

Development of Numerical Model for In-Sewer Treatment

H. Tubail*, D. Elliott**, and V. Kutija**

* State Ministry for Environmental Affairs - Palestine

** University of New Castle Upon Tyne - UK

Abstract

A sewer is a reactor where biological, chemical and physical processes take place. A significant reduction in pollutants' load could be achieved whilst sewage is conveyed in large sewer interceptors. An understanding of the processes involved is important for the application of in-sewer treatment. In this paper a development of a conceptual modeling and numerical solution for in-sewer treatment will be presented. The solution of the advection diffusion equation is carried out employing various formulations of modified implicit TCSD (Third Order Convection Second Order Diffusion) scheme. The paper will show that the fully-time-centered TCSD implicit scheme is efficient to simulate the in-sewer treatment processes where the advection is predominant. On the other hand, to investigate the effectiveness of applying in-sewer treatment, the model was run considering a typical sewage treated in a hypothetical sewer. Desirable predictions were obtained. A 37 to 56 per cent reduction in carbonaceous substrate was predicted with a seeding concentration of 100 to 500 mg biomass COD/l respectively. Before the model can be applied as an analytical tool for in-sewer treatment, it is necessary to carry out a comprehensive validation exercise.

Key words:

In-sewer treatment, Modeling, Convection, Diffusion, Mass Transport Equation

1. INTRODUCTION

Sewer has been predominantly used for the carriage of wastewater. Interest is claimed that, biochemical processes has mainly been limited to minimize of H₂S formation and structural damage. The construction of long large diameter interceptors in many cities provides potential for large plug flow treatment units. Hence, there is a need for comprehensive scientific studies to understand the micro-biological interaction through the flow bulk movement to the downstream treatment plant. The in-sewer model under development is an extension of a river quality model. It is one dimensional model which simulates the organic degradation processes in sewage.

2. CONCEPTUAL MODELLING OF IN-SEWER TREATMENT

A fundamental and conceptual description of the microbial system in sewers in terms of organic matter transformations was presented by (Kan [10], 1997, and Hvitved-Jacson et al. [7], 1998). A conceptual model including main aerobic transformation was described. The simulation of the processes was based on IAWQ Activated Sludge Model No.1 and taking into account the biofilm reactions in the slime layer and surface reaeration of the sewage during the flow.

2.1 Material species in the model

The in-sewer model considers a total of 12 species (Kan, [10], 1997).

(a) Soluble inert organic matter (S_I)

This is the soluble fraction of organic matter present in the sewage which is inert to biological attack. It does not take part in any conversion processes, but is included as it is part of the COD.

(b) Particulate inert organic matter (X_I)

This is the particulate fraction of the organic matters present which is inert to biological attack. Similar to S_I , it does not take part in any reactions, but is included as it is part of the COD.

(c) Readily biodegradable substrate (S_S)

This is assumed to be wholly soluble and the only substrate for the growth of heterotrophic biomass. It is formed from the hydrolysis of slowly biodegradable substrate (X_S).

(d) Slowly biodegradable substrate (X_S)

Slowly biodegradable substrate (X_S) is assumed to be wholly insoluble and is removed from the suspension instantaneously by entrapment in bioflocs. It is then acted upon by heterotrophic biomass to convert it into readily biodegradable substrate (S_S).

(e) Ammonia nitrogen (S_{NH})

This is the sum of the ionized (ammonium) and unionized (ammonia) forms of nitrogen. It is formed by ammonification of soluble biodegradable organic nitrogen (S_{ND}), and taken up during biomass growth and nitrification.

(f) Nitrate and nitrite (S_{NO})

This is the sum of the nitrate and nitrite nitrogen species. It is formed from ammonia nitrogen (S_{NH}) during the growth of autotrophic biomass, and removed in the anoxic growth of heterotrophs.

(g) Soluble biodegradable organic nitrogen (S_{ND})

This is formed by hydrolysis of particulate organic nitrogen (X_{ND}) and converted to ammonia nitrogen (S_{NH}) by ammonification.

(h) Oxygen (S_O)

This is the dissolved oxygen in the solution. It is taken up during biomass growth.

(i) Particulate organic nitrogen (X_{ND})

This is generated from the decay of biomass and removed in ammonification.

(j) Active heterotrophic biomass (X_{BH})

Heterotrophic biomass is formed by growth and lost through decay. It should be noted that X_{BH} should include only the active portion of the biomass, since not all the biomass present in an activated sludge is active (Weddle and Jenkins, 1971).

(k) Active autotrophic biomass (X_{BA})

This is analogous to the heterotrophs.

(l) Particulate products arising from biomass decay (X_P)

This is formed in the decay of biomass and is the fraction of materials which, in the time scale of activated sludge modeling, can be considered as inert to biological attack.

2.2 In-sewer treatment processes

The model considered three categories of process, reactions in suspension, reactions in biofilms, and reaeration. A summary of these processes is presented below.

2.2.1 Reactions in suspension

The model simulates the processes that significantly affect the results of aerobic bio-degradation; these processes are described in the ASM1, for the reactions in the bulk solution (Henze et al., 1986).

(a) Aerobic growth of heterotrophic biomass (X_{BH})

The kinetics of aerobic growth of heterotrophic biomass is assumed to be subject to double nutrient limitation, with the concentrations of both readily biodegradable substrates (S_s) and DO (S_o) being rate determining. This is the major process for carbonaceous material oxidation under aerobic conditions.

$$R_j = \hat{\mu}_H \left(\frac{S_s}{K_s + S_s} \right) \left(\frac{S_o}{K_{oH} + S_o} \right) X_{BH} \quad (2.1)$$

where,

R_j : process rate

$\hat{\mu}_H$: maximum specific growth rate for heterotrophic biomass

S_s : readily biodegradable substrate

So: the dissolved oxygen in solution

K_S : half-saturation coefficient for heterotrophic biomass

K_{OH} : saturation coefficient for oxygen for autotrophic biomass

X_{BH} : Active heterotrophic biomass

(b) Decay of heterotrophs (X_{BH})

Decay is the process used in ASM1 to describe the observed reduction in the rate of growth of biomass as retention time is increased. Though it is taken as a single process, it actually consists of a number of mechanisms including predation, lysis, and the need for maintenance energy.

