Air Drying of Dewatered Biogas Digestate and the use of Dried Product as Bulking Agent

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Abstract
The applicability of using dried biogas digestate as bulking agent in air-drying of dewatered digestate was investigated with bench scale experiments. Different mixing ratios (w/w) of dried and dewatered digestates were tested to find out the optimal mixing ratio in terms of energy consumption. Mixing the dewatered digestate with dried digestate increased the drying rate and decreased the air consumption due to increase of mixture porosity. The drying rate of 3.73 g water/m^2.day for sole dewatered digestate (1:0) increased to 4.55 g water/m^2.day at mixing ratio of 2:1. The drying rate at 2:1 mixing ratio corresponds to 47 L of air consumption for evaporation of one gram of water, which was about 70 L for the sole dewatered digestate (1:0). The lowest drying rate of 3.03 g water/m^2.day was obtained when the mixing ratio increased to 1:1 because of the reduced thermal conductivity due to the low (<40%) initial moisture content of the mixture. Finally, it is concluded that by mixing the dewatered digestate with the dried one at a ratio of 2:1, the energy consumed for aeration to achieve a dry matter content over 90% in the final product decreased from 1.7 to 1.1 kWh/kg-dewatered digestate.

Keywords: dewatered digestate, air drying, bulking agent, sludge, organic fertilizer

1. Introduction

Biogas production via anaerobic digestion of organic wastes is a good option for the sustainable and renewable energy production. However, a nutrient rich residue, digestate, a major by-product is produced and has to be removed or disposed from the biogas plants. It can be considered as a good fertilizer due to the replacement possibility with the artificial ones [1] for the agricultural applications [2]. Nevertheless, these facilities work continuously and as a result everyday they are producing huge amount of digestate. It cannot be used only as a liquid fertilizer even if it fits to the regulations [3].

Solid-liquid separation is one of the sustainable way for the digestate management [4]. Screw press, belt press and centrifugal separators [5] are commonly used for the solid-liquid separation operations [6]. After separation, liquid part can be reused as a dilution water [7] in the biogas plant and solid part can be considered as nutrient rich dewatered digestate. Increasing biomass to energy approach enhance continuous production of dewatered digestate which is now environmental problem that should be solved as soon as possible because of environmental concerns [8].

Dewatered digestate are composed of mostly organic matter (N, P, K) [2] and they enhance soil quality and fertility and also some physical and chemical properties like porosity, water and nutrient catchment capacity and aeration [9,10]. However, solid-liquid separators generally cannot exceed 30% total solid (TS) content; so to get a long-lasting commercial product, water content of the dewatered must be reduced with the suitable drying processes.

Drying is a common mechanism used for dewatered digestate valorisation and utilization. The drying carriers are generally air or steam. The main parameters affecting the drying operation are the air temperature, the relative humidity, diffusion effect, thermal conductivity and the velocity of the air [11,12]. Nevertheless, bulking agents and/or drying aids, such as agricultural residues (straw etc.), sawdust and other wastes could be added to the dewatered digestate to increase the porosity. Adequate porousness improves evaporation and heat transfer between air and water media [12,13].

It seems that to have effective airflow and improve drying performance, the use of dried sludge as a bulking agent may be a good option in the drying of dewatered digestate. It is also a cheap and easy process to handle without any external resource.

In this study, the influence of the porosity on air drying of biogas digestate was investigated. To increase the porosity of the dewatered digestate, formerly dried digestate was used as bulking agent in the experiments. Different mixing ratios (w/w) of dewatered and dried digestates were tested to find out the optimal mixing ratio in terms of energy requirement.

2. Materials and Methods

In this study, the digestate was taken from a biogas plant located in Afyonkarahisar/Turkey. This plant produces biogas from co-digestion of chicken manure (laying hen) and spent poppy straw. Solid-liquid separation of the digestate in that plant is performed by using a screw press separator and a centrifugal decanter operating in series. TS, VS and VS/TS of the dewatered digestate used in the experiments were around 28%, 13% and 46%, respectively (Table 1).

The total and volatile solids (TS) contents of the dewatered digestate and the mixtures of dewatered and dried digestate were determined according to standard methods. Table 1 shows the solids contents of the dewatered digestate and the mixtures of dewatered and dried digestate used in the experiments.

Table 1. The solids content of the dewatered digestate and the digestate mixtures used

Dewatered/dried digestate ratio	$TS_{influent}$, %	$VS_{influent}$, %	$VS_{influent}/TS_{influent}$, %
1:0	28	13	46
1:1	62	29	47
2:1	50	23	47
3:1	44	20	45
4:1	42	19	44
5:1	39	18	46
6:1	37	17	46

The drying experiments were performed in a cylindrical acrylic vessel (Fig. 1) placed in a temperature controlled incubator (36±1^{o}C). The digestate was laid on a stainless steel mesh and aerated continuously by using an air pump (Eheim air pump 100) connected to the opening in the bottom of the vessel. The air flow rate was set to 1665 ml/min. The air pump was outside the incubator, accordingly the temperature of the air supplied to the vessel was in the range of 20 to 23^{o}C (room temperature). The temperature of the air (room temperature) and digestate were monitored on-line with a PLC (programmable logic controller). To increase the efficiency of drying, the digestate was mixed manually once in a day.

