**A preliminary assessment of animal manure utilization in an integrated anaerobic digestion and algal pond system: energy and nutrient outlook**

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**Abstract**

Animal manure is largely seen as annoying waste. Central to this article is the assessment of its waste to value added product potential. The interesting capacity of anaerobic digestion and algal pond integration to profit from manure to energy and fertilizer is examined. The investigation considered three series of animal manures (cattle, swine and poultry varieties). This system proved beneficial and showed vast opportunities. Here, upon evaluation based on 1 ton each of the manure categories, it was found to generate reasonable amount of energy. Using its waste for algae cultivation proves effective as the CO2 is taken care of and utilized as algae feed and the required nutrient can be sourced from within the system. Furthermore, anaerobic digestion of algal biomass was found to be capable of providing additional energy amounting to over a quarter that from any of the crude manure digestion. Overall, the system has surplus nitrogen available. Howbeit, it was found to suffer from intrinsic phosphorous exhaustion, which can be remedied through the supply of fertilizer from outside sources.

**Keywords:** Animal manure, Anaerobic digestion, Algal Pond, Methane, Energy, Nutrient

**1.0 Introduction**

Animal manure is the waste that comes out of animal at terminal stage of the food digestive tract as excreta that is a combination of faeces and urine. It is rich in constituents that are important for biorefinery in the sourcing of value-added products. Also, it can find use as farming manure because of the presence of macro and micronutrients in preponderance proportion, making it a good proposition for product and nutrient extraction. Generally, biogas production offers energy and fertilizer simultaneously. Besides, other notable merits of biogas production are also highlighted in Deublein & Steinhauser [1]. Washington State University and Pacific Northwest National Laboratory (PNNL) in a joint study carried out detailed identification and analyses for components, compositions and chemical information in the characterization of this feedstock as well as the treatment necessary to realize value addition. This investigation, among other benefits, was meant to provide support for extended research on value added chemicals from cattle, swine and poultry manures [2]. Typically, animals produced enormous amount of these wastes. For example, one dairy cattle can make an amount of manure that is around what 20 to 40 people produce daily [3]. Because these wastes are non-edible, their use for biogas generation does not raise the ethical concern of competition with food and feed [5].

Regardless of the subsisting opportunities housed in animal manure, it is a difficult waste to process, its encumbrances are necessitated by the presence of complex components that could inhibit conversion in the quest to actualize value addition. For example, protein availability hinders the carbohydrate transformation to product during biorefining [2]. Contrariwise, in the positive sense, the presence of multiple substrates in its mix also serves as a boon, culminating in better production. Generally, protein has a higher biomethane yield than carbohydrate. Only lipid/fat and oil boast superior yield in this respect than protein among the conventional substrates for anaerobic digestion process, however in practice they may not meet up to these theoretical yields as their presence at elevated amount as seen from slaughterhouse industrial waste demonstrated it could prove inimical to production due to raised volatile fatty acids as well as lengthy chain fatty acids [5,6,7]. Utilizing this biomass that is an admixture of fiber and protein through co-digestion could result in better and more effective way of spending these substrates [8]. Opposed to the often thought of anaerobic digestion as a conversion technology that works best for high liquid containing systems, it is effective for assortment of organic wastes, be it liquid, slurry or solid. Digester design is done to match the kind of waste in view [9,10].

Meanwhile, anaerobic digestion converts the digestible fraction of the manure to biogas which is a mixture of methane and carbon (IV) oxide using anaerobic organisms to ferment this complex waste, leaving off the non-digestible components [11]. The principal among these constituents are lignin and nutrients. And they both hold prospect for additional gains when harnessed. For instance, the lignin through biorefinery could be used to source value added aromatic compounds or burnt to provide heating when required [12]. The nutrient could well serve other vital functions within, where it could help the activity of microorganisms responsible for anaerobic digestion or outside the system. Moreover, algal ponds rely greatly on CO2 and nutrient supply in growing its biomass. For example, blue-green algae do this in the presence of sunlight through a process known as photosynthesis, where it takes up and utilize these supplies within its chlorophyll cells in building and increasing its mass. Algae offer interesting prospect for energy production for reason such as not requiring arable land for cultivation [13,14]. The fusion of anaerobic digestion and algal pond proposed in this work look promisingly an effective pattern that is somewhat symbiotic in nature. Here, the anaerobic digestion in the digester breaks down the manure and gives off waste that can readily find use in the algal pond. The waste in question could be undigested part that emanates from the digester or the by-product of the digestion process like ammonia. Moreover, the waste could act as feed for anaerobic digestion. While the anaerobic digestion of poignant animal manure could go along as a treatment option that offers several advantages, the useless nutrients would pose serious threat, such as eutrophication and its attendant consequences, to water bodies when emptied into it untreated with reckless abandon. Howbeit, this can provide for the nutrient needs in an algal pond [1,12,16].

