WATER RESEARCH 53 (2014) 153–167

Available online at www.sciencedirect.com

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Carbon mass balance and microbial ecology in a laboratory scale reactor achieving simultaneous sludge reduction and nutrient removal

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ARTICLE INFO

Article history:
Received 12 July 2013
Received in revised form
24 December 2013
Accepted 26 December 2013
Available online 11 January 2014

Keywords:
Sludge minimization
Biological phosphorus removal
Polyphosphate kinase
Candidatus Accumulibacter phosphatis
Denitrifiers

ABSTRACT

Solids reduction in activated sludge processes (ASP) at source using process manipulation has been researched widely over the last two-decades. However, the absence of nutrient removal component, lack of understanding on the organic carbon, and limited information on key microbial community in solids minimizing ASP preclude the widespread acceptance of sludge minimizing processes. In this manuscript, we report simultaneous solids reduction through anaerobiosis along with nitrogen and phosphorus removals. The manuscript also reports carbon mass balance using stable isotope of carbon, microbial ecology of nitrifiers and polyphosphate accumulating organisms (PAOs). Two laboratory scale reactors were operated in anaerobic-aerobic-anoxic (A^2O) mode. One reactor was run in the standard mode (hereafter called the control-SBR) simulating conventional A^2O type of activated sludge process and the second reactor was run in the sludge minimizing mode (called the modified-SBR). Unlike other research efforts where the sludge minimizing reactor was maintained at nearly infinite solids retention time (SRT). To sustain the efficient nutrient removal, the modified-SBR in this research was operated at a very small solids yield rather than at infinite SRT. Both reactors showed consistent NH_3–N, phosphorus and COD removals over a period of 263 days. Both reactors also showed active denitrification during the anoxic phase even if there was no organic carbon source available during this phase, suggesting the presence of denitrifying PAOs (DNPAOs). The observed solids yield in the modified-SBR was 60% less than the observed solids yield in the control-SBR. Specific oxygen uptake rate (SOUR) for the modified-SBR was almost 44% more than the control-SBR under identical feeding conditions, but was nearly the same for both reactors under fasting conditions. The modified-SBR showed greater diversity of ammonia oxidizing bacteria and PAOs compared to the control-SBR. The diversity of PAOs in the modified-SBR was even more interesting in which case novel clades of *Candidatus* Accumulibacter phosphatis (CAP), an uncultured but widely found PAOs, were found.

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http://dx.doi.org/10.1016/j.watres.2013.12.035

1. Introduction

Activated sludge processes are the most widely used treatment method for municipal wastewater (Grady et al., 1999; Metcalf and Eddy, 2003). However, excess sludge is the one of the main drawbacks of the activated sludge process. Treatment of this excess sludge requires much energy and labor. Sludge reduction through process manipulation at wastewater treatment plants is increasingly attractive due to rising costs and constraints associated with sludge treatment and disposal. The treatment of excess sludge is expensive and may account for 25–65% of the plant's operational cost (Chen et al., 2001; Camacho et al., 2002; Saby et al., 2003; Cui and Jahng, 2004). Approximately 8.2 million tons of sludge was generated in 2010 in the United States, and the amount has been predicted to continue to grow (USEPA, 1999).

Anaerobic digestion reduces the excess solids by 40–50% with methane gas being a useful byproduct. Several research efforts have shown that electricity (Liu et al., 2004, Min and Logan, 2004) and hydrogen gas (Angenent et al., 2004; Hallenbeck, 2005; Gong et al., 2005) can be generated biologically from the wasted solids. However, challenges still exist regarding the improved yields of electricity and hydrogen gas using microbial fuel cell and solids fermentation biotechniques respectively. Another option for the use of solids includes composting followed by land application. However, land application of biosolids is restricted in many states due to the health risk to man and livestock owing to potentially toxic elements in the sewage sludge, i.e. heavy metals, pathogens, persistent organic pollutants and nutrients (Wei et al., 2003). Hence, it is highly debatable that excess biosolids is a useful commodity. As a result, excess biosolids from activated sludge processes is regarded as an environmental concern and threatens the long term operation of activated sludge treatment processes. The reduction in sludge could dramatically impact the difficulties municipalities are facing today in disposing of or reusing their excess sludge.

