

The Biowin Advantage

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Simulating the Trickling Filter

EnviroSim Associates | McMaster Innovation Park | 114A-175 Longwood Road S
Hamilton, ON | L8P-0A1 | Canada | P: +1 (905) 481-2607 | F: +1 (905) 481-2610
web : www.envirosim.com | email : info@envirosim.com

Introduction

Introducing the Trickling Filter

A Trickling Filter (TF) process flowsheet element was added in BioWin 4.0. This document will describe the features of the TF element and demonstrate its application in a whole-plant simulation. The example file used in this issue was set up in BioWin 5.0.

Download BioWin File : [Simulating the Trickling Filter](#)

The TF unit can be configured for various default media packing types (e.g. rock or plastic media), or the user can customize packing characteristics. The flowsheet

image for the trickling filter changes depending on the type of media selected. An example model flowsheet for a two-stage trickling filter plant would look like the configuration shown in Figure 1. In this flowsheet two trickling filters with *Structured plastic (crossflow)* media are used.

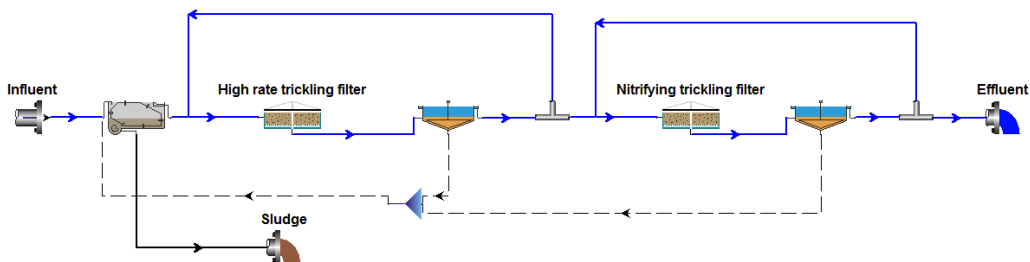


Figure 1 – Two-stage trickling filter plant flowsheet

Media and gas transfer specification

On the *Dimensions* tab the user can specify the type of trickling filter media to be used. The trickling filter elements in BioWin are assumed to be 100% full of media. The following media choices are available (Figure2): Rock, Horizontal, Structured plastic (crossflow), Loose media (random), and Custom. Toggling between the first four options of this list changes the specific area and specific volume (i.e. the volume of liquid displaced per unit volume of media) fields to commonly accepted values for those parameters. For custom media, the specific area and specific volume can be adjusted.

The total thickness of the liquid layer covering the biofilm can be specified for any type of media. This is used to calculate the hydraulic residence time of the trickling filter. Making this parameter larger will increase the hydraulic residence time, and making it smaller will decrease the hydraulic residence time.

The area available for **Gas transfer** to the liquid phase perhaps is the most important parameter in modeling trickling filter performance because it has a direct impact on the amount of oxygen available to the biofilm. Two factors impact the area

available for gas transfer for any type of media. Before discussing the factors, we define the terms used:

- *Media Surface Area = Media specific area * Empty filter volume*
- *Hydraulic Loading Rate = Filter input flow rate / Filter cross-sectional area*

[**Note:** The terms **Hydraulic Loading Rate** and **Wetting Rate** are used interchangeably. Also, input flow rate includes all flow to the filter (including recycles).]

In BioWin the area for gas transfer is calculated as:

- *Gas Transfer Area = Effective Area Fraction * Media Surface Area * Hydraulic Loading Factor*

For any media type, not all of the media surface area is available for gas transfer. For example, pieces of media rest against each other, blocking off part of the surface and reducing the area available for gas transfer, and the area for gas transfer is less than the media surface area. The **Effective Area Fraction** specifies the fraction of the media area available for gas transfer area (liquid/gas interface) under optimal hydraulic loading conditions. We can think of this as the fraction of media surface over which the liquid film flows when liquid is optimally distributed over the filter cross-sectional area. The **Effective Area Fraction** may be quite different for different media types, and probably also is somewhat different for freshly installed media compared with media that has been operational for some extended time. Adjusting the value of the **Effective Area Fraction** provides a means for coarse calibration of filter performance.

