Performance Evaluation of an Up-Flow Anaerobic Sludge Blanket Reactor with a Bio-Filter Liner System

S. Narththanah[1,2], R. T. K. Ariyawansha[3], A.K. Karunarathna[2], B. F. A. Basnayake[2*]

Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya 20400, Sri Lanka[1]
Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka[2]
Sustainable Environment Research Group, School of Technology, Faculty of Engineering and Technology, Sri Lanka Technological Campus (SLTC Research University), Padukka 10500, Sri Lanka[3]

[*] benb@pdn.ac.lk

Abstract - The Up-flow Anaerobic Sludge Blanket Reactor (UASBR) is widely used due to its high potential in converting food waste to bio-gas. Long start-up periods and inhibitions due to high ion concentrations are common issues of UASBRs. Therefore, a prototype UASBR was designed and developed by incorporating biofilter liner system to address these issues. This study was conducted for 40 days to evaluate the performance of UASBR with the modifications in the feeding system, recirculation system, and newly established sludge removal port. Reactor performance was evaluated daily by analysing the physical and bio-chemical parameters. According to the results, several interventions were done to enhance the anaerobic digestion and to accelerate the start-up process. All the parameters fluctuated responding to the interventions. The overall mean pH of the bottom, middle, top, and permeate of the reactor throughout the study period was 3.83 ± 0.61, 4.47 ± 1.94, 4.16 ± 0.48, and 6.69 ± 1.42 respectively. Even though there was a low pH inside the reactor, the percentage of methane gas produced was observed to be in an increasing manner because methanogenic bacteria have started to adapt and acclimatize in the low pH range. Also towards the end, total nitrogen, nitrate-nitrogen, available phosphorous, and total potassium were detected in permeate. Thus, the composite liner system acts as a live biofilter providing optimum conditions in the anaerobic digestion process via reducing the inhibitions and to accelerate the start-up process.

Keywords: Food Waste, Biogas, Bio-Filter Liner System, Up-Flow Anaerobic Sludge Blanket Reactor

I. INTRODUCTION

According to the Food and Agriculture Organization of the United Nations, 2019, 1.3 billion tonnes of food production are wasted every year and it is one-third of world food production. Daily, a large quantity of food waste is generated at different stages along the food supply chain due to several reasons. Anaerobic digestion of food waste is a promising approach for managing biodegradable organic waste materials and biogas is one of the alternative energy sources [1]. The Up-flow Anaerobic Sludge Blanket Reactor (UASBR) is widely used due to its high potential to be applied in households and industries because it is a simple design, easy to construct, convenient to operate and maintain, low operating cost, and cost-effective. The main problem reported of USAB reactors is that a long-time period is needed to start-up process of the reactor due to the time required for the anaerobic granulation [2]. As well as the overload of minerals existing in USAB leads to reducing the efficiency of gas production. Based on all these past studies, a prototype UASBR was established by Bandara, 2018 and it was modified by Senevirathna, 2019. Observations made from those two studies were short performance evaluation period, recirculation frequency was not adequate, mass and energy balances, gas analysis and biochemical transformation kinetic analysis were not done. Hence, it is necessary to evaluate the performance of UASBR for a long period, in order to develop a pilot scale UASB reactor and to commercialize the UASBR.

II. MATERIALS AND METHODS

The prototype UASBR which was established by Bandara, 2018 and modified by Senevirathna, 2019 was re-modified and used as the experimental setup of the study. The modifications that had to be done to the experimental setup was drawn by using AutoCAD 2018. Mainly three modifications such as restoration of the feeding system, modification of the recirculation system and establishment of the sludge removal port were done to the experimental setup as shown in Fig. 1.

