New Developments in BioWin 6.2

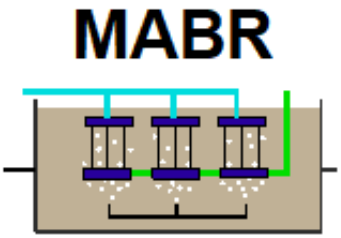
October 27, 2020

BioWin 6.2 contains a new element to model Membrane Aerated Bioreactors. This technology is gaining acceptance worldwide as an effective wastewater treatment approach, particularly for increasing capacity of existing systems and potentially reducing energy consumption.

BioWin 6.2 also contains updates to its Excel reporting templates and functionality, as well as a few minor bug fixes.

Membrane Aerated Bioreactor

A **Membrane Aerated Bioreactor** (MABR) element has been added to represent this process in BioWin configurations. Physically the MABR element is somewhat analogous to the membrane bioreactor unit. Hollow fiber membrane cassettes are immersed in the mixed liquor of a bioreactor, displacing a certain liquid volume. Gas (typically air) is blown through the inner core of the hollow fibers (the lumen), and oxygen diffuses outwards through the membrane wall. A biofilm develops on the outer surface of the fibers. In most current applications of MABR technology, process air typically is introduced only through the membrane fibers and the bulk liquid is not aerated for process purposes. However, additional aeration can be provided *via* diffusers on the base of the reactor with oxygen transfer from the bubbles to the bulk liquid in the reactor.



Modeling of these systems is complex. The simple view of an MABR is to think of oxygen permeating outwards from the inner core of the hollow fibers, and entering the biofilm to provide oxygen for nitrification and other biological growth processes. However, CO_2 is a product of various biological processes and some CO_2 likely will diffuse from the inner biofilm layer back into the lumen, counter-current to the movement of oxygen through the membrane. The mass transfer modeling through the membrane must be applied to all dissolved gases included in the BioWin ASDM (O_2, CO_2, N_2, NH_3, N_2O, H_2,

H_2S, CH_4, and the three industrial components depending on their volatilities) and the direction of movement of individual gas components will depend on the concentration gradient for each component.

BioWin's one-dimensional dynamic biofilm model is used as the basis to represent the biofilm growing on the outside of the membrane. That is, the biofilm is considered as a number of layers of equal thickness. Mass transfer of soluble components and dissolved gases between layers within the biofilm and from the biofilm outer surface to/from the bulk liquid is handled in the same manner as for other attached growth biofilms. This is also the case for attachment and detachment of solids to/from the outer surface of the biofilm and the movement of solids between layers in the biofilm.

The biofilm model incorporates all of the BioWin ASDM model processes including pH calculations and separate diffusion rates for different state variables. The MABR model has been developed to balance pragmatic design elements with mechanistic modeling rigor, to provide quick solution times, and typical process performance predictions.

Model Description for Gas Transfer from the Hollow Fibers to the Biofilm

As noted above, all of the normal biofilm model processes are active in the MABR biofilm, including mass transfer of dissolved gases to/from the biofilm outer surface to the bulk liquid, and diffusion of gases within the biofilm. The MABR model incorporates several processes that describe the mass transfer of gases to/from the supply gas inside the hollow fibers (the lumen), through the membrane wall of the fibers, to the inner layer of the membrane-supported biofilm. These are:

