The Biowin Advantage

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Simulating Upflow Anaerobic Sludge Blanket Reactors

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Introduction

In this issue of the BioWin Advantage, we will be exploring how to simulate Upflow Anaerobic Sludge Blanket (UASB) reactors. We will look at the basic requirements to set up a UASB configuration, and in later issues, we will use this simple configuration to explore start-up and control strategies that might be simulated for this process.

Background on UASB Simulation

The most common application of the anaerobic digester element in BioWin (and arguably the most common application of anaerobic processes in municipal wastewater treatment practice) is for digestion of waste activated sludge (WAS) and primary sludge (PS) in the context of a whole plant simulation (i.e. in Figure 1). Sludge digesters are intended to be operated as complete-mix reactors (although inefficient mixing sometimes reduces the "ideality" of the reactor). Therefore, in sludge digesters, the hydraulic retention time (HRT) should be equal to the solids retention time (SRT).

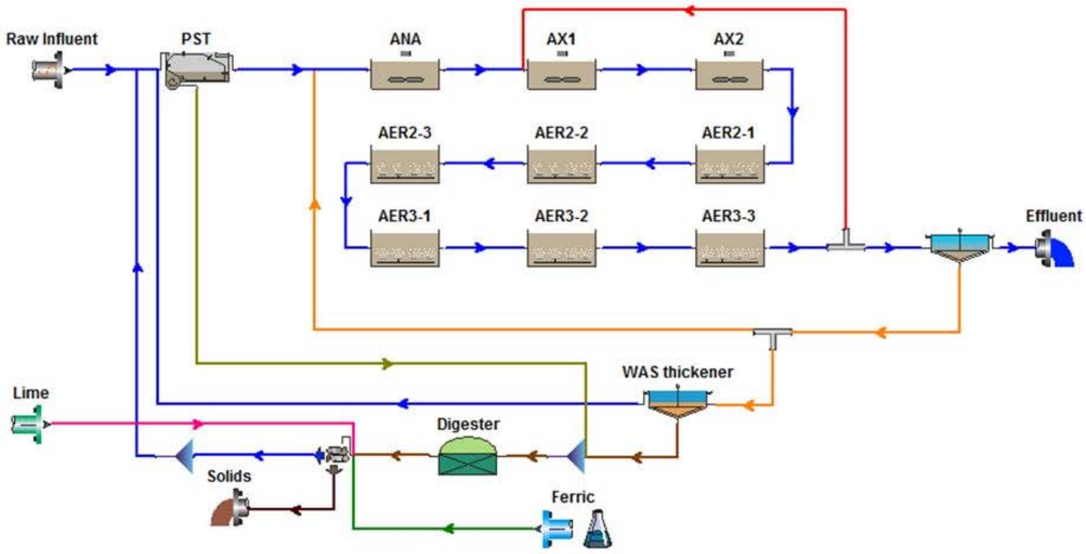


Figure 1: BioWin configuration for whole plant simulation including anaerobic digestion of combined WAS and PS.

Another common application of anaerobic processes is for treatment of wastewaters with high organic strength in so-called "high-rate" anaerobic reactors. The key characteristic of these processes is that biomass is retained in order to de-couple the HRT and the SRT. The UASB process achieves this through the development of a granular sludge bed with high settling velocities and through the use of a solid-liquid-gas separator at the top of the reactor. Although a full discussion of design and operating parameters for UASBs is beyond the scope of this e-newsletter, for simulation purposes we can say that UASB sludge blankets with total suspended solids concentrations in the range of 30,000 to 50,000 mg/L and UASB SRTs of greater than 50 days are typical.

A UASB Configuration in BioWin

The BioWin configuration we will use to simulate a UASB process is shown in Figure 2 below. Some important aspects of this configuration include:

- The UASB process is represented by an anaerobic digester element coupled to a point settler element.
- The underflow rate of the point settler is set to allow a reasonably high recirculation ratio in the UASB.
- The solids removal in the point settler is set to allow accumulation of a TSS concentration in the digester that is typical of these processes.
- The influent in our example configuration is intended to represent a biodegradable industrial influent with high organic strength and a high soluble content.
- The splitter on the influent will be used to adjust the amount of influent that goes to the process when we explore start-up.
- Caustic addition may be required to maintain the pH in the UASB and a State Variable influent element has been included to represent caustic addition.
- The state variable influent element for Seed input represents biomass that would be

added at start-up.

