2.4 The Industrial Wastewater Treatment Design Case

This design case analyzes an industrial wastewater treatment plant and demonstrates how to track the fate of multiple chemical components (constituents) in an integrated facility. The design case file, **IWWT5_0**

, can be found in the **Examples\Indwater** subdirectory. This example is suitable for users with interest in biological wastewater treatment. Other pertinent examples that are provided with SuperPro Designer include the following:

Subdirectory	**Description**
MUNWATER	This example focuses on the modeling and retrofit design of a municipal wastewater treatment plant. It addresses issues of nutrient removal and is recommended for users with interests in industrial and municipal wastewater treatment.
UPWATER	This example deals with water purification (ultra-pure water production) and wastewater treatment at a Semiconductor Manufacturing Facility. Evaluation of recycling options for minimizing city water use and wastewater disposal is included.
GE	This example analyzes an effort to minimize generation of hazardous sludge and wastewater at a manufacturing facility of General Electric. It is recommended for users with interests in waste minimization, water recycling, and pollution control.

Each of these examples has a detailed ReadMe file associated with it. The ReadMe files can be found in the corresponding example subdirectories

2.4.1 Chemical Components

Figure 2.4a displays a flowsheet that represents a simplified version of an industrial activated sludge treatment plant. The flowrate and composition of the influent stream is shown below:

Component	**kg/h**	**g/l**
Water	156,600.00	995.99
Glucose	783.00	4.98
Benzene	100.00	0.63
Biomass	15.66	0.10
Heavy Metals	1.00	0.0064

This corresponds to a relatively small plant with an average throughput of 1 million gallons per day (MGD). Glucose represents the easily biodegradable components while benzene represents the recalcitrant (not easily biodegradable) and volatile components.

Please visit the component registration dialog (select **Tasks \ Register Components & Mixtures \ Pure Components**), to view the physical and environmental properties of the various components. Some of the environmental properties of Glucose are shown below.

Property	Value	Units
COD	1.066	g O2/g
ThOD	1.066	g O2/g
BODu / COD	0.732	g/g
BOD5 / BODu	0.900	g/g
TOC	0.400	g C/g
TP	0.000	g P/g
TKN	0.000	g N/g
NH3-N	0.000	g N/g
NO3-N	0.000	g N/g