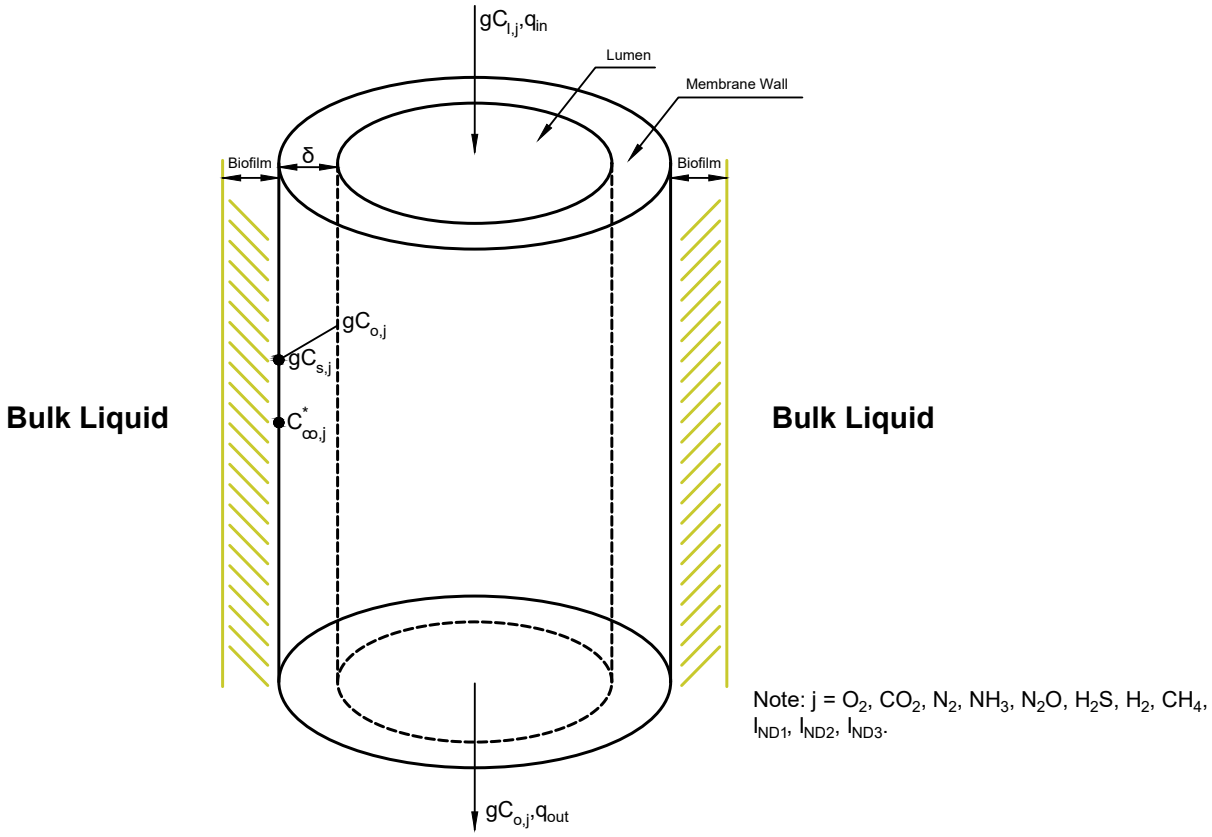
1. The bulk flow of gas through the hollow fiber lumen;

2. The differential transport of the gas components through the membrane fiber wall from the lumen to the edge of the membrane in contact with biofilm; and

3. Mass transfer of the gas at the outer membrane surface into biofilm (liquid).

Parameters related to gas-liquid mass transfer for the MABR element can be found *via* the **Project > Parameters > Aeration/Mass Transfer…** menu command. Note that local settings for membrane supply gas oxygen content and membrane diffusivity parameters can be implemented on the **Model options** tab of any MABR element.

The diagram below illustrates the system material flows:



MATERIAL FLOW IN THE MABR MODEL SYSTEM

Bulk transport through the lumen

Currently it is assumed that the gas phase inside of the hollow fibers (the lumen) is completely mixed. A subsequent release of BioWin will include the capacity to model changes in gas phase composition along the length of the hollow fibers. A mass balance on the gas components in the lumen allows calculation of the lumen gas phase composition:

$$\frac{dm_j}{dt} = \left[q_{in} \cdot gC_{I,j} - q_{Out} \cdot gC_{O,j}\right] + \ gD_j \qquad (1)$$

where

gD_j = Mass of gas component j diffusing through the fiber wall [mol/d]

q_{in} = Gas flow into the lumen of the hollow fibers [m^3/d]

q_{out} = Gas flow exiting the hollow fibers [m^3/d]

$gC_{O,j}$ = Gas concentration of component j in the lumen [mol/m^3].

$gC_{I,j}$ = Supply gas concentration of component j [mol/m^3].

Diffusion through membrane fiber wall

The process describing the diffusion of gas from the lumen through the membrane fiber wall is:

$$gD_j = \mathrm{D}_j \cdot a_{Membrane} \cdot \frac{\left(gC_{S,j} - gC_{O,j}\right)}{\delta} \qquad (2)$$

where

gD_j = Mass of gas component j diffusing through the fiber wall [mol/d]

D_j = Gas diffusivity for component j [m^2/d]

$a_{Membrane}$ = Membrane surface area [m^2]

$gC_{O,j}$ = Gas concentration of component j in the lumen [mol/m^3].

$gC_{S,j}$ = Gas concentration of component j at the membrane outer surface [mol/m^3].

δ = Fiber wall thickness [m]

Gas-liquid mass transfer at the outside surface of fiber wall

The gas-liquid mass transfer processes are very similar to those used in BioWin's general gas-liquid mass transfer model (for further reading, please refer to the Gas-Liquid Mass Transfer Model section of the BioWin manual).