Hydraulic loading also may impact the area available for gas transfer. If the hydraulic loading rate is too low then not all of the media will be “wet” so the gas transfer area will be reduced. On the other hand, if the hydraulic loading rate gets too high then it is possible that the air spaces between the media become filled with liquid, which also will reduce the available gas transfer area. The **Hydraulic Loading Factor**

attempts to account for these less-than-optimal conditions. The **Hydraulic Loading Factor** is determined by a two-sided continuous switching function; an example is shown below:

Editing Tricking filte

Dimensions | Operation | Power | Model | Monitor items

Specify by

- Area and depth
- Volume and depth

Volume: 2.000E+4 m³

Area: 4444.4444 m²

Depth: 4.500 m

Name: Tricking filte

Element type: Tricking filter

Media

Type

- Rock
- Horizontal
- Structured plastic (crossflow)
- Loose media (random)
- Custom

Specific area: 46 m²/m³

Specific volume: 0.06 m³/m³

Liquid thickness: 1.25 mm

Gas transfer

Effective area fraction: 0.50 $0 < EF < 1$

Low hydraulic loading rate switch: 23.50 m/d

High hydraulic loading rate switch: 117.50 m/d

Press F1 for help

OK Cancel

Figure 2 – Tricking Filter Dimensions

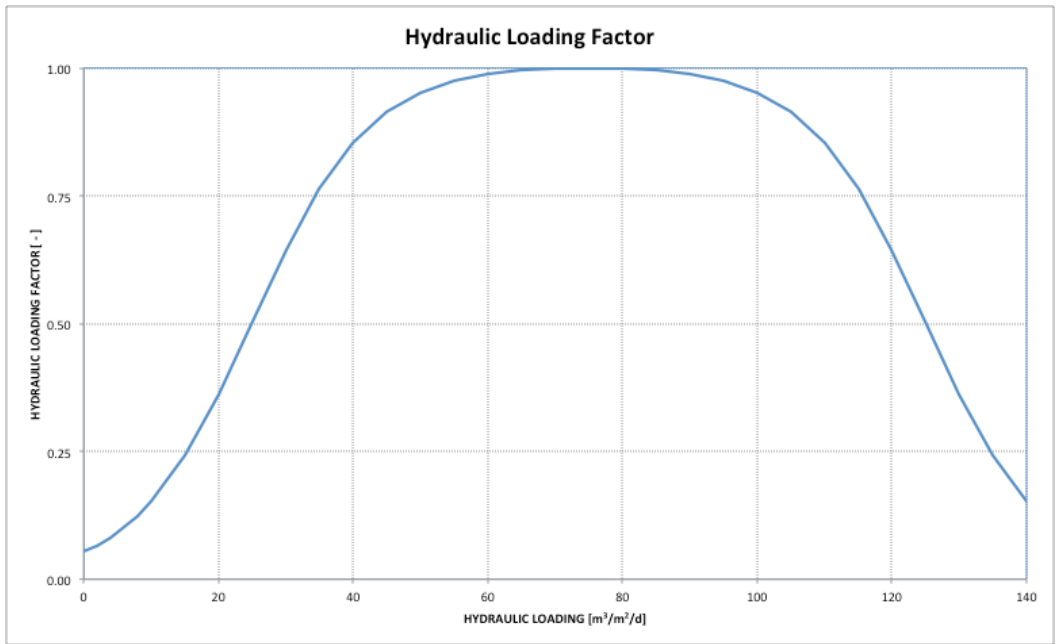


Figure 3 – Hydraulic loading factor as a function of hydraulic loading

Oxygen transfer is the most important factor in determining trickling filter behavior. In addition to the gas transfer area mentioned above, the user also has considerable flexibility to manipulate aeration through specifying DO concentrations or air flow rates, and selecting whether to model gas phase composition on the *Operation* tab. DO concentrations in the liquid phase can be specified as uniform for each section, or BioWin can model the profile through the filter.

Key model concepts

There are three key model concepts associated with modeling trickling filters:

1. **Sectional element** : The depth of the trickling filter is divided into three sections or “slices” of equal height with liquid distributed evenly over the top surface. The sections are used for modeling aspects such as oxygen transfer from the top of the trickling filter to the bottom if the gas phase modeling feature of BioWin used. For example, when dissolved oxygen

concentration is specified for the trickling filter and the gas phase modeling is on, the specified dissolved oxygen concentration value is applied to the top section of the trickling filter. BioWin models the gas-liquid mass transfer in all three sections and the dissolved oxygen concentration is calculated for the middle and bottom sections. The sections are also used to simulate removal gradients down the depth of the trickling filter.