$$R_j = b_H X_{BH} \quad (2.2)$$

where,

R_j : process rate

b_H : decay coefficient for heterotrophic biomass

X_{BH} : Active heterotrophic biomass

2.2.2 Reactions in biofilm

Biofilms occur on the internal surface of sewer wall and sediments. The biofilm reactions are considered to lead to the following:

(a) Degradation of readily biodegradable substrate (S_S)

This process is described as a half-order reaction with respect to dissolved oxygen concentration, combined with a temperature dependent dissolved oxygen diffusion and removal rate (Garsdal et al., 1995). The process results in the removal of readily biodegradable substrate S_S and oxygen S_O . The biomass formed in the biofilm is not included in the model.

$$\text{rate of } S_S \text{ removal} = \theta^{\text{temp}-20} \sqrt{2DK_{of}} S_o^{1/2} A / V \quad (2.3)$$

where,

θ : temperature coefficient,

D : diffusion coefficient of oxygen in water at 20°C,

k_{of} : removal of oxygen in biofilm at 20°C,

A : area of biofilm,

V : volume of sewage.

(b) Oxygen uptake

The rate of oxygen uptake in the biofilm process is in proportion to the rate of substrate degraded, through the stoichiometric coefficients of

$$1 : (1 - Y_H)$$

where Y_H is the yield coefficient of heterotrophic biomass.

(c) Ammonia nitrogen uptake

Analogous to oxygen, the rate of ammonia nitrogen uptake is proportional to the rate of substrate degradation through the stoichiometric coefficients of

$$1 : (Y_H \cdot i_{XB})$$

where i_{XB} is the mass of nitrogen per mass of COD in the biomass.

2.2.3 Reaeration

Surface reaeration of the sewage was described by the following equation (USEPA, 1974) in the model:

$$R_f = 0.96 \left[1 + \frac{0.17 u^2}{g \cdot d_m} \right] \gamma \cdot (su)^{3/8} \cdot (S_{OS} - S_o) / d_m \quad (2.4)$$

where,

R_f : reaeration rate (mg/l.hr),

u : flow velocity (m/s),

d_m : mean hydraulic depth defined as cross-sectional area divided by surface width (m),

γ : temperature function, equal to 1.07 at 20°C,

s : slope of the energy line of the flow,

S_{OS} : saturation concentration of dissolved oxygen at the particular sewage temperature.

3. MODEL DEVELOPMENT METHODOLOGY

The general form of the mass transport equation used to simulate the situation for one dimensional unsteady flow for the in-sewer model can be written in the form (James, [8], 1993):

$$\frac{\partial A h}{\partial t} + \frac{\partial u A h}{\partial x} - \frac{\partial}{\partial x} \left(E A \frac{\partial h}{\partial x} \right) + L a = 0 \quad (3.1)$$

where,

h : concentration of the material,

x : distance in the longitudinal direction,

u : velocity of flow,

A : cross-sectional area of the segment,

E : longitudinal dispersion coefficient,

La : a term for other sources and sinks.

The flow and water quality parameters in the equation are averaged over the cross section, such that variation in the material concentration is assumed to occur in the longitudinal direction only. The cross-sectional area, flow velocity u and dispersion coefficient E are functions of time and distance. E is related to the hydraulic data as follow:

$$E = 22.6 n u y^{5/6} \quad (3.2)$$

where,

n : Manning's roughness coefficient of the stream,

u : flow velocity,

y : flow depth

Plug flow is the predominant mechanism for the sewer flow. The plug flow system is used to simulate equation (3.1). Hence, the major assumptions involved in the model are that the bulk of water, flows downstream with no longitudinal mixing (as a plug) and that instantaneous mixing occurs in the lateral and vertical directions only (Schnoor, [16] 1996).

3.1.1 Formulation of TCSD implicit scheme

As a result of the numerical unstable properties of the explicit schemes, the implicit formulations of TCSD is used to avoid unstable solutions, whilst ensuring that a stable convective sensitivity will be maintained. As demonstrated by Chen and Falconer [3] (1994), different forms of TCSD implicit schemes are more accurate and has wide range of stability than Quick implicit schemes. Hence, various forms of the TCSD scheme are applied to solve the mass transport equation. The general form for various formulations of TCSD scheme as presented by Chen and Falconer (1994) can be written as:

$$\begin{aligned} & h_j^{n+1} + \frac{\varphi 1}{2} \left[C_{r jr}^{n+1} (h_{j+1}^{n+1} + h_j^{n+1}) - C_{r jl}^{n+1} (h_j^{n+1} + h_{j-1}^{n+1}) \right] - \frac{\varphi 2}{6} \left(C_{r jr}^{n+1} \nabla^2 h_j^{n+1} - C_{r jl}^{n+1} \nabla^2 h_{j-1}^{n+1} \right) \\ & - \varphi 1 \left[\gamma_{jr}^{n+1} (h_{j+1}^{n+1} - h_j^{n+1}) - \gamma_{jl}^{n+1} (h_j^{n+1} - h_{j-1}^{n+1}) \right] \\ & = h_j^n - \frac{\varphi 3}{2} \left[C_{r jr}^n (h_{j+1}^n + h_j^n) - C_{r jl}^n (h_j^n + h_{j-1}^n) \right] + \frac{\varphi 4}{6} \left(C_{r jr}^n \nabla^2 h_j^n - C_{r jl}^n \nabla^2 h_{j-1}^n \right) \\ & + \varphi 3 \left[\gamma_{jr}^n (h_{j+1}^n - h_j^n) - \gamma_{jl}^n (h_j^n - h_{j-1}^n) \right] + \frac{\varphi 5}{6} \left(C_{r jr}^{n+1} \nabla^2 h_{j-1}^n - C_{r jl}^{n+1} \nabla^2 h_{j-1}^n \right) \quad (3.3) \end{aligned}$$

where different values for φ_i are given in Table 3.1 to represent various modified TCSD schemes.