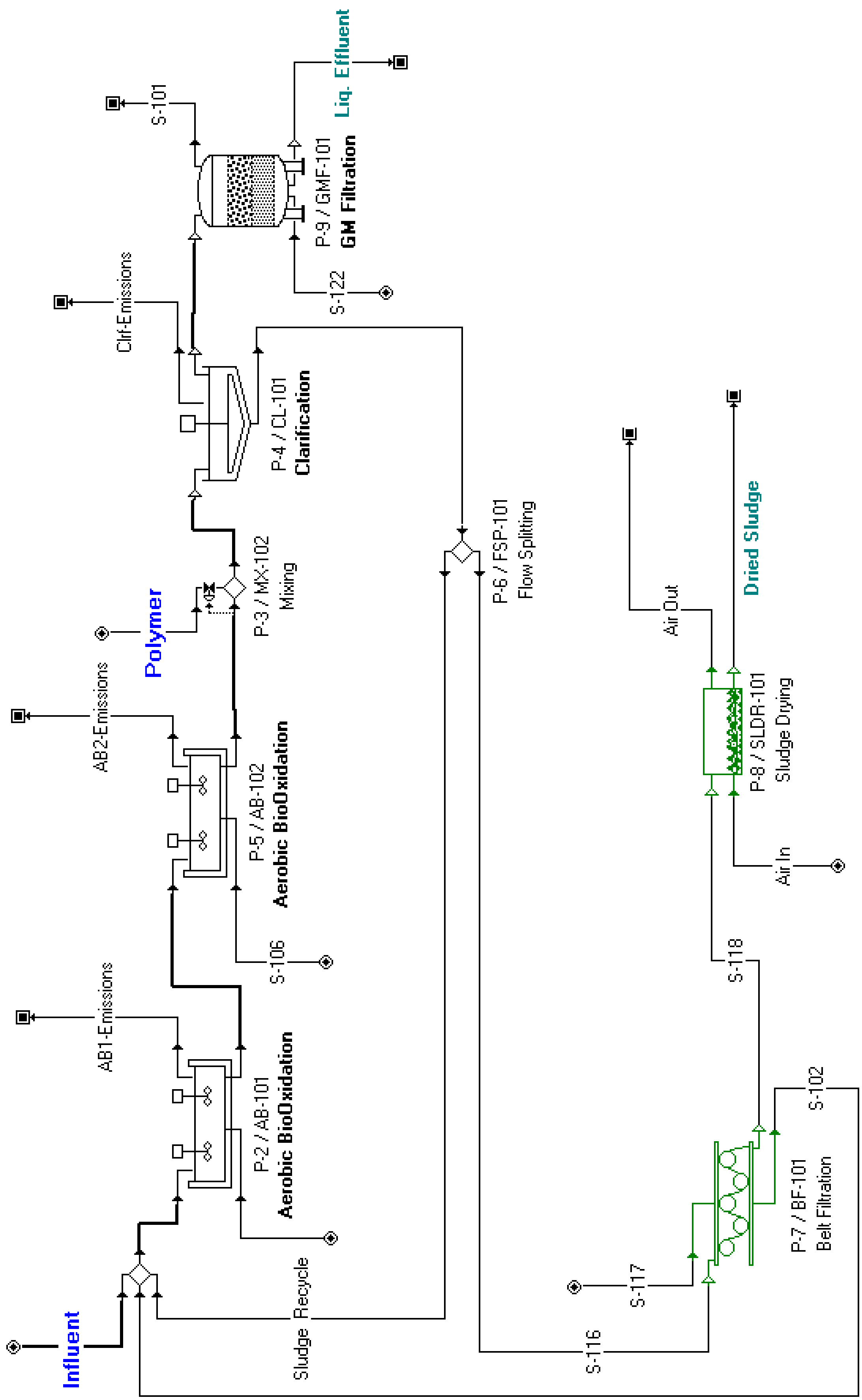
Please note that the above values are displayed when you select the Glucose component by clicking on its line number (# 5) on the left hand side of the 'Registered Components' table and then click on the **Properties** button. Values for such properties are available in the component database for many components. Whenever you enter a new component, you should visit its Properties dialog box to enter appropriate values for the important properties. Note that these values, along with the stream compositions, are used to calculate the lumped environmental stream properties (BOD, COD, TKN, TSS, etc.). More information on component and environmental stream properties can be found in Chapters 3 and 4.

2.4.2 Process Description

The influent stream is combined with the sludge return stream (Sludge Recycle) and is sent to a sequence of two aeration basins (AB-101 and AB-102) for biological oxidation of the organic material. Each aeration basin operates at an average hydraulic residence time of 6 hours and an average sludge residence time of 17.2 hours. A surface aeration system is used to maintain a minimum dissolved oxygen (DO) concentration of 2 mg/l. A clarifier (CL-101) is used to remove the biomass and thicken it to around 10 g/L solids content. The liquid effluent from the clarifier is further treated using a granular media filter (GMF-101) to remove any remaining particulate components. The withdrawn sludge (S-116) is concentrated to a 15% (wt/wt) solids content using a belt filter press (BF-101). The removed water (S-102), which contains small amounts of biomass and dissolved solids, is sent back to the aeration basin. The concentrated sludge stream is dewatered to a final solids concentration of 35% (wt/wt) using a sludge dryer (SLD-101).

At this point, please visit the interface dialogs of the various operations to check the specified parameter values. The bioconversion reaction parameters are explained in detail later in this section.

Fig. 2.4a: Industrial Wastewater Treatment Plant



Flowsheet Sections

A flowsheet section is a group of unit procedures that have something in common. For instance, the flowsheet of this example has been divided into two sections: 1) BioOxidation and 2) Sludge Treatment. All the procedures of the Sludge Treatment section are displayed in green. For information on how to specify flowsheet sections and edit their properties, please see Chapter 15 (Menus & Palettes).

Stoichiometry and Kinetics of Biotransformations

You may view the stoichiometry and kinetics of the various reactions by visiting the reaction dialog window of the aeration basin (see Figure 2.4b). As can be seen, the model offers great flexibility in specifying the kinetics of a bioreaction. A bioreaction operation (e.g., aerobic bio-oxidation) can handle any number of such reactions. Make sure you look at the MUNWATER example if you wish to distinguish between autotrophic and heterotrophic biomass and its impact on oxidation and nitrification / denitrification reactions.

