Methane Gas Production from different composition of Food Waste and Chicken Manure

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Abstract. High carbohydrate content in food waste is one of the characteristic suitable acted as a co-substrate for fermentation to produce methane gas. In this study, co-digestion of chicken manure (CM) and food waste (FW) was used for fermentation process in methane gas production. The different effects of the independent variables (ratio, pH and temperature) is the most significant parameters of methane gas fermentation of CM and FW were investigated. Based on the analytical study showed a good fit between the experimental and the predicted data as the R² values of 0.991 with methane yield to be 537 mL CH₄/g VS at ratio 80:20 (CM:FW); temperature 35 °C; and initial pH 7.11 in 20 days of fermentation. The experiment was then performed based on optimized parameters of pH, temperature and ratio at the highest yield of methane obtained from optimum parameters. After optimization, the result showed that the pH 7.11 at 35 °C temperature and the ratio of 80:20 with methane production yield of 1560.5 mL CH₄/g VS for the 21 days of digestion process.

1. Introduction
According to the Federation of Livestock Farmers’ Associations of Malaysia [1], in the year 2010, more than 548 millions broiler produced in Malaysia. Chicken meat is the most consumed food in Malaysia amongst the residents for urban and rural [2]. The increasing of chicken meat consumption is seen in Malaysia from 36 to 39 kgs of per capita from 2000 to the year 2011 [3]. Therefore large amounts of the poultry waste generated gives environmental problems. Therefore, the increasing of poultry population will increase the production of chicken manure. Anaerobic digestion is one method for the treatment of chicken wastes in the absence of oxygen and proven as an efficient process in green technology for animal manure [4]. Uncontrolled discharge of chicken wastes has negative effects on the environment and necessary to minimize. Chicken manure is a potential substrate to produce the methane gas due to rich in a variety of nutrients where it was...
necessary for bacterial growth for support in fermentation process [5,6]. Food waste is a good co-substrate for waste activated sludge fermentation, with high C:N ratio and abundant organic matters to produce methane gas [7]. The productions of biogas during single fermentation are low compared mixing of two wastes.

2. Experimental Method

2.1 Material preparations

Chicken manure (CM) was collected from the chicken farm located at University Putra Malaysia (UPM), Serdang. Food waste (FW) was collected from the Cafeteria at Restaurants nearest Sri Serdang. FW was separated into three categories; carbohydrate (rice), fiber (vegetable) and protein (meat and fish) at a ratio of 3:2:2. 1000 g of FW was ground in 1000 mL water using a blender (Panasonic) and keep in cool room prior to use.

2.2 Operating Procedure

Batch digestion test was carried out in a polyvinyl chloride pipe (pvc) with a total volume of 2.5 L and a working volume at 2 L. The CM and FW placed in the pvc at different ratios of PM and FW; 100:0, 80:20, 60:40 and 40:60 and incubated in a water bath at different temperatures (25, 30, 35, 40 and 45 °C). The pH values (6.5, 7.0, 7.5 and 8.0) were adjusted using 3M HCl and 3M NaOH. The gas produced was measured on a daily basis. The batch fermentation in the column was carried out for 20 days. Each column was flushed with nitrogen gas for 15 min with a flow rate of 2 L/min in order to remove the oxygen content. The gas from the gas bag was injected to the tubing of the gas detector and the concentration of methane was measured.

2.3 Experimental Design and Optimization

The software Design-Expert 6.0 (Stat Ease Inc. Minneapolis, USA with Design Expert 6.0.6 of central composite design (CCD) was used in the optimization of methane gas production from the mixer at different compositions of FW and CM with 20 runs.

Table 1. Codes at initial pH, temperature and ratio for different substrates of chicken manure and food waste.