2. **Fixed film model** : The fixed biofilm model used in BioWin (applied to both media bioreactor and trickling filter elements) belongs to the class of 1D models as described by Wanner and Reichert (1996) and Reichert and Wanner (1997). Fundamental equations are listed in the two references. The difference between the models in the references and in BioWin is that in the two papers a biological model including six processes was used for biological reactions but in BioWin the biological model (ASDM) includes over 80 biological processes and gas transfer processes. For the trickling filter, the parameters related to the fixed film model can be changed under the *Model* tab. The user can specify the number of layers to use for modeling the biofilm attached to the media and the liquid boundary layer thickness.
3. **Biofilm thickness** : Biofilm thickness will vary with a variety of parameters related to the growth of different biomass populations. Important model parameters include the attachment and detachment rates and the EPS parameters that describe how “sticky” the specific component is to be attached. Maximum biofilm concentrations that define the capacity of the biofilm for a specific component also affect the biofilm thickness. The mentioned parameters can be changed under **Project > Parameters > Biofilm...**

An Example of TF Simulation

The BioWin configuration (Figure 4) below is set up for a trickling filter/ solids contact (TF/SC) pilot-plant process (Parker *et al.*, 1998). The averages of the flow, temperature, and BOD loads are calculated and used as the constant influent inputs in BioWin. The averages of the TF effluent parameters such as BOD and ammonia,

average MLSS of the contact tank, and the average final effluent parameters are calculated for comparison with the simulation results (Table 1).

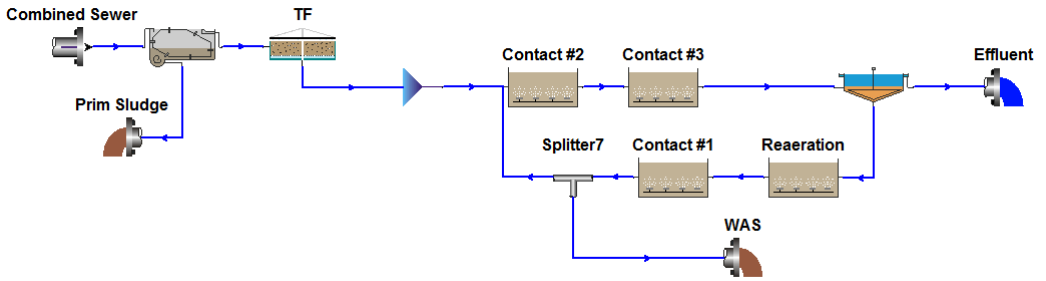


Figure 4 – BioWin set-up for the trickling filter/ solid contact pilot-plant

Table 1 – Average measured data

Location	Parameter	Annual Average	Unit
Trickling filter	Flow	259	m ³ /d
	Temperature	16.6	°C
	BOD load	0.5	kg/m ³ /d
Contact tank	MLSS	2,441	mg/L
Primary effluent	BOD	51	mg/L
	TKN	15.3	mgN/L
TF effluent	sBOD	5.3	mg/L
	NH ₄	2.8	mgN/L
Pilot Plant effluent	TSS	9.8	mg/L
	BOD	6.3	mg/L
	TKN	4.1	mg/L
	NH ₄	1.7	mgN/L
	NO _x	8.2	mgN/L

The removal rate of the primary settler is set as 78% to match the primary effluent parameters (and hence the BOD load on the TF) shown in Table 1. A steady state solution is found with BioWin default parameters.

