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Utilization of Clay in Sludge-solid Waste Decomposition in Sanitary Landfill

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Abstract: In this study, the effect of adding clay minerals and/or wastewater treatment-plant sludge (WWS) to organic fraction of municipal solid waste (OFMSW) in simulated landfill reactors was investigated. The clay minerals and/or WWS were directly co-disposed with solid waste in the laboratory to determine an alternative and effective method for, sludge and solid waste, digestion and disposal. As well as to increase biogases released and improve the quality of the leachate. Two types of models have been used, bench scale models and pilot scale models. The WWS used was a mixture of primary and waste-activated sludge. sludges were supplied from Zinien, a municipal wastewater treatment plant located in Giza. A powdered montmorillonite clay were prepared and supplied. Two sets, each of seven bench scale models were designed and placed in a temperature-controlled water bath. The first set loaded with clay and OFMSW at ratios ranged between 15% to 80% by weight of solid waste to determine the optimum clay-solid waste mixing ratio, The cell receiving 40 % Clay mineral achieved the maximum amount of biogas. The second set loaded with 50 % WWS, OFMSW and different clay ratios ranged between 15% to 80% by weight of solid waste to determine the optimum clay-solid waste mixing ratio. The best mixing ratio that achieved the maximum amount of biogas, was which has 30% clay. Pilot-scale simulated landfill bioreactors were designed, constructed and loaded with solid waste, sludge and/or clay at the best ratios that obtained from the first two sets. In order to assure the previous results and to investigate the effect of pilot scale, leachate collection and recirculation on the degradation of the organic wastes. The stabilization of organic waste in the reactor receiving the mixture of WWS and clay was faster, as indicated by the total gas production and the leachate COD removal. On the other hand, the bioreactor receiving the mixture of clay only with OFMSW achieved better results than that receiving the mixture of WWS with OFMSW, in meaning that clay minerals may be used instead of the WWS to enhance the solid waste degradation in the landfill. Moreover, clay minerals more clean and has less impact on the surrounding environment.

Key words: Anaerobic decomposition; Co-disposal; Landfill stabilization; Sludge disposal; Solid waste degradation, clay minerals.

INTRODUCTION

Sanitary landfills are widely used for the disposal of solid waste. Landfills can result in serious environmental problems if not properly managed and operated. The most common problem associated with landfill operations is the generation of leachate and gases[12,9].

The action of co-digestion of the OFMSW and three different types of wastewater sludges including primary sludge, thickened waste-activated sludge and digested sludge under anaerobic condition was testes by Kayhanian[8]. Results revealed that, the bioreactor receiving the primary sludge and the OFMSW, achieved the optimum gas production and solid removal rates.

Cinar, *et al.*,[4] investigated co-disposal of the OFMSW and three various types of wastewater sludges including primary settling sludge, waste activated sludge and a mixture of primary and waste activated sludge. Four laboratory anaerobic bioreactors were used to determine an alternative method for sludge digestion and disposal. It was observed that, the stabilization of solid waste in the reactor receiving the mixture of primary settling and waste-activated sludges was faster, as indicated by the total gas production and COD removal data.

Leachate produced during solid waste stabilization process, has a considerable negative effect on the landfill surrounding area. Therefore, leachate requires treatment before disgorge to the environment to avoid surface and

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underground water contamination. Leachate recirculation to the landfill is one of the inexpensive methods of leachate treatment. It can improve leachate quality and reduce the final amount of leachate to dispose. Moreover, leachate recirculation is an effective method to enhance gas production and mass transfer of nutrients and microorganisms within the landfill cell[3,14,11,18].

An investigation was carried out by Ashraf,[2] to study the effect of mixing of the digested domestic wastewater sludge and the organic components of solid waste on biogas production rate. OFMSW was mixed with digested sludge at different ratios, ranged from 30% to 100% by weight of the organic solid waste, to determine the best mixing ratio. It has found that the best mixing ratio (which produce the maximum amount of biogas) is the 50% of the weight of the organic solid waste. The biogas produced almost twice amount of biogas produced by the organic solid waste alone.

The ability of clay mineral to take up certain organic substances preferentially has been known for very long time[6]. They usually activate a wide variety of organics leading to transformation and/or decomposition of the adsorbed species[10].

The active component of clay has the highest chemical and physical activity. Clay minerals have high sorption for water, or organic compounds and cations. Moreover, it tends to stick things together and slow the movement of air and water throw mixture. These characteristics are related to the small size of clay crystals.