| Run | Real numbers | SMP | Predicted numbers |
|-----|--------------|-----|-------------------|
|     | X<sub>1</sub> | X<sub>2</sub> | X<sub>3</sub> | (mL CH<sub>4</sub>/g VS) | RSM |
| 1   | 7            | 25   | 80              | 123±0.09            | 106.35 |
| 2   | 7            | 35   | 40              | 152±0.05            | 132.39 |
| 3   | 7            | 35   | 80              | 550±0.05            | 535.13 |
| 4   | 8            | 35   | 80              | 511±0.02            | 503.35 |
| 5   | 7            | 35   | 80              | 544±0.02            | 535.13 |
| 6   | 7.5          | 30   | 100             | 360±0.08            | 376.09 |
| 7   | 7.5          | 30   | 60              | 241±0.05            | 249.21 |
| 8   | 7            | 45   | 80              | 201±0.01            | 199.85 |
| 9   | 6.5          | 40   | 60              | 399±0.01            | 400.71 |
| 10  | 7            | 35   | 100             | 438±0.05            | 445.23 |
| 11  | 6.5          | 40   | 100             | 293±0.06            | 302.59 |
| 12  | 7            | 35   | 80              | 521±0.05            | 535.13 |
| 13  | 6            | 35   | 80              | 498±0.03            | 487.85 |
3. Result and Discussion

3.1 Optimization of initial pH, temperature and ratio of poultry manure and food waste.
The mathematical equation of regression model for analyzing was based on the analysis data of variance (ANOVA) model. The regression models of pH ($X_1$), different temperatures ($X_2$) and different ratios of substrate ($X_3$) for methane gas as follows:

\[
Y_{SMP} = 535.13 + 3.88 X_1 + 23.38X_2 + 7.19X_3 - 9.88X_1^2 - 95.51X_2^2 - 97.09X_3^2 + 0.50X_1X_2 + 15.75X_1X_3 - 40.50X_2X_3
\]  
(1)

Equation 1 of regression model represents specific methane production and Summary of ANOVA is shown in Table 2.

### Table 2. Analysis of variance (ANOVA) for the different composition of chicken manure and food waste.

| Sources  | Sum of square | Df | Mean square | F-value | Prob>F |
|----------|---------------|----|-------------|---------|--------|
| Model    | 3.81E+05      | 9  | 42334.48    | 122.7   | <0.0001|
| $X_1$    | 240.25        | 1  | 240.25      | 0.7     | 0.4235 |
| $X_2$    | 8742.25       | 1  | 8742.25     | 25.34   | 0.0005 |
| $X_3$    | 543.93        | 1  | 543.93      | 1.58    | 0.2378 |
| $X_1^2$  | 2525.84       | 1  | 2525.84     | 7.32    | 0.0221 |
| $X_2^2$  | 2.36E+05      | 1  | 2.36E+05    | 683.76  | <0.0001|
| $X_3^2$  | 1.23E+05      | 1  | 1.23E+05    | 357.2   | <0.0001|
| $X_1X_2$ | 1984.5        | 1  | 1984.5      | 5.75    | 0.0374 |
| $X_1X_3$ | 13122         | 1  | 13122       | 38.03   | 0.0001 |
| $X_2X_3$ | 345.026       | 10 | 345.03      |         |        |
| Residual | 2754.26       | 5  | 550.85      | 3.96    | 0.0787 |
| Lack of fit | 2754.26       | 5  | 550.85      | 3.96    | 0.0787 |

C.V 4.8

$R^2$ 0.991

Adjusted $R^2$ 0.9829

3.2 The optimum response analysis and model validation using RSM.
The optimum conditions for maximizing SMP was set up the partial derivatives of Equation (1) to zero with respect to the corresponding variables. Based on the optimization, the optimum conditions were:
initial pH 7.11 with ratio of chicken manure and food waste being at 80:20 at 35°C of temperature. The maximum response results for SMP was estimated as 537 mL CH₄/g VS. Based on the Table 3, the confirmation of specific methane production of 537 mL CH₄/g VS, which is close to the actual values of 535.13 mL CH₄/g VS by using RSM analysis.

Table 3. The predications using RSM for actual and predicted.

| pH  | Temp (°C) | Ratio (PM:FW) | RSM (mL CH₄/g VS) |
|-----|-----------|---------------|-------------------|
| 7.11| 35        | 80:20         | 535.13            |
| 7   | 35        | 80:20         | -                 |

3.3 Optimization of methane yield

Chicken manure and food waste were used as substrate for methane production at the optimum ratio of 80:20. The characteristics waste at ratio 80:20 used to analyze for study the next fermentation using the optimized parameter. For the first objective, the waste at the different ratios were tested of batch test to represent the optimum parameters for the production of methane gas. The results are tabulated in Table 4 shows the characteristics of two different inoculum sources used consisting of poultry manure and food waste at the ratio of 80:20 under optimized parameters of pH, temperature and ratio of poultry manure to food waste.