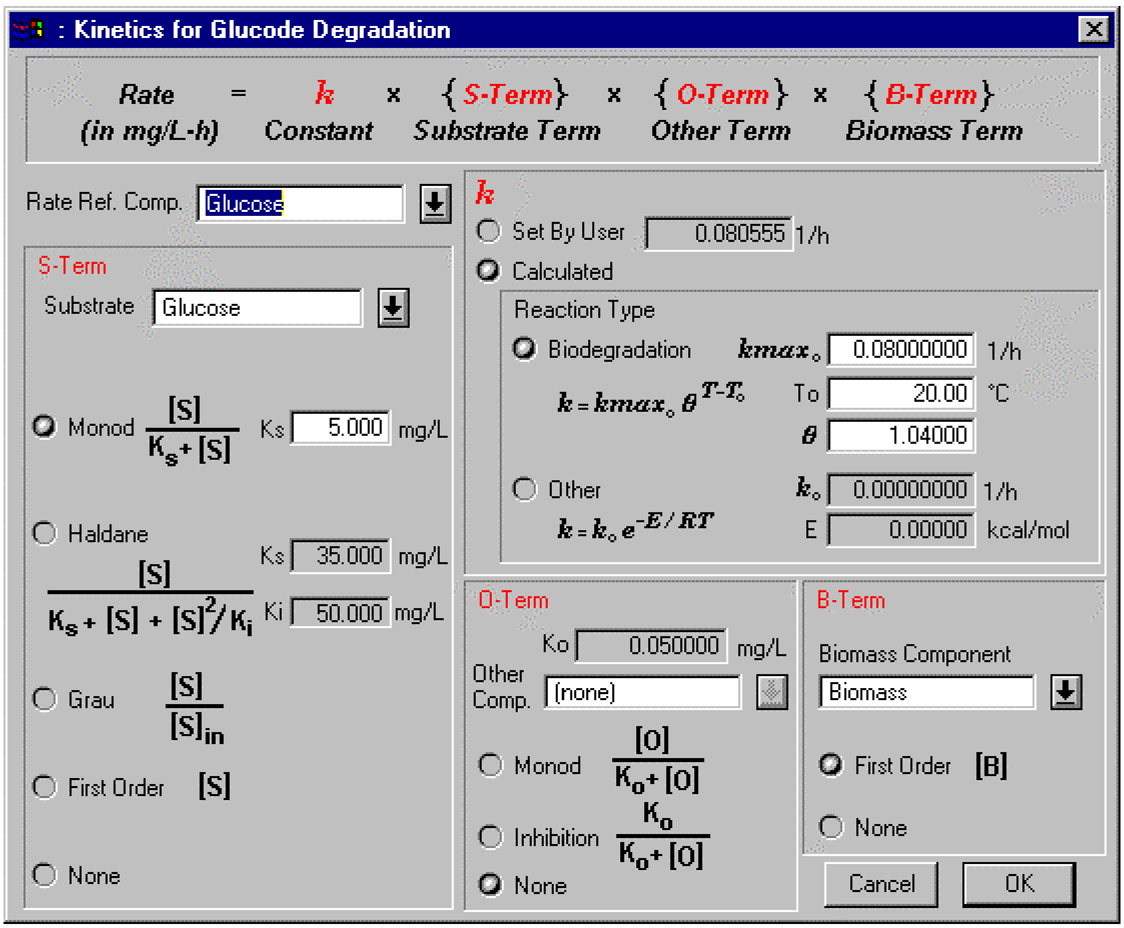


Figure 2.4b: The Kinetics dialog of the Reactions tab of Aerobic BioOxidation.

The stoichiometry and kinetics of the bioconversion reactions of this example are described below. Negative coefficients are used for reactants and positive coefficients for products.

a. Glucose degradation - stoichiometry on a mass basis

Glucose	===>	Biomass	+	H_2O	+	CO_2
-1 g		0.4 g		0.3 g		0.3 g

For those of you who are used to thinking in terms of yield coefficients, the above stoichiometry is equivalent to the following yield coefficient.

Y = 0.4 mg Biomass / mg Glucose

Note that in SuperPro the user never specifies yield coefficients since that information can be extracted from the reaction stoichiometry.

$kmax_o$ = 0.08 1/h at T = 20 deg C

theta = 1.04 (to account for the impact of temperature variations).

