Observer design for the activated sludge process

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The activated sludge process (ASP) is the most common process in biological wastewater treatment. However, they are very costly to operate, with energy for aeration being their largest cost. To optimize the process, a model is needed. The most widely used model for modeling of ASP:s is the Activated Sludge Model NO.1 (ASM1) [1]. It is physically based and a good compromise between accuracy and simplicity, and from this comes its popularity. Unfortunately, the model contains several concentrations that cannot reliably be measured online. Some of these are degradable dissolved and particulate organic matter, and biomass concentration. Totally Suspended Solids (TSS) measurements give indication of biomass concentration though. Online substrate analyzers have been available for many years but have historically been considered unreliable. Under the assumption that all relevant concentrations in the ASM1 were available online, the operation of ASP:s could be optimized to an extent that is not possible today. Some of the inputs to be optimized are the different input flowrates (water), TSS in the sludge recycle flow, the aerobic volume, external carbon addition and the air flowrates in the aerobic compartments. Motivated by this, an observer has been designed for the process based on the ASM1.

Observers based on the ASM1 have earlier been formulated by [3] and [4]. Both of these are for one aerobic reactor in the benchmark model [2] and the biomass concentration is assumed to be known and constant. A reduced order observer model is used in both cases. In [3] an altered version of the ASM1 which only includes one kind of substrate is used as the model for a nonlinear observer. In [4] an extended Kalman filter approach is taken. Different sets of measurements are considered in these cases but in both it is concluded that all relevant variables cannot be estimated at the same time. When lab analysis of substrate in the input is fed to the observers they are convergent though.

In this work we try to estimate all concentrations including unknown inputs in a reduced order model of two aerobic reactors with an extended Kalman filter. The success to estimate all unkwnown inputs compared to [3] and [4] relies on the following features:

- Contrary to the work mentioned above, the process considered here is *predenitrifying with postnitrification in trickling filters*. This means that nitrification stands for a very small portion of the aerobic reactions in the ASP, which in turn leads to that less

concentrations in ASM1 need to be considered. The concentrations in the reduced order model are: S_O (oxygen), S_S (readily biodegradable substrate), X_S (slowly biodegradable substrate) and X_{BH} (heterotrophic biomass). Among these, only oxygen is measured.

- By including two reactors, one additional measurement of oxygen is gained and better coupling between the states is achieved. The process model holds totally 11 states.

- The assumption that the biomass concentration is constant can for most plants in reality only be assumed on a very short time basis (hours). This can namely vary fast with varitions in the ratio between the input flowrates and with TSS in the return sludge flow. On the other hand, the composition of the sludge can be assumed to be slowly time varying. Instead of estimating the unknown input of biomass directly the observer estimates a parameter $\gamma_{X_{BH}}$: the ratio of the return sludge being heterotrophic biomass. The sludge concentration in the reactors can be simulated from TSS measurements in the recycle flow. This approach allows for larger variations in biomass concentration.

- The unknown input concentrations: S_S, X_S and the parameter $\gamma_{X_{BH}}$ are all modeled as random walk processes.

Initially, it was considered to estimate $\gamma_{X_{BH}}$ in the upstream anoxic compartments by using that some of the Monod expressions in the ASM1 model then can be assumed to be saturated. The developed EKF gives close to unbiased estimates of all states. The transient of the filter for three of the estimates of simulated variables are shown in Figure (1). The parameter $\gamma_{X_{BH}}$ is shown for a longer time period because of its slower variation.

(a) Readily biodegradable substrate at the inlet of the first reactor.

(b) Slowly biodegradable substrate at the inlet to the first reactor.

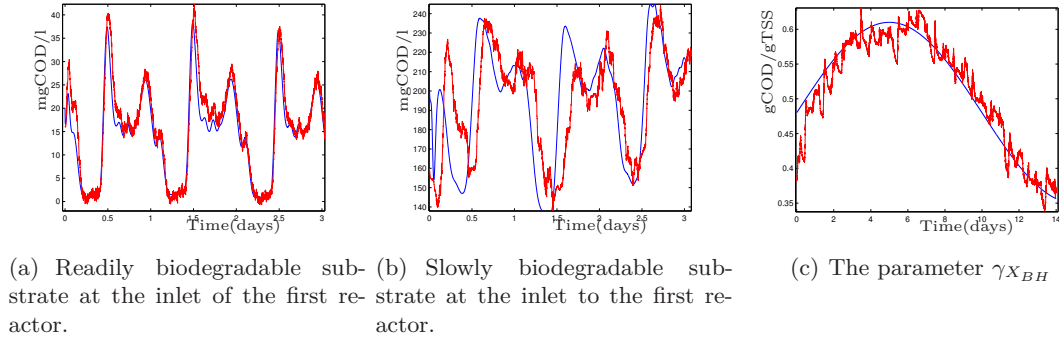(c) The parameter $\gamma_{X_{BH}}$

Figure 1: Estimated (noisy) and true variables (smooth).

Unfortunately, the system can be very sensitive to model errors, especially for errors in the $K_L a$ (Oxygen transfer) function, which is known to be time varying. To make the filter useful in an application it is most probably necessary to estimate the $K_L a$ function on a continuous basis. Most methods for estimating this function needs excitation of the air flowrate. The purpose of the observer is to save money and excitation is costly. However a $K_L a$ estimation method where the air flowrate is excited with small amplitude has been described in [5].

References

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