In related studies on this form of process integration, there had been life-cycle assessment, evaluation of algae strains to support biogas production, among other aspects [17, 18,2]. In this work we are investigating the possibilities that exist in anaerobic digestion and algae pond integration utilizing array of animal manures for biogas production. Additionally, strategic implementation that holds the prospect guaranteeing efficient utilization of the manure and its nutrients in supplanting nutrients requirement for algal cultivation is investigated. This is done through considering the combine processes and units to ensure effective utilization and production.

**2.1 Anaerobic digestion of manure and production**

Three series of animal manures are examined in this investigation and the manure, and their subdivisions are listed with the details of their characterization below in Table 1.

Table 1. Showing the protein, fiber and nutrient in cattle, swine and poultry manures [2]

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Types** | **Crude protein** | **Total fiber** | **Hemicellulose** | **Cellulose** | **Lignin** | **Nitrogen** | **Phosphorus** |
| **% DM** | **% DM** | **% DM** | **% DM** | **% DM** | **% Weight** | **% Weight** |
| **Cattle**  **Manures** | Diary | 18.1 | 52.6 | 12.2 | 27.4 | 13 | 2.9 | 0.48 |
| beef | 12.1 | 51.5 | 17.4 | 21.9 | 12.2 | 1.94 | 0.42 |
| Feedlot | 17 | 41.7 | 21.4 | 14.2 | 6.1 | 2.72 | 0.81 |
| **Swine**  **Manures** | Nursery | 25.1 | 39.2 | 21.9 | 13.2 | 4.1 | 4.02 | 1.51 |
| Grower | 22.7 | 40.8 | 20.5 | 13.9 | 6.4 | 4.26 | 2.45 |
| Finisher | 22 | 39.1 | 20.4 | 13.3 | 5.4 | 3.9 | 1.6 |
| **Poultry**  **Manures** | chick starter | 39.8 | 31.7 | 18.3 | 8.5 | 4.9 | 6.37 | 2.3 |
| pullet starter | 48.4 | 36.4 | 21.5 | 7.7 | 7.2 | 7.74 | 2.6 |
| 17-40 weeks | 31.6 | 34.5 | 20.2 | 12 | 2.3 | 2.93 | 3.4 |
| post-molt | 28 | 31.2 | 16.4 | 10.7 | 4.1 | 3.31 | 3.2 |

DM = Dry matter

The estimation of theoretical biogas using Buswell equation is followed in establishing the mass and energy balance for the digester unit [19]. All substrate components are assumed to be completely digestible as ordinary dry matter (ODM) by the equation except lignin which is assumed to be burnt to meet energy need for the process because it is resistant to bioconversion and has high energy [20,21].

………………………………………………….(1)

A ton of feed manure is taken as basis for this operation. The interplay of the different components of the manure is factored into doing this assessment. Meanwhile, the first lap of component in the manure is the fiber. The other relevant constituent is the crude protein. Fiber is made up of cellulose, hemicelluloses and the lignin. The proportion in which they are present in the waste is found in Table 1. The estimation of yields from the fiber is carried out through using the respective compositions in parallel with the components to get the composite production from carbohydrate components of the manure. The chemical formula for these components is cellulose (), hemicelluloses () and lignin (), and they are gotten from literature [22,23]. For protein, the formula () used is same as that used for its modeling in other related applications such as in Collet et al [7] is maintained. The theoretical and maximum theoretical yields for the basic anaerobic digestion substrates are documented in established papers [8,7]. The potential energy generation from individual manure is estimated using energy per volume factor (36MJ/m3) from literature that was reached from understanding of combination of basic ideal gas equations and stoichiometry of anaerobic digestion process. This was done in manner analogous to that used in other related papers and was taken from Banks [10]. Summarily, the calculated values for material and energy productions are recorded in results section in **Table 2**. This represents the productions for unit one in the overall process description.