Ks = 5 mg Glucose/ L

Note that we express the kinetic constants in terms of Glucose concentration and not BOD5 because BOD5 is not a component in SuperPro but a stream property. We treat BOD5 as a stream property and not as a component because many different components (e.g., Glucose, Benzene, etc.) may contribute to BOD5.

b. Benzene degradation - stoichiometry is on a mass basis

Benzene	===>	Biomass	+	H_2O	+	CO_2
-1 g		0.3 g		0.4g		0.3 g

$kmax_o$ = 0.019 1/h at T = 20 deg C

theta = 1.04 (to account for the impact of temperature variations).

Ks = 13.571 mg Benzene / L

c. Biomass decay

Biomass	===>	DeadBiomass
-1 g		1 g

k = 0.005 1/h

Note that in SuperPro biomass decay is handled through a separate reaction. In other words, you do not specify a decay coefficient but instead you specify a decay reaction with its own kinetic constants. This is a richer representation compared to the traditional way because it enables the user to distinguish between active and inert biomass.

In the above reactions we ignored the consumption of oxygen and nitrogen for the sake of simplicity. If you wish to consider it, simply modify the stochiometry of the reactions and make sure that those components are available in the feed streams of the reactors.

VOC Emissions

Volatile organic compounds (VOC's) in influent streams tend to volatilize from open tanks and end up in the atmosphere. Current US EPA regulations limit VOC emissions from treatment plants to no more than 25 tons per year (Van Durme, Capping Air Emissions from Wastewater, *Pollution Engineering*, pp. 66-71, Sept. 1993). SuperPro Designer can be used to predict VOC emissions using models that are accepted by the EPA. A detailed description of the models is available in Chapter 10 (Emissions).

In this example, emissions occur from the two aeration basins and the clarifier. Please double-click on the emission streams to see the amount of benzene that is emitted. Around 17.4% of the total incoming benzene is emitted from the first aeration basin. A much smaller amount (around 0.04% of the total incoming) is emitted from the second aeration basin and essentially none is emitted from the clarifier.

Sorption on Biomass (Sludge)

In activated sludge plants, certain compounds (e.g., heavy metals) adsorb on biomass and follow its path. In the current version of SuperPro, you can account for that by specifying the sorption (%) for each component that adsorbs on biomass through the "Sorption" tab (see Figure 2.4c) of the biological reaction operations. A sorption model based on the log(Octanol/Water) partition will become available in a future release of the software.