The following calibration steps were taken to improve the agreement between steady state model predictions and the average measured data:

1. **Maximum concentrations of microorganisms and particulate COD components in the biofilm (Project > Parameters > Bioflm...):** These parameters were increased to allow more particulate material (including biomass) to attach to the biofilm without the biofilm becoming too thick.
2. **Boundary layer thickness (Model tab of the TF element):** This value is changed from default 100nm to 54nm. This parameter impacts the degree of DO penetration into the biofilm. A reduced liquid boundary layer allows for more DO to penetration which allows / aids nitrification in the film. The value selected was based on matching the observed TF effluent ammonia level.
3. **Ammonia oxidizing bacteria maximum specific growth rate (Project > Parameters > Kinetic... > AOB):** This parameter is changed from default 0.9/d to 0.75/d to better simulate the degree of nitrification in the solids contact tank and hence the effluent ammonia concentration.
4. **OHO Substrate half-saturation (Project > Parameters > Kinetic... > OHO):** The half-saturation coefficient for OHO growth on readily biodegradable COD was increased to 20mg/L to increase the predicted final effluent BOD.
5. **Wasted sludge through splitter:** The paper reported an SRT between 3 and 4 days. The waste activated sludge (WAS) flow was adjusted to balance agreement with this range and also maintain a good match between predicted and observed solids contact MLSS. A WAS flow resulting in a predicted SRT of ~3.6 days gave a good match to observed solids contact MLSS.

The following figures show a comparison between the steady state simulation results and measured data. Figure 5 shows the simulated ammonia gradient down the depth of the TF. Figure 6 shows the predicted and observed ammonia concentration in the TF effluent.

Ammonia Profile Through Trickling Filter

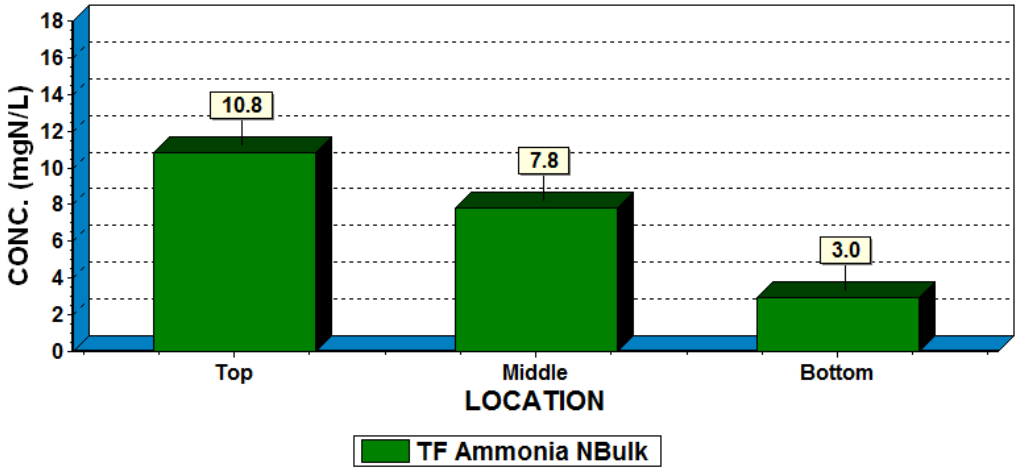


Figure 5 – Simulated bulk liquid ammonia gradient through the trickling filter depth.

Predicted vs. Observed Trickling Filter Effluent Ammonia

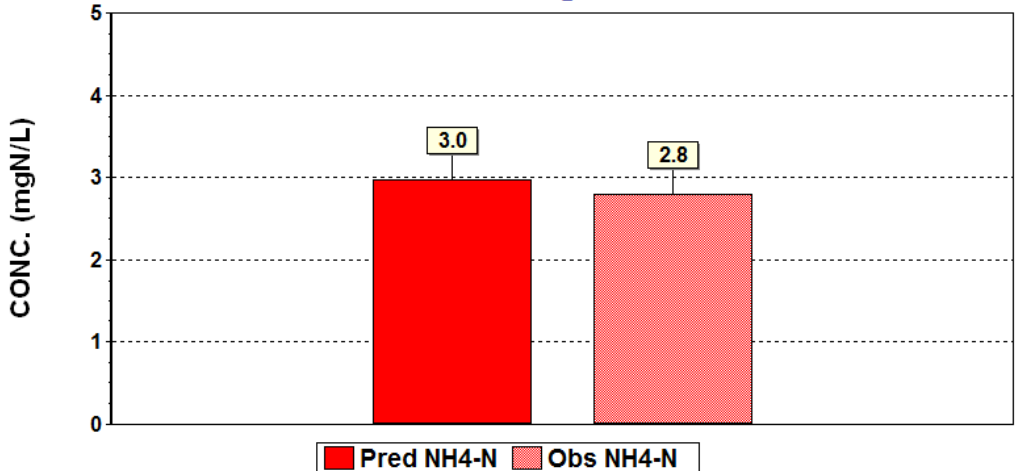


Figure 6 – Predicted and observed TF effluent ammonia.

