OPTIMIZATION OF FOOD WASTE TO SEWAGE SLUDGE RATIO FOR ANAEROBIC CO-DIGESTION PROCESS USING ARTIFICIAL NEURAL NETWORK (ANN) AND GENETIC ALGORITHM (GA)

MARIATUL FADZILLAH MANSOR*[1], NURUL SYAZWANA JAMALUDIN[1], HUSNA AHMAD TAJUDDIN[1]

Department of Biotechnology Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia.

*Correspondin Author:*mariatulf@iium.edu.my*

ABSTRACT: Food waste is a major global issue especially in developed countries. This is because of the abundance of food waste in landfills has contributed to the emission of greenhouse gas (GHG). Therefore, by using anaerobic co-digestion technology, food waste (FW) can be used as a substrate with sewage sludge (SS) to produce a valuable product such as methane gas. In order to find the optimal ratio of FW to SS as well as substrate-to-inoculum (SI) ratio for the highest methane production, the present study utilizes the Artificial Neural Network (ANN) and Genetic Algorithm (GA) model. This study is based on the secondary data sources from various research papers and articles. The digester operational parameters such as mixed substrate ratio and SI ratio were considered. The optimal feedstock ratio was evaluated based on its biochemical methane potential (BMP). The performance of the ANN model was verified to be effective in predicting the methane production accurately with a desirable R^2-value of 0.9838 and 0.9976. The trained ANN model was coupled with GA to optimize the methane production and to find the optimal feedstock ratio. The result of optimal mixed substrates ratio of FW:SS and SI ratio are similar which is 50:50 with the highest methane production of 454.4 mL CH^4/kg volatile solids (VS). However, the comparison of BMP from different substrates ratio shows inconsistency on the optimal ratio. Hence, other parameters such as particle size and mixing rate should be considered.

KEY WORDS: *Optimization; Biochemical Methane Potential (BMP); Food waste; Sewage sludge; Artificial Neural Network; Genetic Algorithm*

1. INTRODUCTION

Energy demand has been escalating every year whereas 88% of energy were based on fossil fuels [1]. However, burning of fossil fuels contribute to the release of harmful gases which will negatively affect the environment [2]. Therefore, the needs for replacing fossil fuels with carbon-free energy as an energy source is increasing in order to reduce the negative impact of fossil fuels.

Renewable resources were found to have a good potential for energy sources [1]. Usage of renewable resources are able to reduce the greenhouse gases (GHG) emissions as well as environmental pollutions [3]. Furthermore, many countries have abundance of biomass waste which include food waste and animal waste. Abundance of biomass waste leads to the emissions of GHG especially methane gas [4].

Mono fermentation poses critical difficulties in terms of both biological and technical process in the interior anaerobic digestion. Anaerobic co-digestion is a viable technology to capture biogas in the form of carbon dioxide and methane. Bioenergy production could be improved by co-digesting one substrate with another type of substrate such as food waste (FW) and sewage sludge (SS). The combination between co-substrates led to positive impacts to AD system, such as balance (C/N ratio, pH and moisture), dilutions of potentially toxic compounds and supplement of trace elements. Thus, studies on AcoD has the potential efficiency to solve the limitations occur during mono AD. [5].

In order to find the maximum methane production of an organic feedstock, biochemical methane potential (BMP) of these feedstocks are measured. BMP is evaluated based on the cumulation methane production at the end of the BMP test [6]. There are various possible parameters that may affect BMP such as substrate, inoculum, temperature and retention time [7]. A good ratio of feedstock or substrate used could enhance the methane yield as well as the BMP [8].

Thus, this study is conducted to study the effect of feedstock ratio on methane production based on its BMP. The previous studies have shown the potential of various feedstock ratios in enhancing the methane production. For example, in [6], the highest methane production was obtained with FW:SS of 100:0. On the other hand, in [9], the optimum FW to SS ratio of 3:1 produced a maximum biogas yield as well as methane yield. However, in [10], they claimed that FW:SS ratios of 50:50 showed a very high methane recovery compared to SS mono-digestion.

