Renew Energy from Municipal Solid Waste in Developing Country

Kim Oanh Le Thi[1*], My Dieu Tran Thi[2], Wim Rulkens[3]

[1, 2]Department of Environmental Technology and Management, Van Lang University, Ho Chi Minh City, Vietnam

[1, 3]Sub-department of Environmental Biotechnology, Wageningen University, the Netherlands

[*1]lethikimoanh@vanlanguni.edu.vn; [2]tranthimydieu@vanlanguni.edu.vn; [3]wim.rulkens@wur.nl

***Abstract*- Anaerobic digestion of mixture of organic fraction of municipal solid waste (OFMSW) with or without pig manure (PM) and digested OFMSW (DOFMSW) by batch reactor with leachate recycling was done at Ho Chi Minh City, Vietnam. The research has carried out in lab- and pilot-scale reactors which have volume of 45 litters and 5 m^3, respectively. Maximum biogas production was 378 mL.gVS^{-1} equal to 59 m^3 biogas/ton mixture with wet weight ratio of 10 OFMSW: 1 DOFMSW: 1 PM. Maximum methane content was 63%. The presence of PM in the mixture increased the biogas production while DOFMSW controlled pH and increased methane content in biogas. Pilot–scale gave higher biogas production rate compared to that of lab-scale experiments. The DOFMSW was converted to compost via static pile composting technology within 7 days. The compost yield was in range of 0.2-0.25 ton mixture of waste.**

Keywords*- *Municipal Solid Waste;Organic Fraction of Municipal Solid Waste; Anaerobic Digestion; Aerobic Digestion; Biogas

I. INTRODUCTION

Ho Chi Minh City generates about 6,500 tons of (commingled) MSW each day in which 50-60% is biodegradable organic matter (called OFMSW) [6]. Although Ho Chi Minh City has invested sanitary landfills, it is still strongly polluting the environment due to leachate and air emission. Specially, every year it needs 10-12 ha new land for landfill cell. Besides, huge amount of PM (about 700 tons/day) are generated from pig farms in sub-urban areas of Ho Chi Minh City [13]. Most of farms have not an appropriate treatment technology. Therefore, the techniques to recycle organic compound seem to be a promising solution. Among that anaerobic digestion is a sustainable technology which can solve the environmental problems and produce energy.

In order to be able to apply anaerobic digestion in Vietnam, a technique is chosen that fits the Vietnamese conditions: the batch reactor technology with leachate recycling. Some advantages of the batch technique are: (1) low investment, operation and maintenance cost; (2) the technique for filling and emptying the reactor is simpler than for a continuous reactor; (3) no operational problems with reactor loading and mixing in the system; (4) less energy consumption due to absence of stirring; (5) no water addition; (6) leachate is recycled into the reactor, so that water and microorganism are distributed uniformly into the solid waste bed in the reactor, and pH and temperature can also be easily controlled. In addition, from many research projects [1, 7, 8, 9, 16, 18, 30]it can be concluded that the biogas productivity increases when the MSW is added inoculate and/or is mixed with other types of wastes such as pig manure, cattle manure, septic tank sludge, bread waste, kitchen waste, etc.

The objectives of this study were to determine the applicability to produce biogas from OFMSW and to assess the possibility to produce compost from DOFMSW at Vietnamese conditions.

II. MATERIALS AND METHOD

A. Anaerobic Digestion Reactors and Composting Reactors

Experiments werecarried out in two anaerobic digestion reactors sizes: lab-scale (indoor) and pilot-scale (outdoor) at ambient weather conditions of Ho Chi Minh City. After anaerobic digestion process the DOFMSW was fed to a composting reactor to produce compost.

1) Lab-scale Anaerobic Digestion Reactors:

For the lab-scale study 45 litter cylindrical reactors located inside were used. The reactors were insulated with polyurethane foam to minimize variations of the reactor temperature which might affect the anaerobic digestion process. Each reactor was tightly closed with rubber tape and a screw cap to assure anaerobic conditions. During the process liquid was recycled over the reactor. The recycled liquid was obtained by filtration of the digester effluent through a screen (mesh size 1 mm) to avoid clogging of pipes and then distributed over the top of the solid waste in the reactor by a pump and spray-taps system. From the cap of the reactor biogas was collected in a biogas bag. The pictures and the detailed design of the lab-scale reactors are shown in Fig.1. Each reactor was loaded with 20kg OFMSW or a mixture of various types of organic solid waste.

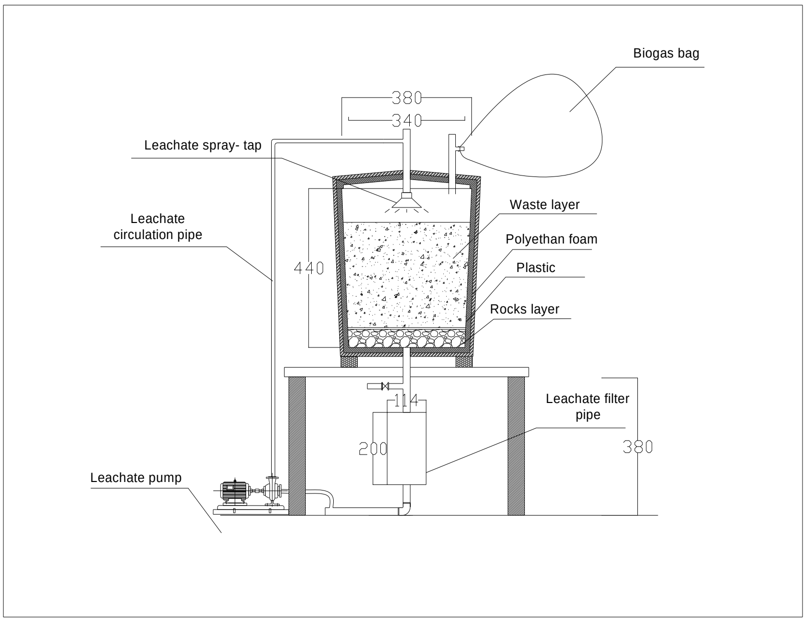

Fig. 1 Lab-scale anaerobic digestion reactor

2) Pilot-scale Anaerobic Digestion Reactors:

Two similar pilot-scale reactors were used with a volume of 5 cubic meters per each. A schematic presentation of the reactor is given in Fig.2. The pilot scale reactors were designed in cylinder shape and constructed from stainless steel. The outside of the reactors was covered with rockwool to protect against temperature variations. The inside wall of the reactors was covered with a composite layer to protect the steel against corrosion. The design of the pilot reactor system was similar to that of the lab-scale reactor regarding the leachate recycling and the biogas collection system. An electric system was installed to automatically control the leachate recycling pump.

