Common Factors Affecting Performance of Anaerobic Digester : A Review

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ABSTRACT

The operation of anaerobic digester depends on number of factors. Some of these factors are hydraulic retention time, solids retention time, organic loading rate, pH, mixing, alkalinity, temperature, and reactor configuration. A study of these factor are performed to know how these effect the performance of anaerobic digester. Recommended parameters are listed in Table 1.

Table 1: Suggested Operation Parameters for Rural Developing World Applications

Operation Parameters	Source(s)
SRT $^{min}_{lim}$(d)	4 (Tchobanoglous et al., 2003)
Safety Factor (SF)	10 – 30 (Rittmann & McCarty, 2001)
SRT (d)	20 – 70 (Garfi et al., 2011)
pH	6.6 - 7.6 (Tchobanoglous et al., 2003)
OLR (kg VS/(d*m^3))	1.0 - 3.5 (Sharma & Pellizzi, 1991)

Keywords : Anaerobic Digester, Biogas

I. INTRODUCTION

Hydraulic Retention Time (HRT)

Hydraulic retention time, θ (days), is defined as the average amount of time one reactor volume of actively digesting sludge stays within the reactor. The numeric definition is

$$\theta = \frac{V}{Q}$$

(1)

where: θ = hydraulic retention time (d)

V = volume of reactor (m3)

Q = influent flow rate (Rittmann & McCarty, 2001).

Hydraulic retention time is important to reactor operation and design because it defines the length of time the substrate and particular constituents targeted for removal will be in contact with the biomass within the reactor. Reaction kinetics of methanogenesis and fermentation are the rate-limiting kinetics in anaerobic digestion (Khanal, 2009). Most often, methanogenesis is the rate-limiting step. Garfi et al. (2011) studied psychrophilic anaerobic digestion at temperatures as low as 10°C, and recommend an SRT of 70 days for a polyethylene tubular anaerobic digester with no mixing. At temperatures close to 30°C, SRT's 20 to 30 days are recommended (Garfi et al., 2011). It is important to design reactors for sufficient retention times so that volatile solids destruction can take place (Vesilind, 1998).

Solids Retention Time (SRT)

Solids retention time, or mean cell residence time, is defined as "the mass of organisms in the reactor divided by the mass of organisms removed from the system each day" (Rittmann & McCarty, 2001). The numeric definition of solids retention time is

$$\theta_c = \frac{\text{active biomass in system}}{\text{production rate of active biomass}} = \frac{V*X}{Q_w * X_w} \quad (2)$$

where θc = Solids retention time (d)
V = reactor volume (m^3)
X = cell concentration in reactor
Q_w = flow rate out of reactor
X_w = cell concentration in the flow out of the reactor

Solids retention time (SRT) is important because if SRT is too low, there will be organism washout. If SRT is too long, then the system becomes nutrient-limited. SRT impacts which organisms have optimal growth conditions within the reactor, and changes the microbial ecology of the system (see Section 2.1). SRT is equal to HRT when there is no solids recycle (Vesilind, 1998). Increasing SRT increases the extent the reactions involved in anaerobic digestion go to completion (Vesilind, 1998). A longer SRT stabilizes the process, lowers the amount of sludge produced, and increases biogas production (Rittmann & McCarty, 2001). According to Rittmann & McCarty (2001), the minimum SRT for an anaerobic CSTR at 35ºC is 10 days.

Organic Loading Rate

Organic loading rate is defined as the mass of volatile solids added each day per reactor volume (Vesilind, 1998) or the amount of BOD or COD applied to the reactor volume per day (Tchobanoglous et al., 2003). Organic loading rate is related to hydraulic retention time by the following equation:

$$OLR = \frac{(Q)(C_{VS})}{V_{reactor}} = \frac{C_{VS}}{HRT} \quad (3)$$

where OLR = Organic loading rate
Q = volumetric flow rate (m^3/d)
C_{VS} = concentration volatile solids (kg VS/m^3)
$V_{reactor}$ = reactor volume (m^3)
HRT = hydraulic retention time.

In the case of no recycle, HRT = SRT and therefore:
$OLR = C_{VS} /SRT$ (4)

Volatile solids (VS) are made up of the active biomass concentration X, cell debris following decay, and non-biodegradable VS (Tchobanoglous et al., 2003).

According to Rittmann & McCarty (2001), the recommended organic loading rate for high-rate anaerobic digestion is 1.6- 4.8 kg VSS/(m^3*d), and the recommended organic loading rate for low-rate anaerobic digestion (digestion with no heat and no mixing) is 0.5- 1.6 kg VSS/(m^3*d). Speece (1996) recommended organic loading rates of 5-10 kg VSS/(m^3*d). Vesilind (1998) recommended that the peak organic loading rate for highrate anaerobic digestion should be 1.9- 2.5 kg VS/(m^3*d). Sharma & Pellizzi (1991) recommended that the organic loading rate for standard – rate anaerobic digesters discussed in this work should be 1.0 – 3.5 kg VS/(m^3*d).

If the loading rate in anaerobic digestion is too high for the system conditions, the two methanogenesis pathways can become inhibited, which can result in the accumulation of volatile fatty acids in the reactor. The presence of VFA's decrease the pH in the reactor and can lead to reactor souring, or failure. Therefore, it is very important that the design organic loading rate be conservative.

