Optimization of anaerobic digestion of rice straw inoculated with piggery wastewater for farm-scale biogas plants

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The motivation for implementing a farm-scale biogas plant using rice straw co-digested with pig manure is three-fold. First of all, this approach offers a sustainable alternative for managing the disposal of agricultural residues, especially considering the abundance of rice straw and animal wastes. The Food and Agriculture Organization of the United Nations estimated that a total of 679 million tons of rice were produced in 2009 (FAOSTAT, 2011), which equates to approximately 916 million tons of rice straw available for energy production (Kadam, Forrest, & Jacobson, 2000). Secondly, it will reduce a significant portion of methane emissions contributing to global climate change. Rice paddy fields are a major line item in the "global methane budget"(Glissmann & Conrad, 2000), as they make up 10 to 13% of the global anthropogenic methane emissions (Blengini & Busto, 2009). Rice straw management (i.e. removal from the fields) is a practical mitigation strategy that can reduce methane emissions from paddy soils by 66 to 68%, depending on the rice variety (Koga & Tajima, 2011). Finally, the priority for any business or farm-based operation is economic gain. In Italy, the government passed a law in July 2009 and agreed to pay €0.28/kWh for electricity generated by agricultural feedstock, which is currently the highest feed-in tariff in Europe (EurObserv'er, 2010).

The objectives of my research are to define and optimize basic operational parameters for an energetically viable farm-scale system using untreated rice straw co-digested with piggery wastewater. Pre-treatment strategies and additional chemicals added as buffering agents will be avoided since they are often impractical for a farm-scale plant. Dry digestion conditions (≥ 20% TS) will be evaluated to minimize water consumption and waste disposal issues.

Two pilot-scale (1m^3) digesters filled with untreated rice straw and co-digested with raw pig wastewater were operated to obtain design parameters for a farm-scale biogas plant. Both digesters contained 50 kg of dry straw mixed with diluted pig wastewater to create dry digestion conditions (20% TS) and operated for 189 days with leachate recirculation. Digester A was designed for optimum performance (150 L of pig wastewater and mesophilic temperatures) while Digester B was designed to establish minimum inputs (60 L of pig wastewater at ambient temperatures). The pig wastewater provided sufficient buffering capacity to maintain appropriate pH values (between 7.0 and 8.1) and nutrient balances (TOC to TKN ratios of 20 in Digester A and 32 in Digester B). Total biogas production was 22,859 L in Digester A and 1,420 L from Digester B, resulting in specific methane yields of 231 and 12 L CH_4/kgVS added, respectively. Gas production in Digester A was directly correlated with temperature, but the overall lack of methanogenic activity was caused primarily by the reduced wastewater volume. Based on the results of Digester A, a farm-scale plant was proposed for 100-hectare rice farm producing 600 tons of rice straw annually. Since the digestion time was approximately six months, 300 tons of rice straw could be loaded and digested twice a year if mesophilic temperatures were maintained. A total of 833 cylindrical bales of rice straw along with 900 tons of piggery wastewater and 600 tons of water would be loaded at a time, requiring a digester design volume of 2177 m^3. The system could theoretically produce 100,365

m^3CH_4/yr, yielding approximately 328 MWh (assuming a 33% electrical conversion efficiency), amounting to a gross gain of 91,850€/yr.

A farm-scale anaerobic co-digester loaded with rice straw and pig wastewater was started in December 2010 on a 365-hectare rice farm in the Pavia region of Northern Italy. The entire digester consisted of two anaerobic cells with a total storage capacity of 15,000 m^3, filled with approximately 1825 tons of rice straw in cylindrical bales. One cell was active during the one-year study period. The working volume of the active cell was 6600 m^3 and it consisted of 727 tons of rice straw, 250 tons of pig wastewater, and approximately 1000 tons of water added over time which equated to an overall TS concentration of 47%. A 200-kW internal combustion engine modified to run on biogas was combined with a 400-volt generator to produce electricity. Waste heat was recovered from the engine through a dual heat exchange system and transferred to the digester through an extensive leachate recirculation system. The specific methane yield determined after one year was 175 LCH_4/kgVS. Daily power production was directly correlated to the digester temperature, which ranged from 15 to 35°C. The maximum daily power production was 2.7 MWh/d, which equated to a daily methane yield of 1.6 L/kgVS-day. A total of 295 MWh was produced during the first year with gross earnings of €82,600. This could serve the electrical needs of approximately 84 typical homes in Italy for one year (ENEA, 2006).

In an attempt to accelerate the biogas production of the farm-scale system, anaerobic sludge from a pulp and paper mill plant was added as an inoculum in a series of laboratory-scale, anaerobic batch digesters. The hypothesis is that the acclimated bacteria in this particular sludge can accelerate the decomposition of the lignin content of the rice straw and speed up the digestion process without the need for a separate pretreatment step. The goal is to determine if the bacteria from the sludge and wastewater can function symbiotically without additional chemicals or buffers, and to quantify how much sludge is necessary to improve methane yields. The digesters are operating in dry (20% TS) and mesophilic (35°C) conditions for a projected duration of 100 days. The experiments consist of 18 1-L bottle tests with varying ratios of straw, pig wastewater, and sludge. The biogas is measured manometrically in the first set and methane is measured directly using a liquid-displacement method (Valcke & Verstraete, 1983) in the second set of experiments. Preliminary results show a considerable improvement in biogas production and methane yields with the paper mill sludge addition. Quantitative results from these experiments will be presented in the summer school session if they are available.

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