Some design and operation details of this configuration are summarized in Table 1.

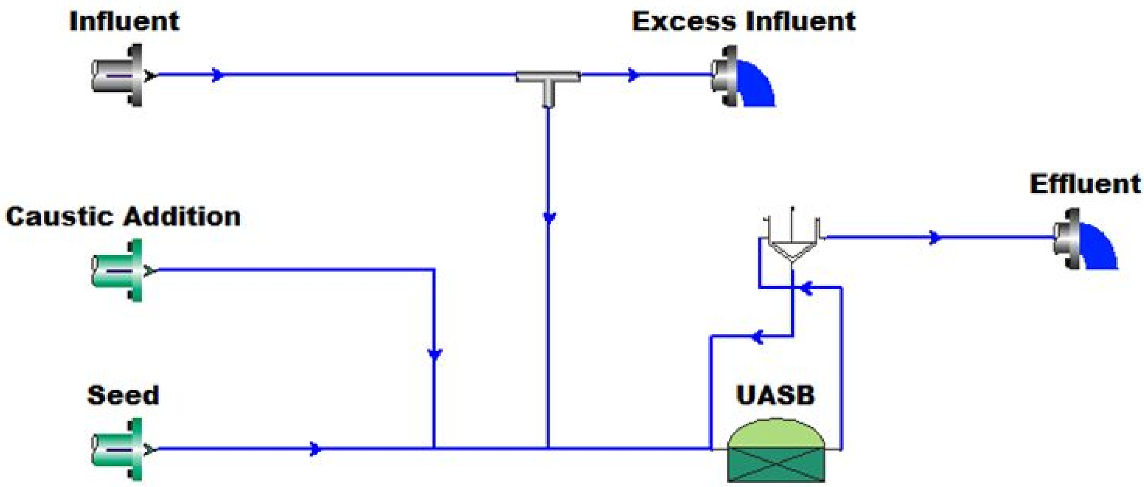


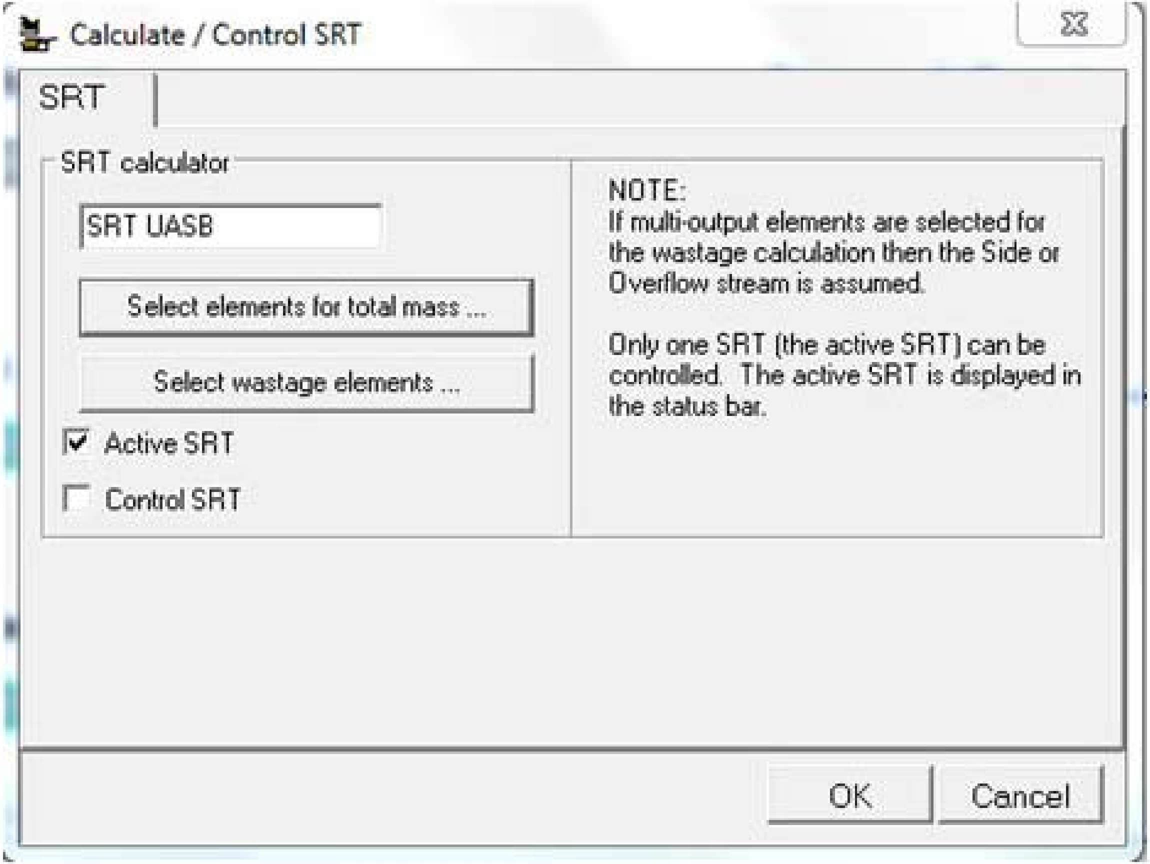
Figure 2: BioWin configuration for simulation of a UASB.