In addition clay minerals can stimulate the microorganisms to grow and use the organic compound as a food and energy source by creating a favorable environment for them this occurs by providing a combination of oxygen, nutrients and moisture besides[16].

In a study performed by Hanan,[5] an investigation was carried out to utilize different clay minerals to activate the wastewater digested sludge in order to increase and/or control the production of off-gas. The effect of different mixing ratios of the wastewater digested sludge with clay minerals including kaolinite and montmorillonite and the PH of the mixture have been studied. Experimental results indicated that the optimum mixing ratio for kaolinite was 80% and for montmorillonite was 40%, both at PH 7.

In this study, WWS and/or clay minerals were codisposed with the solid waste in order to investigate the digestibility of organic compound in landfills under anaerobic conditions and their impact on solid waste stabilization. Moreover, the effect of adding WWS and/or clay minerals with leachate recirculation on the degradation of the solid waste and leachate quality have been studied. During this study the optimum (sludge-solid waste), (clay-solid waste) and (sludge and clay–solid waste) ratios were determined, then checked by using of pilot-scale bioreactors. In addition, leachate recirculation has been applied on the bioreactors.

MATERIAL AND METHODS

Simulated Landfill Reactors Construction: The *Bench-scale model* cell consists of three components including reactor, gas collector and gas measure. The reactor is a 5 liter glass (20 cm in height and 17 cm in diameter) with cap sealed with rubber O-ring, it was equipped with a port outlet at the top to measure the gas generated. Gas collector was a glass cylinder of diameter 12 cm and 17 cm height, with cap sealed with rubber O-ring. The reactor and the gas collector were connected to each other by P.V.C tube of diameter 1cm. The gas measure was an open glass jar of 3 litter volume.

These reactors were kept at 32°C in a constant-temperature water bath to maintain the optimal temperature for the growth of anaerobic microorganisms (Fig. 1).

The *Pilot-scale model* bioreactors were consists of four components including reactor, gas collector, gas measure and leachate collector. The reactors used in this work were glass columns with square cross-section, 35 cm * 35 cm and 100 cm in height with a glass cover sealed with a silicone sealant to maintain anaerobic conditions. Two ports were provided on the top flange of the bioreactor for withdrawing gaseous and leachate recirculation. A perforated PVC leachate collection pipe with a diameter of 2.5 cm was laid in the bottom of the reactor. A 5 liter sealed glass container was used as a leachate collector. A 1 cm PVC vertical tube with valve was installed to connect the perforated pipe in the bottom of the reactor at one end and the leachate collector at the other end. A leachate sampling port was provided on the leachate collection pipe for withdrawing leachate samples. A peristaltic pump was used to deliver the leachate collected in the storage container to the recycle reactor. The gas produced from the reactors was collected and its volume measured by the same technique used in the bench-scale model. The gas collector and gas measure were 5 liter glass containers (Fig. 2).

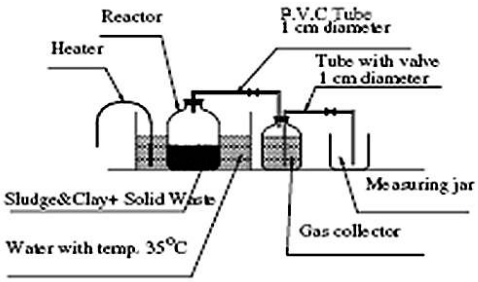

Fig. 1: The schematic diagram of the cell

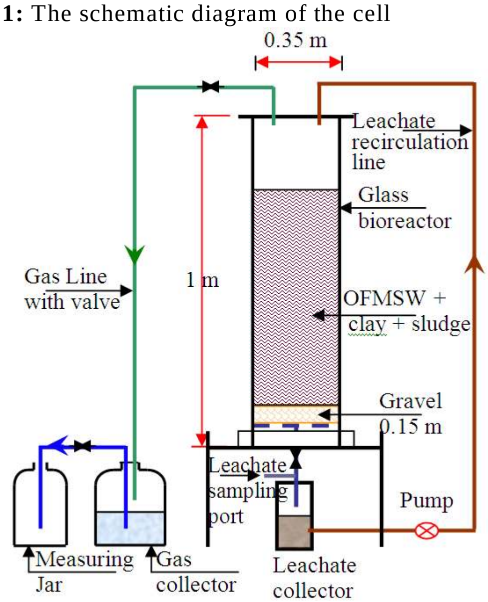

Fig. 2: Pilot-scale simulated landfill reactor with leachate recycle.