For sludge reduction at the source, a number of technologies have been developed that are one or a combination of physical, chemical, biological and thermal processes (reviewed by Ødegaard, 2004). However, cost savings from sludge minimization using one or a combination of physical, chemical, and thermal processes (Fig. 1A) must be compared to costs involved in implementing these processes. All these alternatives are expensive and could increase the overall energy consumption of the plant (Böhler and Siegrist, 2006).

Sludge minimization through anaerobiosis (also called the fasting of solids) of returned activated sludge using a sidestream anaerobic reactor is a relatively new sludge minimization approach which has been primarily investigated in laboratory scale set ups with few full scale installations in the U.S. under the trade name of Cannibal™. In this approach, a portion of the settled solids is taken to an anaerobic sidestream reactor (fasting of sludge) and an equal volume of the mixed liquor from this sidestream reactor is sent back to the main bioreactor (feasting conditions). The circulation of solids through the anaerobic sidestream to the main bioreactor causes a net reduction in the overall observed solids yield. Cycling of a portion of the secondary clarifier underflow through the anaerobic sidestream tank induces certain conditions (not fully known) under which the process achieves a net reduction in biosolids.

Despite many significant advantages, several factors preclude the widespread application of activated sludge configurations which achieve a net sludge reduction through anaerobiosis. These factors include; **(1)** the lack of proven mechanisms of sludge reduction in these processes although some theories like iron is reduced and proteins are released and solubilized in the sidestream reactor were proposed (Novak et al., 2006), **(2)** the absence of information on the fate of carbon, i.e. lack of carbon mass balance, and **(3)** most importantly, the absence of a nutrient removal component in these processes. From the wastewater operator's perspective, the first two factors may not be too important as long as the process works efficiently. The last one is more essential because nutrient removal is mandated by federal and state regulatory agencies to protect the quality of receiving waters and, consulting world does not have a sound design basis of these sludge minimizing processes.

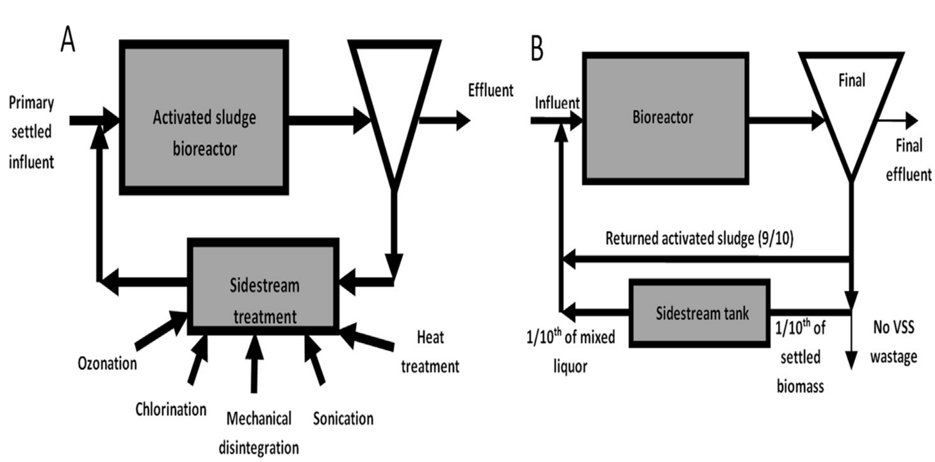

Fig. 1 – Schematic of activated sludge configurations; (A): Various physical and chemical methods used to achieve biomass reduction, (B) schematic of a typical sludge minimizing activated sludge process through returned biomass fasting (in the sidestream tank) and feasting (in the bioreactor).