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EVALUATION OF THE ANAEROBIC DIGESTION OF AGRICULTURAL WASTE IN LEACH-BED REACTOR FOR BIOGAS PRODUCTION

Abstract. Anaerobic digestion processes for agricultural wastes are widely used to reduce environmental and social issues and as a way of alternative renewable energy production. Anaerobic dry fermentation of agricultural waste (cattle manure) was investigated to evaluate an efficiency of the single-stage leach-bed process for biogas production. The experiments were performed in batch-operation mode at the temperature of 40±0,2°C. Bioreactor with a working volume of 50 L had been constructed by modifying leach-bed reactor and fixed-bed reactor. The reactor was equipped with immobilization device positioned at the bottom as a layer of polyethylene packing rings. Experimental reactors were tested during a period of 28 days in Run 1 and 21 days in Run 2. The performance of the reactor was analyzed in terms of the biogas production. According to the results, the average cumulative biogas yield was (0.331±0.005) Nm^3 $(kg\ oDM)^{-1}$, average percentage of methane was (47.13±1.40)% during the anaerobic digestion. Anaerobic digestion of agricultural waste in leach-bed reactor is feasible and stable process for biogas production without anaerobic pretreatment and mixing, and immobilization of microflore on the supporting material improved methane production.
Keywords: anaerobic digestion, biogas, agricultural waste, methane, leach-bed reactor.

Introduction. Nowadays, anaerobic digestion processes for agricultural wastes are widely used to reduce environmental and social issues in the areas of livestock and poultry farms, and it has become an alternative way of renewable energy production. Numerous studies had been conducted in order to increase and stabilize biogas yield, optimize anaerobic biogas technologies. One of the ways of optimization of biogas production is improvement of bioreactors design. Since successful application of anaerobic fermentation technologies for treatment of organic waste from agricultural and industrial production is largely dependent on the development and use of high-rate anaerobic bioreactors. In such reactors, a large amount of substrate is processed, and optimally designed bioreactor can reduce processing time and improve the processing efficiency, resulting in an overall reduction in processing cost [1].

And such high-rate reactors as the anaerobic stirred tank reactor, the anaerobic contact process, the anaerobic sequentially cyclic reactor, the anaerobic fixed-bed reactor, the expanded or fluidized-bed reactor, the upflow anaerobic sludge blanket reactor, the anaerobic barrier reactor, leach-bed reactor can be mentioned [2;3]. In such reactors, the average growth rate of methanogenic bacteria is much lower than the growth rate of acidogenic bacteria and the overall rate of biomethanogenesis process is controlled by methanogenesis stage in anaerobic fermentation of waste water with the low solids content. Parawira (2004) [4] in his works found out, that the biomethanogenesis rate can be accelerated by increase of conversion rate of VFA into methane by increasing the concentration of the methanogenic bacteria in the reactor, and offered two ways to increase of microflora concentration:

- use of separate cellular agglomerates in the form of "sludge granules" to improve their sedimentation properties and reduce the washing out degree of microflora;
- allow methanogenic bacteria cells cells to grow in the immobilized form in inert "carriers", which have high specific gravity higher than cells [4, 5].

In this present paper we give results of investigation and evaluation of the performance of single-stage leach-bed reactor for treatment of solid cattle manure, concentrating on the biogas production and biogas composition.