Before the reactors were filled with OFMSW, a 15 cm thick layer of 2.5 cm diameter gravel was placed at the bottom of each reactor to prevent clogging of the reactor drainage system.

Table 1: The physical and chemical properties of solid waste.

Parameters	Average values
PH	6.2
Total solids (%)	41.0
Total volatile solids (%)	60.0

Table 2: The physical analysis of montmo-rillonite.

physical property	montmorillonite
Coefficient of permeability	1.5×10^{-7}
Water content (%)	1.92
Specific gravity	1.12
PH	6.91
Coefficient of permeability	1.5×10^{-7}

Simulated Landfill Reactors Loading: Simulated landfill reactors were filled with shredded and compacted synthetic organic solid waste (foods only). The bench-scale bioreactors and the pilot-scale bioreactors loaded by 1 Kg and 48 Kg of food waste respectively. The density of compacted solid waste is in the range of 500–700 kg/m3[15].

In this investigation, the waste was compacted to a density of 650 kg/m3. chemical and physical properties of the solid waste reported in (Table. 1).

Samples of primary and waste activated sludge were obtained from Zinein wastewater treatment plant located at Giza, south of the capital of Egypt (which receives only domestic sewage influent). Samples of primary and waste activated sludge were mixed together in ratio of 1:1.

The clay mineral used in this study was montmorillonite. It was obtained from Sinai Manganese Company (Specialist Company in Egypt). The physical analysis of montmorillonite is presented in (Table 2).

Simulated landfill reactors operation: The experimental study was divided into four operational runs (Table 3).

Table 3: Operational stages employed and bioreactors loading, throughout the experimental study.

				Run IV			
Run no.	Run I	Run II	Run III	Phase 1	Phase 2		
Model type	Bench scale	Bench scale	Bench scale	Pilot scale			
Number of models	7	7	7	4			
Leachate Recirculation	_____	_____	_____	_____		Twice weekly	
Time (weeks)	8	11	11	14		6	
				Bioreactors loading			
Column No.				Rw	Rs	Rwc	Rws
OFMSW (gm)	1000	1000	1000	48000	48000	48000	48000
Clay minerals (gm)		150: 800	150: 800			19200	14400
Water (ml)		530: 660	30: 160	24000		27840	2880
WWS (ml)	150: 800		500		24000		24000
The Variation	WWS ratios	Clay ratios	Clay ratios	Model	Scale & Leachate recirculation		

Optimum WWS-OFMSW mixing ratio: Throughout Run I, OFMSW was mixed with different ratios of WWS ranged from 15% to 80% (by the wet weight basis of solid waste) in order to determine the best mixing ratio that gives the maximum off-gas volume and to determine the best moisture content for the biological processes.

***Effect of mixing clay-OFMSW*:** In Run II, different ratios of clay mineral have been mixed with OFMSW, ranged from 15% to 80% by weight of solid waste. in order to determine the best clay mixing ratio that gives the maximum off-gas volume. To reach the best moisture content, which was obtained from Run I, moisture content was measured and water was added to the mixture.

Effect of mixing clay & WWS –OFMSW: In Run III different ratios of clay mineral have been mixed with OFMSW and WWS, ranged from 15% to 80% by weight of solid waste. The ratio of WWS added to the mixture was the optimum ratio which achieved from Run I. 20% additional water (by the dry weight of clay minerals) was needed to compensate the water absorbed by the dry clay minerals and to reach the optimum moisture content. Run III was conducted to determine the best clay mixing ratio that gives the maximum off-gas volume when mixed with OFMSW and WWS.

Effect of leachate recirculation and mixing clay & WWS –OFMSW: four pilot-scale bioreactors were constructed to carry out Run VI. Throughout Run VI, col. 1 work as a control reactor and loaded with OFMSW and water only (Rw). Col. 2 loaded with OFMSW and WWS only (Rs); col. 3 loaded with OFMSW, water and 40% clay (Rwc); finally col. 4 loaded with OFMSW, WWS and 30% clay (Rsc) (by the wet weight basis of solid waste). Two phases were applied, during the first 98 days no leachate recirculation was applied. In the second phase, twice weakly leachate recirculation was applied for all columns for 77 days.

The gas production was measured through all the experimental days. Leachate COD, TVS and PH were tested through the second phase only. Run IV was carried out in order to observe clay minerals and WWS effects on waste stabilization and then on leachate treatment.