Table 3.1 - ϕ value for various modified TCSD schemes

Scheme	$\phi 1$	$\phi 2$	$\phi 3$	$\phi 4$	$\phi 5$
(i) Forward explicit TCSD	0.0	0.0	1.0	1.0	0.0
(ii) Fully-time-centered implicit TCSD	0.5	0.5	0.5	0.5	0.0
(iii) Backward implicit TCSD	1.0	1.0	0.0	0.0	0.0
(iv) Semi-time-centered implicit TCSD	0.5	0.0	0.5	0.5	0.5
(v) Semi-backward implicit TCSD	1.0	0.0	0.0	0.0	1.0

in which, $\nabla^2 h_j^n = h_{j+1}^n - 2h_j^n + h_{j-1}^n$

where, $C_{r,jr}^n = u_{jr}^n \Delta t / \Delta x$, and $\gamma_{jr}^n = E_{jr}^n \Delta t / \Delta x^2$ are the Courant and diffusion number respectively at the right face for the grid j at time level n , and with similar expressions for their face values at time level $n + 1$. While j_r and j_l , are the corresponding right and left face values for appropriate variable at grid point j . The solution methods for implicit schemes require special techniques for handling systems of simultaneous equations. In solving various finite difference equations presented in Table 3.1, schemes (iv) and (v) involved three unknowns at upper time level which required the solution of a tri-diagonal system, whereas schemes (ii) and (iii) required the solution of a quadri-diagonal system for steady unidirectional flow, and a penta-diagonal system for unsteady directional flow (Kutija, [11], 1997).

4. AN OVERVIEW OF THE MODEL IMPLEMENTATION

The fundamental equation used by Kan ([10], 1997), to build up the structure of the mathematical model that presents the sum of these processes is (Ding et al. [4], 1989):

$$\frac{\delta h}{\delta t} = \nabla(\nabla E h - u h) + L_a(h, t) \quad (4.1)$$

Where,

- $\delta h / \delta t$: time rate of change in concentration (M/L.T)
- h : concentration (M/L³)
- E : dispersion coefficient (L²/T)
- u : water flow velocity (L/T)
- L_a : net rate of reaction (sink/source term) (M/L³.T)

The in-sewer model employed the standard operator-splitting method to divide Equation (4.1) into two parts.

$$\frac{\delta h}{\delta t} \Big|_{A\&D} = \nabla(\nabla Dh - uh) \quad (4.2)$$

$$\frac{\delta h}{\delta t} \Big|_{La} = (h, t) \quad (4.3)$$

The method then solved these equations separately and then recombines them to form Equation (4.4) below:

$$\Delta h = h_f - h_o = \Delta h_{A\&D} + \Delta h_{La} \quad (4.4)$$

Where,

Δh : change in material concentration over a time step

h_f : concentration at end of time step

h_o : concentration at beginning of time step

$\Delta h_{A\&D}$: change in concentration due to advection and dispersion

Δh_{La} : change in concentration due to reactions

Operator-splitting method solves the non-reactive solute transport term ($\Delta h_{A\&D}$) first. The result is an intermediate solution (h^*) that includes only the effects of advection and dispersion over the time interval Δt . It then uses this intermediate solution as the initial concentration to solve the reaction term (Δh_{La}) for the concentration at the end of the time step. Figure 4.1 illustrates graphically this method.

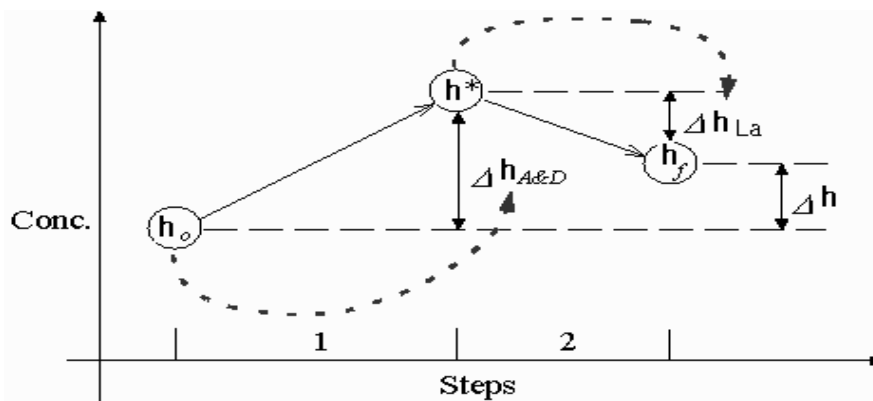


Figure 4.1 - Standard Operator-splitting Procedure

The dashed arrows in Figure 4.1 illustrate dependencies. $\Delta h_{A\&D}$ is a function of the initial concentration (h_o). The reaction term, Δh_{La} , is a function of the intermediate solution (h^*).

4.1 Simulation Kinetic Reactions

The model uses the linear integrated (LI) method to calculate the change in concentration due to kinetic reactions. The LI method assumes that the rate of change in concentration over a time period remains constant, but allows it to change between time intervals. This linearization simplifies the calculation of changes in concentration, especially when reaction rates are dependant upon multiple species. The equation for change in nodal concentration due to kinetic reaction is:

$$\Delta h_k = \sum_i^n A_i \int_0^{\Delta t} R_i \left(\frac{h_f - h^*}{\Delta t} t + h_o \right) dt \quad (4.5)$$

Where,

Δh_k : change in concentration array due to kinetic reactions

C_f : concentration array at beginning of time step

C_o : concentration array at end of time step

A_i : stoichiometric array of the i^{th} reaction

R_i : rate function of the i^{th} reaction

Δt : time step

n : number of kinetic reactions

Equation (4.5) uses vector notation because some reaction rates can be a function of multiple species, and may change more than one species at a time. It is also noted from Equation (4.5) that the change in concentration is function of the time step.

4.2 Numerical values of the model parameters

The following is a summary of the numerical parameter adapted from Kan, [10], (1997).

