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Process intensification with inline pre and post processing mechanism for valorization of poultry litter through high rate biomethanation technology: A full scale experience

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A B S T R A C T

High rate biomethanation technology based on anaerobic gas lift reactor (AGR) for the treatment of poultry litter (PL) has been demonstrated to generate biogas and digestate. The plant was installed and operated continuously for 95 weeks (September 2012 to June 2014) under ambient temperature conditions (in the range of 24–31 °C) for the treatment of 1000 kg of PL per day containing 254 kg of total solids and 220 kg of volatile solids. Biogas (68 m^3/day) produced in the plant was successfully converted to electrical power (89 kWh/day) that was utilized to operate water pumps in the agricultural fields. The digestate (105 kg/day) was effectively employed in the nearby fields as an organic fertilizer. The plant was operated by establishing an intensified process mechanism incorporating inline pre and post processing unit assembly along with ammonia inhibition control mechanism. It is understood from the full scale experience of this plant that, decentralized off grid power generation from PL could be a remunerative option to poultry farmers.

1. Introduction

Poultry industry is one of the largest and fastest growing agro-based industries in the world. It is inevitable that huge quantities of waste would be generated due to the handling of large volume and high density poultry productions [1,2]. It is reported that litter produced by 1000 poultry birds per day ranges between 80 and 120 kg with an annual waste generation of 29.2–43.8 tonnes per annum. As per the recent estimates, 12 million tons of PL is produced from 500 million poultry population in India [2,3]. Large scale accumulation of wastes may pose disposal problems such as eutrophication, odor related issues causing water, soil and air pollution unless environmentally and economically sustainable management technologies are employed [4–7]. Poultry litter is viscous in nature with good amount of biodegradable organic matter, calcium shells (21–52 kg/ton) and is a major source of nutrients (nitrogen (13.5–35.5 kg/ton), phosphorus as phosphorous pentoxide (8–34.5 kg/ton), potassium (28.3–37 kg/ton)) and micronutrients (zinc (0.07–0.36 kg/ton), copper (0.01–0.26 kg/ton), iron (24.9–114 kg/ton) and selenium (4.3–8.2 kg/ton)) for crop production [8]. Hence it is effective in improving physical and biological fertility of agricultural fields, indicating that land application remains as the main option for the utilization of this valuable resource [9–11] upon stabilization. The characteristics of poultry litter vary from farm to farm depending on the method of collection, feed composition and bedding material [12–14]. Besides, it proves to be a suitable substrate for anaerobic digestion (biomethanation) to generate biogas and nutrient rich digestate [15,16]. Further anaerobic digestion of poultry litter is one of the best treatment options currently exploited for the waste disposal and improving the hygiene in and around the poultry farms [17]. Biomethanation of poultry litter is associated with the generation of renewable energy in the form of methane rich biogas along with

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digestate [5,18,19]. However, low C/N ratio is a major constraint for sustainable operation of the process due to inhibition of methanogens by ammonia. In depth studies were carried out on biomethanation of poultry litter with and without ammonia inhibition control mechanism employing conventional as well as novel high rate digesters [4,6,19,20] which are restricted to laboratory and small scale (below 3 m^3) [21]. Thus, there is a need to demonstrate the high rate biomethanation of poultry litter in higher scale in the range of 1–2 tons per day. In the earlier communications [17], a multi stage high rate biomethanation technology for the treatment of poultry litter was reported where in two self-mixed anaerobic digesters (SMAD) were connected in series with an Up flow anaerobic sludge blanket (UASB) reactor [22]. The authors endeavored to scale up the aforementioned scheme for the treatment of one ton poultry litter per day to implement a full-scale plant and found to be uneconomical since many unit operations were involved in the process (SMAD I and II followed by UASB). It is reported that there are more than 1000 AD plants being set up in Italy for the treatment of agricultural waste [23] to generate biogas and digestate. Most of the biogas produced is being used for combined heat and power (CHP) applications. In order to scale up the digester designs for full scale application, extensive research with associated engineering aspects in the reactor design incorporating pre and post processing mechanism is highly warranted. The aim of this work is to demonstrate a full scale high rate biomethanation plant based on Anaerobic Gas lift Reactor (AGR) [24] for the treatment of 1000 kg of poultry litter per day at source. This work aimed at analyzing the effect of seasonal ambient temperature variation, volatile solid organic rate, biogas yield, volatile solids reduction (%) and power generation. It also emphasizes the process intensification involved in design and installation of the plant illustrating the outputs obtained through performance analysis for longer period of operation for 15–18 months.