Physicochemical Analysis: Fresh waste samples were used for the determination of moisture contents, TS% and VS% (heating to 105 °C; Kalra and Maynard, 1991) and volatile and fixed solid contents (heating the samples to 550 °C). Gas production was measured daily by observing the displacement of confining solution at every gas collection unit.

During phase 2 in Run IV (six weeks), Leachate collected from both reactors was analyzed for pH, chemical oxygen demand)COD(. All of the analyses were performed according to Standard Methods (1989).

RESULTS AND DISCUSSION

Gas Production: The cumulative gas production for bioreactors of Run I, which contain different ratios of WWS-OFMSW, is given in Fig. (3). The overall volume of gas produced was much larger in the 50% WWS reactor than in the other reactors. While the 50% WWS

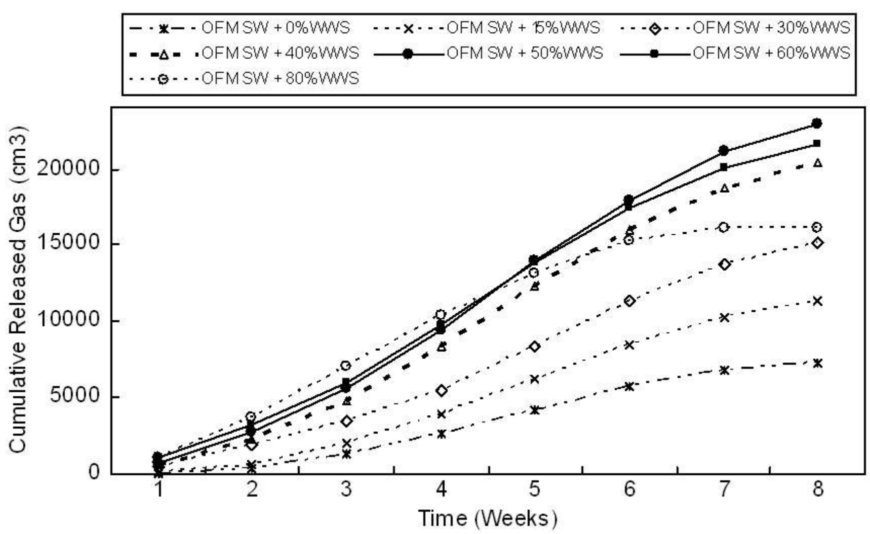

Fig. 3: Cumulative gas production (Run I).

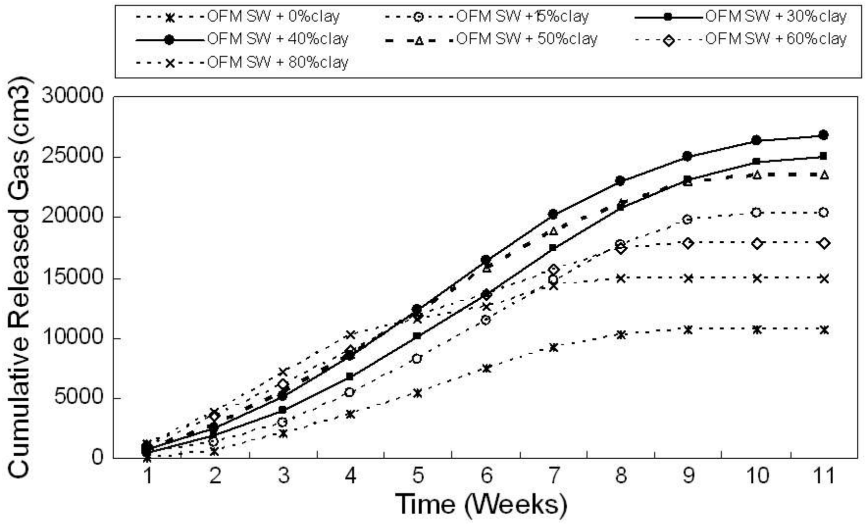

Fig. 4: Cumulative gas production (Run II).

reactor produced 23 l of gas, the 40% WWS and 60% WWS reactors produced 20 l and 21 l of gas respectively. This might be attributed to enrich of microorganisms and nutrients, in addition to the optimum moisture content[17]. The other reactors produced gas ranged between 7 l: 16 l. it could be explained by in sufficient microorganisms for WWS ratio less than 40 %, on contrary, for WWS more than 60 % this occurred due to decrease in the total field capacity of the solid waste required to enhance the mobility[7].