Figure 7 shows the good match between predicted and observed solids contact tank MLSS at the ~3.6 day simulated SRT.

Predicted vs. Observed Solids Contact MLSS

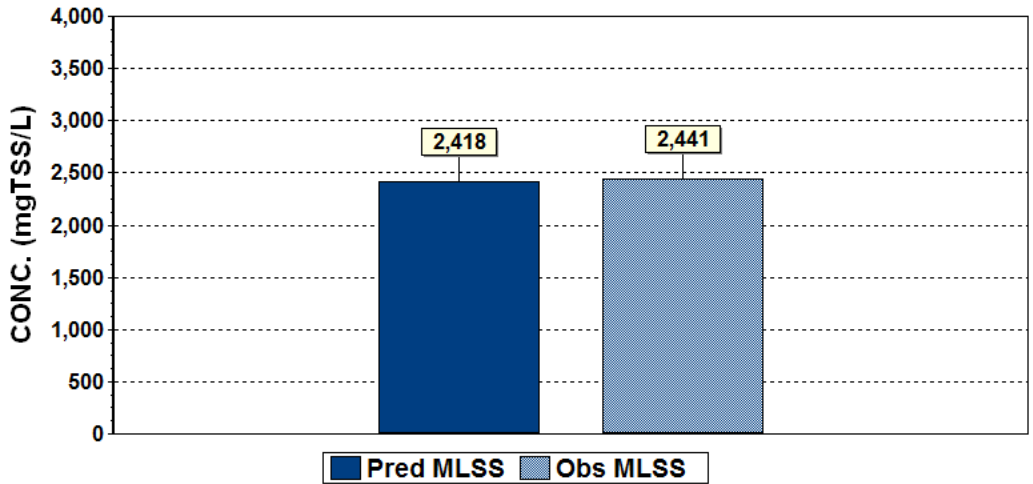


Figure 7 – Predicted and observed solids contact MLSS.

Figures 8, 9, and 10 show generally good agreement between predicted and observed effluent parameters.

Predicted vs. Observed Effluent cBOD

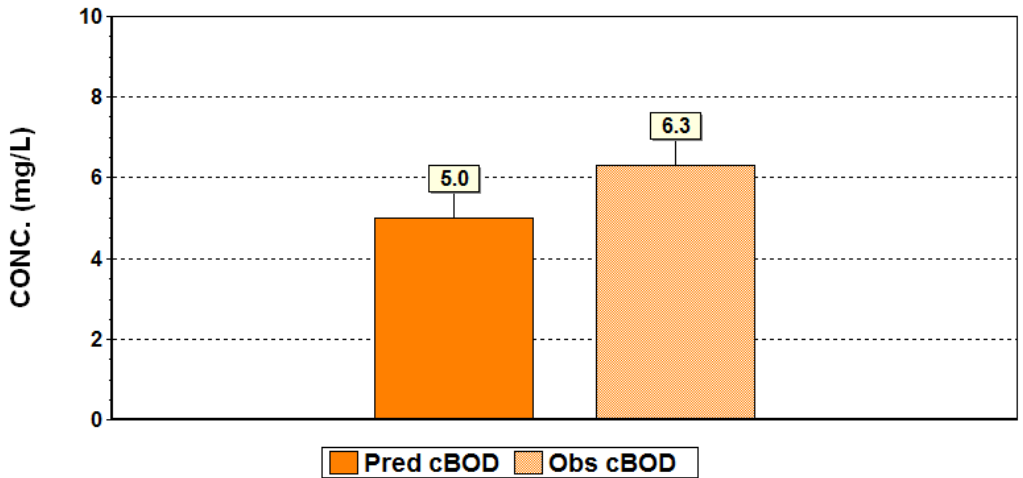


Figure 8 – Predicted and observed pilot plant effluent cBOD.