**2.2 Algae production and Nutrient**

The CO2 produced from the anaerobic digester is used as a basic feed to the algal pond. The photosynthetic process used by alga in growing its biomass, by increasing in weight is well documented in literature. The algae formula,, is used for this evaluation [24]. It is described with two half-cell equations that demonstrate the way algae make use of CO2 and nutrients (nitrogen and phosphorus). The uptake of these components at the appropriate stoichiometric proportion when sunlight is available enables alga to build its biomass [25,26,27]. The equations are presented below:

…………….(2)

…… (3)

Following this stoichiometry, with equation (1) taken as the only pathway for nutrient uptake and utilization, since the CO2 production has already been determined, and the nutrients are assumed to be the expensive resource. For supplied CO2, the nutrient required, and the algal biomass made is evaluated. This stays as the target nutrient for the respective manures in this work, and the results are documented in **Table 3**.

**2.4 Anaerobic digestion of Algae**

Here, the digestion of harvested algal biomass grown from anaerobic digestion waste and nutrient is determined. Meanwhile, microalgae had been reported to give higher biomethane yield than conventional crop as maize in prior investigation [8]. Algae formula used at this point is the reduced form  where the phosphorus component is discarded as it is present in negligible amount compared to other elements [24]. The convertible component of the biomass is taken to be half its dry weight which is a conservative assessment given that higher yields are well documented in established articles [28]. Evaluation of biomethane production is performed in the same way as in **Section 2.1**. The results are documented in the **Table 4**.

**2.3 Further Nutrient Matters**

Nitrogen (N) and phosphorous (P) are the main macro nutrients required for the cultivation of algae, and they are the nutrients which are assessed in this work. The acquisition of these nutrients is possible in three separate ways. One, the manure itself contains macro and micronutrients, and so could be a good source of obtaining them. Next, commercial nutrient can be sourced externally to make up for nutrient short fall. Lastly, typical algal biomass possesses low C/N ratio which may bring about increased total ammonia concentration in the system [29]. This could result in decrease methane production from ammonia intoxication [8]. But this ammonia could be employed in providing a portion of nitrogen fertilizer needed for algae cultivation. This becomes the case in the situation of co-digestion with algal biomass recycled to the first reactor (digester) as substrate; this resultant byproduct of anaerobic digestion becomes an alternative source. The nutrient requirement is first established in this work and the capacity of each source supply to compensate for this nutrient is evaluated. With the results for target nutrient already ascertained from the previous section, the remaining aspect of the first unit is to check the sources of nutrients enumerated above for capacity to meet the nutrient demand in the algal pond. The result is presented in **Table 5**.

**3.0 Results**

Table 2. Showing component balance, volume and energy productions from anaerobic digestion

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **CH4** | **CO2** | **NH3** | **CH4** | **CO2** | **Biogas** | **Energy** |
| ***Kg*** | ***Kg*** | ***Kg*** | ***m3*** | ***m3*** | ***m3*** | ***MJ*** |
| **Cattle manures** | Diary | 191.2 | 502.1 | 36.6 | 267.7 | 255.6 | 523.3 | 9635.9 |
| beef | 166.5 | 442.0 | 19.4 | 233.1 | 225.0 | 458.1 | 8390.6 |
| Feedlot | 175.8 | 461.1 | 34.3 | 246.1 | 234.8 | 480.8 | 8858.7 |
| **Swine manures** | Nursery | 206.9 | 536.1 | 50.8 | 289.7 | 272.9 | 562.6 | 10427.8 |
| Grower | 195.2 | 507.1 | 45.9 | 273.3 | 258.2 | 531.4 | 9838.1 |
| Finisher | 190.2 | 494.3 | 44.5 | 266.3 | 251.7 | 518.0 | 9588.1 |
| **Poultry manures** | chick starter | 241.6 | 612.2 | 80.6 | 338.2 | 311.6 | 649.8 | 12174.6 |
| pullet starter | 284.0 | 717.7 | 97.9 | 397.6 | 365.4 | 763.0 | 14315.0 |
| 17-40 weeks | 224.6 | 576.2 | 63.9 | 314.4 | 293.3 | 607.7 | 11317.8 |
| post-molt | 194.6 | 498.5 | 56.6 | 272.4 | 253.8 | 526.2 | 9806.8 |

Table 3. Showing Algae production, nutrient requirement and available CO2 and N-NH3 from protein

