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Renewable Energy Potential of Diluted Poultry Manure during Ambient Anaerobic Stabilisation

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***Abstract*—**In this study, the anaerobic treatability of chicken manure diluted with tap water (with an influent feed ratio of 1 kg of fresh chicken manure to 6 liter of tap water) was investigated in a lab-scale anaerobic sludge bed (ASB) reactor inoculated with the granular sludge already adapted to chicken manure. The raw waste digested in this study was the manure from laying-hens having average total solids (TS) of about 30% with ca. 60% volatile content. The ASB reactor was fed semi-continuously at ambient operating temperature range (17-23°C) at a HRT of 13 and 26 days for about 6 months, respectively. The respective average total and soluble chemical oxygen demand (COD) removals were ca. 90% and 75%, whereas average biomethane production rate was calculated ca. 180 lt per kg of $COD_{removed}$ from the ASB reactor at an average HRT of 13 days. Moreover, total suspended solids (TSS) and volatile suspended solids (VSS) in the influent were reduced more than 97%. Hence, high removals of the organic compounds with respective biogas production made anaerobic stabilization of the diluted chicken manure by ASB reactor at ambient operating temperatures viable. By this way, external heating up to 35°C (i.e. anaerobic processes have been traditionally operated at mesophilic conditions) could be avoided in the scope of this study.

***Keywords*—**Ambient anaerobic digestion, biogas recovery, poultry manure.

I. Introduction

ANAEROBIC digestion is a biological process providing more sustainable livestock waste management practices and anaerobic reactors have been used extensively for poultry manure treatment for biogas recovery for many decades [1]. Waste from the poultry industry consists of a mixture of excreta, bedding material or litter like wood shavings or straw, waste feed, dead birds, broken eggs and feathers. Other wastes from poultry houses include those from cage, conveyer belt and water flushing systems. Although the litter and manure component of this waste has a high nutritional value to be used as an organic fertiliser, over-application of this material can lead to an enriching of water nutrients resulting in eutrophication of water bodies, the spread of pathogens, the production of phytotoxic substances, air pollution and emission of greenhouse gases [2]. Hence, in recent years, one of the most significant challenges encountered in many countries is; how the produced environmental problems are going to be solved in a safe and in an environmentally sustainable manner. In this respect, new waste management strategies like waste-to-energy technologies combine cost-effective treatment technologies together with recycling and most waste-to-energy technologies convert waste matter into various forms of fuel that can be used to supply energy [3]. Today, anaerobic digestion of organic wastes is considered as one of the most appropriate treatment alternatives due to useful by-products such as biogas and nutrients. It is used worldwide as a unit treatment for industrial, agricultural, municipal wastes and waste by-products [4]. Anaerobic digestion consists of the stabilisation of organic materials (i.e. in poultry litter, organic components can be classified into broad biological groups: proteins, carbohydrates and lipids or fats) under anaerobic conditions and the degradation occurs by microbial organisms that leads to the formation of methane and inorganic products including carbon dioxide. Stabilization of poultry litter under anaerobic conditions is a relatively efficient conversion process for producing a collectable biogas mixture with an average methane content of 60% (i.e. the produced methane can be used as a fuel for boilers, as a replacement for natural gas or fuel oil and can also be fired in engine-generators to produce electricity for on-farm use or sale to electricity companies) [2].

To date, energy demand in Turkey has been rapidly increasing that leads to an energy gap problem. In Turkey, more than 8×10^6 tonnes of poultry manure is produced annually [5]. Therefore, the development of clean and renewable energy using this manure has been one of the most vital issues in order to ease the energy short fall. In this respect, rather than being a problem of waste, poultry litter might be a renewable energy source. On the other hand, poultry litter might be also a nutrient source because of the fact that the residual sludge is stable and can be used as a soil fertiliser following anaerobic digestion [2], [6]. Currently, several engineering biogas designs are applied for anaerobic digestion of the substrates like poultry manure (e.g. upflow anaerobic sludge bioreactor) [7], [8]. Since ammonia toxicity has been reported in the digestion of poultry manure (i.e. may contain more than 4 g/L NH3±N); ammonia toxicity could be suppressed by co-digestion with other organic substrates (i.e. co-substrates) and/or dilution of these wastes [4], [9]. In this respect, the objective of this study is to investigate the performance and biogas potential of a lab-scale anaerobic sludge bed (ASB) reactor treating the diluted chicken manure.