Table 4.1 - Numerical values of model parameters kinetic parameters

Parameters		Value at 20° C	Unit
μ	maximum specific growth rate for heterotrophic biomass.	6.0	d ⁻¹
μ_A	maximum specific growth rate for autotrophic biomass.	0.8	d ⁻¹
b_H	decay coefficient for heterotrophic biomass	0.57	d ⁻¹
b_A	decay coefficient for autotrophic biomass	0.15	d ⁻¹
k_S	half-saturation coefficient for heterotrophic biomass	20.0	g COD m ⁻³
k_{OH}	half-saturation coefficient for oxygen for heterotrophic biomass	0.20	g O ₂ m ⁻³
k_{OA}	half-saturation coefficient for oxygen for autotrophic biomass	0.50	g O ₂ m ⁻³
k_{NO}	half-saturation coefficient for nitrate	0.50	g NO ₃ . Nm ⁻³
k_{NH}	ammonia half-saturation coefficient for autotrophic biomass	1.0	g NH ₃ . Nm ⁻³
k_X	half-saturation coefficient for hydrolysis of slowly biodegradable substrate	0.03	g X _s COD. (g cell COD) ⁻¹
k_h	maximum specific hydrolysis rate	3.0	g X _s COD.(g cell COD.d) ⁻¹
k_a	ammonification rate	0.08	m ³ .COD.(g.d) ⁻¹
η_g	correction factor for μ_H under anoxic conditions	0.8	-
η_h	correction factor for hydrolysis under anoxic conditions	0.4	-
D	diffusion coefficient of oxygen in water at 20° C	20x10 ⁻¹⁰	m ² /s
k_{of}	removal rate of oxygen in biofilm at 20° C	3.0	g/m ³ .s

Table 4.2 - Numerical values of model parameters stoichiometric parameters

Parameters			
Y_H	yield for heterotrophic biomass	0.63	g cell COD. (gCOD.oxidized) ⁻¹
Y_A	yield for autotrophic biomass	0.24	g cell COD.(g N.oxidized) ⁻¹
f_p	fraction of biomass yielding particulate products (X _p)	0.08	-
i_{XB}	mass of nitrogen per unit mass of COD in biomass	0.086	g N (g COD) ⁻¹ in biomass
i_{XP}	mass of nitrogen per unit mass of COD in particulate products from biomass.	0.06	g N (g COD) ⁻¹ in endogenous mass

5. TEST RUNNING OF THE MODEL

The test runs are conducted under steady flow conditions using the full time-centered implicit TCSD scheme in solving the mass transport for the different species in concern. In addition to that further test runs were carried out to investigate the affects of pipe design parameters in sewer treatment (Tubail, [18], 1998). A summary of these test runs are presented in the following sections.

5.1 Details of Numerical Test Run

The numerical tests were carried out using a hypothetical sewer considering a 30 km sewer length, 1.0 m pipe diameter, 0.005 m/km slope and 0.52 m³/s upstream flow. The conducted test runs simulates a hypothetical sewage. The sewage is assumed to be of domestic origin with a total COD of 600 mg/l with the following composition.

Table 5.1 - Sewage characteristics for model test run

Material species	Concentration	Units	Typical range and references
S _I	30	mg/COD/l	5 -10% of total COD (Henze et al, 1995)
S _S	150	mg/COD/l	12 -30% of total COD (Henze et al, 1995)
X _I	60	mg/COD/l	10 -15% of total COD (Henze et al, 1995)
X _S	335	mg/COD/l	45 -65% of total COD (Henze, 1992)
S _O	5	mg/COD/l	-
S _{NH}	30	mgN/l	-
S _{NO}	0.5	mgN/l	-
S _{ND}	0.6	mgN/l	(Henze, 1992)
X _{ND}	10	mgN/l	(Henze, 1992)
X _{BH}	25	mg/COD/l	10-20% of total organic matter (Kappler and Gujer, 1992)
X _{BA}	0	mg/COD/l	-
X _P	0	mg/COD/l	0, (Henze et al., 1986)

Source: Tubail, [17], (1998)

Test runs were carried out using $\Delta x = 250\text{m}$ distance mesh points space and 100 sec for Δt , consequently the Courant number is maintained less than unity and with a retention time 7 hours, is sufficient to predict the numerical reactions for the different processes. A summary of test runs results is presented in the following sections.

5.2 Test cases

The model is run first considering the activated biomass existed in the hypothetical sewage as listed in Table 5.1. After that, the model is run with seeding active biomass feeding at upstream end point with concentrations of 100, 200, 300, 400, and 500 mg COD/l.

5.2.1 Unseeded sewage

Figure 5.1 shows the biodegradation of carbonaceous materials and biomass along the length of the sewer. The following points are observed from the figure:

- (i) the readily biodegradable substrate S_S is utilized much faster than slowly biodegradable substrates X_S .
- (ii) the biomass utilizes the substrate for growth but the increase in biomass concentration is small owing to the small number of organisms present.
- (iii) the effluent from the sewer has an average substrate removal rate of 135 mg/l (initial concentration = 485 mg/l, 27%), and a TCOD concentration of 481 mg/l. For the retention time removal is 7 hrs.
- (iv) The fully-centered-TCSD implicit scheme suffers from over-shoot and down-shoot; this is clearly shown in Figure 5.1 for the changes in oxygen concentration. However these fluctuations do not grow exponentially and will not affect the results.

5.2.2 Seeded sewage

Figures 5.2 to 5.6 show the variation in total substrate concentration ($S_S + X_S$). The analogy of utilizing substrate is the same as described in Figure 5.1. It is noted that the utilization rate of the substrate occurred faster when seeding biomass concentration is increased. Table 5.2 shows the removal rate of the substrate for different seeding concentrations.

Table 5.2 - Simulation results at the end of pipe using seeding biomass at upstream end

Item (mgCOD/l)	Seed concentration (mg biomass COD/l)					
	Unseeded	100	200	300	400	500
$(S_S + X_S)$ removal	131	187	214	238	262	285
Biomass concentration	38	166	279	386	490	592
TCOD concentration	481	555	641	724	805	885

5.3 Treatment effectiveness

Treatment effectiveness is illustrated by the percentage of substrate removed. As shown in Table 5.3, with the period of retention time available in sewer (7.0 hrs.), the substrate removal rate ranges from 37% to 56% for a seeding concentration up to 500 mg active biomass COD/l. This shows that a reasonable level of treatment is achievable.

5.3.1 Treatment efficiency

Under all seeding concentrations, substrate removal is increased due to additional biomass; however, substrate utilization rate is dependant on the hydraulic retention time (HRT). Thus, it will be useful to consider the specific substrate utilization rate (U) and the process efficiency (EF) which are calculated as follows:

$$U = \frac{S_o - S}{X * HRT} \quad (5.1)$$

$$EF = \frac{S_o - S}{S_o} 100 \quad (5.2)$$

where,

S_o : influent substrate concentration ($S_S + X_S$)_{influent}

S : effluent substrate concentration ($S_S + X_S$)_{effluent}

X : biomass concentration (X_{BH})

HRT: hydraulic retention time

Numerical values of the specific utilization rate (U), and the process efficiency (EF) for seeded biomass case run are tabulated in Table 5.3.