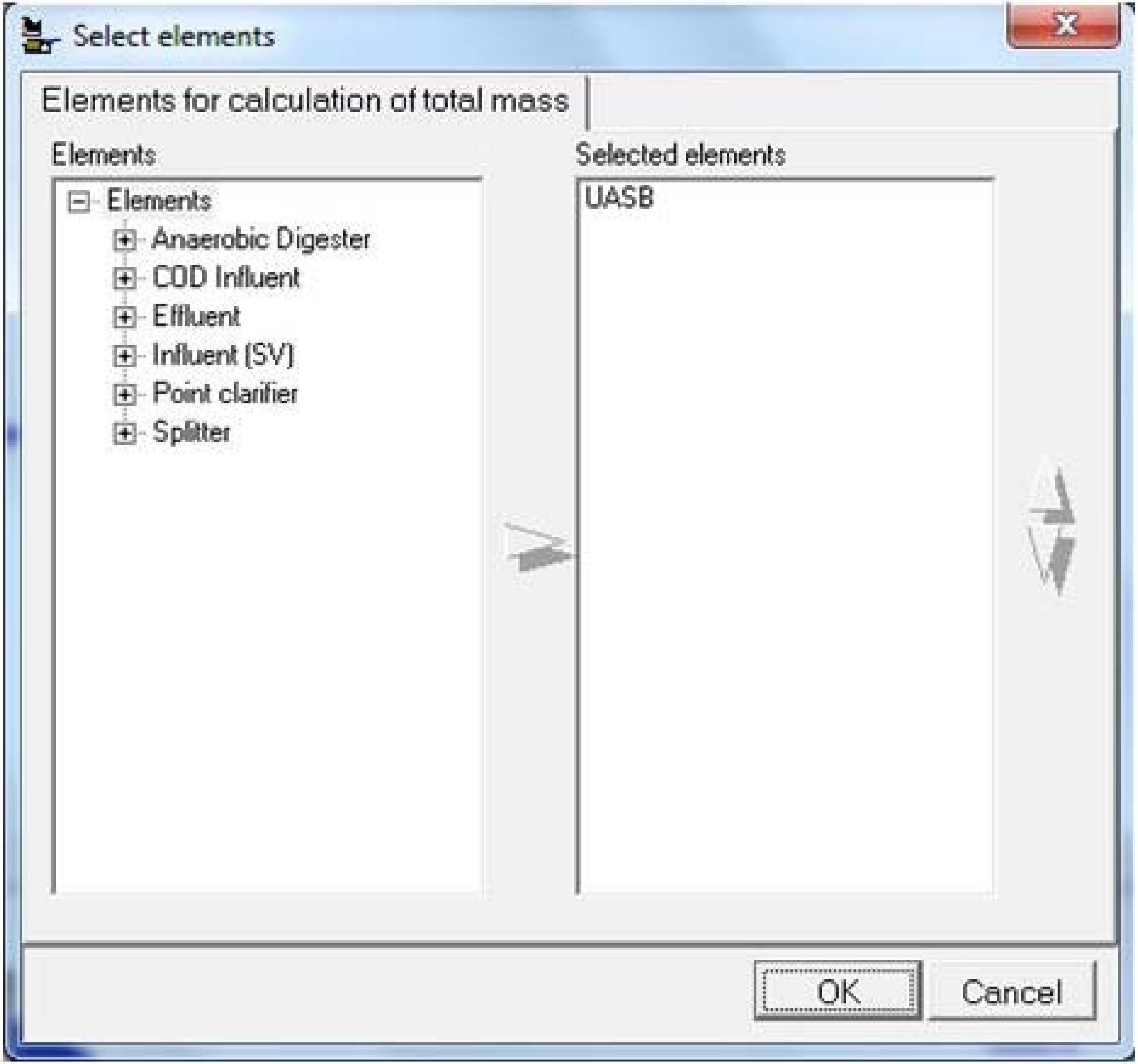
Table 1: Pertinent UASB Configuration Design and Operating Details