In Run II, gas volume was also monitored as an indication of the progression of waste decomposition in the reactors. Cumulative gas volumes produced in the reactors are given in Fig. 4. As indicated in this figure, the amount of gas generated from reactor receiving a mixture of 40 % clay-solid waste ratio, was higher than the other reactors, it was 26.8 l, it can be attributed to the application of clay minerals, which work as a catalyst in the degradation of the organic compounds. However, in the presence of clay minerals, additional reaction and/or degradation occurred in the municipal solid waste due to the catalytic cracking of hydrocarbons[5,16].

For the ratios less than 40 % clay – OFMSW, during all the experiment, the percentage of cumulative released gas increase with the increase of time but still less than that of 40 % clay – OFMSW ratio, the cumulative off-gas ranged between 10.6 l: 25 l. The ratios more than 40 % clay – OFMSW give a high amount of off – gas at the early time till the end of the fourth week, after that the 40 % clay – OFMSW ratio started to precede these values during the rest of time. This is could be due to

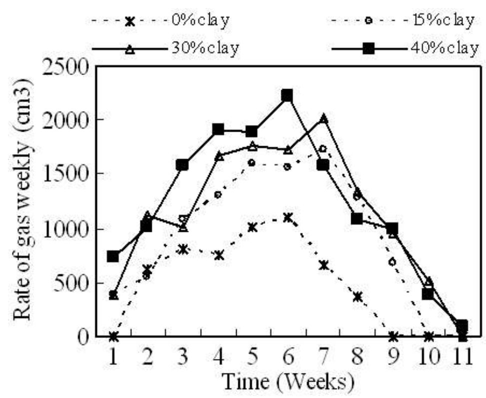

Fig. 5: Rate of gas production (0%:40% clay).

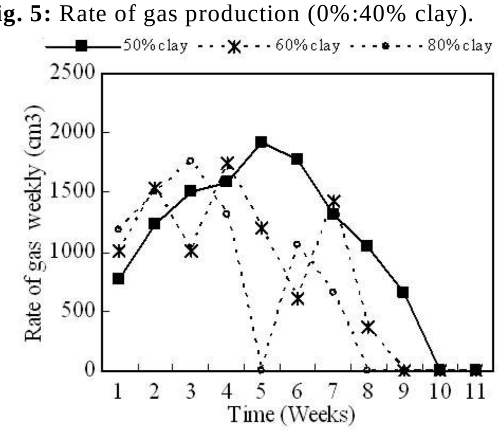

Fig. 6: Rate of gas production (50%:80% clay).

the increase of the clay content that is responsible for enhancing degradation and biogases released. By the time montmorillonite adsorb water, ions and organic

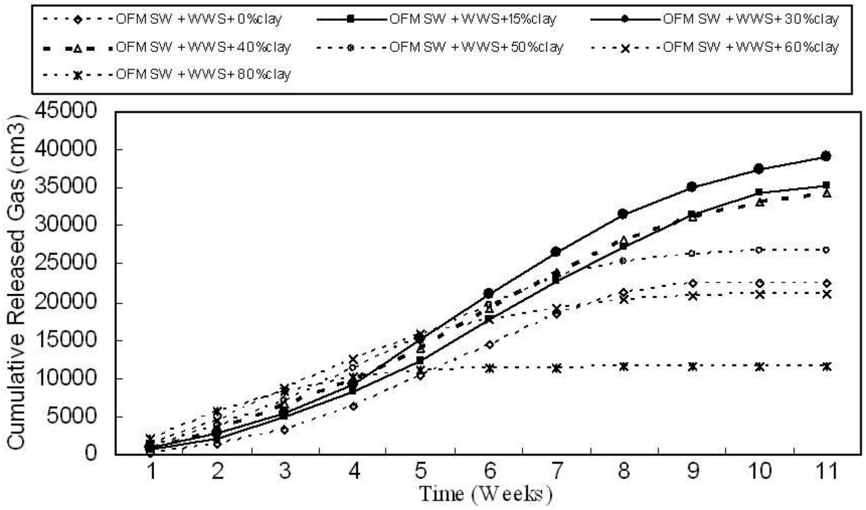

Fig. 7: Cumulative gas production (Run III).

molecules move between the sheets of the clay crystals. As a result the clay expands and tends to close the pores in the mixture and consequently, the bacteria could not find its food. Hence, the degradability of the organics decreases[1]. The cumulative off-gas ranged between 15000: 23000 cm^3. The rates of gas produced in the reactors are given in Fig. 5 and Fig. 6. As indicated in the figure, the maximum rate of gas production was 2221 cm3 achieved by reactor receiving a mixture of 40 % clay-solid waste ratio at the end of the sixth week. The 40 % clay reactor reaches the maximum rate before the reactors of 15% and 30 % clay. It could be due to the optimum clay additions, which stimulate the biological interaction within the bioreactor. On the other hand, the bioreactors contain more than 40% (50%: 80%) clay reached the maximum rate at earlier time with a values ranged between (17.5: 19.1 cm^3) and the interaction stopped earlier. This might be attributed to enrich of clay minerals, in addition to the difficulty face microorganisms and nutrients to move in the gelatinous clay medium.