Table 5.3 - Specific substrate utilisation rates

Item	Specific substrate removal rate (mg COD of substrate removed/ mg COD of seed added) at a seed concentration (mg biomass COD/l)				
	100	200	300	400	500
EF	37	43	47	52	56
U	0.26	0.15	0.11	0.09	0.08

Note: HRT = 7 hrs, and influent concentration of substrate = 485 mg COD/l

However, it is common in practice to use a term closely related to the specific utilization rate U, it is known as the food -micro-organism ratio (F/M), which defined as follows:

$$F / M = U \frac{100}{EF} \quad (5.3)$$

Figure 5.8 shows a plot of these parameters for the case of seeded biomass. Although the utilization rate of the substrate increasing when high seeded biomass concentrations are applied, care should be taken in determining the concentration of the seed, as any biomass input becomes part of the suspended solids loading of the sewage, which needs to be taken out subsequently by sedimentation or other methods.

5.4 Numerical stability of the model

A comparison was carried out using various formulations of modified TCSD implicit and QUICKEST scheme. Numerical oscillations would not occur as long as the algorithm is employed within its appropriate numerical stability limits, see Figure 5.8. To investigate the affects of sewer design parameters on the aerobic processes occur in sewer, test runs should be carried out using a full hydrodynamic simulation for the flow types that would occur along the sewer. It is noted that, the developed hydrodynamic components included in the model simulates only the sub-critical flow, therefore output of these tests will not completely reflect the real condition of the sewer flow. However, Figure 5.9 shows a plot of the model simulation using different pipe line slopes under steady state conditions. It could be noted from Figure 5.9 that the rate of utilizing substrate is significantly affected by the changing the slope of the sewers. The changes in utilization rate refer to the important influence of the pipe line slope - under steady flow conditions the slope of the pipe line equal the slope of the energy line of the flow- in the reaeration rate, consequently the availability of oxygen.