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II. Materials and Methods

A. Anaerobic Reactor and the Inoculum

The anaerobic treatability study was conducted in a lab-scale semi-continuous scale anaerobic sludge bed (ASB) reactor. The reactor had an effective volume of 6.45 L with a Plexiglas column of 1.0 m in height and 90 mm in diameter. On the top of the reactor, a special gas-solids-liquid separator was installed and the produced biogas was collected via this separator. The schematic view of the reactor is shown in Fig. 1.

The ASB reactor was originally seeded with active methanogenic sludge from the mesophilic anaerobic Internal Circulation (IC) reactor treating the wastewater produced at a pulp and paper industry (i.e. 0.71 L granular sludge with a TS concentration ca. 300 g/L; VS/TS ratio of ca. 37%). Hence in this study, the ASB reactor included the same granular inoculum which had been already adapted to diluted chicken manure (i.e. TSS concentration ca. 90 g/L; VSS/TSS ratio of ca. 44%).

B. Raw Manure and the Influent Slurry Characteristics

Raw manure was taken fresh from a big enterprise with a daily capacity of about 20,000 eggs from 275,000 livestock. The waste produced in this industry was the manure from the laying-hen having average total solids (TS) of about 30% with the volatile content of ca. 60%. The characterization of the slurry used in this study is presented in Table I.

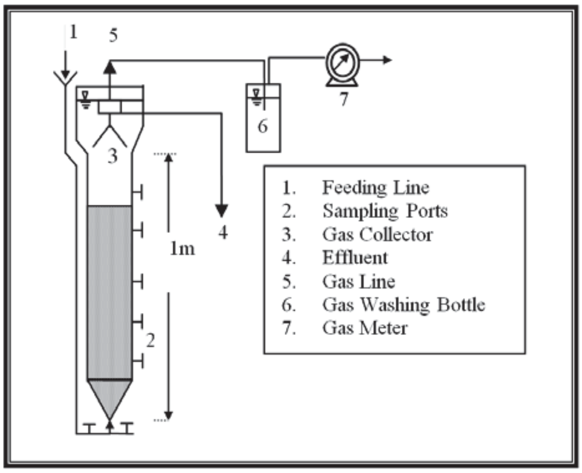

Fig. 1 Schematic view of the ASB reactor used in this study

TABLE I
Characterization of the Slurry Used in This Study

Parameter	Unit	Median
Total COD	mg/L	29635
Soluble COD	mg/L	11916
TSS	mg/L	28508
VSS	mg/L	17404
Alkalinity*	mg/L	2900
pH	-	7.59

*as $CaCO_3$

C. Operating Conditions

The ASB reactor was operated with the hydraulic retention time (HRT) of 13 and 26 days during a total feeding period of about 180 days. The reactor was fed daily (from the bottom port) with 250-500 mL diluted chicken manure (with an influent feed ratio of 1 kg of fresh chicken manure to 6 liters of tap water). Since, the poultry litter contains a higher fraction of biodegradable organic matter other than other livestock wastes, high levels of organic nitrogen due to the high content of protein and amino acids generally result in operational problems during anaerobic digestion, especially when these wastes are treated alone. Hence, a possible solution to solve this problem is to dilute the material and by this way, the adverse effect of ammonia inhibition could be also eliminated [10].

The ASB reactor has been operated at ambient temperature observed in the range of 17 to 23◦C during the study depending on room temperature. Khoiyangbam et al. [11], reported increased biogas production using poultry manure as a feedstock, where operating temperature played a key role in the anaerobic digestion process. Although the daily biogas generation increased with increased temperature, ambient operating temperature (i.e. 17 to 23◦C) in this study still indicated satisfactory anaerobic digestion of the diluted chicken manure and hence heat requirement (for raising the temperature of the incoming feed up to mesophilic range; 35◦C) was eliminated with less operating costs.

Total COD, soluble COD, total solids (TS), volatile solids (VS), total suspended solids (TSS), volatile suspended solids (VSS), nitrogen, phosphorus, and alkalinity parameters were performed according to the Standard Methods for the Examination of Water and Wastewater [12].