In Run III, cumulative gas volumes produced in the reactors are given in Fig. 7. The highest amount of cumulative gas was generated from reactor receiving a mixture of WWS and 30 % clay-solid waste ratio, it was 39000 cm^3, it may be attributed to the application of WWS in addition to clay minerals, they work together, the WWS to provide microorganisms and nutrients to the mixture and the clay minerals which has the highest chemical and physical activity to provide a favorite environment for interaction[10].

The rates of gas produced in the reactors are given in Fig. 8 and Fig. 9. The maximum rate of gas production was 3596 cm3 achieved by the reactor receiving a mixture of WWS and 30 % clay-solid waste ratio at the end of the fifth week. The 30 % clay reactor reaches the maximum rate one week before the reactor of 15% clay. On the

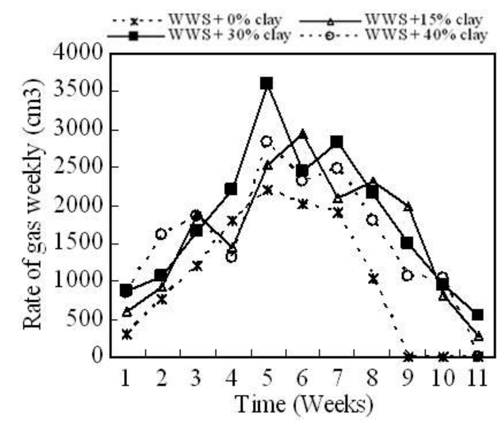

Fig. 8: Rate of gas production (0%:40% clay) Run III.

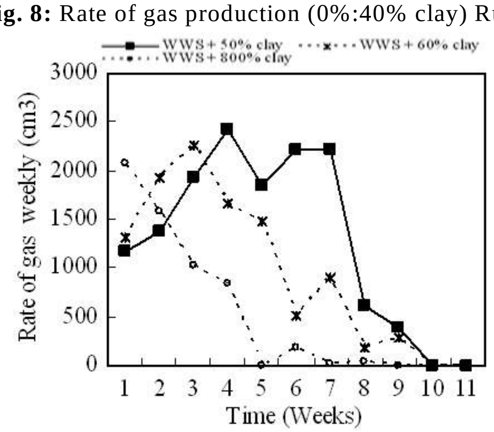

Fig. 9: Rate of gas production (50%:80% clay) Run III.

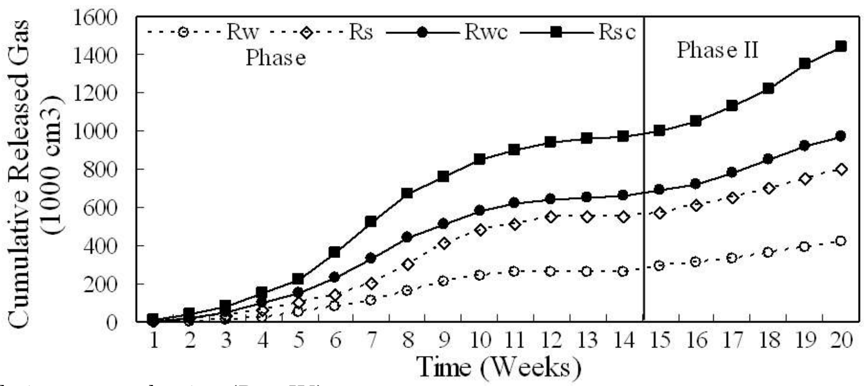

Fig. 10: Cumulative gas production (Run IV).

Table 4: Rates of gas production (Run IV).

	Rate of gas (l/week)	
	Phase 1	Phase 2
Rw	18.8	25.7
Rs	39.0	41.8
Rwc	47.4	51.3
Rsc	69.4	77.8

other hand, the reactors of clay ratios more than 30% (40%, 50%, 60% and 80%0 reach the maximum rate at earlier time. But the reactor of 40% and 50% clay stopped after ten and nine weeks respectively. Also, the reactor of 60% and 80% clay, not only stopped after nine and eight weeks respectively, but also gave irregular rates. It means that, they recorded a small values followed by a high values, this could be due to minimum level of moisture content and a high percentage of clay, which form isolated plants for production of off–gas by the help of physical properties of clay in the absence of nutrients exchange, the produced gas not easy to crack a path in the clayey medium, so the gas come together and released as pulses in high rates after a small rates.