The mixture with the best results regarding biogas production and methane content in the lab-scale test was selected for the experiments with pilot-scale reactors. The pilot-scale reactors were installed outdoor, where the temperature was on average 27°C (max= 38°C, min= 20°C). Two reactors were used to have results in duplicate. Each reactor was loaded with 2,400 kg of a mixture of organic solid wastes.

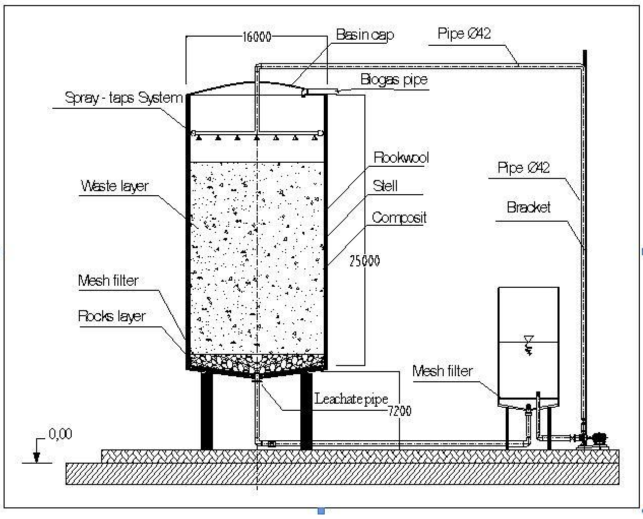

Fig. 2 Pilot scale anaerobic digestion reactor

3) Lab-scale Reactors for Aerobic Composting:

The lab-scale reactors for aerobic composting were made of composite material with a rectangular shape having (L * W * H) dimensions of 0.3 m * 0.2 m * 0.2 m. The bottom of the reactor was provided with an air supply system. Leachate from the reactors was collected at the bottom of the reactors and discharged through a discharge pipe. This leachate was stored and redistributed to the composting process when the moisture content of the waste decreased. Fig.3 shows the technical design of the composting reactors.

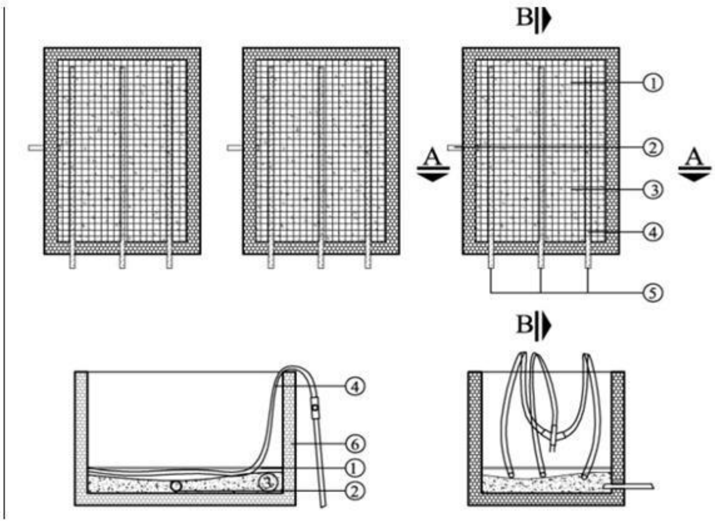

Fig. 3 Technical design of composting reactors

Note: 1. Screen, 2. Leachate collection, 3. Rock, 4. Air supply system, 5. Pump.

B. Input Material-Waste Types

(Commingled) MSW was collected from anMSW transfer station in the BinhChanh District. The separated OFMSW was food, kitchen, garden waste, etc, which was used in the experiments, represented about 58-67% of total MSW. PM was collected from small pig farms in the BinhChanh District. In all small and medium sized pig farms in Vietnam, pig manure and wastewater are collected separately. Therefore, the pig manure has a low moisture and low nitrogen content. The OFMSW and pig manure were collected, stored and used in the experiments in the same day. DOFMSW, produced in previous research projects, was used for this research. This DOFMSW was stored and used within one month.

C. Processing, Sampling and Analysing

1) Processing:

The procedure for processing and sampling the waste is presented in Fig.4. Commingled MSW was sorted by hand to separate the OFMSW. Before taking a sample for analysis, the OFMSW was cut (~3 cm for lab-scale and 20 cm for pilot-scale experiments) and mixed to get a homogenous mixture.

Several experiments were performed with only OFMSW or with a mixture of OFMSW and/or pig manure (PM) and/or DOFMSW in different ratios. Each sample was analyzed for pH, TS, VS and C/N. The ratio of each mixture of OFMSW and PM/DOFMSW was calculated by wet weight.

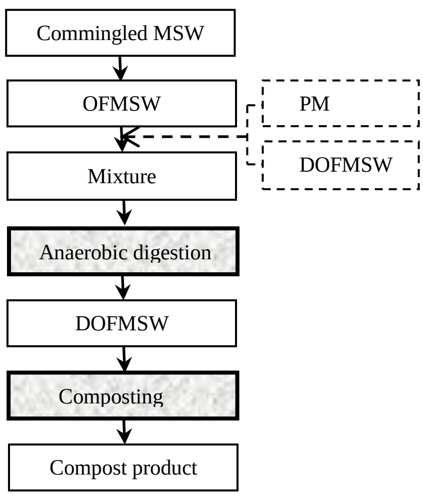

Fig. 4 Procedure for processing

After loading, the pH was measured in the leachate and controlled (if nessesary) every day, in the morning and in the evening. The pH is controlled by mixing liquid NaOH 6N into leachate and spreading on MSW. Biogas production was measured once per day. The biogas composition was analyzed three times: at the beginning, in the middle and at the end of the digestion period.

The DOFMSW from anaerobic digestion experiments was loaded into the composting reactors, after controlling pH and moisture content for optimal process performance. The moisture content of the DOFMSW was higher than the optimum range for aerobic composting. Therefore, the DOFMSW is spread on the floor under the sun for 1 or 2 days. The temperature was measured at least three times per day during about 3 days after the start of the process and two times per day afterwards. An air supply of 0.003 m^3/kg.hour was used [14]. The stability and maturity of compost product was tested by means of the Dewar self-heating test [30]. The Dewar kit included: (1) a 2-liter, steel-encased Dewar vessel of 100 mm inner diameter, (2) a thermometer to measure the ambient temperature and (3) a thermometer to insert into the vessel. Before filling the vessel the compost product was mixed intensively to provide a homogeneous sample and re-moisturized to about 55-60% with water. The temperature inside the vessel was measured three times per day during the 7 days of operation. The compost product was analyzed in detail to compare its quality with the Vietnamese standards for compost quality [24].

