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Recycling separated liquid-effluent to dilute feedstock in anaerobic digestion of dairy manure

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ABSTRACT

The major concern of recycling anaerobic digestion (AD) effluent in the digester centers on accumulation of total ammonia nitrogen (TAN) and salinity, both of which can potentially inhibit methane production. In the current study, 30%, 50%, and 80% of separated-liquid AD effluent, were recycled in a series of batch AD experiments. The inhibitions to specific methane potential (SMP) caused by TAN and salinity were evaluated. Recycling up to 80% of un-treated effluent resulted in the best SMP averaging 0.265 ± 0.005 m^3 [CH_4] Kg^{-1} [volatile solids], which averaged 10% more compared to recycling 80% treated effluent and 5% more compared to no recycling (the control). After acclimation, up to 6.39 g N L^{-1} increase in TAN resulted in SMP averaging 0.112 ± 0.002 m^3 [CH_4] Kg^{-1} [volatile solids] and up to 12 parts per thousand increase in salinity resulted in SMP averaging 0.163 ± 0.005 m^3 [CH_4] Kg^{-1} [volatile solids]. A mass balance for a hypothetical 5000 cows dairy farm showed effluent recycle of up to 66% for maintaining 8% solids in anaerobic digester. Moreover, in the proposed system, the effluent going off-farm was on w/w basis 64% less water, 66% less solids, and 52% less nitrogen compared to the effluent produced with no recycle facility.

1. Introduction

Anaerobic digestion (AD) is a proven manure management technology that mitigates emissions of odor, pathogens, and greenhouse gases [1]. Moreover, the production of bio-methane as renewable energy and nutrient rich digestate are additional benefits of AD technology [2]. In U.S, AD technology mostly utilizes a slurry approach (i.e. complete mix, plug-flow), receiving influents with total solids (TS) in the range of 4–12% resulting from typical “flushing” or “scraping” manure collection systems [3]. Either way, the AD influent requires some degree of dilution, using either fresh, parlor, or lagoon water. The dilution of manure and operation of the slurry digester yields benefits to microbial action and engineering design [4]. However, it also results in greater wastewater volume (2–6 times that of as-produced manure) requiring eventual disposal to fields or treatment in potentially expensive post-AD nutrient separation/recovery systems to meet environmental regulations [1,5]. In 1999, USDA and USEPA developed a unified strategy to address the environmental and public health concerns related to animal feeding operations. Accordingly, all animal feeding operations were expected to develop and implement a farm specific Comprehensive Nutrient Management Plan [6] to reduce the environmental and public health risks posed by animal feeding operations [7]. A CNMP is a site-specific conservation plan that documents on farm conservation practices (for example, manure handling, storage, and land application) dealing with the concerns related to soil erosion, livestock manure, and disposal of organic by-products. To further reduce the public health and environmental impacts of animal feeding operations, particularly, the concentrated animal feeding operations the National Pollutant Discharge Elimination System (NPDES) permits are required to show the compliance with clean water act. These permits ensure the proper handling and utilization of the animal manure generated on-farm and its proper land application. These regulatory

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Nomenclature

AD	Anaerobic digestion
TAN	Total ammonia nitrogen (g N L^{-1})
SAL	Salinity (ppt)
SMP	Specific methane potential (m^3 CH_4 Kg^{-1} volatile solids)
ppt	Parts per thousand
LF	Loading factor
AS	Acclimated seed
UAS	Un-acclimated seed
TE	Treated effluent
UTE	Un-treated effluent

interventions are devised not only for environmental and public health safety related to animal manure but the compliant farms also get tax incentives [7]. Thus, timely interventions to mitigate the environmental and economic concerns associated with voluminous amounts of wastewater generated by livestock industry are required to enhance the sustainability of on-farm organic waste management [8]. One potential method to alleviate this wastewater volume concern is to utilize the liquid stream of digested effluent as return or dilution water to dilute the next batch of feedstock entering the digester. This can reduce fresh water inputs to the digester, leaving a portion of the effluent continually within the system and, therefore, not in need of disposal to fields. This practice can be particularly beneficial to high fiber content substrate like dairy manure. For high fiber substrates, about 25–30% of the methane potential is estimated to remain intact even after AD [9]. Thus, efficient utilization of this residual methane potential can be realized through the proposed recycling of AD effluent.