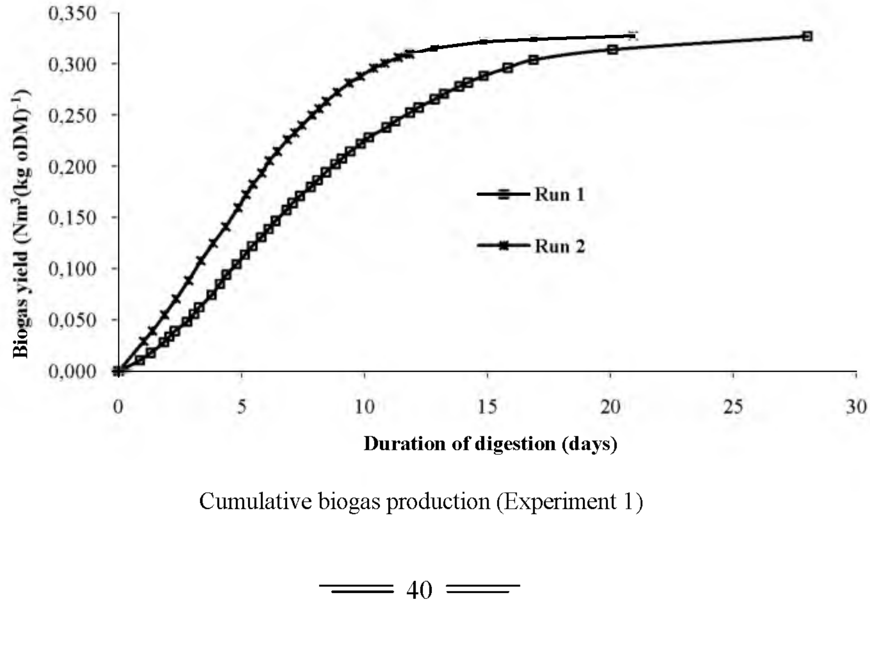
Materials and methods

Feedstock. Cattle manure was provided by livestock farm of the University of Hohenheim. For each experiments and runs were required 3 kg of cattle manure and 19 L of inoculum. The inoculum was fermented cattle slurry that was used as leachate for the microbial initiation of single-phase leach-bed process with immobilization of microorganisms and for recirculation system. Fresh manure (FM) as received and inoculum samples were analyzed in triplicate for its Dry Matter (DM) and moisture content, Organic Dry Matter (oDM) and ash content according to standard methods of APHA (1995) [6]. Accordance with results of tested substrate analysis, DM content of cattle manure was 25.93% and 84.07% of solids were oDM.

Experimental set-up and operation. Bioreactor with a working volume of 50 L had been constructed by modifying leach-bed reactor and fixed-bed reactor. Full characteristics of the experimentdl set-up are given in Korazbekova et al. (2013) [1]. The experiments were conducted in the biogas laboratory of the State Institute of Agricultural Engineering and Bioenergy of the University of Hohenheim (Stuttgart, Germany). The reactors were maintained at 40±0,2^{0}C and operated at a batch mode until biogas production was detected. Anaerobic digestion was performed in two runs, lasted 28 days for Run 1 and 21 days for Run 2 of Hydraulic Retention Time (HRT) in three replicate indicated as Experiments.

Results and discussion

Experimental reactors were tested during a period of 28 days in Run 1 and 21 days in Run 2 to assess the dry fermentation of cattle manure on a modified leach-bed with immobilization device reactors. Biogas production was depicted by biogas volume and methane content. Cumulative biogas and methane production were determined by summing daily biogas and methane yield, respectively. All the experimental repetitions of 2 runs showed similar findings. To describe the features of the cumulative biogas and methane yield was selected Experiment 1. Results of cumulative biogas production from Experiment 1 are shown in Figure. The rapid initial biogas production was due to readily biodegradable organic matter and presence of high content of the methanogens as depicted in Fig.1. The biogas generation started after inoculating, kept increasing until reaching the peak, and then began to decline (Li et al., 2011) [7]. Run 1 showed the maximum biogas production on day 4 in the amount of 0.032 Nm^3 $(kg\ oDM)^{-1}$ and daily biogas generation was observed more than 0.018 Nm^3 $(kg\ oDM)^{-1}$ between days 2 and 10, reduced to less than 0.005 Nm^3 $(kg\ oDM)^{-1}$ after day 19. The cumulative biogas yield was indicated as 0.327 Nm^3 $(kg\ oDM)^{-1}$ at the end of Run 1. Biogas production started faster in Run 2, i.e.



Cumulative biogas production (Experiment 1) peak biogas generation (0.047 Nm^3 (kg oDM)$^{-1}$) was achieved up to day 3 of the experiment demonstrating the maximum degree of biogas formation till days 9 (daily production more 0.02 Nm^3 (kg oDM)$^{-1}$) and intensive metabolism of microorganisms, since reactor was enriched with methanogens because of biofilm formation and use of fermented leachate from previous run. The cumulative biogas production was 0.328 Nm^3 (kg oDM)$^{-1}$ at the end of 21-day of HRT. There were not observed several peaks during the digestion process in both two runs as reported by Li et al. (2011) [7].