2) Sampling:

- For every experiment, the input materials (MSW, PM and DOFMSW) were collected and sampled;
- After the anaerobic process and the composting process, the DOFMSW and compost product are sampled and analyzed;
- During the anaerobic process the pH of the leachate was measured and controlled and also the biogas production was measured and its composition analyzed;
- During the composting process the pH and moisture content were measured and controlled. The temperature inside the reactor was also measured and controlled. The air supply was continuously checked and controlled.

3) Analysing:

The pH, TS, VS, C/N, heavy metals, E. coli and total Coliforms were analyzed according to Standard Methods 2005. For on-site measurement of temperature and pH, a portable glass thermometer and a hand-held pH meter were used. Biogas production was measured at ambient condition (± 27 ℃) by a gas meter (Kokokchina Gas Meter number 217029). In the case of lab-scale, biogas wasmeasured via the method of water displacement by biogas. Biogas was sampled for biogas composition measurement from the biogas storage bag and analyzed with a Gas Surveyor 431 Portable Gas Detector (GMI Gas Measurement Instruments Ltd., Scotland and UK).

III. RESULTS AND DISCUSSIONS

The pH, moisture content (%), VS/TS and C/N of individual samples (before blending the mixtures) and of each mixture of all the experiments are shown in Tables 1 and 2.The initial pH of OFMSW varied from 5.05 to 6.20 and decreased fast directly after starting the anaerobic digestion experiments (about 1.0-1.2 unit/24 hours). Therefore the pH of OFMSW had to be strongly controlled to keep it in a range of 6-8 [26, p687]. The pH of OFMSW depended on the way MSW was collected. If MSW was discharged and collected within one day, the pH of OFMSW was in the optimal range for anaerobic digestion. If not, it was too low and adjustment of the pH was necessary. The pH of DOFMSW varied from 6.92 to 7.50 while the pH of PM varied from 6.95 to 7.80. Those wastes with a high pH can be appropriate buffers for OFMSW.

TABLE 1 CHARACTERISTICS OF ORIGINAL OFMSW, DOFMSW AND PM USED IN EACH EXPERIMENT

Materials	**pH**	**Moisture Content (%)**	**VS/TS (%)**	**C/N**
EXPERIMENTS 1: mixture of OFMSW and DOFMSW				
OFMSW in lab scale	5.05	77.3	83.4	27.6
DOFMSW in lab scale	6.92	71.0	54.4	20.8
OFMSW in pilot scale	5.80	84.3	81.9	28.7
DOFMSW in pilot scale	7.50	62.7	57.9	21.3
EXPERIMENTS 2: mixture of OFMSW and PM				
OFMSW in lab scale	5.16	86.1	83.9	30.4
PM in lab scale	6.95	78.6	72.8	11.6
OFMSW in pilot scale	6.20	80.1	87.6	28.6
PM in pilot scale	7.80	81.2	80.8	12.3
EXPERIMENTS 3: mixture of OFMSW and PM and DOFMSW				
OFMSW in lab scale	6.20	81.6	75.6	29.1
PM in lab scale	7.10	83.8	75.6	10.9
DOFMSW in lab scale	7.00	72.2	61.8	23.1
OFMSW in pilot scale	5.60	78.4	89.2	27.9
PM in pilot scale	7.20	85.4	77.1	10.2
DOFMSW in pilot scale	7.10	68.2	55.2	22.7

TABLE 2 CHARACTERISTICS OF MIXTURES OF OFMSW, DOFMSW AND PM (RATIOS IN WET WEIGHT) USED IN EACH EXPERIMENT

Name, Type of Experiments, Ratio of Mixture	**pH**	**Moisture Content (%)**	**VS/TS (%)**	**C/N**
EXPERIMENTS 1: OFMSW only, and mixture of OFMSW and DOFMSW				
1.1 Lab scale, OFMSW only	5.05	77.3	83.4	27.6
1.2 Lab scale, ratio 10: 1	5.75	76.7	80.8	27.0
1.3 Lab scale, ratio 5: 1	5.83	76.3	78.6	26.5
1.4 Pilot scale, ratio 10: 1 (reactor 1)	5.39	82.3	79.7	28.0
1.5 Pilot scale, ratio 10: 1 (reactor 2)	5.39	82.3	79.7	28.0
EXPERIMENTS 2: mixture of OFMSW and PM				
2.1 Lab scale, ratio 20: 1	5.12	85.7	83.4	29.5
2.2 Lab scale, ratio 10: 1	5.08	85.4	82.9	28.7
2.3 Lab scale, ratio 5: 1	5.17	84.9	82.1	27.3
2.4 Pilot scale, ratio 10: 1 (reactor 1)	5.41	80.2	87.0	27.1
2.5 Pilot scale, ratio 10: 1 (reactor 2)	5.41	80.2	87.0	27.1
EXPERIMENTS 3: mixture of OFMSW and DOFMSW and PM				
3.1 Lab scale, ratio 20: 1: 1	5.92	81.3	75.0	28.0
3.2 Lab scale, ratio 10: 1: 1	6.04	81.0	74.5	27.1
3.3 Pilot scale, ratio 10: 1: 1 (reactor 1)	6.18	78.1	85.4	26.0
3.4 Pilot scale, ratio 10: 1: 1 (reactor 2)	6.18	78.1	85.4	26.0

The C/N ratio of OFMSW was about 27.6-30.4 while it was 20.8-23.1 and 10.2-12.3 for DOFMSW and PM respectively. Therefore, the mixtures of OFMSW and PM and/or DOFMSW had a suitable balanced composition regarding the pH and the C/N content.

The moisture content of DOFMSW, OFMSW and PM were 62.7%-72.2%, 77.3%-86.4% and 78.65-85.4% respectively. The TS content was high enough for batch dry digestion in which the TS content is usually about 20%-35% [26, p.687] and about 30%-40% for the Biocel technology [12, 20, 27].

DOFMSW contained a relatively high fraction of VS (54.4%-61.8% of TS). Probably, most of these TSs were hard to biodegrade. However, the primary aim of mixing DOFMSW was to supply microorganisms to produce biogas and not to supply organic matter [15, 18, 19].The volatile solids concentration in OFMSW was relatively high (75.6%-82.9%), while in PM the VS content was somewhat lower (72.9%-80.8% of the TS). Most of the OFMSW and PM samples had VS higher than 82% and 76%, respectively. In general, the TS in OFMSW of Ho Chi Minh City are low and the VS are high compared to other data. For example, the research of Forster et al. [15] and Guendouz et al. [18] showed that TS values were 32%-37% and VS values 34%-58%. In other literature references, the TS and VS values were higher. Laclos et al.[22] for example measured TS values of 37%-55% and VS values of 32%-65% and Bolzonella et al. [4] found TS values of 27%-47% and VS values of 55%-90%.