The concerns surrounding recycling of the digestate during AD is the potential for accumulation of key chemical inhibitors to the AD microbiology like ammonia and salinity [10–12]. In the AD process, ammonia is a product of breakdown of organic compounds and exists either as ammonia (NH_3), ammonium (NH_4^+), or combination of both, commonly referred to as total ammonia nitrogen, TAN (NH_3 + NH_4^+), depending on pH-conditions. Bacteria need some of this ammonia for their growth; however, excessive accumulation can be inhibitory for methanogens [10]. High concentrations of ammonia can disturb the optimum C/N in the digester resulting in loss of methanogens and lowering of biogas production [13]. Salinity is another important factor which can cause inhibition of the AD process [11,12]. While moderate concentration of salts is necessary for methanogenic growth, high salt content may cause dehydration of methanogenic cells [14]. Thus, a viable solution to the accumulation of ammonia and salinity is necessary in order to recycle AD digestate with minimal effect on either biogas or methane yield.

Past studies evaluating the effects of recycling AD digestate on methane production present contradicting results. For instance, Jagadabhi et al. [9] observed a decrease in methane production during recycling of alkali treated solid portion of the digestate, whereas Estevez et al. [15] observed a 16% increase in methane yield with liquid digestate recycling as compared to no recycling. In the latter case the solids accumulation in the digester finally resulted in a reduction in methane production. In a recent study, accumulation of ammonia caused by digestate recycling during AD was associated with 43% reduction in biogas production [16]. However, subsequent treatment of pH adjusted digestate (ammonia air stripping), to remove ammonia, resulted in biogas recovery. In general, inhibition to biogas production due to solids accumulation, ammonia accumulation, or chemical input to adjust pH, for that matter, can limit the amount of digestate that can be recycled.

This study investigated the recycling of only the separated-liquid portion of the digestate after solids removal through centrifugation. The hypothesis was that a combination of AD and post-AD solids separation would effectively control potential inhibitory components, particularly salinity and TAN, which would allow substantial re-use of separated liquid-effluent as dilution water for dairy manure entering AD. The specific objectives of this study were to: (1) determine the effects of salinity and TAN accumulation due to recycling of separated liquid-effluent on methane production; and (2) present mass balances of water, solids, and nutrients for a typical dairy farm with an effluent-liquid recycle system.

2. Materials and methods

2.1. Feedstock and inoculum

Fresh “as excreted” dairy manure collected from the Knotts Dairy Center, a Research facility at Washington State University, Pullman, WA, USA was used as substrate in this study. Total solids (TS), volatile solids (VS), pH, and total ammonia nitrogen (TAN) of the manure were 13.72 ± 0.08%, 12 ± 0.07%, 7.80 ± 0.02, and 1.30 ± 0.02 g N L^{-1}, respectively. Mesophilic anaerobic digested sludge (inoculum) with 1.54 ± 0.14% TS and 1.11 ± 0.01%VS was collected from a local Municipal Wastewater Treatment Plant located in Pullman, WA.

2.2. Test setup and experimental design

A series of batch AD tests were performed following the principles described by Owen et al. [17] and modified by others [18,1]. During these tests, specific methane potential (SMP) was used as the performance indicator of the substrate's methane production. The SMP for this study was defined as the total volume of methane produced over the course of digestion period per unit weight of the substrate's volatile solids (i.e. m^3 CH_4 Kg^{-1} substrate VS). The use of SMP as a performance indicator remedied the skew of methane production caused by some input changes or volatilization of VS for the treated recycle-liquid during TAN treatments.

The substrate and anaerobic digester sludge were inoculated at 1:1 (substrate VS: inoculum VS) in 500-mL serum bottles. The digesters were then flushed with nitrogen for 3 min and sealed immediately with screw caps equipped with rubber septa. Afterwards the digesters were placed in temperature-controlled room for 20 d at mesophilic temperature (37 ± 1 °C) and 150 RPM mixing. Previous research indicates that the 20 d digestion time of dairy manure yields 80–90% of total potential biogas production [19]. To measure background methane production from the inoculum, two additional bottles with “inoculum only” were also placed in the temperature-controlled room.

After 20 d digestion time, 100 mL of mixed liquor effluent (20% v/v) was saved as seed for the subsequent digestion, while the remaining 400 mL mixed liquor effluent (total discharge volume) was centrifuged at 4500 rpm for 5 min to remove fine suspended solids. Following centrifugation, 30%, 50%, and 80% of the separated liquid-effluent (v/v) were recycled in the next digestion cycle as three separate treatments. All treatments were studied in duplicates and the resulting TAN, salinity, and SMP values expressed as means and standard deviations. To determine the inhibitory effects caused exclusively by salinity and TAN, two different sets of AD digesters were studied with the same recycle ratios. To study the effects of salinity only, the digestate was treated (aerated) before