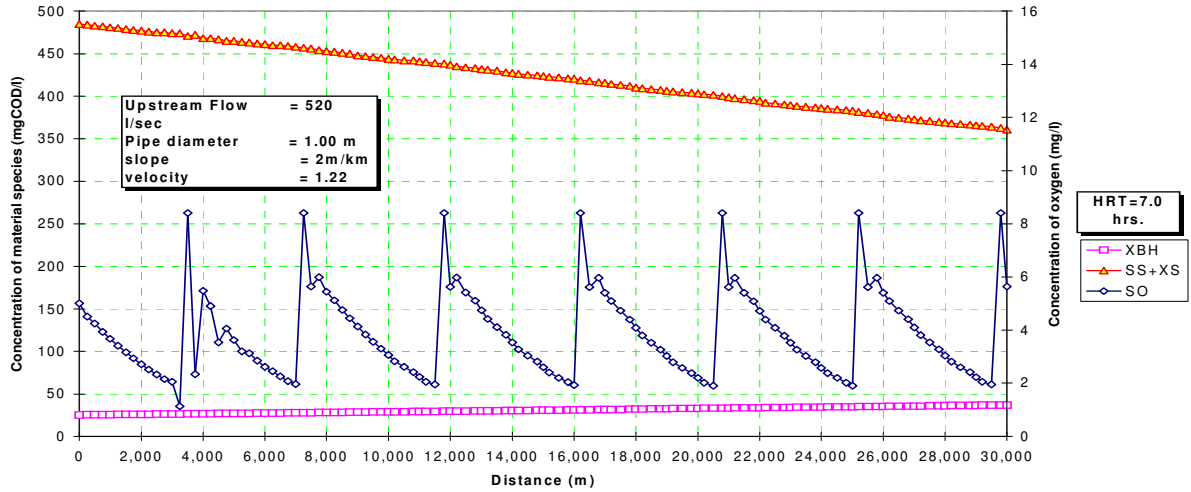


Figure 5.1- Model output for the case without seeding

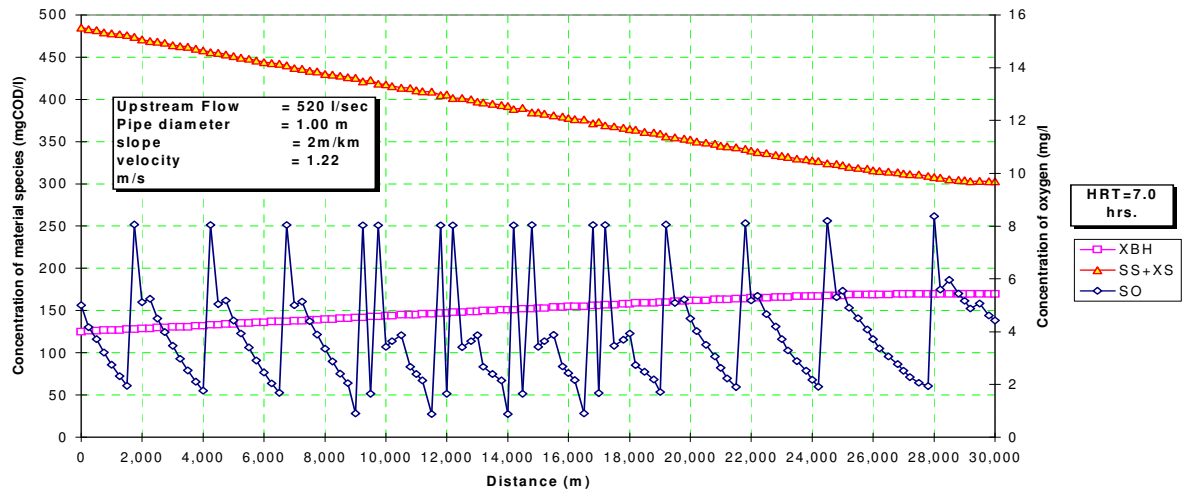


Figure 5.2- Model output for the case with (100 mgCOD/l) biomass seeding

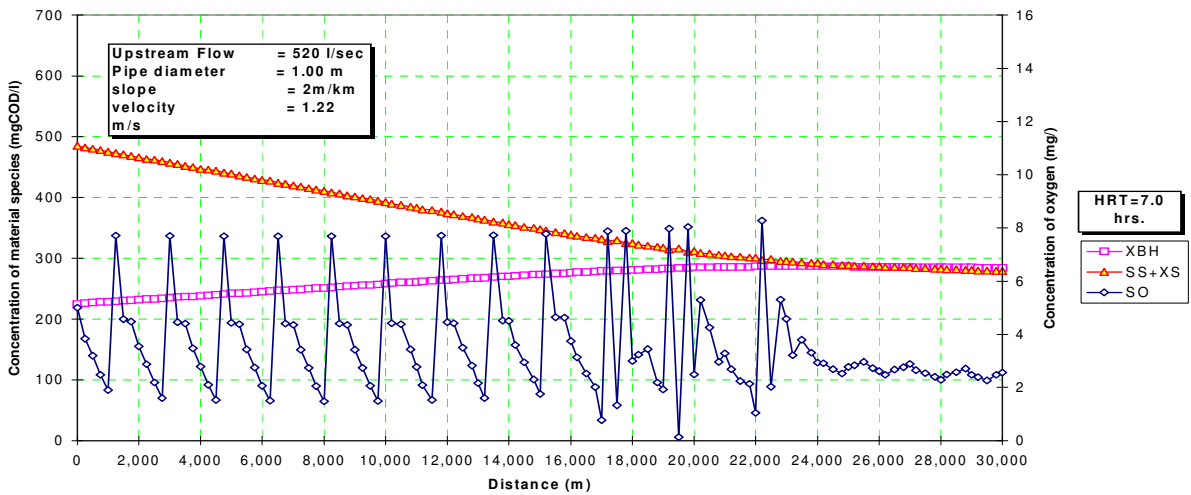


Figure 5.3- Model output for the case with (200 mg COD/l) biomass seeding

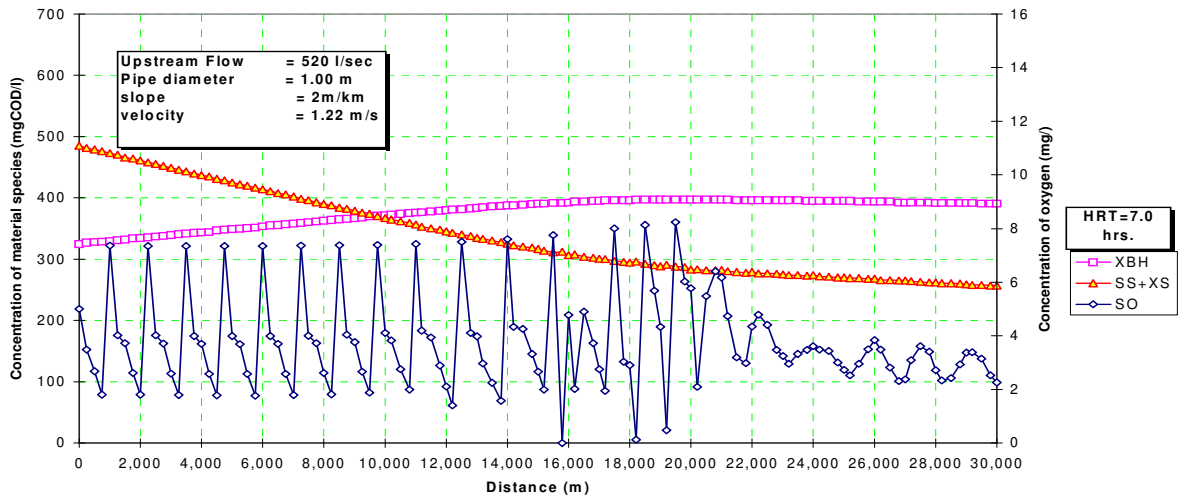


Figure 5.4- Model output for the case with (300 mg COD/l) biomass seeding

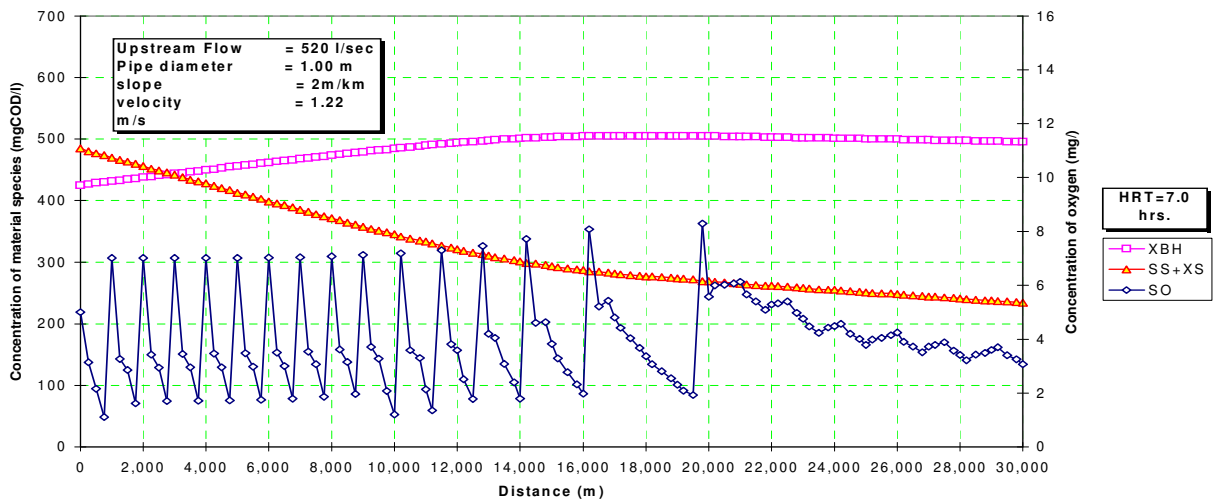