Four pilot- scale bioreactors were used to achieve Run IV. The cumulative gas production plotted in Fig. 10. Through the two phases reactor Rcs achieve the highest cumulative gas production, it was 96210 cm^3. the reactor Rwc record a higher biogas released in comparing with that bioreactor containing 50 % sludge only (Rs) by about 22 %. In other words, the clay minerals addition may be used as an alternative method substituting the addition of WWS. More over, Clay minerals have a less impact on the surrounding environment.

As shown in Table 4, The rate of gas production increased during phase II. It indicate that, leachate recirculation can stimulate the interaction within the bioreactors. The Rsc reactor has a highest increase percentage in comparing with Rs and Rwc. This might be attributed to the addition of WWS and clay minerals; they activate and stimulate the chemical and physical interaction within Rsc reactor.

Leachate Characteristics

COD: The COD was monitored as an indicator parameter of the leachate organic strength. The initial COD concentration in the two bioreactors, Rw and Rs without clay, were close to each other and it was 16100 and 17400 mg/l Rw and Rs reactors respectively. According to Cinar, *et al.*, [4] the initial COD concentrations were high, indicating the presence of an acidogenic environment due to the accumulation of volatile fatty acids. Then an increase has been observed during (day 3 and 7) and it was 18250 and 20100 mg/l respectively. It could be due to the first washout of the bioreactors from top to bottom.

On the other hand, the initial COD concentration in Rwc and Rsc were 12100 and 13250 mg/l respectively. during the rest of weeks it indicate a continuous decrease until the end of the experiment.

The final COD concentration reached 480 and 290 mg/l for Rwc and Rsc respectively. It could be explained by the filtration of clay medium to the organic compound of the leachate. As shown in Fig. (11).

Fig. (12) illustrate that, the Rsc reactor achieved maximum COD removal efficiency duo to the effect of WWS microorganisms and the adsorption of clay minerals. The percentage of COD removal efficiency for the four reactors Rw, Rs, Rwc and Rsc; were 78.26%, 84.5%, 96% and 97.81% respectively. As shown in the figure, note that the negative values were neglected.

pH: The initial pH values were low and ranged between 4.3 and 5.2. According to Cinar *et al.*,[4], the low pH values were attributed to the generation and accumulation of volatile organic acids during the Phase I. This was also supported by the high leachate COD

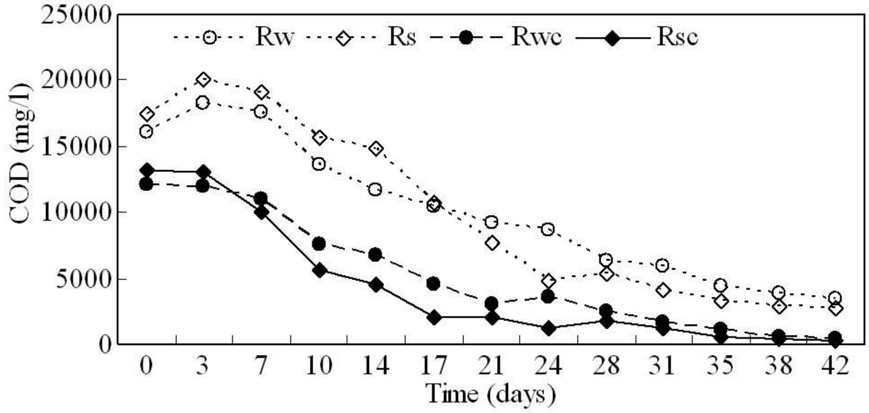

Fig. 11: Leachate COD concentration (Run IV-Phase II0.