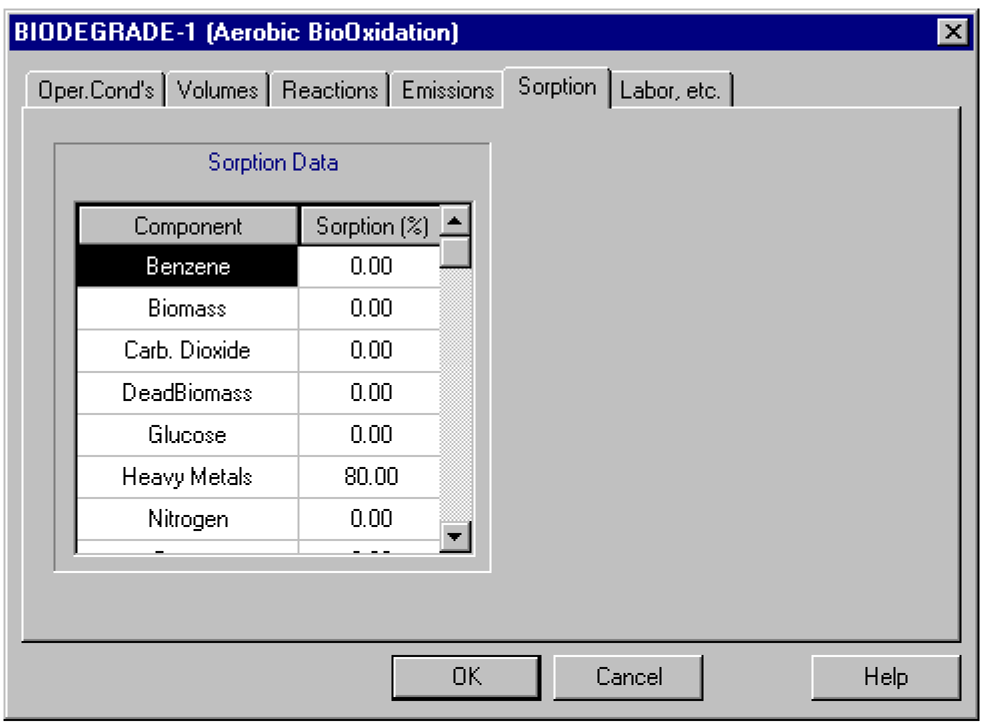
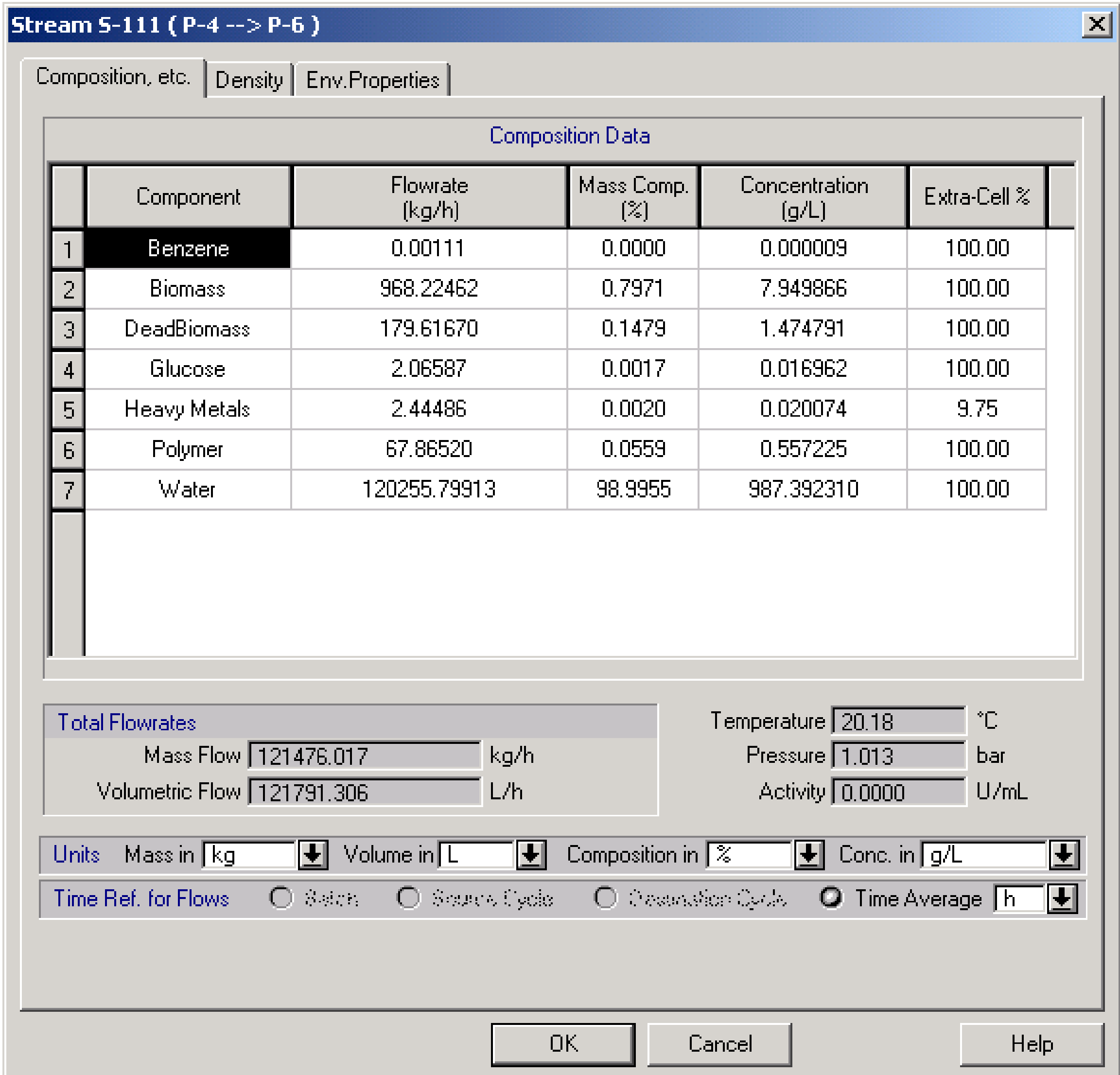


Figure 2.4c: The Sorption tab of Aerobic BioOxidation.

