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Review

Optimal design and operation of activated sludge processes: State-of-the-art

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HIGHLIGHTS

- The paper deals with the optimal control and design of activated sludge processes.
- Studies on the topic are critically reviewed.
- Focus is set on the problem formulation that allows one getting reliable solutions.
- The selection of appropriate cost functions and constraints is discussed.
- Aspects related to dealing with model mismatch are presented.

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ABSTRACT

The activated sludge process (ASP) is the most commonly used process for wastewater treatment. Improving its performance is necessary from economic and environmental point of views. In this context, dynamic optimization is a powerful tool for assisting engineers in determining optimal operations and designs for ASPs.

However, the real optimality of the solution strongly depends on the optimization problem statement, for which unfortunately, there is no standard or commonly accepted formulation. In a hopeful attempt to provide a guideline for future works on the topic, this paper reviews the literature devoted to optimal control and design of ASPs. The main issues to be addressed in order to get reliable solutions are discussed, among which: (1) Managing the inevitable mismatch between the model predictions and the real ASP operation. (2) Dealing with the unpredictable variations in the wastewater characteristics. (3) Accounting for the slowest dynamic processes occurring in ASPs. (4) Appropriately selecting the decision variables and the flowsheet structure in order to simplify the problem formulation from a mathematical perspective. (5) Conveniently choosing the cost functions expressions/correlations. (6) Successfully selecting the mathematical constraints in order to guarantee physically relevant operations.

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1. Introduction

A wastewater treatment plant, WWTP, is an industrial facility where a combination of mechanical, physical, chemical and biological processes is used to achieve pollutants removal from the incoming wastewater. These pollutants are various, and in the case of some industrial wastewaters, they may require specific treatment strategies/techniques: this review paper will focus only on biological nutrient removal from sewage water, i.e. domestic and municipal wastewaters. In such WWTPs, a primary treatment ensures the separation of particulate pollutants (debris, sand, oils, grease and particulate wastes), in particular, thanks to gravitational separation in a large settling tank (referred to as primary settler). However, colloidal and dissolved wastes are not sufficiently removed by these separation processes, and therefore, must be eliminated by a secondary treatment stage. In the case of sewage, characterized by a low COD (chemical oxygen demand) to BOD_5 (five-day biological oxygen demand) ratio, biological secondary treatment is the most cost-effective process. Nowadays, given its efficiency, relatively simple operation and low cost, the activated sludge process (ASP) is by far the most widely used for sewage biological secondary treatment.

The infrastructure of a basic ASP (Fig. 1) consists of: (1) a single bioreactor operated continuously where suspended microorganisms consume the colloidal and dissolved organic matter. The

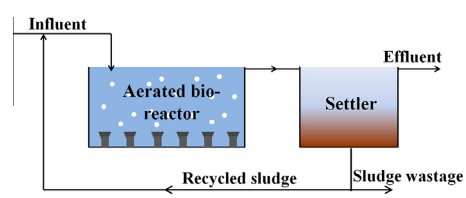

Fig. 1. The basic ASP.

reactor is aerated to provide dissolved oxygen (DO) for aerobic biodegradation. Bacteria consume one part of the colloidal and dissolved carbonaceous compounds to satisfy their energetic needs (catabolism), and synthesize another part – along with a small proportion of ammonium and phosphorus – into new cellular tissues (anabolism). (2) A settling tank (referred to as secondary settler or clarifier) where activated sludge (flocculated biomass) is gravitationally separated from the treated wastewater. The effluent overflows into the receiving waterbody, but in some WWTPs, it may undergo additional treatments (e.g. filtration and disinfection) before being discharged. A minimum solids retention time (SRT, also referred as 'sludge age') of about 3 days is required for bacteria to aggregate into flocs (bio-flocculation) so as to enable their gravitational separation. (3) A sludge recycle line returning the major proportion of the settled sludge to the bioreactor, thus allowing