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | **Avail. CO2** | **N-NH3** | **N** | **P** | **Algae Prod.** |
| **Cattle manures** | Diary | 502.1 | 30.1 | 27.8 | 3.8 | 440.3 |
| beef | 442.0 | 16.0 | 24.5 | 3.4 | 387.6 |
| Feedlot | 461.1 | 28.3 | 25.5 | 3.5 | 404.4 |
| **Swine manures** | Nursery | 536.1 | 41.9 | 29.7 | 4.1 | 470.1 |
| Grower | 507.1 | 37.8 | 28.1 | 3.9 | 444.7 |
| Finisher | 494.3 | 36.7 | 27.4 | 3.8 | 433.5 |
| **Poultry manures** | chick starter | 612.2 | 66.4 | 33.9 | 4.7 | 536.8 |
| pullet starter | 717.7 | 80.6 | 39.7 | 5.5 | 629.4 |
| 17-40 weeks | 576.2 | 52.6 | 31.9 | 4.4 | 505.3 |
| post-molt | 498.5 | 46.6 | 27.6 | 3.8 | 437.1 |

Table 4. Showing component balance, volume and energy productions from anaerobic digestion algal biomass

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **CH4** | **CO2** | **NH3** | **CH4** | **CO2** | **Biogas** | **Energy** |
| ***Kg*** | ***Kg*** | ***Kg*** | ***m3*** | ***m3*** | ***m3*** | ***MJ*** |
| **Cattle manures** | Diary | 52.0 | 146.3 | 44.3 | 72.8 | 74.5 | 147.3 | 2619.4 |
| beef | 45.7 | 128.8 | 39.0 | 64.0 | 65.6 | 129.6 | 2305.7 |
| Feedlot | 47.7 | 134.4 | 40.7 | 66.8 | 68.4 | 135.2 | 2405.7 |
| **Swine manures** | Nursery | 55.5 | 156.2 | 47.3 | 77.7 | 79.5 | 157.2 | 2796.6 |
| Grower | 52.5 | 147.8 | 44.7 | 73.5 | 75.2 | 148.7 | 2645.4 |
| Finisher | 51.2 | 144.1 | 43.6 | 71.6 | 73.3 | 145.0 | 2578.8 |
| **Poultry manures** | chick starter | 63.4 | 178.4 | 54.0 | 88.7 | 90.8 | 179.5 | 3193.5 |
| pullet starter | 74.3 | 209.2 | 63.3 | 104.0 | 106.5 | 210.5 | 3744.2 |
| 17-40 weeks | 59.6 | 167.9 | 50.8 | 83.5 | 85.5 | 169.0 | 3005.8 |
| post-molt | 51.6 | 145.3 | 44.0 | 72.2 | 74.0 | 146.2 | 2600.4 |

Table 5. Showing pond nutrient requirement, sources and substitution achievable

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Pond demand** | | **Free Manure Nutrient** | | | | **Protein** | | **Algae** | |
| **N** | **P** | **N** | **% sub.** | **P** | **% sub.** | **N-NH3** | **% sub.** | **N-NH3** | **% sub.** |
| **Cattle manures** | Diary | 27.8 | 3.8 | 2.9 | 10.43 | 0.48 | 12.63 | 30.1 | 108.27 | 36.48 | 131.23 |
| beef | 24.5 | 3.4 | 1.94 | 7.92 | 0.42 | 12.35 | 16 | 65.31 | 32.12 | 131.09 |
| Feedlot | 25.5 | 3.5 | 2.72 | 10.67 | 0.81 | 23.14 | 28.3 | 110.98 | 33.52 | 131.44 |
| **Swine manures** | Nursery | 29.7 | 4.1 | 4.02 | 13.54 | 1.51 | 36.83 | 41.9 | 141.08 | 38.95 | 131.15 |
| Grower | 28.1 | 3.9 | 4.26 | 15.16 | 2.45 | 62.82 | 37.8 | 134.52 | 36.81 | 131 |
| Finisher | 27.4 | 3.8 | 3.9 | 14.23 | 1.6 | 42.11 | 36.7 | 133.94 | 35.91 | 131.04 |
| **Poultry manures** | chick starter | 33.9 | 4.7 | 6.37 | 18.79 | 2.3 | 48.94 | 66.4 | 195.87 | 44.47 | 131.18 |
| pullet starter | 39.7 | 5.5 | 7.74 | 19.5 | 2.6 | 47.27 | 80.6 | 203.02 | 52.13 | 131.31 |
| 17-40 weeks | 31.9 | 4.4 | 2.93 | 9.18 | 3.4 | 77.27 | 52.6 | 164.89 | 41.84 | 131.15 |
| post-molt | 27.6 | 3.8 | 3.31 | 11.99 | 3.2 | 84.21 | 46.6 | 168.84 | 36.24 | 131.29 |