For the sorption specifications to have an impact, you also need to identify the Primary Biomass component through the component registration dialog (select **Tasks \ Register Components and Mixtures \ Pure Components**…). If you use more than one biomass component (e.g., heterotrophic, autotrophic, etc. as in the MUNWATER example), you should identify the heterotrophic bacteria (the most abundant) as your primary biomass.



	Component	Flowrate (kg/h)	Mass Comp. (%)	Concentration (g/L)	Extra-Cell %
1	Benzene	0.00111	0.0000	0.000009	100.00
2	Biomass	968.22462	0.7971	7.949866	100.00
3	DeadBiomass	179.61670	0.1479	1.474791	100.00
4	Glucose	2.06587	0.0017	0.016962	100.00
5	Heavy Metals	2.44486	0.0020	0.020074	9.75
6	Polymer	67.86520	0.0559	0.557225	100.00
7	Water	120255.79913	98.9955	987.392310	100.00

Figure 2.4d: Dialog of an intermediate stream.

In a stream, the percentage of a component that is not associated with primary biomass is displayed on the stream dialog (see Figure 2.4d) with the “Extra-Cell %” variable. In the above case, 9.75% of the total amount of Heavy Metals is extracellular (in solution) and consequently 90.25% is associated with primary biomass. This information is utilized in the material balances of separation operations. For instance, if the removal percentage of the primary biomass in a clarifier is 98%, then 98% of a sorbed component will follow the primary biomass component. Please visit the “Liquid Effluent” and “Dried Sludge” streams to see how the Heavy Metals are distributed between the two output streams.

2.4.3 Process Analysis

At this point, you may want to change the values of certain operating parameters and redo the calculations (be selecting **Tasks \ Solve M&E Balances**). The calculated flowrates and compositions of intermediate and output streams can be viewed by revisiting the input/output dialog windows of each stream (double click on a stream line or click with the right mouse button and select **Simulation Data…)**.

Clicking on the "Env. Properties" tab of a stream dialog will bring up the window shown in Figure 2.4e. This dialog window displays the compositions and flowrates of the traditional environmental stream properties (e.g., BOD, COD, TOC, TSS, etc.). The values of these properties are calculated based on the chemical composition of the stream and the contributions of the various stream components to these properties (see section 2.4.1 as well as Chapter 3).