An emerging artificial intelligent (AI) tool such as Artificial Neural Network (ANN) and Genetic Algorithm (GA) are considered to be efficient for modelling and designing an optimal solution for various engineering problems [11]. Here, ANN and GA are applied to find the optimum feedstock ratio for methane production. There are several studies used the hybrid tool of ANN-GA for optimization problem. In [12], they utilizes ANN and GA for modelling and optimization of biogas production from a waste digester. This study able to define the best digester operational conditions for maximum methane production [12]. In [11], an ANN topology of 5-2-1 had successfully predicted the biogas performance on saw dust and served as a fitness function for the GA optimization process. In result, the biogas production was increased up to 8.64% than the actual value [11]. In [13], they applied ANN-GA tool to predict and optimize the biogas production process in respect of biogas production rate.

Optimizing the input parameters especially the feedstock ratio will help to improve the methane production as well as enhance the performance of biogas plant. Hence, this study will discuss the optimal mixed substrates ratio of FW and SS, optimal SI ratio and comparison of various substrates ratio on BMP from different papers.

2. METHODOLOGY

2.1 Data collection

The articles were obtained from several databases such as Google Scholar and Scopus. To obtain relevant articles for this study, a series of criteria were defined. The following criterias were considered to be included in the papers or articles:

- Search for papers published in the last 10 years (2011-2021)
- Ensure that the articles contain at least one keyword in their title or abstract

This study focuses on a single-stage process at the mesophilic condition. The range of parameters considered in this study is shown in Table 1.

Table 1: Summary of input dataset characterization

Food Waste (%)	Sewage Sludge (%)	Substrate (%)	Inoculum (%)	Retention Time (days)	Temperature (°C)
0-100	0-100	0-100	0-100	20-60	30-37

2.2 Analytical Procedure

2.2.1 Development of ANN model

For the prediction of methane production, a feedforward neural network embedded in MATLAB R2020a ANN toolbox was applied. The collected data were fed into the ANN model and the connection weights were adjusted by using back-propagation (BP) algorithm. ANN model included an input layer, a hidden layer and an output layer is shown in Figure 1.

Four input layers and one output layer were chosen based on the number of input and output variables. Here, ANN model with 6 hidden neurons was able to simulate the reactor operational parameters with a good accuracy. Trial and error approach were used in the simulation process to obtain the best values of network parameters.

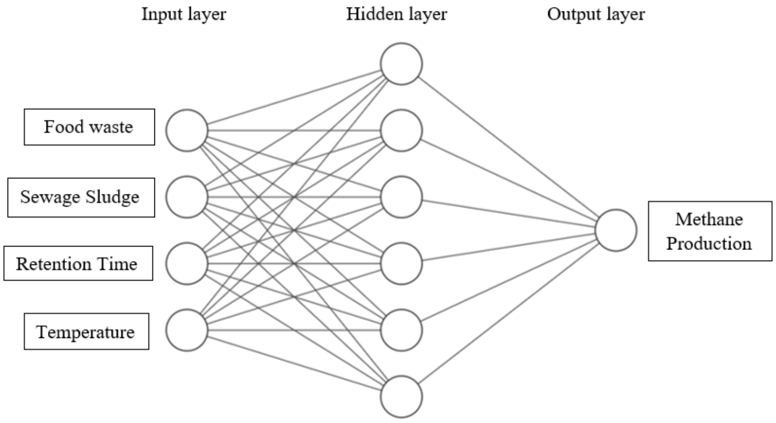

Figure 1: Architecture of ANN model (4-6-1)

A similar method was applied to the second objective. Here, the ANN model with four hidden neurons were chosen. The architecture of ANN model is shown in Figure 2.