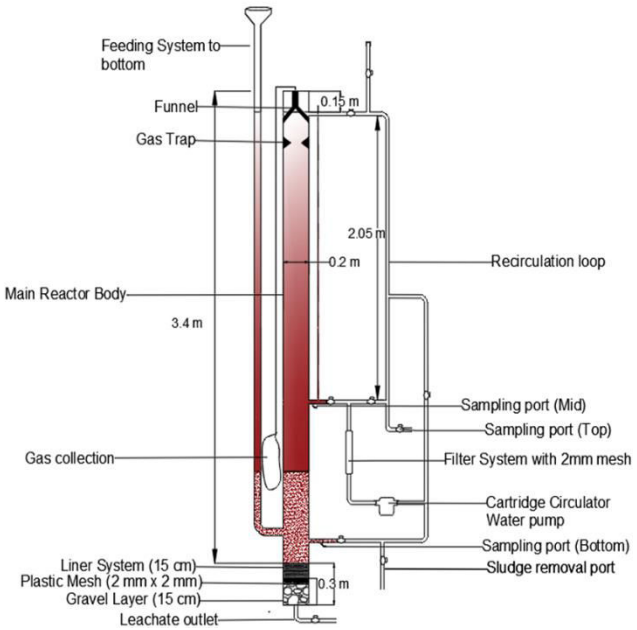

Fig. 1 A schematic diagram of the modified UASB reactor

In this study, food waste was prepared rather than collecting the food waste so as to ensure the optimum elemental composition of the feed required for anaerobic digestion and to formulate mass and energy balances. Initially, ingredients which are needed to be cooked were weighed according to the calculations done by using MS Excel Solver. The cooked food mixture weighed 24 kg. The cooked food mixture was blended by using an electric blender. Then it was mixed with 90 L of river water and fed to the reactor. 52 g of Triple super phosphate (TSP) was also added to the slurry in order to balance the C: N: P: S ratio. Before feeding, the feed characteristics were analysed for pH, conductivity, salinity, total dissolved solids (TDS), total solids (TS), volatile solids (VS), total nitrogen, available phosphorous, and total potassium by using standard methods and instruments. Samples were collected daily at 8.00 am from permeate, bottom, middle, and top of the reactor and stored in sampling bottles. Interventions such as recirculation, addition of water, 1M KOH, and triple super phosphate (TSP) and inoculum were done to accelerate the start-up process, based on daily evaluation results. Continuous feeding was initiated when the start-up process was observed to reach stable conditions. On 34th and 35th days and on 39th and 40th days 500 g (wb) food waste mixed with 3 L water was fed to the reactor from the bottom port. Performance evaluation was done for 40 days by analysing the samples which were collected from bottom, top, mid, and permeate in triplicates from the established UASBR by using the standard analytical procedure.

III. RESULTS AND DISCUSSION

The study was conducted only for 40 days. According to the results, the reactor has not completed the start-up process and stabilization during the experimental period. Even though there was a low pH value inside the reactor, the percentage of methane gas produced was observed to be increasing manner. On the 39th day, the percentage of produced methane gas out of the total percentage of gas composition was 1.55. So, it can be deduced that methanogenic bacteria have started to adapt and acclimatize in the low pH range. Some other interventions could be used in addition to the interventions that were used in this study, in order to accelerate the start-up process of the reactor and to increase the efficiency of the reactor. In this study, food waste which is 6 % of the total volume of the reactor was fed to the reactor but a continuous pH drop inside the reactor due to extreme hydrolysis and acidogenesis was observed. Thus, it is also necessary to study the pattern of organic loading rate in order to optimize the reactor performance. Beer addition also can be done to enhance the anaerobic condition inside the reactor and to accelerate the start-up process [3]. Inoculum with pH 6.98 was used in this study which was not within the desired pH range so inoculation with good quality can be used to enhance the methanogenic activities and to enhance the anaerobic digestion process. The top to middle recirculation is not possible with the existing recirculation system. In this study, top to bottom recirculation was done along with the addition of inoculum, which could led to the disturbance of the stratification process inside the reactor. Hence, top to middle recirculation has to be installed to overcome this consequence and to improve the efficient start-up process. Modified recirculation system, prepared slurry with a proper C:N:P elemental composition of 100:4.4:0.8 which was needed for anaerobic digestion, biofilter liner system with the permeability fluctuated between 2.0 x 10^{-6} - 5.2 x 10^{-6} cm/s and the established sludge removal port were the strengths for the performance of the UASB reactor.

IV. CONCLUSION

Performance evaluation of UASBR with biofilter liner system portrayed that the food waste used as feeding material was successfully converted to useful products. The pH particularly was an influential parameter which was intervened to increase the low pH values after the phases such as hydrolysis and acidogenesis of anaerobic digestion. In this experiment, establishment of the sludge removal port, modification of the recirculation system, and the feeding system did considerable influence to accelerate the start-up process. Towards the end, total nitrogen, nitrate-nitrogen, available phosphorous, and total potassium were detected in permeate and also, the permeability of the composite liner system was within the desired range. Thus, the composite liner acts as a live biofilter to make anaerobic system biologically stable, providing optimum conditions for anaerobic digestion via reducing the inhibitions. The study was terminated on 40th day due to the outbreak of COVID-19. Hence, the reactor had not completed the start-up and reached stabilization during the study period. It is recommended to continue the evaluation process with more interventions such as beer addition, the addition of good quality inoculum, installation of top to middle recirculation system, etc. to accelerate and stabilize the start-up process of the UASBR.

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