Figure 5.5- Model output for the case with (400 mg COD/l) biomass seeding

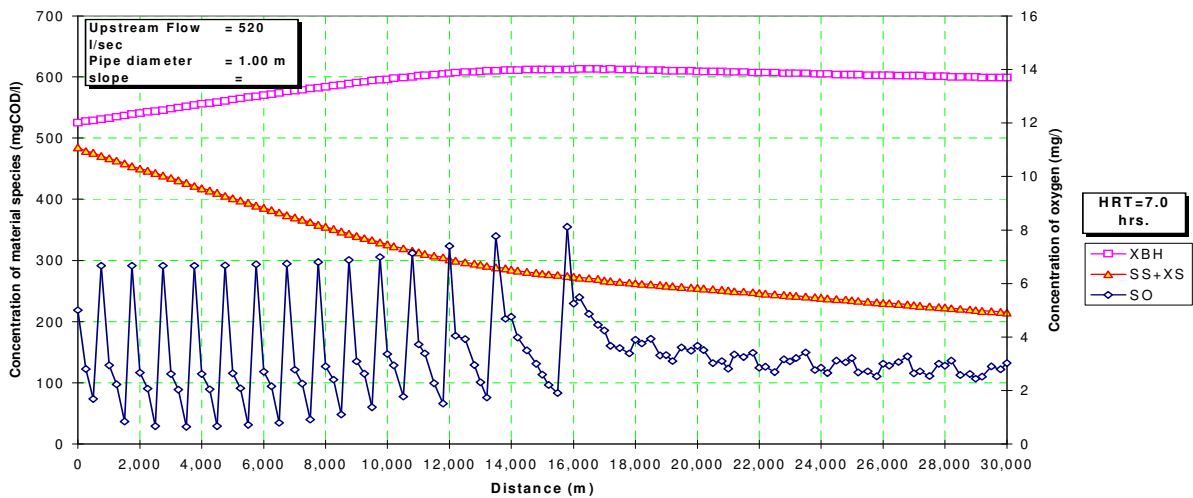


Figure 5.6- Model output for the case with (500 mg COD/l) biomass seeding

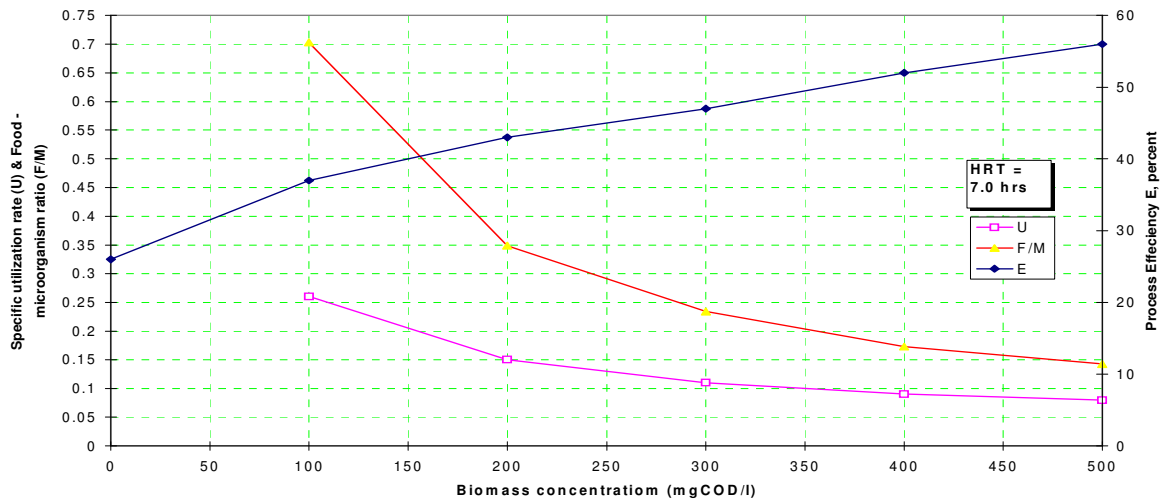


Figure 5.7 - Removal efficiency, specific substrate utilization rate, and Food-microorganism ratio under different seeds concentrations

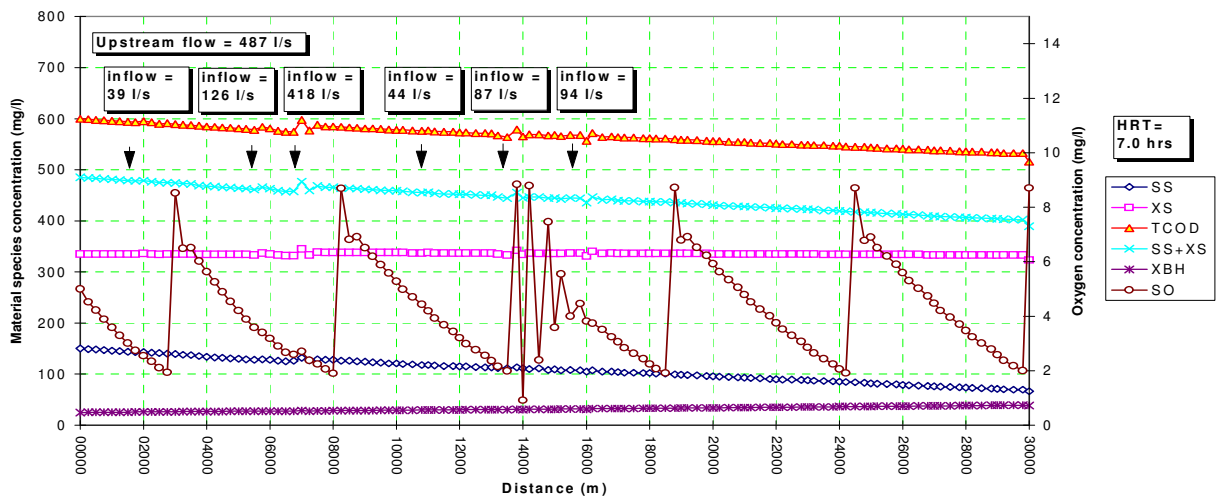


Figure 5.8- Model output using Fully time-centred TCSD implicit scheme for oscillations investigation at points abrupt changes