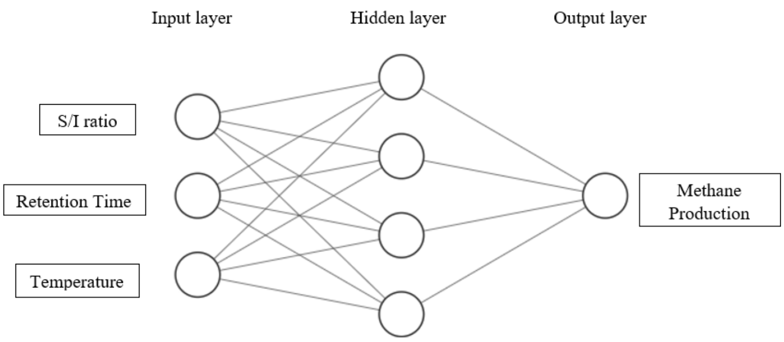

Figure 2: Architecture of ANN model (3-4-1)

2.2.2 Development of GA model

After developing the trained ANN model, GA model was used to optimize the input variables (Food Waste and Sewage Sludge ratio), with the objective to maximize the methane production. The GA model was executed by using ANN train model as the fitness function to give the optimization solution for the problem [14]. In this study, the following algorithm parameters were applied: crossover fraction of 0.8 and four individuals with population size of 200.

A similar method was applied to the second objective, where the trained ANN model was used to develop the GA model for the optimization of input variables (SI ratio) with the objective of maximizing the methane production. Here, the following algorithm parameters were used: crossover fraction of 0.8 and 3 individuals with population size of 200.

2.2.3 Comparison of Biochemical Methane Potential

The BMP of the substrate was evaluated based on the cumulative methane yield (CMY) at the end of the BMP test [6]. The BMP can be calculated by using Eq. (1),

$$\text{BMP} = \frac{V_{CH_4} - V_{CH_4.\ \text{blank}}}{(\text{Mass of VS fed in biodigester})} \quad (1)$$

BMP can be defined as the amount of methane production per gram of volatile solids (VS). Following the results, the BMP of mixed substrates (FW and SS) from different substrates ratios were obtained and compared to validate the result of the current study. In addition, the SI ratio of the articles collected must be similar with the optimal SI ratio obtained from this study.

3. RESULTS AND DISCUSSION

3.1 Optimization of FW and SS ratio using ANN-GA model

An ANN model was used to simulate and predict the methane production process using the operational parameters of a digester as inputs. A group of 20 data were obtained and the collected data were fed to the ANN model to train, test and validate the network randomly with 65% train data, 25% test data and 10% validation data [14].

The performance of ANN model were evaluated using statistical indicators techniques such as Mean Square Error (MSE), correlation coefficient (R) and coefficient of determination (R^2). A good network model was validated with maximum values of R and R^2 and minimum value of MSE [15].

Figure 3 illustrates the validation performance and mean squared error of the ANN network. The figure shows the ANN model for 20 data points revealed the least MSE at epoch 2 which has the best validation performance of 156.3. It can be seen that the ANN model was succeeded in reducing the MSE until epoch 2.

Next, the ANN model was evaluated based on the value of correlation coefficient (R). The correlation coefficient value or regression value of ANN model is shown in Figure 4. Based on the figure, the training, validation and testing set shows a desirable R-value which is near to 1. The R-value is 0.9934, 0.94143 and 0.99997 for training, validation and testing steps, respectively. These values indicate a good ANN model that provides a good performance of network [16].

The other statistical indicator technique used to evaluate the network is the coefficient of determination (R^2). Figure 5 illustrates the simulation capable of predicting the methane production very accurately, which implies the relationship between the operational parameters (input to the digester) and the methane production. The high determination coefficient (R^2) of 0.9838 shows that the predicted value fits well with the actual values.