A. Biogas Yield

The results of the daily and cumulative biogas yields of all experiments are shown in Figs. 5-10. Fig. 5 shows the daily and cumulative biogas yields obtained in the lab-scale anaerobic reactors filled with OFMSW or with a mixture of OFMSW and DOFMSW in different ratios (Experiments 1.1-1.3). The peak values are 28, 42 and 31 $mL.gVS^{-1}.d^{-1}$ for the experiments with ratio 1:0, 10:1 and 5:1 and the cumulative biogas yields are 146, 214 and 169 $mL.gVS^{-1}$ respectively. This result is 10% higher than the results obtained by Forster [15] who performed their research with anaerobic dry digestion in batch reactors filled with OFMSW (20% TS) and 30% inoculums.

Comparison of the biogas production of only OFMSW and of mixtures of OFMSW and DOFMSW shows that the presence of DOFMSW did significantly improve the cumulative biogas production with 47%. This was probably due to microorganisms in DOFMSW that are responsible for the conversion of a fraction that is indigestible without the inoculums. This result matches with conclusions of Hartmann and Ahring [19] and Nwabanne et al. [25] that digesters for MSW will require inoculation of the feed with microorganisms to stimulate the digestion process. The better balance of the pH and/or C/N ratio when DOFMSW is added may also be a reason for the acceleration and increase of the biogas production. Between the two tested mixtures (ratio of 10:1 and 5:1) the ratio of 10:1 gave better results. This implied that in a mixture of 5 OFMSW:1 DOFMSW, the volume of DOFMSW added is more than required for obtaining an optimal inoculation, C/N ratio or pH buffer. In addition, the residual VS of the DOFMSW was difficult to digest, therefore the total digestible VS in the mixture with a ratio of 5:1 was lower than in the mixtures with a ratio of 1:0 or 10:1. The requirement of inoculation found in this research was lower than that found by Forster et al. [16] and Guendouz et al. [18]. Forster et al. [16] used 30% inoculate and Guendouz et al. [18] added 60%-80% industrial digestate as inoculate.

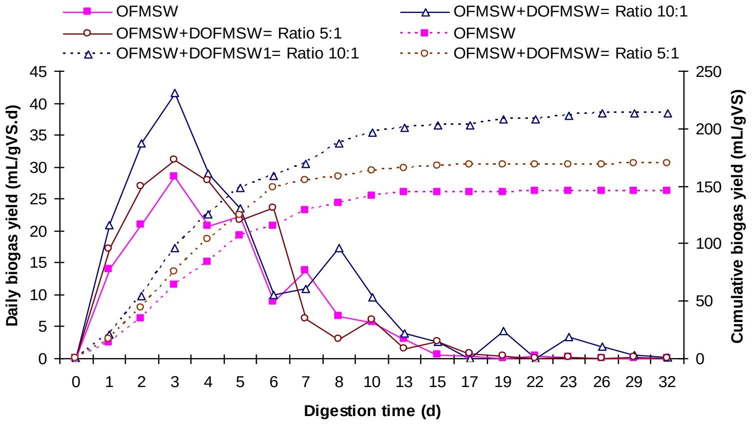

Fig. 5 Daily and cumulative biogas yield of mixture OFMSW and digested OFMSW in lab scale

Fig. 5 shows that most biogas is produced within 15 days for all mixture ratios of OFMSW and DOFMSW. With the mixture of 10:1, the cumulative biogas production could be enlarged when the digestion process was continued to about 30 days. However, this extra biogas production in the period of 15-30 days was small. Therefore, for economic reasons, it may be useful to stop the digestion process at day 15. In general, in the lab-scale experiments of the Experiment 1, the Experiment 1.2 with the mixture OFMSW and DOFMSW in a ratio 10:1, gave the best results for the cumulative biogas amount and biogas production rate. Therefore, this ratio was applied in duplicate in two pilot plant reactors with the same volume to measure the biogas production and to compare this production with that obtained in the lab-scale experiments (Experiments 1.4 and 1.5).

Fig. 6 presents the averages and the standard deviation of the daily and cumulative biogas yields of the Experiments 1.4 and 1.5. The results showed that the average peak in the daily biogas production is 56 $mL.g\ VS^{-1}.d^{-1}$ and the average cumulative biogas production is 244 $mL.gVS^{-1}$.These results were higher than the results obtained in the lab-scale experiments. This was probably due to the higher stability of the pilot-scale process regarding the leachate recycling and temperature fluctuations. The moisture content of the mixture used in the pilot-scale was about 8% higher than in the lab-scale experiments. Similar to the results in the lab-scale experiments, most of biogas was produced within 7-8 days after the start of the experiment and the biogas production was completed at day 15-20.

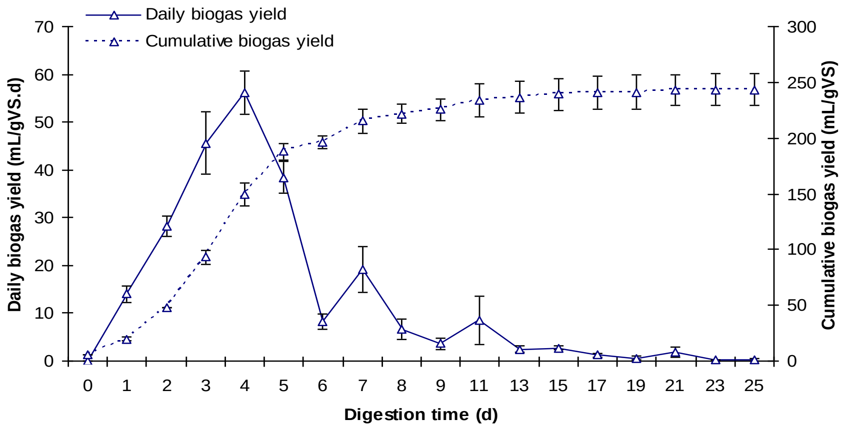

Fig. 6 Average daily and cumulative biogas yield of mixture OFMSW and digested OFMSW with ratio 10:1

Fig. 7 shows the daily and cumulative biogas yield of lab-scale anaerobic digestion of mixtures of OFMSW and PM (Experiments 2). The peak daily yield and cumulative biogas yield of the mixtures 20:1, 10:1 and 5:1 were 59, 72 and 76 $mL.gVS^{-1}.d^{-1}$ and 273, 317 and 301 $mL.gVS^{-1}$, respectively. These results are 2.2 times (317/146) higher than that of Experiment 1. It can be compared to the two-phase anaerobic research of Corral et al. [8] showed the production of 37 and 172m^3 methane/ton dry waste for only OFMSW and the mixture of OFMSW and cattle manure respectively. The presence of cattle manure resulted in an increase in biogas production with a factor of 4.6. This was possibly due to the comparatively higher nitrogen content and digestible VS of pig manure and moisture content.