For the liquid (biofilm) in direct contact with the membrane, the gas transfer term is based on the membrane area surface rather than dispersed phase area so the mass of material transferred becomes:

$$M_{j\,T} = \Phi_j \cdot k_{L,j} \cdot a_{Membrane} \cdot \left(C^*_{\infty,j} - C_{UN,j}\right) \qquad (3)$$

where

$M_{j\,T}$ = Mass of component j (total of all ionization states) transferred to the liquid phase [g/d]

Φ_j = Mass transfer factor for component j [Dimensionless]

$k_{L,j}$ = Liquid phase mass transfer coefficient for component j [m/d]

$a_{Membrane}$ = Membrane surface area [m^2]

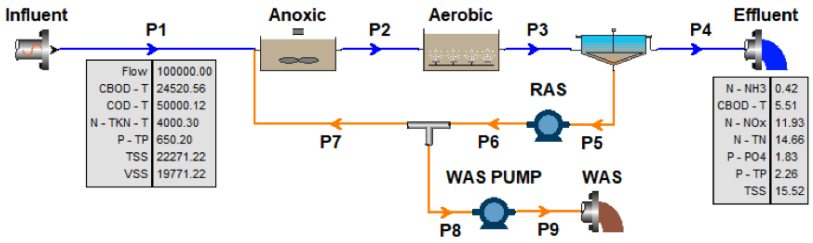
$C^*_{\infty,j}$ = Saturated concentration of component j at the gas/liquid interface (based on the gas partial pressure of component j at the surface of the membrane wall in contact with the biofilm) [mg/L]

$C_{UN,j}$ = Bulk liquid concentration of unionized component j [mg/L]

Excel Reporting Updates

Based on user feedback, a new type of table has been added to the Excel report templates that ship with BioWin. This table shows the origin and termination of all pipes in a layout. The picture below shows an example of this table in an Excel report which is found on a tab named “Connections” in the templates that ship with BioWin:

Pipe-Element Connections Table

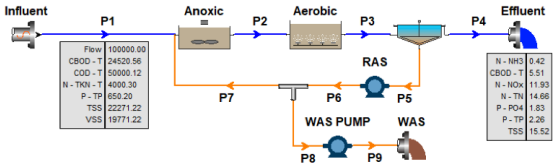


Pipe Name	Pipe Origin Location	Pipe Termination Location
P1	Influent.Output	Anoxic.Input
P2	Anoxic.Output	Aerobic.Input
P3	Aerobic.Output	Sec Settler.Input
P4	Sec Settler.Output	Effluent.Input
P5	Sec Settler.Underflow	RAS.Input
P6	RAS.Output	WAS Split.Input
P7	WAS Split.Output	Anoxic.Input
P8	WAS Split.Output (Side)	WAS PUMP.Input
P9	WAS PUMP.Output	WAS.Input

As a reminder, the Excel reporting feature that was introduced in BioWin 6.0 has a number of other powerful features, including:

- Automatic rapid generation and export of data, charts, *etc.* to Excel
- Ideal for generating Mass Balance tables to use in PFDs

- Preconfigured templates are customizable
- Reports can incorporate calculations (*e.g.* MLVSS/MLSS, COD/BOD) not output by BioWin through use of Excel formulas
- Option for including both steady state and dynamic simulation databases
- Reports can include BioWin charts – these are converted to Excel charts with surfaced data



PARAMETER	UNITS	P1	P2	P3	P4	P5	P6	P7	P8	P9
FLOW	m3/d	100,000.0	196,570.0	196,570.0	96,570.0	100,000.0	100,000.0	96,570.0	3,430.0	3,430.0
COD	mg/L	500	2,719	2,603	45	5,074	5,074	5,074	5,074	5,074
	kg/d	50,000	534,400	511,678	4,316	507,362	507,362	489,960	17,403	17,403
BOD	mg/L	245	731	655	6	1,281	1,281	1,281	1,281	1,281
	kg/d	24,521	143,682	128,674	532	128,142	128,142	123,747	4,395	4,395
TSS	mg/L	223	2,334	2,287	16	4,481	4,481	4,481	4,481	4,481
	kg/d	22,271	458,834	449,613	1,498	448,114	448,114	432,744	15,370	15,370
VSS	mg/L	198	1,842	1,778	12	3,483	3,483	3,483	3,483	3,483
	kg/d	19,771	362,040	349,511	1,165	348,346	348,346	336,398	11,948	11,948
TKN	mg/L	40	149	134	3	262	262	262	262	262
	kg/d	4,000	29,247	26,422	264	26,159	26,159	25,262	897	897
NH_4-N	mg/L	26	15	0	0	0	0	0	0	0
	kg/d	2,640	3,035	82	40	42	42	40	1	1
NO_x-N	mg/L	0	0	12	12	12	12	12	12	12
	kg/d	0	4	2,345	1,152	1,193	1,193	1,152	41	41
TP	mg/L	7	65	65	2	126	126	126	126	126
	kg/d	650	12,803	12,803	219	12,585	12,585	12,153	432	432
PO_4-P	mg/L	3.25	6.24	1.83	1.83	1.83	1.83	1.83	1.83	1.83
	kg/d	325	1,226	360	177	183	183	177	6	6

BioWin Tankage Summary

Volume Units: m3

Reactors	Name	Volume
	Aerobic	70,000.0
	Anoxic	25,000.0
	Group Total	**95,000.0**

Secondary Clarifiers	Name	Volume
	Sec Settler	16,000.0
	Group Total	**16,000.0**

Total Volume for All Units 111,000.0