The pH values in the samples were measured by HI 2211-02 HANNA Model pH meter. Total biogas was measured by Ritter Milligas Counter 770991000 Model gas meter. Perichrom PR2100 Model GC with a TCD detector was used in order to measure the methane and carbon dioxide content of the produced biogas. Temperature and the biogas produced were measured daily.

III. Results and Discussion

Results of this study showed a successful anaerobic treatment of the diluted chicken manure by a lab-scale ASB reactor at ambient operating temperatures. Respective average total and soluble COD removals of ca. 90±5% and 75±7% (OLR ~ 2.0 kg COD/m^3.day) were obtained (Figs. 2 (a) and (b)).

The influent TSS and VSS concentrations could reach up to 35310±17690 and 21270±12260 mg/L, respectively. TSS and VSS profile in the ASB reactor is presented in Table II. Results indicated that both total and volatile suspended solids could be reduced ca. 97%. pH and alkalinity results in the effluent during the study showed stability with average values of ca. 8.24 and 1980 mg $CaCO_3$/L, respectively.

Ammonia nitrogen concentrations in the influent and in the effluent were 1170 and 1150 mg/L, respectively. It was

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reported that endogenous ammonia-nitrogen concentrations increase considerably during anaerobic digestion of poultry litter and although a certain amount of ammonium ions can be utilised by some anaerobic bacteria, an excess of ammonium can inhibit the destruction of organic compounds, the production of volatile fatty acids and methanogenesis [2], [10]. During the study, no free ammonia inhibition was observed due to dilution of the raw chicken manure.

Krylova et al. [10] found that an excess of ammonia nitrogen in a fermentation medium can cause inhibition of the anaerobic process in the following ways: (1) free ammonia, which is more toxic for anaerobic microflora than ammonium ion, is formed during the fermentation process; (2) amination of a-ketoglutaric acid from the metabolic pool of the tricarboxylic acid cycle can cause difficulties in the metabolism of organic compounds; and (3) the release of ammonia-nitrogen may result in accumulation of volatile fatty acids. For these reasons, the minimisation of levels of ammonia is an important priority during the anaerobic treatment of poultry litter. A possible solution to solve this problem is to dilute the material to 0.5–3.0% total solids. Since raw chicken manure was diluted before fed into the ASB reactor, no free ammonia inhibition was observed in this study [13].

Average CH_4 production rate was calculated ca. 180 L per kg of total $COD_{removed}$ from the ASB reactor at an average HRT of 13 days. Methane content of the produced biogas was measured about 60%. On the other hand, the average CH_4 production rate was calculated ca. 275 lt per kg of VSS_{added} from the ASB reactor at average HRT of 13 days. Daily and cumulative biogas production in the ASB reactor is indicated in Fig. 4.