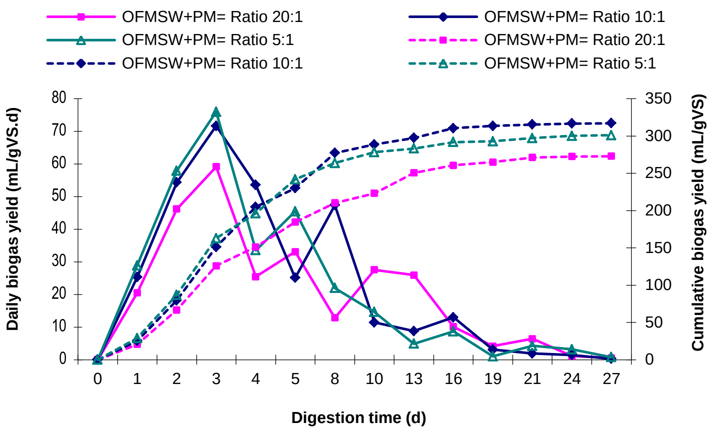

Fig. 7 Daily and cumulative biogas yield of mixture OFMSW and PM

The average results of the pilot-scale experiment (Fig. 8) were better than the results from the lab-scale experiments with the same ratio of OFMSW and PM (10:1). Average peak and cumulative biogas yields were 72 $mL.gVS^{-1}.d^{-1}$ and 351 $mL.gVS^{-1}$, respectively.

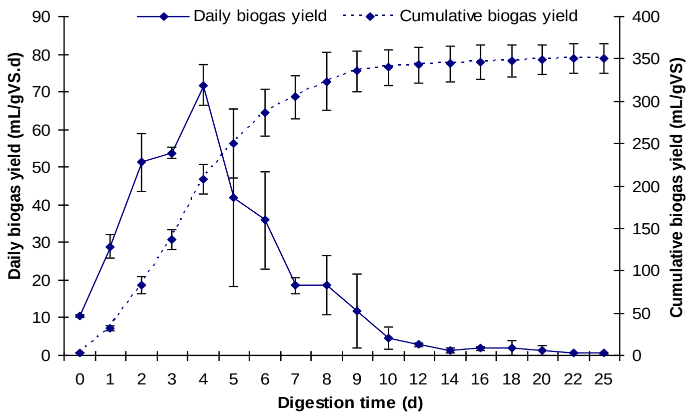

Fig. 8 Average daily and cumulative biogas yield of mixture OFMSW and PM with ratio 10:1.

Fig. 9 shows the daily and cumulative biogas yields of the digestion on lab-scale of mixtures of OFMSW, DOFMSW and PM (Experiments 3.1-3.2). Total biogas production from the mixture of OFMSW, DOFMSW and PM was the highest among all the evaluated mixtures. The peak values of the daily biogas yield were 59 and 64 $mL.g\ VS^{-1}.d^{-1}$, while the cumulative biogas yields were322 and 362 $mL.g\ VS^{-1}$, respectively. This could be attributed to the fact that the PM heightened the nitrogen content in the mixture, which was limited in OFMSW, and the DOFMSW supplied the microorganisms responsible for the conversion of organic compounds into biogas. The mixture with ratio OFMSW: DOFMSW: PM equal to 10:1:1 gave a 12% higher cumulative biogas yield compared to the mixture with ratio 20:1:1.

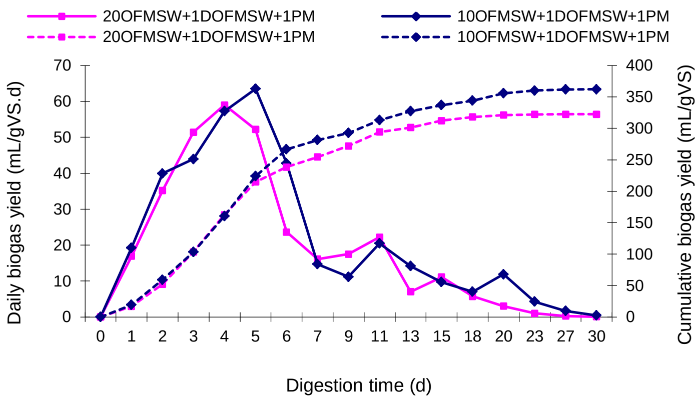

Fig. 9 Daily and cumulative biogas yield of mixture OFMSW, DOFMSW & PM

The maximum total biogas production of our experiments was 378 mL $biogas.g\ VS^{-1}$, corresponding to 227 mL $methane.g\ VS^{-1}$ or 59 m^3 biogas per ton wet waste mixture (Fig. 10). This was higher than the yield obtained by Forster et al. [17], who found 80 mL methane.g VS^{-1} with anaerobic digestion of MSW in a dry-batch reactor, provided with a stirring system and operated at thermophilic conditions. Our yields were also higher than those of Hartmann and Ahring [19] with Biocel (dry anaerobic digestion in a batch reactor) technology applied on MSW with 35% TS. They found 260 mL biogas.g VS^{-1}. Our yields were in the same range as the results of Laclos et al. [22] and Guendouz et al. [18] who also investigated dry digestion at mesophilic conditions in a continuous or semi-continuous one stage system with stirring. However, our yields were very low compared to those found with wet digestion of MSW by Hartmann and Ahring[19], Angelidaki et al. [2], Davidsson et al. [10], Capela et al. [5] and Zhu et al. [31] which were in range of 450-800 mLbiogas.gVS^{-1}. If we compare the biogas production based on reactor volume, then dry digestion showed a higher efficiency than wet digestion. In addition, wet digestion needs the addition of a high amount of water and at the end a liquid residue is obtained unfit for composting due to its elevated moisture content. Accordingly, from an economic point of view dry digestion could be the preferable technology.