Predicted vs. Observed Effluent TSS

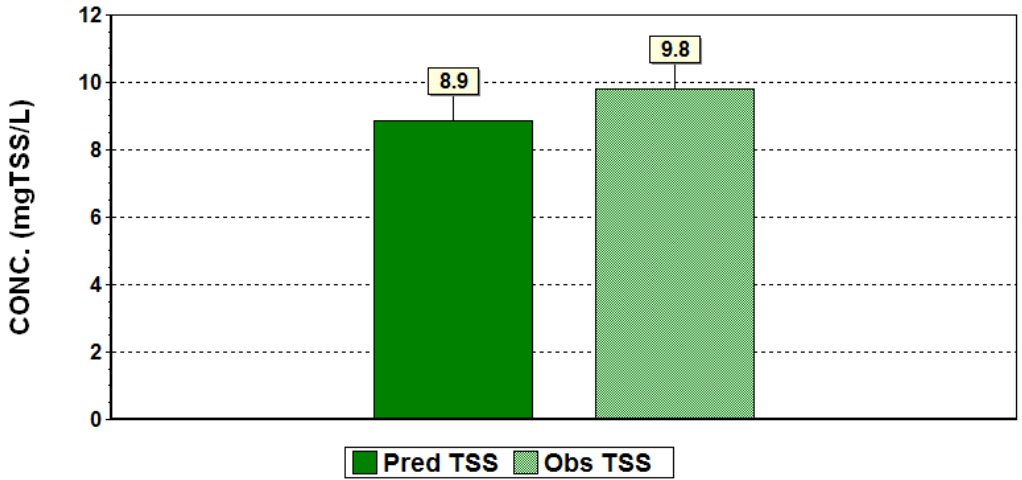


Figure 9 – Predicted and observed pilot plant effluent TSS.

Predicted vs. Observed Effluent Ammonia

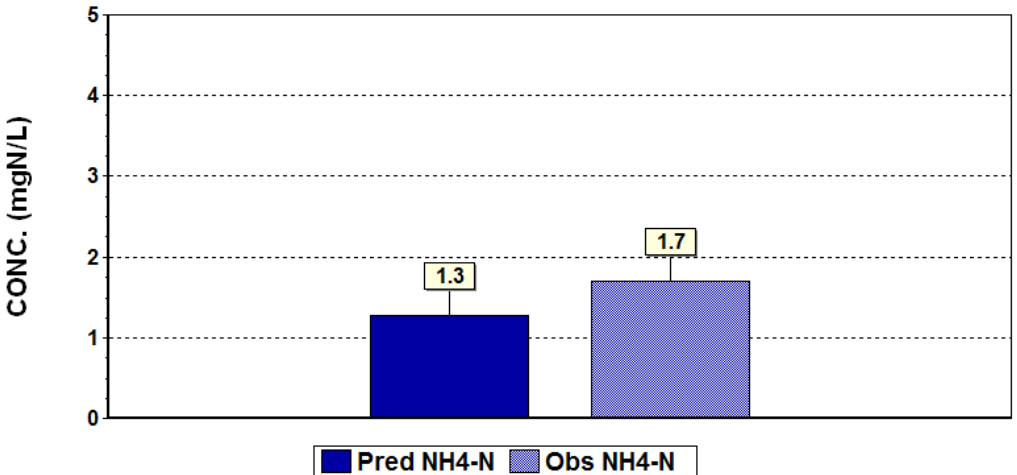


Figure 10 – Predicted and observed pilot plant effluent ammonia.

Summary

In this document, we introduced BioWin's trickling filter element and described its key parameters and concepts. The trickling filter element was used in a TF/SC configuration to simulate pilot plant performance (Parker *et al.*, 1998). This exercise

demonstrated the adjustment of various model and trickling filter element parameters to improve the match between the model results and the observed data.

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

Reference:

D. S. Parker, L. S. Romano, and H. S. Horneck (1998). **Making a trickling filter/solids contact process work for cold weather nitrification and phosphorus removal.** *Water Environment Research*, 70(2), 181-188.

P. Reichert and O. Wanner (1997). **Movement of solids in biofilms: significance of liquid phase transport.** *Water Science & Technology*, 36(1), 321-328.

O. Wanner and P. Reichert (1996). **Mathematical modeling of mixed-culture biofilms.** *Biotechnology and Bioengineering*, 49, 172-184.