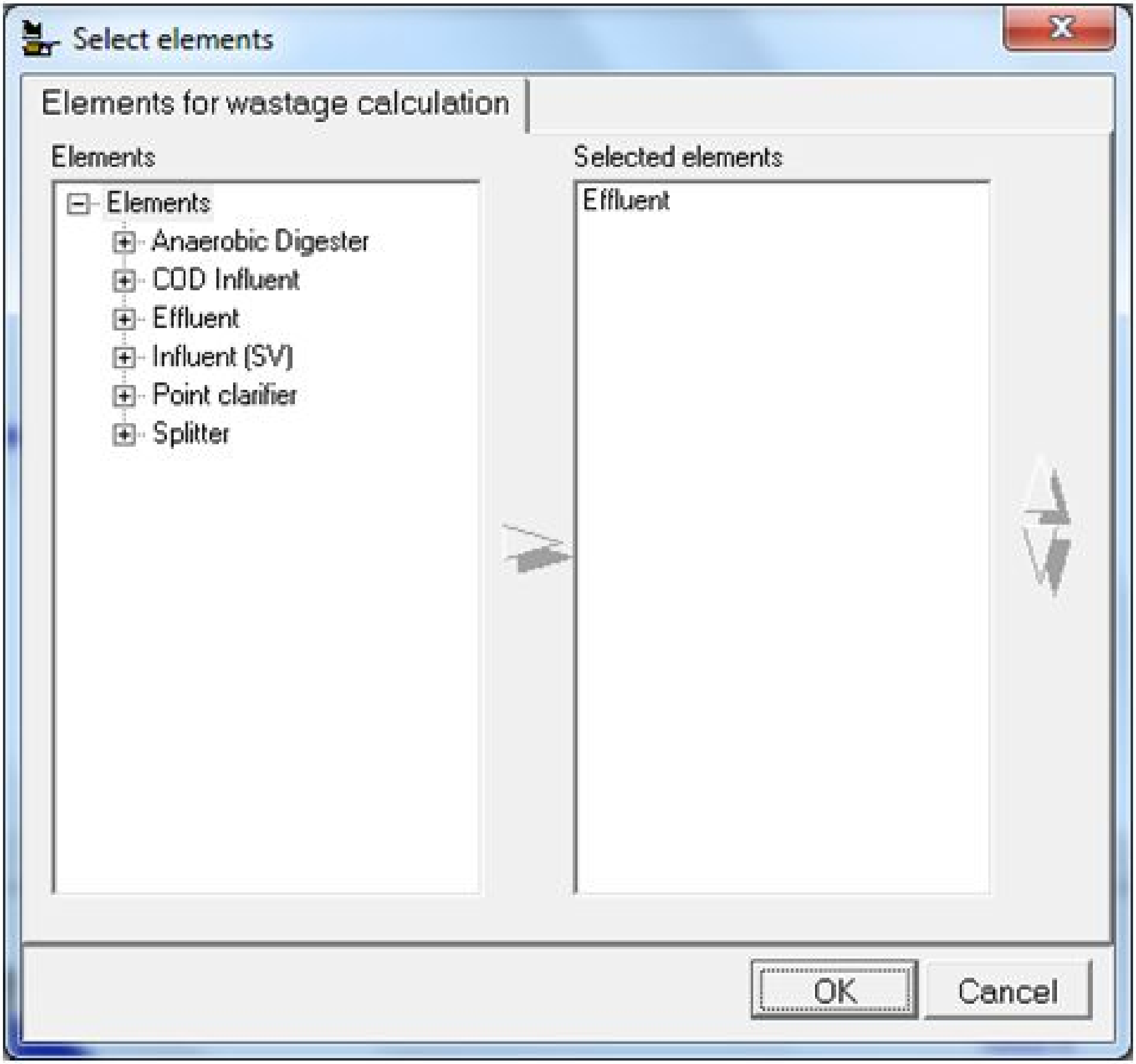
Parameter	**Value**
Influent flow	2000 m^3/d
UASB volume	2000 m^3
UASB operating temperature	35°C
Point settler underflow	4000 m^3/d
Point settler solids removal rate	99.6%
Influent Wastewater characteristics	
COD concentration	5000 mg/L
TKN concentration	100 mg/L
TP concentration	15 mg/L
ISS concentration	35 mg/L
pH	5.2
Alkalinity	1.5 mmole/L
F_{bs} Readily biodegradable COD	0.65 g COD/g of total COD
F_{ac} Acetate	0.50 g COD/g of readily biodegradable COD
F_{xsp} Non-colloidal slowly biodegradable	0.75 g COD/g of slowly degradable COD
F_{US} Unbiodegradable soluble	0.10 g COD/g of total COD
F_{UP} Unbiodegradable particulate	0.10 g COD/g of total COD