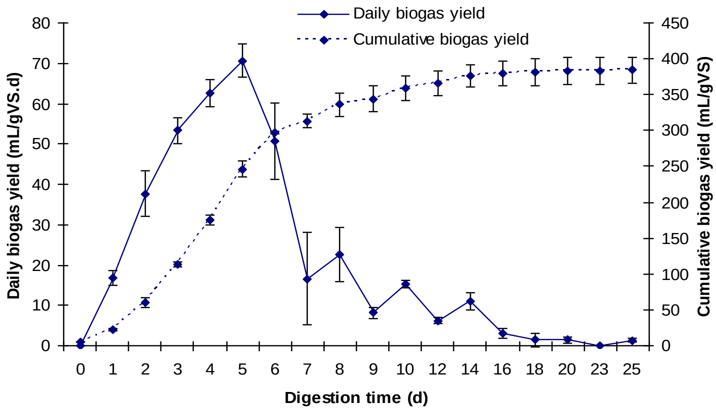

Fig. 10 Average daily and cumulative biogas yield of mixture OFMSW, DOFMSW and PM with ratio 10:1:1

B. Methane Content of Biogas and Methane Yield

Biogas concentration was analysed three times during the digestion period: at Day 1, 4 and 7. Similar to the results of Zhu et al. [31], the results of this research showed that methane concentration of the biogas increased quickly from Day 1 to Day 4 of the digestion period and slowly from Day 4 to 7 (Table 3).

TABLE 3 METHANE CONTENT (%) OF THE BIOGAS PRODUCED IN THE PILOT PLANT REACTORS FOR DIFFERENT MIXTURES OF SOLID WASTE AND AT DIFFERENT PRODUCTION DAYS

Mixture of Waste	**Ratio**	**Reactor**	**Day**		
			1	**4**	**7**
OFMSW+DOFMSW	10:1	1	56	65	66
		2	53	63	65
OFMSW+PM	10:1	1	48	55	57
		2	44	54	53
OFMSW+DOFMSW+PM	10:1:1	1	55	67	68
		2	57	62	64

Table 4 summarizes the peak values, cumulative and methane content in biogas from differences experiments. Zhu et al. [31] and Corral et al. [8] found that biogas methane concentrations were more or less similar for different types of waste mixtures. It varied from 52% to 61% for mixtures of MSW and paper waste, mixtures of MSW and bio-solids, mixtures of bio-solids and paper waste. However, in our research, the methane content differed with each type of waste mixture: the maximum difference of methane concentration was as high as 30% (Table 4).

TABLE 4 PEAK VALUE AND BIOGAS YIELD FOR DIFFERENT RATIOS (IN WET WEIGHT) OF MIXTURE IN LAB AND PILOT SCALE EXPERIMENTS

Type of Experiments and Mixture of Waste	**Ratio**	**Reactor**	**Peak Value (mLbiogas.$gVS^{-1}.d^{-1}$)**	**Cumulative (mLbiogas.gVS^{-1})**	**Methane Content (%CH_4/biogas)***
Lab OFMSW+ DOFMSW	1:0	-	28	146	48
	10:1	-	42	214	53
	5:1	-	31	169	52
Pilot OFMSW+ DOFMSW	10:1	1	53	233	60
	10:1	2	59	254	59
Lab OFMSW+ PM	20:1	-	59	273	43
	10:1	-	72	317	52
	5:1	-	76	301	46

Pilot OFMSW+ PM	10:1	1	68	338	53
	10:1	2	76	363	49
Lab OFMSW+ DOFMSW+PM	20:1:1	-	59	322	53
	10:1:1	-	64	362	59
Pilot OFMSW+ DOFMSW+PM	10:1:1	1	74	353	63
	10:1:1	2	68	378	60

*Note *methane content (%) in the total volume of biogas production.*

The methane content in the total biogas of the complete digestion period was lowest for a mixture of OFMSW and PM and highest for a mixture of OFSMW and DOFMSW and PM. The best results achieved were 63% CH_4 (sampling at the stored biogas bag at the end of digestion time).

C. TS and VS

TS and VS output after digestion and the VS reduction efficiency are shown in Table 5.

TABLE 5 RATIO OF TS & VS (%) IN DOFMSWS AND VS REDUCTION EFFICIENCIES (%) MEASURED FOR EXPERIMENTS

Name, Type of Experiments, Ratio of Mixture in Wet Weight	**TS Output (%)**	**VS Output (%)**	**VS Reduction Rfficiencies %**
EXPERIMENTS 1: OFMSW and mixture of OFMSW+DOFMSW			
1.1 Lab scale, ratio 10: 0	33.7	73.5	35
1.2 Lab scale, ratio 10: 1	30	64	49
1.3 Lab scale, ratio 5: 1	33	65.2	42
1.4 Pilot scale, ratio 10: 1	25.4	56	50
1.5 Pilot scale, ratio 10: 1	26.7	52	51
EXPERIMENTS 2: mixture of OFMSW+ PM			
2.1 Lab scale, ratio 20: 1	27	74.6	41
2.2 Lab scale, ratio 10: 1	25	74	47
2.3 Lab scale, ratio 5: 1	29	72.4	41
2.4 Pilot scale, ratio 10: 1	30	78.3	52
2.5 Pilot scale, ratio 10: 1	28.7	77.6	55
EXPERIMENTS 3: mixture of OFMSW+DOFMSW+PM			
3.1 Lab scale, ratio 20: 1: 1	27.2	52.6	59
3.2 Lab scale, ratio 10: 1: 1	28.8	48.4	61
3.3 Pilot scale, ratio 10: 1: 1	32.8	51	64
3.4 Pilot scale, ratio 10: 1: 1	31	53.3	65

The TS concentration in the output of the reactors ranged from 25% to 34%, which meant that it was necessary to dry this DOFMSW before subjecting it to aerobic composting. The VS was still high: 48%-78%. The VS reduction efficiencies (kg VS reduction/kg VS input) were in the range of 35%-65%. The maximum VS reduction efficiency of 65% was obtained in the digestion of a mixture of OFMSW with PM and DOFMSW in a ratio of 10:1:1 (Experiment 3.4).

D. pH

Figs.11, 12 and 13 show the pH values of the waste as a function of the digestion time of Experiments1, 2 and 3, respectively. For the days at the beginning of the experiments, the pH was measured twice: the first in the morning without pH control and the second after adding chemicals (NaON 6N) to obtain the optimum pH range. After some days, when pH was stable, pH adjustment was not necessary and the measurement was one per day or one per some days.

In the case of OFMSW only and mixture of OFMSW and PM (Figs. 11 and 12), the pH dropped rapidly at the beginning of each experiment as the easily digestible fraction of organic matter was hydrolyzed and converted to fatty acids. While methanogenes was not in balance caused an accumulation of volatile fatty acid in the reactors. The pH was more or less stable when the input materials were mixture of OFMSW and DOFMSW and mixture of OFMSW, DOFMSW and PM (Figs.11 and 13).