% Sub. Describes the amount of nutrients (N, P) requirement that can be replaced by these alternatives to commercial fertilizer inherent in the system

**4.0 Discussions**

The anaerobic digestion of one ton of manure gave significant biogas and energy in all manure series considered (**see Table 2**). The higher biomethane productions being from poultry wastes, in increasing order of 17-14 weeks, chick starter and pullet starter that showed the best potential (41.39% increase energy over the cattle manures, beef, which is the least productive). It is noteworthy that the characteristics of waste that control composition and subsequently production depend not just on genetics alone but also on feeding scheme and the type of feed the specific strain of animal is subjected to [30]. Hence, the manures from livestock investigated here is only reflective of animal species under study. Therefore, variability of some sort may be experienced across the manure series.

In **Table 3**, although it appears that the greater the nutrient available to algae the more the production, however the growing of algae biomass is a time-based progression that can best be described by an unsteady state model. They get to a point and then start to die over time. The nutrient required when reached despite any further supply will not guarantee improvement in production [12]. It is only assumed that macronutrient utilization tantamount to supply. Thus, algae do not use or get disturbed when nutrients are in excess as embodied in this work.

Because the algal biomass was dependent on the CO2 availability, the respective manure types with the higher biogas yield (from **Table 2**) consequently gave better algae production in **Table 3**. Therefore, they ended up providing the better energy yield when their algae were digested in the anaerobic digester as evidenced in **Table 4**. The digestion of algae gave as much biogas comparable to over one quarter that generated by parent manure digestion in all manure series considered. A contribution relevant enough to supplement for over 25% energy the anaerobic digestion was capable of in every of the animal waste examined. In as much as the present of protein content in animal manure and algal biomass has contributed to the higher theoretical yield, the impact of ammonia presence, at higher concentration, in the mix upon digestion could hamper production. This could whittle down the realistic production from reaching theoretical expectation [8].

On nutrient orientation, importantly, there exist a few fine avenues for tapping nutrient from within the system to satisfy nutrient demand for algae cultivation. These have been explored in this task, exhaustingly. The nitrogen provision from algae and manure protein digestion by far satisfy completely the algal pond demand in all situations except for beef manure digestion and in the digestion of algae grown from it. Meanwhile, the phosphorus need in these cases will be gotten from commercial fertilizer. But in some situation, for a raceway pond that is like a lake, it is possible for it to be rich in phosphorus depending on environment. Thereby reducing or probably obviating the need for phosphorus supply commercially. In the use of free manure nutrient, it will be stressed out if it is the single nutrient source on ground. It holds the potential to provide nitrogen and phosphorus, howbeit, partially. This can make available about 7-19% of nitrogen and 12-84% phosphorus needs across manures series studied. The nutrient may not be this much available as some will be used to facilitate the anaerobic digestion reaction that is unaccounted for in this article. However, excess nutrient is dangerous to aquatic ecosystem and phytoplankton, leading to algal blooms, among other demerits. Therefore, there is the need to control and limit its concentration to acceptable level [16].

Finally, there may be need to know the energy input to output ratio of the digester and the cost indices of the plant to ascertain the viability of this integrated system overall. However, for mesophilic operating digester in the tropics there is rarely any demand for external energy to power and maintain the reaction as anaerobic digestion is a heat yielding process [9]. Perhaps, the energy from burning of lignin would be sufficient to balance heating requirement should the need arise.

**5.0 Conclusions**

This study has theoretically investigated the opportunities in animal manure utilization for energy and fertilizer. It was carried out by considering the use of array of well documented animal waste in integrated system where anaerobic digestion is coupled with algal pond. This was demonstrated to be very interesting considering the symbiotic nature of the combination. In this evaluation, it was found that the system proves invaluable for biomethane production. Animal manure generates good quantity of energy and using its waste for algae cultivation proves effective as the CO2 is taken care of as algal food and the required nutrient can be sourced from within the system. Farther afield, the digestion of algal biomass was found to be capable of providing substantial additional methane and energy in the tune of over a quarter that from any of the raw manure digestion. Also, the post-digestion waste from it could further widen the alternative means to nitrogen nutrient. However, the system by default suffers from intrinsic phosphorous exhaustion. This phosphorus deficiency can be remedied through the supply of commercial fertilizer, except the pond is enriched with this macronutrient probably by reason of location.

**Conflicts of Interest**

The author declares no conflict of interest.

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