Table 4. Characteristics of poultry manure and food waste used at ratio 80:20 used.

| Parameters                        | Unit | PM+FW         |
|-----------------------------------|------|---------------|
| pH                                | --   | 7.3           |
| Total Solid (TS)                  | mg/L | 89400         |
| Total Suspended Solid (TSS)       | mg/L | 78330         |
| Total Volatile Solid (TVS)        | mg/L | 52000         |
| Volatile Suspended Solid (VSS)    | mg/L | 38530         |
| Chemical Oxygen Demand (COD)      | mg/L | 44500         |

Characteristics of the chicken manure and food waste at ratio 80:20 was studied. pH of the sample changed to 7.3 which is an alkaline condition. pH is an important parameter due to influenced enzymatic activity because each enzyme is active at specific range and display maximum activity at an optimum pH. This results is in agreement with Zinder (1994) which reported that the highest yield of methane production was found at initial pH 7.0 – 7.2. At this optimum pH level it will increase biogas production during digestion process.

3.4 Methane yield production from co-digestion of poultry manure and food waste.

It is known that pH plays an important role influencing the biogas production. In this study, different initial pH (6.5, 7.0, 7.5 and 8.0) were tested for methane production. Based on the first objective during optimization process, the optimum methane yields were produced at pH 7.11 at 35 °C.
temperature and at the ratio of 80:20 mix of poultry manure to food waste respectively. These were chosen as the controlled parameters throughout the 21 days of fermentation process.

Figure 1 Methane yield of chicken manure and food waste at 80:20 ratio.

Figure 1 shows time courses profile of methane along the incubation period for fermentation conducted at pH 7.11, at 35 °C temperature and the ratio at 80:20 mix of chicken manure and food waste. The ratio 80:20 mix of chicken manure and food waste had the highest methane yield compared with the ratio at 100:0, 60:40 and 40:60 respectively without controlling the parameters of pH, temperatures and ratios of mix. After optimization of pH, temperatures and ratios respectively, methane yield was calculated to be 1560.5 mL CH₄/g VS. Based on the comparison for the controlled and uncontrolled parameters, the results indicated that more than 50 % of methane yield increased after controlling the pH, temperatures and ratios during fermentation.

4. Conclusions
RSM can be viewed as the best value of the response, can also be used to gain a better understanding of the overall response system if discovering the fit value beyond the available resources of the experiment and finally simplified equivalent response surface may be obtained by a few numbers of runs to replace the complicated analysis. The maximum response value for methane production was estimated as 537 mL CH₄/g VS at pH 7.11, ratio of CM to FW at 80:20 and temperature at 35 °C. The experiment was then performed based on optimized parameters of pH, temperature and ratio at the highest yield of methane obtained from optimum parameters. The result showed that the pH 7.11 at 35 °C temperature and the ratio of 80:20 gave the highest methane production yield of 1560.5 mL CH₄/g VS for the 21 days of digestion process.
References

[1] Federation of LiveStock Farmers’ Associations of Malaysia (FLFAM). (2014). Retrieved 14 July 2014 from Federation of LiveStock Farmers’ Associations of Malaysia/Persekutuan Persatuan Penternak-penternak Malaysia: http://www.flfam.org.my.

[2] Norimah A K, Safiah M, Jamal K, Siti H, Zuhaida H, Rohida S, Fatimah S, Siti N, Poh B K, Kandiah M, Zalilah M S, Wan Manan W M, Fatimah S and Azmi M Y 2008 Malay. J. of Nutrition 14 (1): 25-39.

[3] Jayaraman K, Unira H, Dababrata C and Iranmanesh M 2013 Int. Food Res. J. 20(1) 165-174.

[4] Wan C X, Zhou Q C, Fu G M and Li Y B 2011 Waste Management 31 1752-1758.

[5] Hartmann H, Angelidaki I and Ahring B K 2002 In: Mata-Alvarez, J. editor. Biomethanization of the organic fraction of municipal solid waste. IWA Publishing, London. 181–200.

[6] Lahdheb H, Bouallagui H and Hamdi M 2009 Bioresource Technology. 100: 1555–1560.

[7] Zinder S H 1994 Chapman & Hall, New York, 128-206