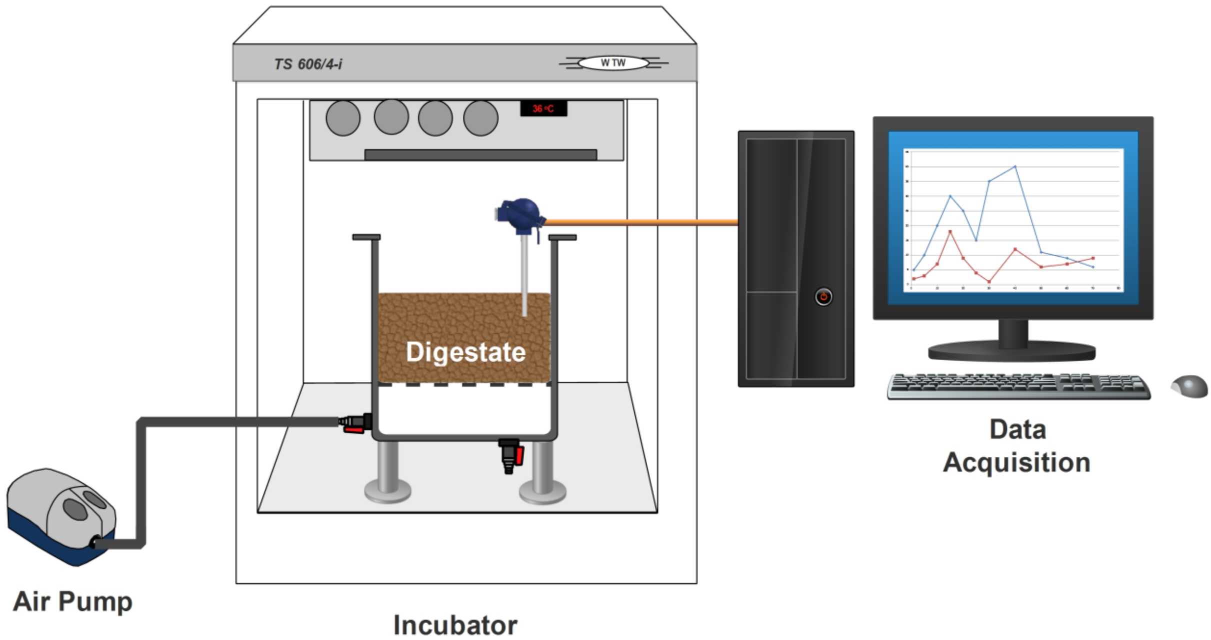

Fig. 1. The set-up used in air drying experiments

3. Results and Discussions

The first experiment was performed with sole dewatered digestate as control. It took about 7 days to reach a dry matter content of about 95%. The result of this experiment clearly showed that drying of the dewatered digestate alone is not effective and took quite long time to reach the intended final dry matter content, which should be due to lack of sufficient porosity in the digestate. Mixing the dewatered digestate with a bulking agent is a common approach in composting and drying processes to improve the porosity of the material for easier migration of air. In the literature, there are many studies about the use of bulking agent in drying of dewatered digestate. Yuan et al. [14] was inquired the impact of the cornstalks and wood peat on biostabilisation and drying of municipal solid wastes. In another study, [12] has investigated the effect of chopped rice straw on natural solar sludge drying. In this study, we mixed the dewatered biogas digestate with a formerly air dried product in order to increase the porosity of the mixture. Table 2 summarizes the results at different mixing ratios.Yang et al. [13] used a similar approach and tested in biodrying of sewage sludge.

Table 2. Mixing ratios of the dewatered digestate and experimental results

Dewatered/dried digestate ratio	TS_{in}, %	TS_{out}, %	Air consumed, L/g water evaporated	Drying rate, g-H_2O/m^2.day	VS_{out}/TS_{out}, %
1:0	28	95	57	3.73	47
1:1	62	94	70	3.03	47
2:1	50	90	47	4.55	44
3:1	44	90	60	3.55	43
4:1	42	89	55	3.85	46
5:1	39	81	57	3.74	47
6:1	37	82	56	3.76	46

Except the one with the sole dewatered digestate, all experiments lasted about 2-3 days (Fig. 2). The duration of the drying experiments decided according to the final dry matter content of the digestate. A minimum final dry matter content of 80% was selected not to allow the regrowth and activation of the microorganisms in the digestate (Fig. 3). Yeager, Ward [15] reported that if the solids content of a sludge is above 80%, only very limited microbial growth occurs and if the drying ratio is more than 85%, no growth may occur. During the drying process, VS loss was not observed throughout the tests. Hence, water in the digestate was mainly lost due to evaporation during air-drying, not as a result of bacterial activity like in bio-drying process [16]. These results also indicated that, the digestate used in the experiments were very stable and could be used as commercial product.