The curve of cumulative methane production gave volume of 0.148 Nm^3 (kg oDM)$^{-1}$. Run 2 showed a rapid initiation of methanogenesis from the early days and the maximum methane yield was 0,022 Nm^3 (kg oDM)$^{-1}$, 1.6 times more than in Run 1 due to the high content of methane-producing bacteria resulted in immobilization of microorganisms on the supporting materials. The total methane yield was 0,150 Nm^3 (kg oDM)$^{-1}$ at the end of the digestion process.

The biogas quality for Experiment 1. As depicted, the initial percentage of methane in the biogas has increased and exceeded 26.5% after 3 days of start-up, and 50% on day 5 and kept it up to the end of Run 1 presenting stable phase of the digestion. The methane content reached 35% on 2 days and increased sharply to 66% on day 7 as a peak percentage of methane in Run 2. But the maximal methane percentage in Run 1 achieved one day later than in Run 1 on day 8 (56.1%). The percentage of carbon dioxide exceeded the methane percentage during 4 days. The maximum percentage of carbon dioxide was 53.4% on day 2 in Run 1 and 50% on day 3 in Run 2, those were followed by a gradual decrease to 37%. The percentage of carbon dioxide has stabilized in between 42 to 45% from day 6 and 5, respectively in Runs 1 and 2. High initial percentage of carbon dioxide and low methane percentage associated with the biochemical transformation of organic matter in anaerobic digestion. In the second stage of anaerobic digestion (acidogenesis) 70% of low molecular weight compounds, such as simple sugars, amino acids and fatty acids decomposed to acetate, carbon dioxide and hydrogen, and the remaining 30% to volatile fatty acids (VFA) and alcohols [7, 8]. In addition, the regeneration time of acidogenic bacteria (Bacterioids, Clostridia) is 24-36 h [9]. The methane content increased intensively and the maximum percentage also achieved faster for 1 day earlier in Run 2, because Run 2 was initiated with leachate from Run 1, which contained a high concentration of microorganisms [10].

Final data of biogas production on the results of experiments are shown in table. And in accordance with table 1, (0.331±0.005) Nm^3 (kg oDM)$^{-1}$ biogas (standard error = 0.003) with an average percentage of methane (47.13±1.40)% was obtained during the anaerobic fermentation of cattle manure in the reactor with immobilization device.

Production and energy content of the biogas from the anaerobic fermentation in the leach-bed reactor

Experiment	Biogas yield, Nm^3 (kg oDM)$^{-1}$	Average methane content, %	Maximum methane content,%	Methane yield, Nm^3 (kg oDM)$^{-1}$	Energy value, kWh (kg oDM)$^{-1}$
Experiment 1[a]	0.328±0.001	45.50±0.3	61.10±7.10	0.149±0.001	14.8±0.14
Experiment 2[a]	0.337±0.002	48.10±1.4	68.10±0.14	0.162±0.006	16.1±0.56
Experiment 3[a]	0.329±0.008	47.75±2.5	65.25±0.07	0.157±0.004	15.6±0.40
Final mean value	0.331	47.13	64.80	0.156	15.50
Standard deviation	0.005	1.40	3.52	0.007	0.66
Standard error	0.003	0.82	2.03	0.004	0.379
Final range [b]	0.331±0.005	47.13±1.40	64.80±3.52	0.156±0.007	15.50±0.66

1 [a] – Data are expressed as mean±standard deviation of two runs.
2 [б] – Data are expressed as mean±standard deviation of three runs and experiments.

The maximum methane percentage was found in the value of (61.10±7.10)% in Experiment 1, (68.10±0.14)% in Experiment 2 and (65.25±0.07)% in Experiment 3. The final value was (64.80±3.52)% with a standard error of 2.03%. Cumulative methane yield was (0.149±0.001); (0.162±0.006) and (0.157±0.004) Nm^3 (kg oDM)$^{-1}$ for Experiments 1, 2 and 3, and the final range was (0.156±0.007) Nm^3 (kg oDM)$^{-1}$ with a standard error of 0.004 Nm^3(kg oDM)$^{-1}$. Energy content ranged between 14.8-16.1 in three experiments. Calculated final range lies in the amount of (15.50±0.66) kWh (kg oDM)$^{-1}$ with the standard error of 0.379 kWh(kg oDM)$^{-1}$.