Safety Factor

A large scale reactors are designed with safety factors for various reasons, including: the lack of operator oversight, variability of waste water stream, and fluctuations in operating conditions. Safety factors in biological treatment systems are different from safety factors used in structures. The minimum SRT, or the SRT at which washout occurs is multiplied by a safety factor. Because the minimum SRT is the borderline of system failure, it is important to have a large safety factor.

Mixing

Mixing is another important parameter to consider in the design of an anaerobic digester. Mixing increases the rate kinetics of anaerobic digestion, accelerating the biological conversion process. Additionally, mixing allows uniform heating of the reactor (Tchobanoglous et al., 2003). Mixing can be done mechanically through motorized impellers or turbines within the reactor or pneumatically by injecting gas (in anaerobic digestion, methane and carbon dioxide gas) via spargers at the bottom of the reactor (Tchobanoglous et al., 2003).

pH

The pH of the digester is important parameter in anaerobic digestion. The pH should be maintained between 6.6 - 7.6 (Rittmann & McCarty, 2001). One difficulty is maintaining pH above 6.6. During digester start-up, overloading, or instability, organic acids are intermediate products produced by the microorganisms. The presence of too high a concentration of organic acids decreases the pH, decreases methane production, and can cause reactor souring or reactor failure (Rittmann & McCarty, 2001). The carbonic acid system dominates pH control most of the time in anaerobic digestion.

Alkalinity

Alkalinity is defined as the capacity of water to neutralize acid (Rittmann & McCarty, 2001). In anaerobic digestion, the normal percentage of carbon dioxide in the gas phase is 25 – 45%. For anaerobic digestion where the carbonate system dominates, the following proton condition applies:

$[H^+] + [Alkalinity] = [HCO_3{-}] + 2 [CO_3{^2}{-}] + [OH{-}]$

In comparison with the remaining species, carbonate, hydroxide, and hydrogen are present in negligible concentrations. Finally, taking the logarithm of both sides of the reduced equation, the following equation relating pH, bicarbonate alkalinity, and % carbon dioxide is derived:

$$pH = pK_{a_1} + \log\left(\frac{\frac{Alk.(bicarb.)}{50000}}{\frac{[CO2(g)]}{KH}}\right)$$

(6)

Bicarbonate alkalinity of at least 500 – 900 mg/L CaCO3 is required for a pH greater than 6.5. The addition of alkaline materials when proper carbonate buffering is not present in the wastewater helps to maintain the pH in the recommended range for anaerobic digestion. Lime, sodium hydroxide, and ammonia are three of the least expensive chemicals available for the addition of alkalinity. Finally, from the equation for pH above, if pH and bicarbonate alkalinity are known for the anaerobic system, the partial pressure of carbon dioxide may be calculated, which is important

for monitoring the digestion process (Rittmann & McCarty, 2001).

Temperature

Because bacterial growth is mediated by a complex set of enzymatic chemical reactions and the reaction rate of all chemical reactions depends on temperature, bacterial growth rate depends on temperature. As a general rule, bacterial growth rates double for each 10°C rise in temperature over a temperature range, which varies by bacterial species. Above normal temperatures for the particular bacterial species, essential enzymes may denature, or permanently lose their structure and function, killing the microorganism (Rittmann & McCarty, 2001).

For mesophilic anaerobic digestion, the operational temperature range is 10 to 30°C. Above 40°C, enzyme denaturation is a concern. The operational temperature range for thermophilic anaerobic digestion is 55 to 65°C. Specific methane production rates are 50 to 100 percent higher for thermophilic anaerobic digestion than for mesophilic anaerobic digestion (Rittmann & McCarty, 2001).

Volatile Solids Reduction

In order to measure VFA concentration and carbonate alkalinity, Lahav & Morgan (2004) reviewed different published titration methods. They concluded that computerized and programmable titration equipment was sufficiently accurate for monitoring of anaerobic digesters in developing countries (Lahav & Morgan, 2004).

Gas Production

Aklaku et al. (2006) used a Hermann Sewerin GmbH SR2-DO portable gas analyzer to analyze the gas composition of the anaerobic digester. After an initial analysis, it was determined that ammonia was absent and that the composition of hydrogen sulfide gas was 0.002 %wt. basis. Therefore, in the interest of time, Aklaku et al. (2006) measured the %wt. carbon dioxide in the gas mixture and used the following formula to determine the %wt. methane in the mixture (since there

was a negligible amount of hydrogen sulfide gas): $CH_4 = 100 - CO2$.

II. CONCLUSION

By properly operation the anaerobic digester, we can increase its performance. Many anaerobic digesters operating in the field are operated with no monitoring. However, if a study is conducted in the field, parameters commonly monitored include: total solids, volatile solids, organic loading rate, conductivity, pH, alkalinity, temperature, ammonia, total nitrogen, total phosphorus, COD, BOD, TOC, HRT, SRT, gas production, and gas composition (Aklaku et al., 2006; Lang & Smith, 2008). Additionally, if a community digester is having difficulty with operation, monitoring may be an option to improve operation

III. REFERENCES

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