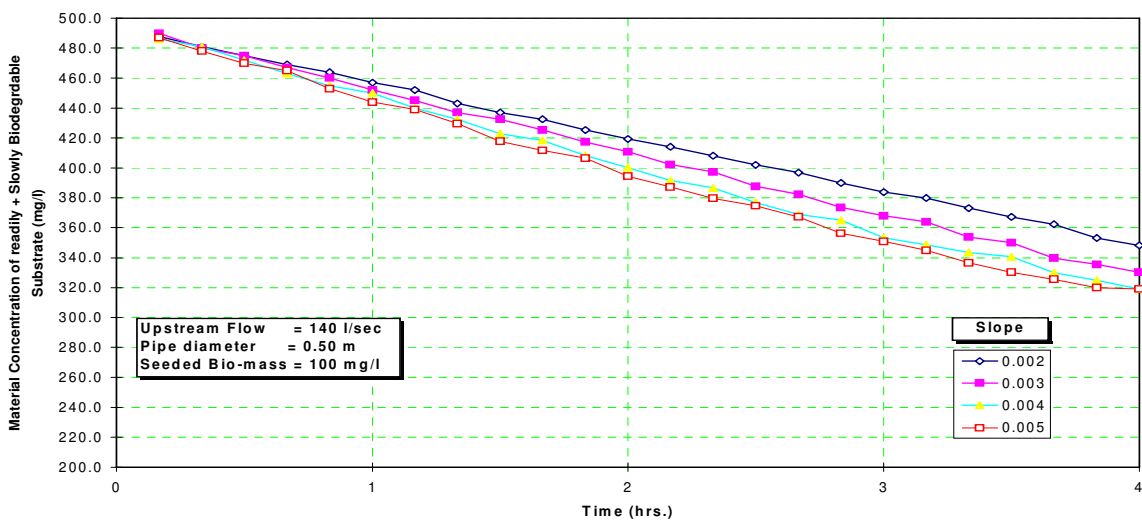


Figure 5.9 - Model Simulation of Changing Pipe Slope

6. CONCLUSIONS AND RECOMMENDATIONS

Various formulations of modified implicit TCSD schemes were used to solve the mass transport equation. The study shows (Tubail, [17], 1998) that the fully-time-centred TCSD implicit scheme is efficient to simulate the in-sewer treatment processes where the advection is predominant.

In terms of the scheme accuracy, test runs were conducted and results show that the fully-time-centred implicit TCSD scheme is a third order accurate in respect to the advection term. Furthermore, the importance of employing the full-time-centred implicit TCSD scheme, that it is unconditionally stable, and will enable the model for further development regarding the hydrodynamic components development.

Different approach were conducted to investigate the numerical oscillations, the obtained results show that, whilst employing the QUICKEST scheme which is a third order accuracy in space and time will not cause any numerical oscillations as long as the Courant number less than unity.

There is a remarkable need to develop the hydrodynamic components of the model to simulate a full hydrodynamic model. Without this the investigations of the effects of sewer design parameters on in-sewer treatment processes will not reflect the importance considerations of these design parameters (slope and diameter).

Test runs indicate an effective treatment is achievable specially when seeded biomass is used. The model predicts a 27 % average substrate reduction in the effluent from the sewer for unseeded sewage maintained in aerobic conditions, moreover this percentage is increased to a 56% when the sewage is seeded at a concentration of 500 mg biomass COD/l.

The following work is recommended to develop the model into more a comprehensive predictive tool for in-sewer treatment.

- (i) modifying the downstream boundary condition to achieve a more accurate approximation for the mass transport problem.
- (ii) modifying the hydrodynamic components of the model to include simulation of a multi-regime pressurized flow in sewer.
- (iii) a comprehensive validation exercise is considered necessary for the model to determine the parameters included using experimental techniques .
- (iv) expansion of the biofilm process in the model.
- (v) expansion of the process occurred in-sewer to include sediment transport.

REFERENCES

1. Abbott, M.B., and Basco, D.R., 1989, *Computational-Fluid Dynamics, An-Introduction for Engineers*, Longman Scientific & Technical, UK.
2. Cao, Y.S. and Alaerts, G.J. (1995). Aerobic biodegradation and microbial population in a channel with suspended and attached biomass. *Water Science and Technology* **31** (7), 181-189
3. Chen, Y., and Falconer, R. A., (1994). Modified forms of the third-order convection, second-order diffusion scheme for the advection-diffusion equation. *Advanced In Water Resources* **17**, 147-170.
4. Ding, Daoyang, Liu, Philip L-F., (1989). An operator-splitting algorithm for two-dimensional convection-dispersion-reaction problems, *International Journal for Numerical Methods in Engineering*, **28**, 1023-1040.
5. Dold, P.L., Ekama, G.A. and Marais, G.V.R. (1980) A general model for the activated sludge process. *Prog. Wat. Tech.* **12**, 47-77.
6. Henze, M. (1992). Characterisation of wastewater for modeling of activated sludge processes. *Water Science and Technology* **25** (6), 1-15.
7. Hvitved-Jacson, T., Vollertsen and Nielsen, P.H., (1998). A process and model concept for microbial wastewater transformations in gravity sewers. *Water Science and Technology* **37** (1), 233-241.
8. James, A. And Elliott, D.J. (1993). Models of water quality in rivers. Chapter 7 of *An Introduction to Water Quality Modeling*, Ed. James, A., John Wiley & Sons.
9. Jensen, N.A. (1995). Empirical modeling of air-to-water oxygen transfer in gravity sewers. *Water Environment Research* **67** (6), 979-99.
10. KAN, H. (1997). *Modeling of In-sewer Treatment of Sewage*. MSc. thesis, University of Newcastle upon Tyne, UK.
11. Kutija, V., (1996). *Flow adaptive schemes*, PhD Thesis IHE Delft, A. A. Balkema, Netherlands.

12. Leonard, B. P. (1979). A stable and accurate convective modeling procedure based on quadratic upstream interpolation. *Computer Methods in Applied Mechanics and Engineering* **19**, 59-98.
13. Malik, M. (1995). *In-sewer Treatment of Domestic Sewage*. Ph.D. thesis, University of Newcastle upon Tyne, U.K.
14. Nielsen, P.H., Raunkjwr, K., Norsker, N.H., Jensen, N.A. and Hvitved-Jacobsen, T. (1992). Transformation of wastewater in sewer systems - a review. *Water Science and Technology* **25** (6), 17-31.
15. Raunkjwr, K., Havited-Jacobson, T. and Nielsen, P.H. (1995). Transportation of organic matter in a gravity sewer. *Water Environment Research* **67**, (2), 181-188.
16. Schnoor, J. L., (1996). *Environmental Modeling: Fate and Transport of Pollutants in Water, Air, and Soil*. John Wiley & Sons.
17. Tubail, H. (1998). *Development of numerical model for in-sewer treatment*. MSc. thesis, University of Newcastle upon Tyne, UK.