In conclusion, dry fermentation of cattle manure with dry matter content of 25.93% in leach-bed reactor without anaerobic pretreatment and mixing is feasible and stable process for production of biogas from agricultural wastes. Immobilization of methanogens on the supporting materials (polyethylene packing rings) in leach-bed reactor improved biogas production.

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БИОҒАЗ ӨНДІРІСІ ҮШІН СІЛТІЛЕНДІРУ ҚАБАТЫ БАР РЕАКТОРДА АУЫЛ ШАРУАШЫЛЫҚ ҚАЛДЫҚТАРЫНЫҢ АНАЭРОБТЫ АШУЫН БАҒАЛАУ

Аннотация. Ауыл шаруашылық қалдықтарының анаэробты ашу процесі экологиялық және әлеуметтік мәселелерді төмендету, сонымен қатар қалпына келтірілетін энергияның альтернативті өндірілуі үшін бүкіл әлемде кең қолданылады. Биогаз өндіруде бір сатылы сілтілендіру қабаты бар процестің тиімділігін бағалау үшін ауыл шаруашылық қалдықтарының (ірі қара мал қиы) құрғақ анаэробты ферментациясы жүргізілді. Тәжірибелер 40±0,2°С температурада кезеңді режимде жүрді. Жұмыс көлемі 50 л. биореактор сілтілендіру қабаты бар реактор мен бекітілген қабаты бар реакторды модификациялау жолымен құрастырылды. Реактор полиэтилен буылған сақиналар қабаты түріндегі иммобилизациялау қондыргысымен жабдықталған. Ол реактор түбінде орналасқан. Тәжірибелік реакторлар Сынақ 1-де 28 күн, ал Сынақ 2-де 21 күн бойы сыналды. Реактордың өнімділігі биогаз өндіру бойынша талданды. Нәтижелерге сәйкес, анаэробы ашу кезінде биогаздың кумулятивті шығуы (0,331±0,005) Nм^3(кг oDM)$^{-1}$, метанның орташа пайызы (47,13±1,40)% құрады. Ауыл шаруашылық қалдықтарының анаэробты ашуы сілтілендіру қабаты бар реакторда араластруды және алдына ала анаэробты өңдеуді қажет етпейтін, жүзеге асыруга болатын және орнықты процесс болып табылады және микрофлораны қондыргыда иммобилизациялау метанның шығуын жақсартады.

Түйін сөздер: анаэробты ашу, биогаз, ауыл шаруашылық қалдықтары, метан, сілтілендіру қабаты бар реактор.

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ОЦЕНИВАНИЕ АНАЭРОБНОГО БРОЖЕНИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ОТХОДОВ В РЕАКТОРЕ СО-СЛОЕМ ВЫЩЕЛАЧИВАНИЯ ДЛЯ ПРОИЗВОДСТВА БИОГАЗ

Аннотация. Процессы анаэробного сбраживания сельскохозяйственных отходов широко используются во всем мире для уменьшения экологических и социальных проблем, а также как альтернативное производство возобновляемой энергии. Была проведена анаэробная сухая ферментация сельскохозяйственных отходов (навоз крупного рогатого скота) для оценки эффективности одностадийного процесса со-слоем выщелачивания для производства биогаза. Эксперименты проводились в режиме периодического действия при температуре 40±0,2°С. Биореактор с рабочим объемом 50 л был сконструирован путем модификации реактора выщелачивания и реактора с неподвижным слоем. Реактор был оборудован иммобилизационным устройством, расположенным на дне в виде слоя полиэтиленовых упаковочных колец. Экспериментальные реакторы были испытаны в течение 28 дней в опыте 1 и 21 дней в опыте 2. Производительность реактора была проанализирована с точки зрения производства биогаза. По результатам средний кумулятивный выход биогаза составил (0,331±0,005) $Nм^3$ $(кг\ oDM)^{-1}$, средний процент метана (47,13±1,40)% в течение анаэробного сбраживания. Анаэробное сбраживание сельскохозяйственных отходов в реакторе со-слоем выщелачивания является осуществимым и стабильным процессом производства биогаза без анаэробной предварительной обработки и смешивания, а иммобилизация микрофлоры на подложке улучшает производство метана.

Ключевые слова: анаэробное сбраживание, биогаз, сельскохозяйственные отходы, метан, реактор со-слоем выщелачивания.