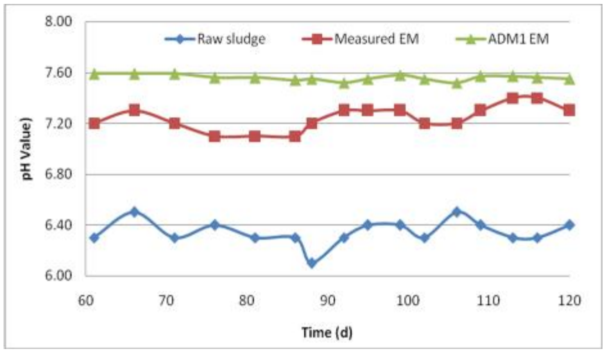
16.22(g/L) and 22.16(g/L), the actual effluent CODs ranged between 700(mg/L) and 970(mg/L) while the CODs predicted by the ADM1 EM ranged between 730(mg/L) and 1030(mg/L), the actual effluent VFAs ranged between 400(mg/L) and 690(mg/L) while the VFAs predicted by the ADM1 EM ranged between 305(mg/L) and 511(mg/L), the actual pH value ranged between 7.1 and 7.40 while the pH value ADM1 EM prediction ranged between 7.52 and 7.59. These results show that the assumed biochemical parameters and percent composition of the total COD could be accepted.

Also the actual gas production was lower than the predicted values by the ADM1 EM this insures the assumption that there was a leakage in the collected gas.









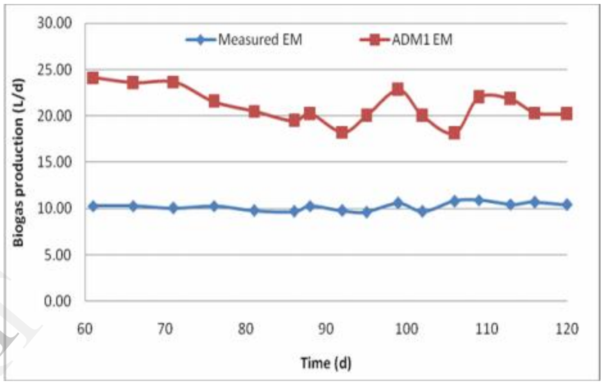


Figure 4 Actual and ADM1 prediction for COD, CODs, VFAs, pH and gas production for the EM digester

5. Conclusion

In this paper, An implementation of the ADM1 model was tested in order to describe the behaviour of mesophilic anaerobic digester, The ADM1 proved to be powerful tool for the prediction and control of mesophilic anaerobic digesters as the model predicted the behaviour of the control digesters with reasonable values for COD, CODs, VFAs and pH value, an extension was required for the model to describe the effect of using of effective microorganisms on the degradability of sludge, the extended ADM1 model also gave a good and acceptable values for the tested parameters, while a further investigation and testing is required for the extended model.

6.References

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