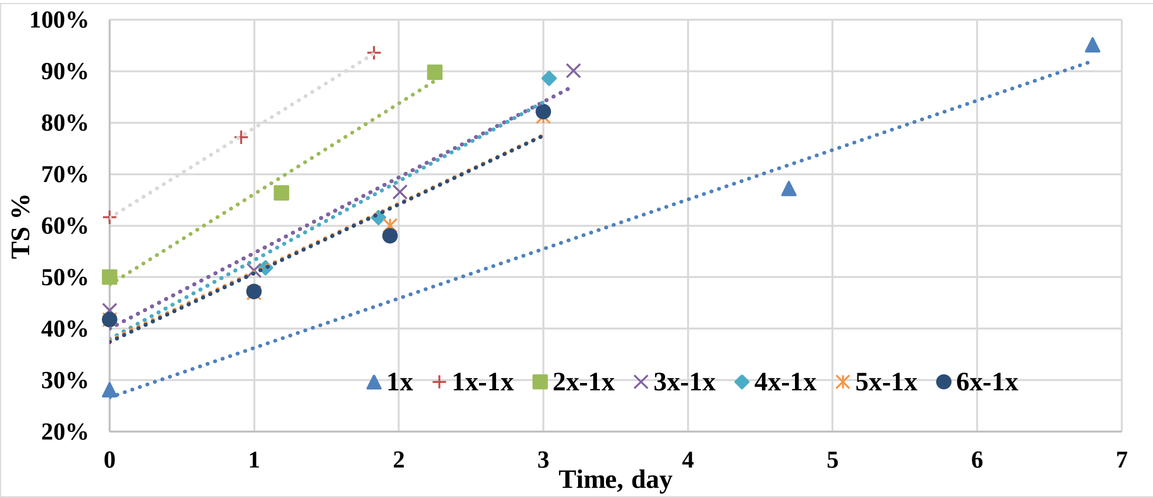

Fig. 2. Variations of the total solids (TS) content with the time

Increasing dewatered to dried digestate ratio resulted in different outcomes. The drying rates achieved with 3:1 to 6:1 mixing ratios were very similar to the one obtained when the dewatered digestate was used alone without being mixed with dried product. However, because of the higher initial moisture content of the sole dewatered digestate, it took more than 6 days to reach to a dry matter of 90% (Fig. 2). The photographs of the air-dried biogas digestate are shown in Fig. 3.

The lowest drying rate of 3.03 g water/m^2.day and the highest air consumption was obtained when the mixing ratio increased to 1:1, although the initial dry matter content of 62% was the highest among the tested mixing ratios. It is accepted that the high initial dry matter content reduced the thermal conductivity and thus restricted the effectiveness of aeration. It is known that the moisture content of the solids is directly proportional to its thermal conductivity [17]. Although the increasing water content increases the thermal conductivity, increasing the porosity beyond a value may decrease the thermal conductivity [18]. In a similar study where the rice straw was used as bulking agent and 1, 2 and 3% rice straw addition to sludge improved the drying rate (Cai et al. [8]. However, when the amount of rice straw increased to 5%, the drying rate reduced because of the decrease in thermal conductivity of the sludge/rice straw mixture.

Fig. 3. Photographs of air-dried biogas digestate (1. dewatered digestate, 2. partially dried and 3. dried product)

The highest drying rate and the lowest air consumption was achieved with dewatered to dried digestate ratio of 2:1. Every 47 L of air supplied resulted in evaporation of 1 g of water from the digestate mixture. At this mixing ratio, air could penetrate into the digestate mixture easier compared to the other sets, which resulted in increased evaporation rate. The maximum drying or water evaporation rate achieved at the optimal mixing ratio was 4.55 g water/m^2.day, which was 18% higher than the second highest rate obtained at the ratio of 4:1.

Conclusions

Mixing (w/w) the dewatered and dried digestate at a ratio of 2:1 increased the drying rate of dewatered digestate due to increasing the porosity. However, the drying rate at a mixing ratio of 1:1 decreased to 3.03 g water/m^2.day due to decrease in thermal conductivity of the mixture. The maximum evaporation rate of 4.55 g water/m^2.day was observed at a mixing ratio 2:1. Hence, the formerly dried product can be successfully used as a bulking agent in air drying of biogas digestate due to the advantages of high efficiency, cost-effective and easy application.

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