INTRODUCTION/PROBLEM STATEMENT

Regulatory agencies in North America and Europe continue to mandate stringent effluent discharge requirements for wastewater treatment plants (WWTPs) to reduce adverse impact on receiving water bodies. As a result, WWTPs are incentivized to upgrade existing treatment processes to accommodate effluent standards while minimizing operational costs (energy consumption).

Most small-scale WWTPs in North America and Western Europe employ a variation of the conventional activated sludge process (ASP), known as alternating-activated sludge (AAS). AAS utilizes an aeration system periodically to perform biological nitrogen removal. The aeration system requires significant energy and is responsible for majority of the operational cost of WWTPs.

The aeration system is generally controlled by pre-determined air-on/air-off sequences for a day. The sequences do not vary daily. The proposed approach recommends specifying on-off switching conditions using dynamic optimization techniques based on detailed mathematical models. For the purposes of this report, the dynamic model is calibrated using a set of input/output measurements from an industry partner. The model is evaluated over a long-term period, under both wet weather (large precipitation/storm events) and dry weather (drought) conditions, to ensure AAS performance is reliable.

VARIABLES AND PROCESS OVERVIEW

The following process, variables and function are used to model nitrogen removal.

* Aerobic conditions – ammonia nitrogen is converted to nitrate by autotrophic bacteria. Referred to as nitrification.
* Anoxic conditions - nitrate consumed by heterotrophic bacteria to degrade organic substrate. Referred to as denitrification.

Insert table of variables

OBJECTIVES

The two objective functions are as follows:

* Minimize nitrogen discharge
* Minimize operation costs

MODELLING

Initially, an Activated Sludge Model 1 (ASM1) is built with stoichometric coefficients containing data regarding mass balance kinetics for Nitrogen removal and oxygen supply in a traditional AAS. The inputs utilized for the ASM1 model are as follows:

Table of inputs for ASM1

Some of the above inputs are obtained from literature and experimental data. The outputs provide a set of ODE equations that can be used to solve subsequent

Using the ASM1 as a basis, a dynamic model is developed where the aeration profile over a given time (to, tf) is based on the number of cycles (Nc). For each aeration cycle, two time (air -on and air-off) durations are required, as shown in the following figure.

Figure xx. Illustration of number of cycles with proposed approach

*An optimization modelling time period of 10-15 days is identified to be the preferred duration to generate meaningful results as 15 days is the absolute time required for adequate growth of autotrophic bacteria.* Furthermore, two key assumptions made for this approach are that each aeration time profile is identical from day to day (no daily variance) and all aeration cycles are of equal length.

Objective 1- Dynamic Approach

The ASM1 model is used as a basis to simulate nitrogen removal in the aeration tank via microorganisms. The function used to minimize nitrogen over a given duration from (to, tf) is as follows:

Insert function.

In order to maintain adequate bacteria growth and continue nitrogen degradation in a safe manner, four key operating constraints listed below are required:

* Minimum and maximum air-on and air-off periods within a cycle are 15 mins and 2 hours respectively
  + Ensures activated sludge is conveniently re-aerated and mixed
  + Short air-on periods can lead to bulking phenomena or decline in aerobic bacteria population
  + Prevent turbines from damaging by avoiding frequent start/stop sequences
  + Too long air-off periods can give rise to sludge sedimentation within aeration tank and produce anaerobic conditions with anaerobic bacteria dominating other microorganisms

Additional WWTP discharge constraints are also imposed based on criteria enforced by regulatory agencies

* TN max = 10 mg/L
  + For the purposes of this report, total nitrogen is considered as a priority contaminant and therefore above effluent criteria must be satisfied. In reality, there are various other constituents in wastewater effluent that must meet regulatory guidelines

The aeration policy that minimizes total nitrogen concentration in the effluent is as follows

Objective 2 – Dynamic Approach

Since energy consumption via aeration system is responsible for majority of the WWTP’s operational costs, a function that models power over a given duration nfrom (to, tf) is used for subsequently analysis.

The power used by the aeration system (mechanical turbines) is assumed to be strictly a function of air-on periods (proportional to number of cycles with air-on). A dimensionless approach is further developed to have performance correspond to mean aeration rate over optimization time period.

SUMMARY

Insert pic here with objective funcs and constraints

OPTIMIZATION RESULTS

Insert results