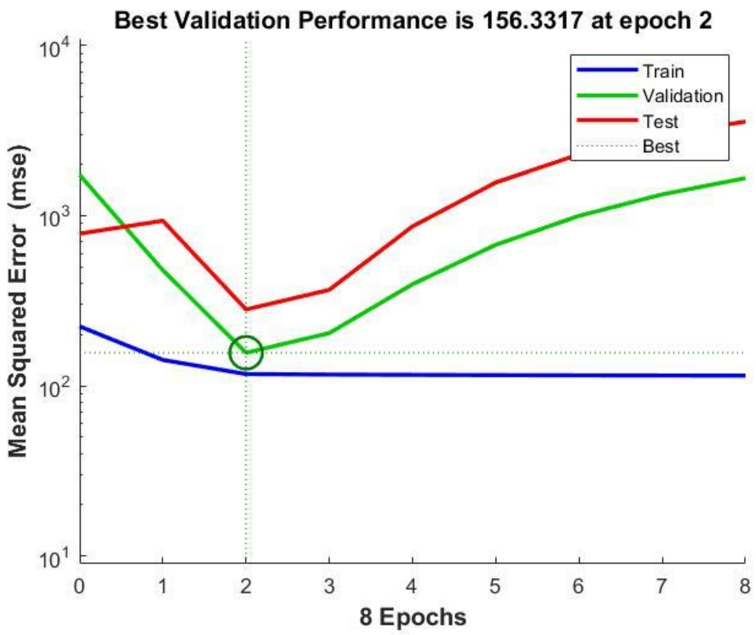

Figure 3: Best validation performance of ANN model

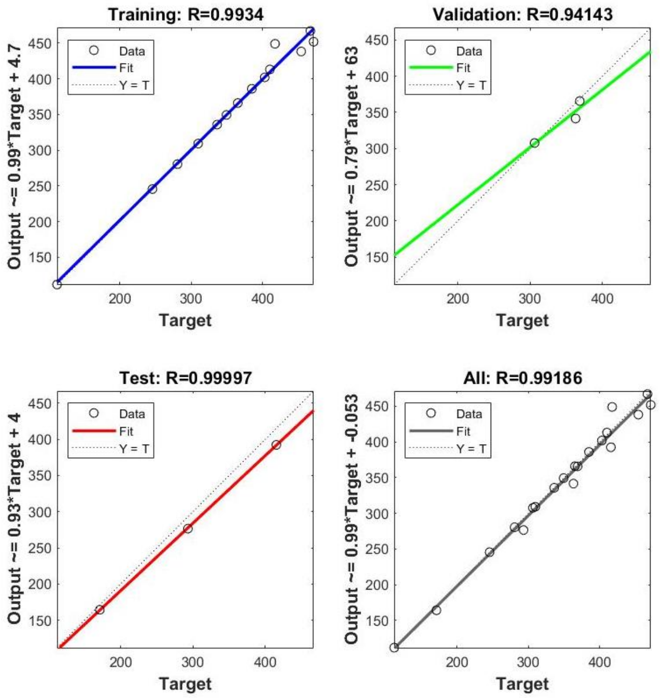

Figure 4: Regression value of ANN model

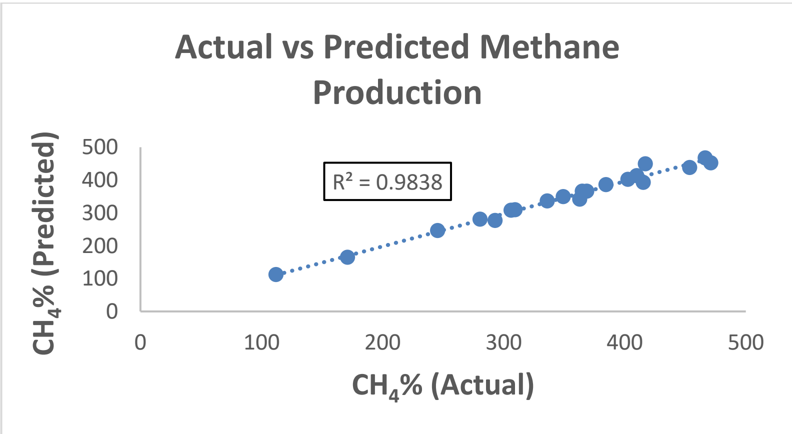

Figure 5: Actual versus predicted methane production from ANN model

Next, the ANN model was integrated with a GA model to predict the optimal combination of the operational parameters of a digester for maximum methane production. The model was run without constraint with crossover fraction of 0.8 and a population size of 200. According to the results, the highest methane yield obtained from the GA model is 471.1 mL CH_4/kg VS. Hence, the optimal ratio for the co-digestion of food waste and sewage sludge is tabulated in Table 2.

Table 2: Optimal ratio of FW and SS as determined by GA optimization process

Operational Parameters	**Optimal Value**
Food waste ratio	50
Sewage sludge ratio	50

3.2 Optimization of SI ratio using ANN-GA model

The collected data were based on the optimal FW and SS from this study which are 50:50. Due to that, there were only few papers that were relevant for this study. Therefore, all the data collected were applied to training set as the data is not enough to be applied to validation and test set.

Figure 6 shows the training performance of ANN model. Based on the figure, the best training performance was achieved at epoch 17, which has the least MSE value. Besides, the MSE of training step was succeeded to be reduced from a large value to a small value. According to the figure, the best training performance is 4.28e-19 which is closed to zero. It shows that the actual outputs and the ANN model outputs for the training set is close to each other [17].

Figure 7 illustrates the correlation between the actual targets and the network outputs values for training step. According to this figure, the training shows a desirable R-value which is 0.9976. The R-value shows a strong association between the two variables, targets and outputs. Therefore, this ANN model can be considered as a good model as the model shows a good fit between the targets and the outputs.

A default crossover fraction of 0.8 and 200 populations were used to execute the GA model. The optimal methane production obtained from the GA optimization results against the SI ratio are shown in Figure 8. Based on the figure, a higher SI ratio has a lower methane production. In addition, the highest methane production obtained from the GA model is 454.4 mL CH_4/ kg VS with SI ratio of 50:50. Therefore, the SI ratio of 50:50 is the best ratio to produce higher methane production.