Compared to Experiment 1 (Fig. 11), the pH in Experiment 2 (Fig. 12) was fluctuating more and needed more buffer. The pH values of experiment 2 were higher at the end of the digestion period. That may be due to a higher nitrogen concentration originating from the pig manure, resulting in a higher ammonia concentration in the residue at the end of the process.

The pH in Experiment 3 (Fig. 13) decreased slowly; therefore it was not necessary to add a buffer.The pH of the OFMSW and DOFMSW mixture was more stable than that of the other mixtures. In contrast, the pH of only OFMSW was not stable, especially during the first 7-8 days of the digestion.

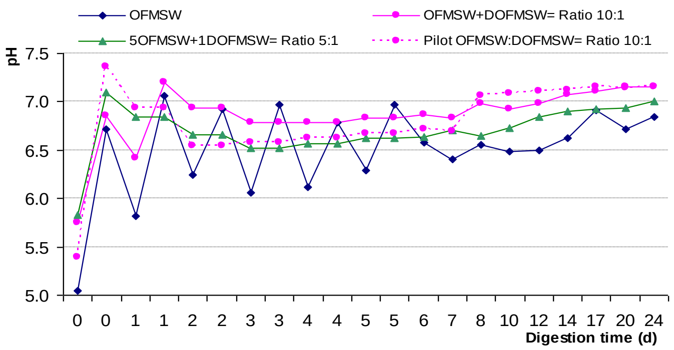

Fig. 11 pH of OFMSW and mixture OFMSW and DOFMSW in differences ratios of mixing in lab scale and pilot scale of anaerobic digestion experiments (Experiment 1)[1*]

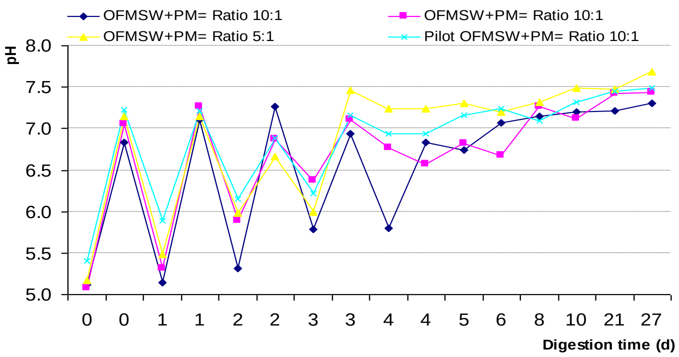

Fig. 12 pH of mixture OFMSW and PM in differences ratio of mixing in lab scale and pilot scale anaerobic digestion experiments (Experiment 2)[*]

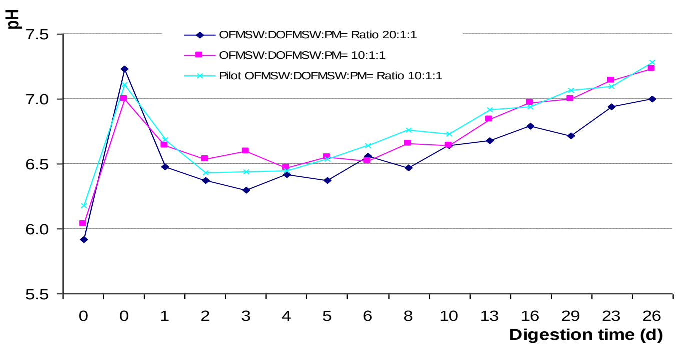

Fig. 13 pH of mixture OFMSW, DOFMSW and PM in lab scale and pilot scale (Experiment 3)[*]

E. Composting and Compost Product

The DOFMSW from the anaerobic digestion of the mixture OFMSW, PM and DOFMSW 10:1:1 at pilot-scale and lab-scale experiments were used as input for the composting experiments. The composition of the DOFMSW is presented in Table 6.

TABLE 6 COMPOSITION OF THE DOFMSW FROM THE ANAEROBIC DIGESTION OF MIXTURE OF OFMSW, PM AND DOFMSW IN RATIO OF 10:1:1 OBTAINED IN LAB AND PILOT SCALE EXPERIMENTS (EXPERIMENT 3.2 AND 3.3)

Descriptions	Units	Pilot scale	Lab scale
pH	-	7.2	7.3
Moisture content (%)	%	67	71
VS (%VS/TS)	%	51	48
C/N	-	18.7	20.2

The DOFMSW had higher moisture content than the optimum range for aerobic composting. Therefore, before putting it into the composting reactors, the residue was dried under sunshine in 1-2 days to reduce the moisture content to 55%-60%.

[*]*Note: In digestion time versus, there are two number of the same day, the first data is actual pH and the second data is adjusted pH to reach the optimum condition for anaerobic digestion.*

1) Temperature:

Temperature should be controlled during the aerobic biological process to assure optimal environmental conditions for the microorganisms and to obtain a safe product with respect to pathogenic organisms [24].

Fig. 14 shows the temperature development during composting of the digested mixture of OFMSW, PM and DOFMSW (ratio 10:1:1) induplicate. The development of temperature in the duplicates was more or less the same. Most of pathogenic organisms are expected to be destroyed during composting at a temperature of about 55°C [26] but such a high temperature was not reached here (max 46°C). Therefore, the compost produced during this experiment could still contain pathogens. The relatively small and short temperature leap could be due to low remaining fraction of degradable organic matter in the input material (DOFMSW). The figure also shows that the composting process was finished after 7 to 8 days.

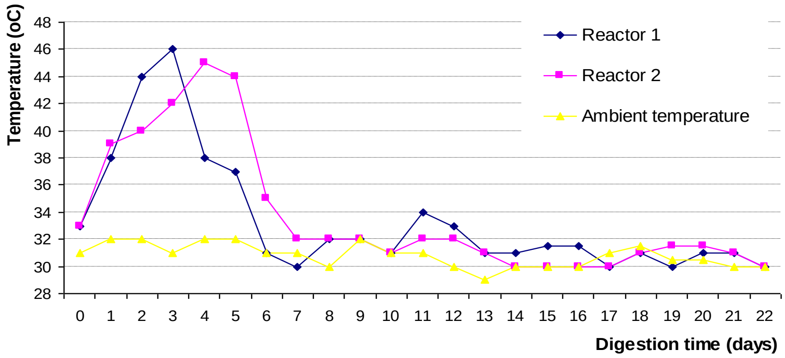

Fig. 14 Fluctuation of temperature of two aerated composting processes which input were DOFMSWs from anaerobic digestion of mixture OFMSW, PM and DOFMSW in ratio of 10:1:1

2) pH:

The final pH is an indicator for the quality of the compost product and a parameter to check the applicability of the compost product [28]. If the pH of the composting process is higher than 8.5 the quality of the compost product is expected to be low due to the lack of nitrogen [26].