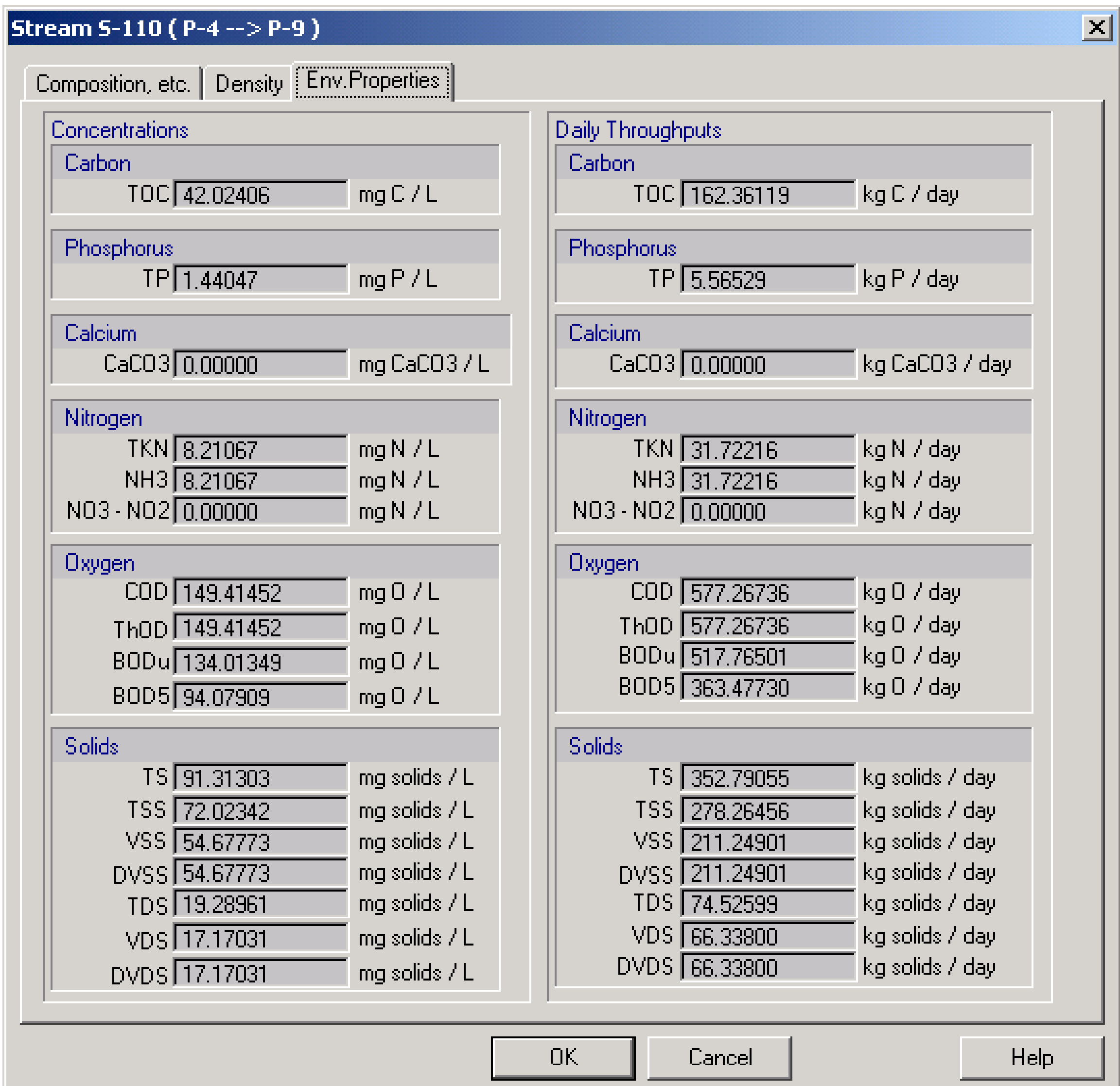


Figure 2.4e: Environmental and Aqueous Stream Properties

Note: Information about water hardness expressed in CaCO3 is used in water purification processes for sizing Ion Exchange columns and characterizing the purity of water.

To view the flowrates and compositions of every stream on the flowsheet, you can generate the Stream Report by selecting **Tasks \ Generate Stream Report** and then view it by selecting **View \ Stream Report**.

You may also want to have a look at the environmental impact assessment report (EIR), which contains information on the amount and type of waste that is generated by a manufacturing or waste treatment facility. The EIR also displays the compositions and flowrates of the traditional environmental stream properties (e.g., BOD, COD, TOC, TSS, etc.) for all the input and output streams of a process.

2.4.4 Economic Evaluation

Before looking at the cost analysis and economic evaluation reports, it is useful to visit the Input/Output Stream Classification dialog window by selecting **Tasks \ Revenue, Raw Material and Waste Streams...** Please note that the "Influent" stream has been classified as a Revenue stream with a unit processing cost of $0.008/kg (or $80/m^3). In other words, we assume that this plant will charge $80/m^3 to the waste generators that use this facility to treat their wastewater. Please also note the unit cost of treatment/disposal that has been assigned to the various output streams.

The table below provides a breakdown of the annual operating cost. The equipment-dependent cost is the most important item even when depreciation is ignored. Depreciation can be ignored for very old plants or for plants that were built with public funding. The equipment-dependent cost includes Depreciation, Maintenance, Insurance, Local Taxes, and Factory Expense (see Chapter 8 of the manual for more detailed information). To estimate the labor cost, it was assumed that a total of 5 operators (3 in the BioOxidation section and 2 in the Sludge Treatment section) are required to run the plant on a 24-hour basis. The unit labor cost was assumed to be $18/hour. Depending on plant location, this cost may require adjustment. The sludge disposal cost was assumed to be $50/ton. Again this may vary considerably depending on plant location.

	Including Depreciation		**Excluding Depreciation**	
Cost Item	**$/Year**	**%**	**$/Year**	**%**
Raw Materials	294,000	3.74	294,000	6.07
Labor-Dependent	414,000	5.28	414,000	8.56
Equipment-Dependent	6,005,000	76.55	2,998,000	61.96
Laboratory/QC/QA	62,000	0.79	62,000	1.28
Waste Trt/Disp	1,065,000	13.57	1,065,000	22.01
Utilities	5,000	0.07	5,000	0.11
Total	**7,845,000**	**100.000**	**4,838,000**	**100.00**

To eliminate the cost of depreciation, the value of "Portion of Purchase Cost Already Depreciated" for all the equipment items was set to 100%. The above variable is displayed on the **Adjustments** tab of the **Equipment Data** dialog of each unit procedure (right click on a procedure icon and select Equipment Data...). The material for the above table was extracted from the itemized cost report (ICR) of the base case and the case that excluded depreciation.