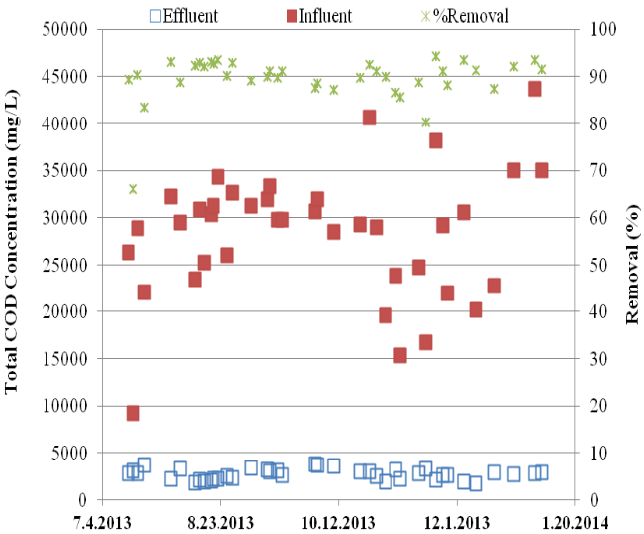

Fig. 2 Total COD profile in the ASB reactor

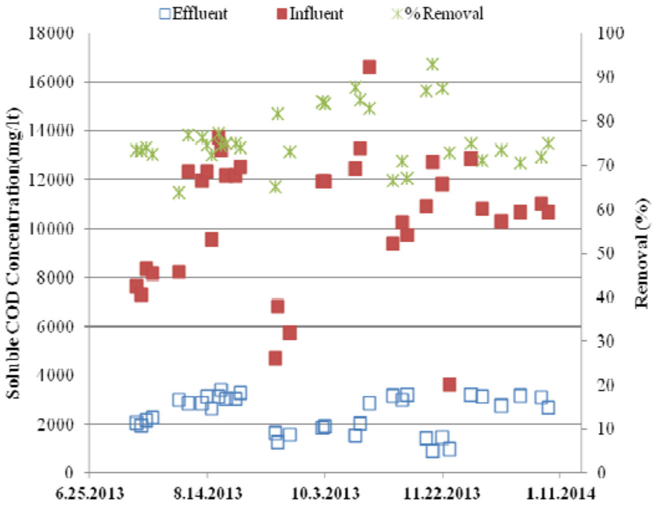

Fig. 3 Soluble COD profile in the ASB reactor

TABLE II
TSS AND VSS CHANGES IN THE ASB REACTOR TREATING DILUTED CHICKEN WASTE

Parameters	Unit	Minimum	Maximum	Mean ± Std. Dev.	Median
$TSS_{influent}$	mg/L	15652	93333	35309±17691	28568
$TSS_{effluent}$	mg/L	215	3735	1095±728	960
TSS removal	%	93	99	96±1.47	97
$VSS_{influent}$	mg/L	7826	56667	21270±12263	17196
$VSS_{effluent}$	mg/L	105	2025	682±419	580
VSS removal	%	90	99	96±1.98	97

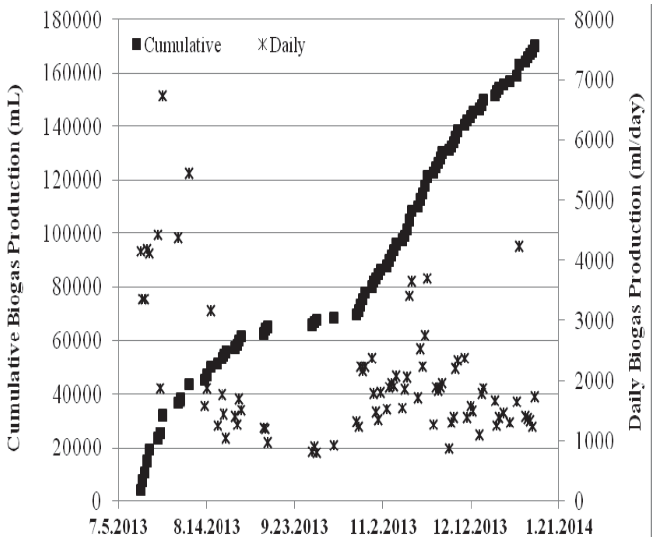

Fig. 4 Biogas profile in the ASB reactor

IV. CONCLUSION

To date, the rapidly increasing energy demand in the developing countries like Turkey has led to an energy gap problem. Annual poultry manure production in Turkey is more than 8×10^6 tonnes and hence the development of clean and renewable energy using this manure has been one of the most significant topics to ease the energy shortfall. In this respect, rather than being a problem of waste, poultry litter might be a

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renewable energy source when managed by suitable treatment systems like the anaerobic digestion process. However, for anaerobic digestion of poultry waste to be financially viable, the heat energy resulted from the quantity of biogas produced should satisfy the energy demand of the chicken farm during the winter period. Moreover, in order to eliminate the adverse effect of free ammonia inhibition, proper dilution is recommended. In this respect, anaerobic treatability of the diluted laying-hen manure was investigated at ambient operating temperature range (17-23°C) in this study. During the digestion of the diluted manure at low operating temperatures, results still indicated effective performance in terms of organic compounds' removal and biogas production. Average CH_4 production rates were calculated ca. 180 L per kg of total $COD_{removed}$ and 275 lt per kg of VSS_{added} from the ASB reactor at an average HRT of 13 days. However, the necessity to comply with discharge limits has still become a matter of increasing concern to the poultry industry that might require an effective post-treatment unit following anaerobic digestion.

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