Steady State UASB Simulation

The BioWin file described above accompanies this document here : Steady State UASB Simulation. For the steady state example we will leave the Caustic and Seed flows at 0. If we run a steady state and hover the cursor over various elements in the configuration we can review some of the results. First, an SRT calculator for the UASB process was set-up as shown below:

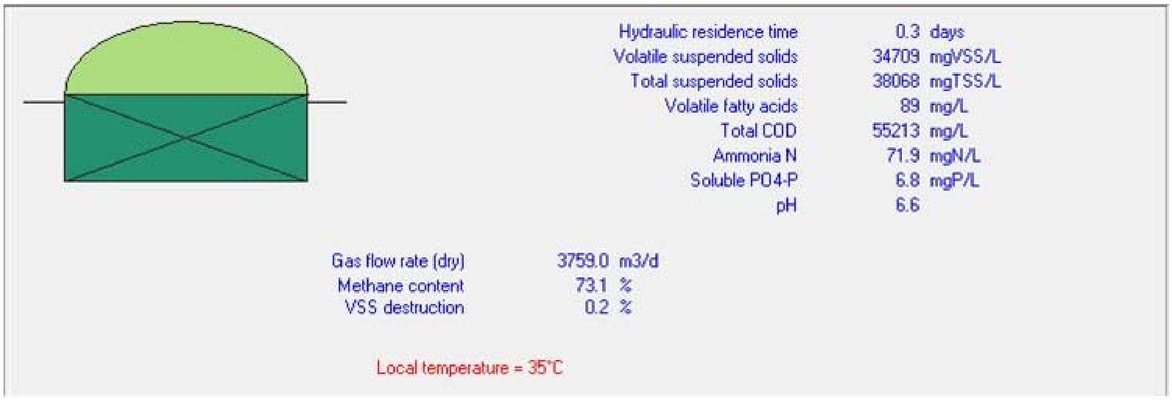

Calculate / Control SRT
SRT
SRT calculator
SRT UASB
Select elements for total mass ...
Select wastage elements ...
Active SRT
Control SRT
NOTE:
If multi-output elements are selected for the wastage calculation then the Side or Overflow stream is assumed.
Only one SRT (the active SRT) can be controlled. The active SRT is displayed in the status bar.
OK
Cancel


Select elements
Elements for calculation of total mass
Elements
Selected elements
Elements
Anaerobic Digester
COD Influent
Effluent
Influent (SV)
Point clarifier
Splitter
UASB
OK
Cancel