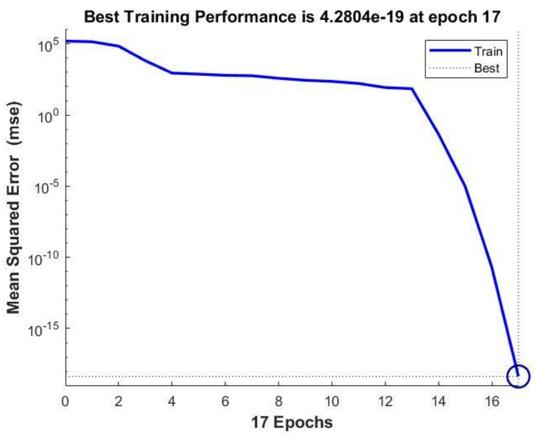

Figure 6: Training performance of ANN model

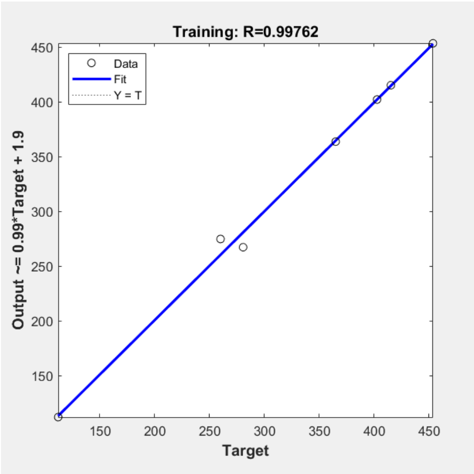

Figure 7: Training regression value of ANN model

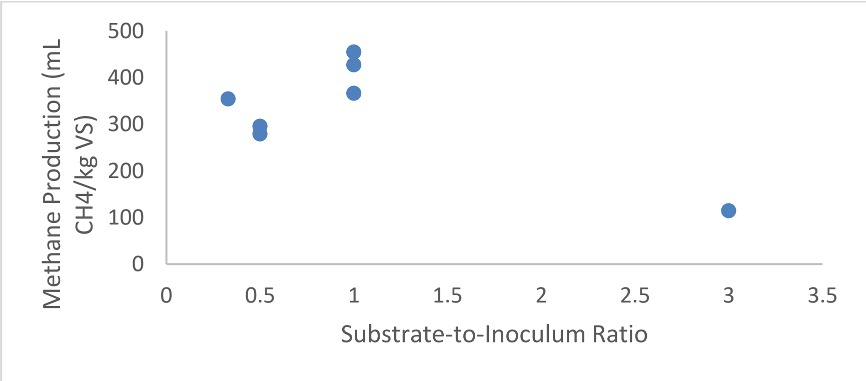

Figure 8: Methane production versus SI ratio

3.3 Comparison of BMP from different substrate ratios

BMP can be defined as the amount of methane production per gram of volatile solids (VS). Based on the result, the BMP of the substrate is 454.4 mL CH_4/ kg VS. The collected data obtained for this study were similar to the previous objective in which the SI ratio must be 50:50.

The BMP for co-digestion of FW and SS with different ratios are illustrated in Figure 9. According to the figure, the highest BMP was obtained at 33% FW, followed by 75% FW and 50% FW where the BMP is 471.1, 466.5 and 454.4 mL CH_4/ kg VS, respectively. However, based on the BMP trend, the lower the FW ratio, the lower the BMP is. Recent reviews on BMP shows a lack of consistency among the studies as different studies claim different ratios of mixed substrate for the highest BMP.

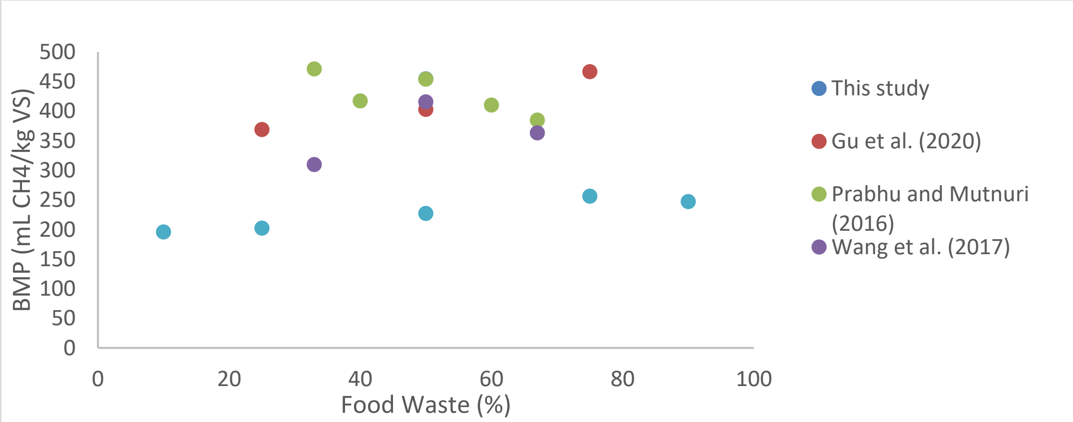

Figure 9: Food waste versus BMP

A lower BMP was obtained at lower FW ratio [6,18]. The BMP of the mixed substrates (FW and SS) increased as the fraction of FW increased which shows the degradation rate of FW to produce methane is higher than SS [6]. Similar to [18], the BMP increased as the FW increased but only up until 75% FW in which at 90% FW, the BMP starts to decrease. This is because 90% FW had some inhibition to produce methane as it has the slowest rate of methane production. Co-digested 75% FW with 25% SS is beneficial as FW produce high amount of methane due to its high biodegradation rate while SS acts as a buffer [18]. However, it was opposed by [19] where highest BMP was obtained at the lowest ratio of FW (33:67). FW and SS at a ratio of 33:67 produce the highest methane production (471.1 mL/ g VS) followed by a co-digestion ratio FW:SS 50:50 (453.7 mL/ g VS) [19].