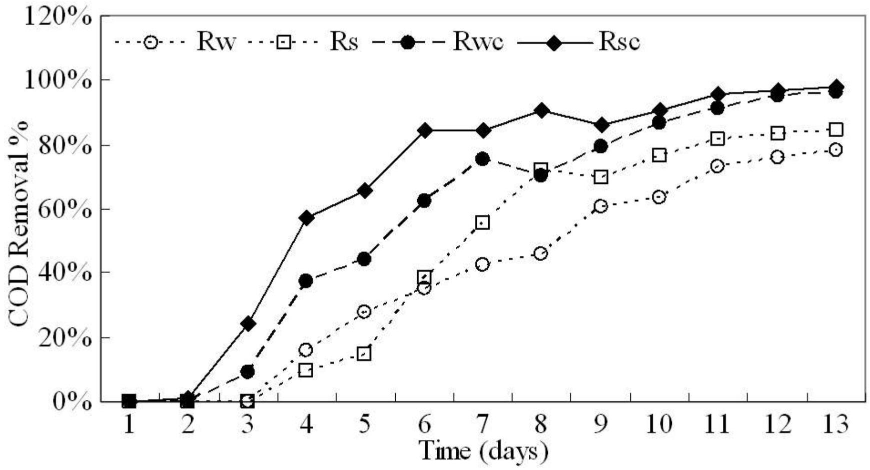

Fig. 12: Leachate COD removals (Run IV-Phase II).

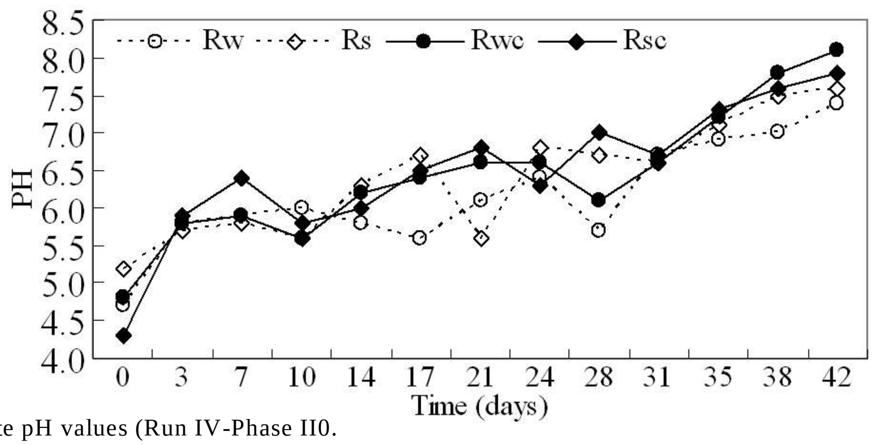

Fig. 13: Leachate pH values (Run IV-Phase II0.

concentrations observed during this week. The pH values of leachate from the four bioreactors are given in Fig. 13. In the first week, the pH values of all reactors exhibited a similar trend. Then, during the next three weeks a slight increase in pH of the leachate was observed. This was accompanied with an increase in methane production indicating the onset of anaerobic stabilization in the reactor (Irem Šan *et al.*, 2001) and was accompanied with the decrease of the COD during this period. By the time, methane producing bacteria becomes more predominate.

These bacteria degrade the volatile acids to methane and carbon dioxide, resulting in a rise in pH to reach about 7.4 to 8.1 at the end of the experiment[5].

Conclusion: Based upon the experimental results obtained from this study, the following conclusions can be drawn:

- Using Clay minerals that mixed with OFMSW can improve the biodegradation of the solid waste. Clay minerals work as a catalyst in the degradation of the organic compounds. However, in the presence of clay minerals, additional reaction and/or degradation occurred in the municipal solid waste due to the catalytic cracking of hydro-carbons.
- Clay minerals and WWS that mixed with solid waste, improves the biodegradation of the mixture and achieved the best results. The optimum mixing ratio that show the maximum biogases released was 30 % clay minerals, 50% WWS with OFMSW.
- Reactor Rsc, receiving a mixture of WWS and 30% clay menials, showed 97.87% in the leachate COD removal efficiency and a 3.4 times the cumulative gas production in Rw (control reactor), indicating enhancement of solid waste stabilization. This can be explained by the favorable environment created by the addition of WWS and clay minerals. While WWS addition increased the bacterial population and the concentration of available soluble substrate required by the bacteria, clay addition work as a catalyst in the degradation of organic compound.
- The Rwc reactor achieves a higher biogas released in comparing with that bioreactor containing sludge only (Rs). The cumulative gas production was 1.22 times that of Rs. In addition, the final COD concentration was 480 mg/l and 3500 mg/l respectively. In other words, the clay minerals addition may be used as an alternative method substituting the addition of WWS. Clay minerals have a less impact on the surrounding environment. More over, the final product of the sanitary landfill after long time may be used as a fertilizer to the plant or to improve the characteristics of the desert soil which can not keep the irrigation water (A.D. Noble, 2007).

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