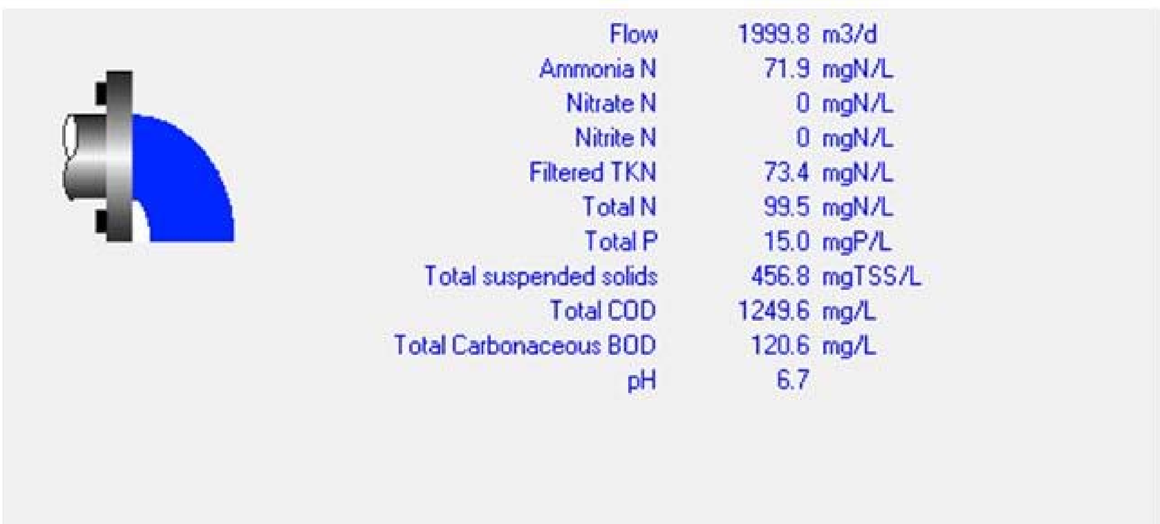
The resulting steady state UASB SRT is 83 days:

Looking at the digester summary pane, we see that the sludge bed TSS concentration is within the expected range. The pH value, the concentration of volatile acids in the reactor, and the biogas production rate and quality indicate a stable operating point has been achieved. The VSS destruction usually is of interest when simulating sludge digestion but is not relevant in this case because the process is treating a wastewater that is largely soluble and the influent solids loading to the reactor includes the re-circulation from the point settler.