If we had to build a plant of this size, the capital investment would be around $33.4 million. Other relevant economic results for this case appear below.

Including Depreciation:

TOTAL CAPITAL INVESTMENT	33,406,000	$
OPERATING COST	7,845,000	$/year
PROCESSING RATE	1,247,389,387	kg/year of Influent
UNIT PROCESSING COST	6.289	$/MT of Influent
TOTAL REVENUES	9,979,000	$/year
GROSS MARGIN	21.38	%
RETURN ON INVESTMENT	12.84	%
PAYBACK TIME	7.79	years

Excluding Depreciation:

TOTAL CAPITAL INVESTMENT	33,406,000	$
OPERATING COST	4,838,000	$/year
PROCESSING RATE	1,247,389,387	kg/year of Influent
UNIT PROCESSING COST	3.878	$/MT of Influent
TOTAL REVENUES	9,979,000	$/year
GROSS MARGIN	51.52	%
RETURN ON INVESTMENT	9.23	%
PAYBACK TIME	10.83	years

The detailed results of the economic evaluation can be produced by selecting **Tasks \ Generate Economic Evaluation Report**. To view the report, you will need to select **View \ Economic Evaluation Report**. Note that several multipliers are used to estimate the capital investment of a treatment plant and perform its cost analysis and economic evaluation. Please read the first example of this chapter for more information on how to access and modify those multipliers. Many of the current default multipliers in SuperPro are more appropriate for chemical manufacturing plants than for wastewater treatment plants. Future versions of SuperPro will be provided with setting files that will include application specific multipliers. Presently, you may do something equivalent by creating a template file using your own validated multipliers. The **IWWT4_7** file used for this example is a good starting point.

2.4.5 Modeling Challenges

This example can be used as a good starting point for modeling your own wastewater treatment plants. You may add more components and/or unit procedures to this flowsheet in order to better approximate your own processes. For instance, you may add O_2, NH_3, and PO_4, and introduce appropriate reactions for tracking the consumption and generation of those compounds. The example on municipal wastewater treatment (directory MUNWATER) provides information on modeling of nitrogen removal.

Warning! As you increase the number of components, reactions, process steps, and recycle loops, SuperPro will take longer to converge. Consequently, you are strongly advised to increase the complexity of your flowsheets in small steps so that you can be in a position to readily identify the changes that really slow down the convergence. For instance, reactions with very different reaction rates specified in a single unit procedure slow down the calculations considerably and may even cause convergence to fail. In such situations, it may be better to simplify your model by ignoring a slow reaction, at least at the early stages of analysis. Similarly, if you have a very fast reaction, you may want to model it using a generic reaction box (in which you specify the stoichiometry and the extent of conversion) and assume 100% conversion.

A New Way of Thinking. The use of SuperPro, like most other software tools, requires a new way of thinking. This is particularly important for those of you who have little or no previous experience in process simulation. Remember that with simulation we only attempt to approximate the behavior of the real world. It is impossible to completely represent the behavior of a treatment plant on the computer. Consequently, your objective should be to limit the analysis to those variables that are of interest to you from a design (if the objective is to design a new plant or retrofit an existing one) or operations (if the goal is to improve the performance of an existing plant) point of view.

Commonly Asked Questions. Almost all new users that attempt to model biological wastewater treatment processes using SuperPro ask the following question:

"Very often we design and operate wastewater treatment processes based on overall stream properties such as BOD, COD, TKN, SS, etc. We have no information on individual chemicals (constituents) in influent and effluent streams. Since SuperPro performs material balances on constituents, how can we use it to design processes based on traditional stream properties such as BOD, COD, etc.?"

Answers to this and other questions can be found in the Q&A file (a hypertext type of file) that is provided with the software. For this particular question, click on Components and look at the first Q&A. The municipal wastewater treatment example (directory MUNWATER) provides additional information related to the above question.

If you have difficulty using SuperPro to its full potential, please do not hesitate to contact our tech-support office. Our staff will be happy to assist you and provide you with guidance. Also, it may be a good idea to attend one of our training courses or arrange for a training course at your company's site.

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