In [20], the authors claimed that the highest BMP was obtained at 50% FW while FW with 33% ratio has the lowest BMP. The co-digestion of FW and SS with mixing ratio of 50:50 produce the highest methane yield of 415.3 mL/g VS. A similar composition of FW and SS has balanced the C/N ratio and improve the performance of anaerobic digestion. In addition, the BMP from co-digestion of 50:50 FW/SS was 14.4% higher than that of 33:67 FW/SS. This happen due to the high proportion of SS which contains high amount of non-biodegradable organic matters. Besides, VFA accumulation and increase in acidification reduce the methane production which happen with higher ratio of FW. On the other hand, higher amount of SS contributes to lower substrate degradation and C/N ratio which significantly decrease the methane production [20].

It can be concluded that the BMP from co-digestion of mixed substrate (FW and SS) varied depending on the study. Methane yield of anaerobic digestion of FW is highly variable as it depends on the FW quality such as particle size, composition, mixing as well as if any pre-treatment method was used [18].

4. CONCLUSION

Parameters such as mixed substrates ratio (Food Waste and Sewage Sludge) and substrate-to-inoculum (SI) ratio used in the co-digestion of food waste and sewage sludge process have affected the biochemical methane potential (BMP). The ANN-GA hybrid model was proven to be capable of simulating the methane production process and identified the optimal feedstock ratio. Based on the results, the ANN model was validated to be highly correlated to the real data as the coefficient of determination, R^2 values are 0.9838 and 0.9976. The results show that the optimum ratio of mixed substrates and the SI ratio obtained from this study were similar, which is 50:50. However, different studies have different optimum ratios, hence, the optimum value should be depending on various parameters including substrate composition, particle size and mixing rate.

It is recommended in the future to study the impact of other parameters such as pH, total solids, organic loading rate and volatile solids in order to obtain more accurate results. Besides, the results obtained from this study should be verified by the full-scale operation in order to optimize the methane production. Using a large data set is advisable to obtain more accurate results.

ACKNOWLEDGEMENT

The authors thanked the IIUM Research Acculturation Grant Scheme 2018 (IRAGS18-018-0019) for supporting this work.

REFERENCES

[1] Sawyerr, N., Trois, C., & Workneh, T. (2019). Identification and characterization of potential feedstock for biogas production in South Africa. Journal of Ecological Engineering, 20(6), 103–116.

[2] Ullah Khan, I., Hafiz Dzarfan Othman, M., Hashim, H., Matsuura, T., Ismail, A. F., Rezaei-DashtArzhandi, M., & Wan Azelee, I. (2017). Biogas as a renewable energy fuel – A review of biogas upgrading, utilisation and storage. Energy Conversion and Management, 150(October), 277–294.

[3] Fitamo, T., Triolo, J. M., Boldrin, A., & Scheutz, C. (2017). Rapid biochemical methane potential prediction of urban organic waste with near-infrared reflectance spectroscopy. Water Research, 119, 242–251.

[4] Khalid, A., Arshad, M., Anjum, M., Mahmood, T., & Dawson, L. (2011). The anaerobic digestion of solid organic waste. Waste Management, 31(8), 1737–1744.

[5] Hosen. M. S., Mansor, M. F. & Alam, M. Z. (2019). Anaerobic co-digestion of food waste and sewage sludge as a promising alternative for waste management and energy production. Biological and Natural Resources Engineering Journal, Vol. 2, No. 1,27-46.