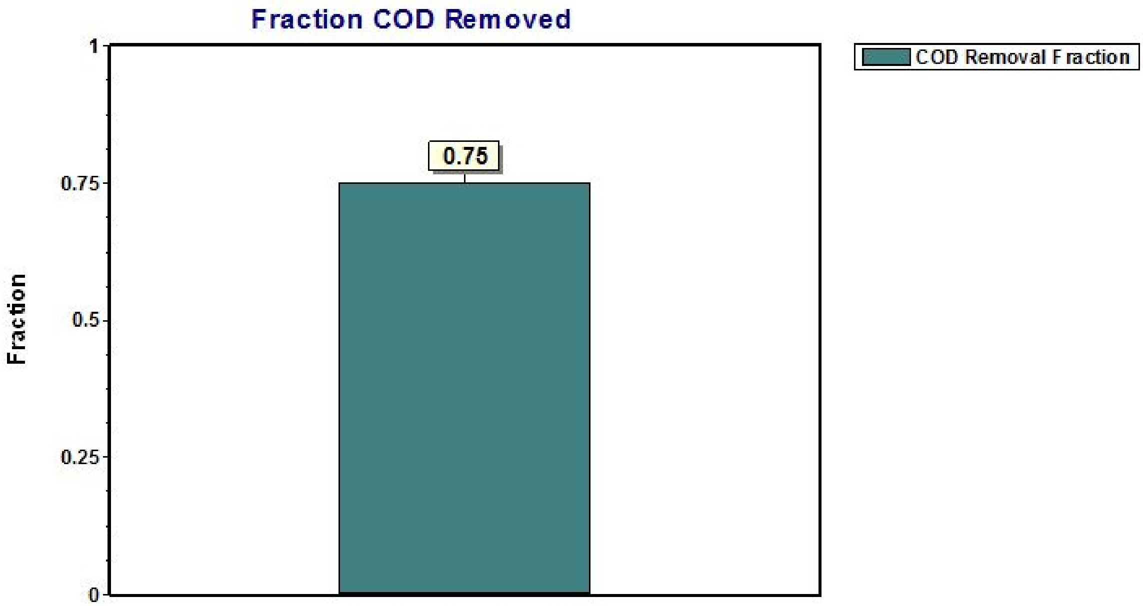


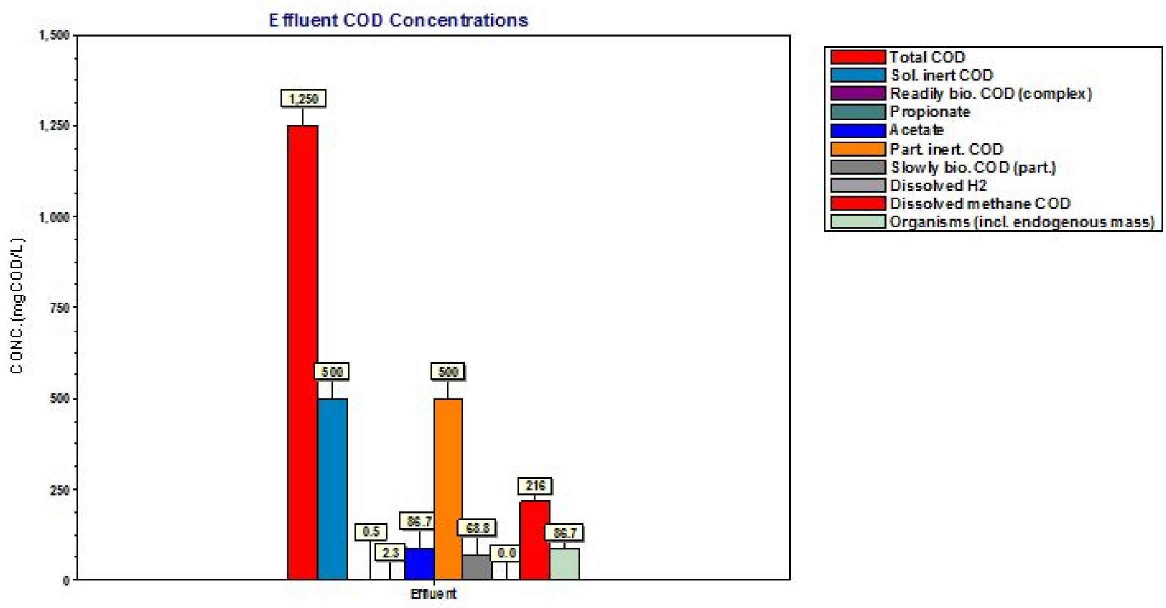
Examining the effluent in the summary pane below, we see that:

- The concentrations of ammonia and phosphorus indicate that there were excess nutrients available in the influent (not always the case with industrial influents!).
- The TSS concentration obviously is higher than we see in the effluent from secondary treatment processes. However, this is not unusual and not unexpected given the high solids concentrations in the sludge bed. In this simulation, all of the wastage is in the effluent and we have reached a steady state sludge bed solids concentration. In practice, the sludge bed TSS concentration may increase over time and there will be occasional intentional wastage of the sludge granules (possibly to be used for start-up of other UASBs).
- The elevated effluent COD and BOD concentrations indicate that effluent polishing may be necessary, unless this effluent is to be discharged to a municipal sewer.



In the album, a plot has been created to calculate the COD removal fraction through the UASB process, as shown below. With a removal of only 75%, it is instructive to examine the components of the effluent COD. This is illustrated below in another album plot . The first bar in the chart shows the total effluent COD concentration, and the remaining bars show the main components of the effluent COD. The effluent unbiodegradable soluble COD concentration is a result of the influent wastewater characteristics and comprises 40% of the total effluent COD. The unbiodegradable particulate COD represents another 40%, and this is partly due to influent wastewater characteristics, but also related to the performance of the solid-liquid-gas separator. The next largest component is dissolved methane COD. This result is different from what would be seen in simulating a sludge digester where the HRT is in the range of say 15-30 days, where there would be plenty of time for slightly soluble gases such as methane to be released to the gas phase. In contrast, in a high-rate anaerobic process such as a UASB, loading is higher so there is higher biogas production per unit volume, and the HRT is usually 24 hours or less, so a more significant amount of methane may leave the system dissolved in the effluent. Note that the BioWin state variable for the dissolved methane concentration is reported as methane. In the plot shown here, the reported dissolved methane has been multiplied by 4 (*i.e.* the g CH_4/g COD ratio) to arrive at the COD equivalent of the dissolved methane.





Conclusions

A number of extensions to this example could be investigated. One interesting study would be the use of a model settler to retain the sludge bed. This would allow performance and bed retention to be more directly linked to process loading (obviously sludge settling parameters would be quite different from mixed liquor!). In later issues we will extend this example with dynamic simulations to explore start-up using both manual strategies and automated approaches using BW Controller first to simulate a typical manual control strategy, and then to simulate a potentially more optimal on-line control strategy.

We trust that you found this technical topic both interesting and informative. Please feel free to contact us at info@envirosim.com (Subject: The BioWin Advantage) with your comments on this article or suggestions for future articles.

Thank you, and good modeling.

The EnviroSim Team

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