2. Materials and methods

2.1. Feedstock procurement

Around 1000 kg of poultry litter (PL) was collected from nearby poultry farm on a daily basis and was stored. The stored poultry litter was used as feed for operation of the plant.

2.2. Analytical methods

PL was initially characterized for pH, total solids (TS), volatile solids (VS), moisture content.

(MC), fixed solids, carbon (C), hydrogen (H), Nitrogen (N), sulfur(S) and Phosphorus (P) as per the standard methods [25] on daily or weekly as per the requirement. Free ammoniacal nitrogen (FAN) was estimated from TAN as discussed by others [6,14]. The quantity of C, H, N and S was estimated with CHNS analyzer (Vario Micro Cube Elementar, Germany). The volume of biogas produced was measured using wet gas flow meter and the composition was estimated using Orsat apparatus and GC (Shimadzu, Japan) [25,26]. Hydrogen sulphide (H_2S) present in the biogas was analyzed using Tutweiler's apparatus [27]. Analysis is carried out in triplicate and the variation is found to be within ±1.0%. All the chemicals used for analysis during the experiments were of analaR (AR) grade reagents.

2.3. Process intensification involved in design and installation of the plant

The performance of full scale plant on long term basis depends on many factors such as design features of digester such as mixing, scalability, in-line pre and post digester assembly with respect to the feed characteristics etc. It was reported that the performance of self mixed anaerobic digesters (SMAD) in terms of VS reduction, biogas yield, methane yield, HRT and VS loading rate was better compared to convention fixed dome anaerobic digester (CFDAD) due to intermittent mixing created through self mixing mechanism even though parameters such as pH, temperature, volume of the digester, slurry consistency etc. was same in both the digesters [19]. Therefore, installation of high rate digester coupled with mixing and novel design features ~~to~~ for the biomethanation of poultry litter is highly essential in order to overcome the difficulties associated with the conventional digesters as well improve the performance. A pilot scale study was carried out in these lines where the plant design consisted of a feed preparation system, two reactors SMAD in series with vibro screen-I and II, leachate tank, Upflow anaerobic sludge blanket (UASB) reactor, UASB recirculation tank and floating dome type biogas holder. The authors endeavored to scale up the afore mentioned scheme for the treatment of one ton poultry litter per day to implement a full scale plant and found to be uneconomical since many unit operations were involved in the process (SMAD I and II followed by UASB) [22,28,29]. In this framework, it was understood that in order to make the process economically viable for full scale implementation, process needs to be intensified so that number of unit operations could be abridged and the overall capital cost of the plant could be reduced considerably [30,31]. These efforts resulted in developing and implementing a high rate biomethanation plant for the treatment of 1000 kg of poultry litter per day based on AGR. The process intensification resulted in replacement of SMAD-I, SMAD-II and UASB [6] with AGR [24].

2.4. Description of the plant

The plant consists of 2 m^3 circular underground feed slurry preparation tank (FPT) made of bricks and cement, 2 m^3 circular settling tank (ST) with conical bottom and a damper to remove grits, 5 m^3 rectangular hydrolysis tank (HT) equipped with drain valve to remove solids at the bottom, 55 m^3anaerobic gas lift reactor (AGR), 2 m^3 underground gravity filter (GF) fitted with stainless steel mesh, 8 m^3 biogas balloon (BB), air compressor, moisture trap (MT) fabricated with MS pipes, packed bed of iron fillings and a biogas engine (Hindustan motors make, 15 kVA rating). ST, HT, AGR were made up of mild steel (MS). Outlet of the air compressor was connected to FPT, ST and HT. The plant was installed a plant at Pedda Shivanoor Village, Chegunta Mandal near Hyderabad, Telangana, India by M/s Ahuja Engineering Services (AES), Secunderabad [32,33].

2.5. Description of high rate digester -AGR

AGR is a vertical cylindrical tank with height/diameter (L/D) ratio of 2:1with two compartments, which were hydraulically connected. AGR is an improved version of SMAD that was reported previously [19]. The influent was pumped into the bottom compartment of the reactor using an efficient distribution system, and was mixed with anaerobic biomass. In the lower part of the reactor most of the organic components were converted into methane (CH_4) and carbon dioxide (CO_2). The biogas generated at the bottom compartment (1st stage) creates sufficient pressure that forces the liquid upwards through the riser into the upper compartment (2nd stage). AGR is equipped with a three-phase separator in the 1st compartment comprising baffles, inverted cone and a downer pipe shown in Fig. 1. The purpose of erecting a three-phase separator inside the reactor is to separate biogas, active biomass and liquid. Liberation of biogas from the reactor takes place through the three-phase separator at the top of the