[6] Gu, J., Liu, R., Cheng, Y., Stanisavljevic, N., Li, L., Djatkov, D., Peng, X., & Wang, X. (2020). Anaerobic co-digestion of food waste and sewage sludge under mesophilic and thermophilic conditions: Focusing on synergistic effects on methane production. Bioresource Technology, 301(November 2019), 122765.

[7] Raposo, F., De La Rubia, M. A., Fernández-Cegrí, V., & Borja, R. (2012). Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. Renewable and Sustainable Energy Reviews, 16(1), 861–877.

[8] Hobbs, S. R., Landis, A. E., Rittmann, B. E., Young, M. N., & Parameswaran, P. (2018). Enhancing anaerobic digestion of food waste through biochemical methane potential assays at different substrate: inoculum ratios. Waste Management, 71, 612–617.

[9] Latha, K., Velraj, R., Shanmugam, P., & Sivanesan, S. (2019). Mixing strategies of high solids anaerobic co-digestion using food waste with sewage sludge for enhanced biogas production. Journal of Cleaner Production, 210, 388–400.

[10] Pan, Y., Zhi, Z., Zhen, G., Lu, X., Bakonyi, P., Li, Y. Y., Zhao, Y., & Rajesh Banu, J. (2019). Synergistic effect and biodegradation kinetics of sewage sludge and food waste mesophilic anaerobic co-digestion and the underlying stimulation mechanisms. Fuel, 253(December 2018), 40–49.

[11] Gueguim Kana, E. B., Oloke, J. K., Lateef, A., & Adesiyan, M. O. (2012). Modeling and optimization of biogas production on saw dust and other co-substrates using Artificial Neural network and Genetic Algorithm. Renewable Energy, 46, 276–281.

[12] Abu Qdais, H., Bani Hani, K., & Shatnawi, N. (2010). Modeling and optimization of biogas production from a waste digester using artificial neural network and genetic algorithm. Resources, Conservation and Recycling, 54(6), 359–363.

[13] Beltramo, T., Klocke, M., & Hitzmann, B. (2019). Prediction of the biogas production using GA and ACO input features selection method for ANN model. Information Processing in Agriculture, 6(3), 349–356.

[14] Karimi, H., & Ghaedi, M. (2014). Application of artificial neural network and genetic algorithm to modeling and optimization of removal of methylene blue using activated carbon. Journal of Industrial and Engineering Chemistry, 20(4), 2471–2476.

[15] Mohamed, Z. E. (2019). Using the artificial neural networks for prediction and validating solar radiation. Journal of the Egyptian Mathematical Society, 27(1).

[16] Hamadi, A. S., Jassim, M. K., & Mahmood, T. A. (2020). Use of artificial neural networks for predicting water separation in water oil emulsion. *AIP* Conference Proceedings, 2213(March).

[17] Chamikara, M.A.P.. (2014). Re: What is best validation performance in artificial neural network?. Retrieved from: https://www.researchgate.net/post/What-is-best-validation-performance-in-artificial-neural-network/547f377bd3df3e434a8b47fc/citation/download.

[18] Burmistrova, J. (2019). Assessment of anaerobic co-digestion of food waste and wastewater solids for sustainable waste management in Yosemite National Park, USA. *UC Merced*. ProQuest ID: Burmistrova_ucmerced_1660M_10537. Merritt ID: ark:/13030/m5576k4f. Retrieved from https://escholarship.org/uc/item/5fz253hh

[19] Prabhu, M. S., & Mutnuri, S. (2016). Anaerobic co-digestion of sewage sludge and food waste.

[20] Wang, N., Zheng, T., & Ma, Y. (2020). New insights into the co-locating concept on synergistic co-digestion of sewage sludge and food waste towards energy self-sufficient in future WWTPs. Bioresource Technology Reports, 10, 100351.