The pH increased during the first 6-7 days together with the temperature (Fig. 15). When the biological process slows down and stopped pH stabilized at 8-8.3.

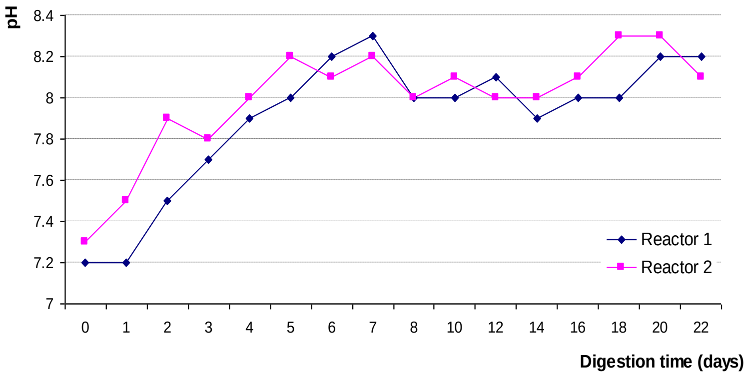

Fig. 15 Fluctuation of pH of two aerated composting processes which input were DOFMSWs from anaerobic digestion of mixture OFMSW, PM and DOFMSW in ratio of 10:1:1

3) VS:

The VS in the DOFMSW was still high (48%-51%). During the aerobic composting the VS was reduced but not much, reaching about 41%-42% at the end of the experiment (Fig. 16). The total VS reduction during the composting process was about 9%-10%.

4) Compost Product:

Fig. 17 presents the temperature development found by means of the Dewar self-heating test of compost products. The temperature in this test increased to a maximum of 28°C – 29°C, which was about 6°C higher than the ambient temperature. In the protocol of the Dewar self-heating test it was stated that if the temperature in the self-heating test increases less than 10°C the compost qualifies as the official class of stability V, meaning that the compost product is "very stable and considered as a well-aged compost" [28]. The compost product of our experiment satisfied the protocol for obtaining the qualification class V.

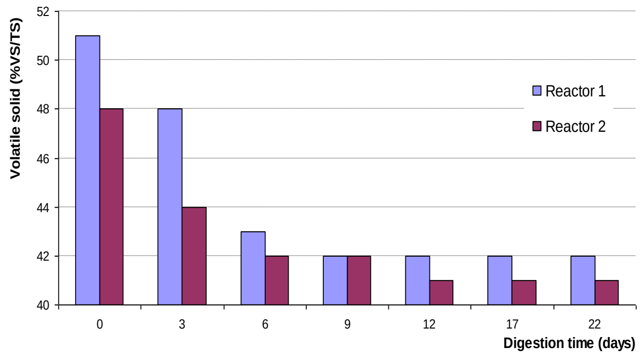

Fig. 16 The reduction of VS during the composting process of DOFMSWs from anaerobic digestion of mixture OFMSW, PM and DOFMSW in ratio of 10:1:1

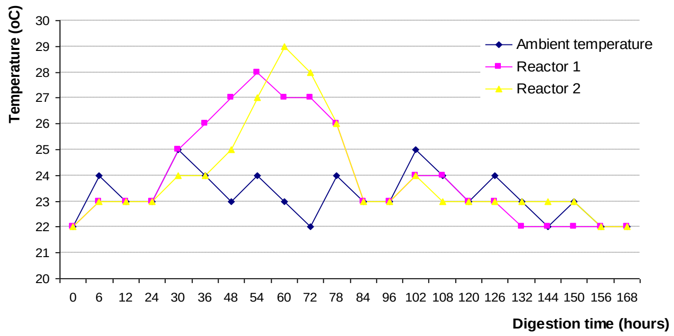

Fig. 17 Fluctuation of temperature in self-heating test of compost products

The compost product quality was compared to the compost quality standards of Vietnam [23] (Table 7). In the last column the standard of compost product from MSW of the Ministry of Agriculture and Rural Development of Vietnam is given. Table 7 shows that the compost product satisfied the Vietnamese standard in terms of toxic components. However, the nutrient content (N, P, K) was low. Therefore, this compost could be used as a raw material for organic fertilizer production for which there is a considerable demand in Vietnam.

TABLE 7 COMPOST QUALITY

Descriptions	**Units**	**Composition of Compost**	**Vietnam's Standard** (*)
Effectively to agriculture		-	good
Maturity		good	good
The size of compost partical	mm	based on size of waste	4-5
Maximum moisture	%	41	35
pH			6.0 – 8.0
Minimum effectively microorganism	CFU/ g	-	106
Minimum total carbon	%	22	13
Minimum total nitrogen	%	**1.1**	2.5
Minimum total phosphate	%	**1.6**	2.5
Minimum total kali	%	**0.8**	1.5
Density of Salmonella in 25 g sample	CFU	-	0
Maximum Pb content	mg/kg	trace	250
Maximum Cd content	mg/kg	nd	2.5
Maximum Cr content	mg/kg	trace	200
Maximum Cu content	mg/kg	trace	200
Maximum Ni content	mg/kg	nd	100
Maximum Zn content	mg/kg	trace	750
Maximum Hg content	mg/kg	nd	2
Minimum storing time	Month	-	6
E.coli	Ecoli/g	0	-
Coliform	Coliform/g	$1*10^2$	-

Note: nd: not detected

(*) Branch standard for compost produced from MSW (Ministry of Agriculture and Rural Development of Vietnam, 2002).

IV. CONCLUSIONS

Addition of pig manure and DOFMSW to OFMSW led to a significant increase of the biogas production. The maximum accumulated biogas production found was 378 mL.gVS^{-1}, which was equal to 59m^3 biogas (with 60% methane content) per ton mixture of OFMSW, DOFMSW and PM with ratio 10: 1:1. The results were not high may be due to relatively simple technology used and also perhaps by the nature of the MSW, which contained a high concentration of the difficultly biodegradable lingo cellulose [22]. However, this research showed the possibilities of this technology in Ho Chi Minh City in terms of reduction of environmental problems, applicability and production of biogas and compost.

The digestion time was about 20 days with VS reductions and VS in residues and compost were 59%-65%, 48%-53% of TS and 41%-42% of TS, respectively. pH was more stable if DOFMSW was added in the mixture. The pilot-scale anaerobic digestion was more stable than the lab-scale process. Aerated static pile composting of DOFMSW took only one week to produce compost. The compost product yield was in range of 0.2-0.25ton MSW or mixture of wastes.

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