

66481

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ATIKSULARDA PARTİKÜLER İNERT KOİ TAYİNİ

Yüksek Lisans Tezi

Kimya Müh. Özlem KARAHAN

Tezin Enstitüye Verildiği Tarih : 9 June 1997
Tezin Savunulduğu Tarih : 26 June 1997

Tez Danışmanı : Prof. Dr. Derin ORHON

Diğer Jüri Üyeleri : Doç. Dr. Seval SÖZEN

Doç. Dr. F. Germirli BABUNA

[Signature] 25/7/97
[Signature] 25.7.97
[Signature] 25/7/99

HAZİRAN 1997

THE ASSESSMENT OF INITIAL INERT PARTICULATE COD
IN WASTEWATERS

M.S. THESIS

Chemical Eng. Özlem KARAHAN

Date of Issue : 9 June 1997

Date of Presentation : 26 June 1997

Thesis Adviser : Prof. Dr. Derin ORHON

Members of Jury : Assoc. Prof. Seval SÖZEN

Assoc. Prof. F. Germirli BABUNA

Derin Orhon 25/7/97
Seval Sözen 25.7.97
F. Germirli Babuna 25/7/1997

JUNE 1997

PREFACE

Assessment of initial inert particulate COD has gained importance in designing activated sludge systems when multicomponent modelling approach is used. The study presents a detailed literature survey and a number of experimental data on the subject.

The recently proposed experimental ways of determination of initial inert particulate COD are tested and evaluated. The experimental findings lead the study, to cover a related area, that is the generation of particular microbial products. With the literature survey and the designed experiments on the subject this COD fraction is also examined in detail. By combining data on the two COD fractions, the best experimental and calculational procedure and method of assessment of the inert particulate COD is achieved.

The contributions of all people to the preparation of this study are gratefully acknowledged. Special thanks are due to my family, for their support and understanding.

June, 1997

Özlem KARAHAN

TABLE OF CONTENTS

PREFACE	ii
TABLE OF CONTENTS	iii
LIST OF SYMBOLS	vi
TABLE OF FIGURES	viii
LIST OF TABLES	x
SUMMARY	xii
ÖZET	xiii
SECTION 1 INTRODUCTION	1
1.1 MEANING AND SIGNIFICANCE OF THE SUBJECT	1
1.2 AIM AND SCOPE OF THE STUDY	2
SECTION 2 THEORY AND MODEL	4
2.1 ACTIVATED SLUDGE SYSTEMS	4
2.1.1 Conventional Activated Sludge Systems	4
2.1.2 New Concepts in Activated Sludge Systems	5
2.2 WASTEWATER CHARACTERIZATION	6
2.2.1 Chemical Oxygen Demand (COD)	7
2.2.2 COD Fractionation	7
2.3 MULTICOMPONENT MODELLING OF CARBON REMOVAL IN COMPLETELY MIXED SYSTEMS	11
2.3.1 Endogenous Decay Model	12
SECTION 3 ASSESSMENT OF INITIAL PARTICULATE INERT CHEMICAL OXYGEN DEMAND OF WASTEWATER	19
3.1 FORMERLY PROPOSED METHODS FOR THE ESTIMATION OF INITIAL INERT PARTICULATE COD	19
3.1.1 Experimental Method Proposed by Ekama et al. [7]	20
3.1.2 Experimental Method Proposed by Orhon et al. [8]	21

3.1.3 Experimental Method Proposed by Kappler and Gujer [9]	22
3.1.4 Experimental Method Proposed by Lesouef et al. [10]	23
3.1.5 Experimental Method Proposed by Germirli et al. [11]	23
3.1.6 Experimental Method Proposed by Orhon et al. [3]	24
3.2 LITERATURE SURVEY ON THE PARTICULATE MICROBIAL PRODUCTS	25
3.2.1 The Study of Kountz and Forney [4]	26
3.2.2 The Study of McKinney [3]	28
3.2.3 The Study of Washington and Symons [6]	29
3.3 EXPERIMENTAL PROCEDURES CARRIED OUT IN THIS STUDY FOR THE ESTIMATION OF INITIAL INERT PARTICULATE COD	30
3.3.1 Conceptual Approach	31
3.3.2 Experimental Procedure	33
3.3.2.1 Acclimation	33
3.3.2.2 Experiments	34
3.3.3 Evaluation Procedure	35
3.3.3.1 Method 1 [3]	35
3.3.3.2 Method 2 [11]	37
3.3.3.3 Method 3 [8]	40
SECTION 4 EXPERIMENTAL RESULTS	43
4.1 CONDUCTED EXPERIMENTS	43
4.2 EXPERIMENTAL DATA AND CALCULATIONS	45
4.2.1 Experimental Data of Set 1	45
4.2.2 Calculation of X_I , by Method 1	48
4.2.3 Calculation of X_I , by Method 2	49
4.2.4 Calculation of X_I , by Method 3	50
4.3 EXPERIMENTAL RESULTS AND DISCUSSION	52
4.3.1 Results of Experiments Performed With Tannery Wastewater	52
4.3.2 Determination of The Inert Fraction of Biomass	54
4.3.3 The Results With Experimentally Determined f_{EX}	62
4.3.4 Evaluation of The Three Proposed Methods	63
4.4 INITIAL INERT PARTICULATE COD OF DOMESTIC WASTEWATER	65
RESULTS AND RECOMMENDATIONS	67
REFERENCES	69

APPENDIX A	CALCULATIONS AND RESULTS OF EXPERIMENTS ON TANNERY WASTEWATER	72
	A.1 EXPERIMENTAL DATA OF SET 2	72
	A.1.1 Calculation of X_I , by Method 1	75
	A.1.2 Calculation of X_I , by Method 2	77
	A.1.3 Calculation of X_I , by Method 3	77
	A.2 EXPERIMENTAL DATA OF SET 3	78
	A.2.1 Calculation of X_I , by Method 1	81
	A.2.2 Calculation of X_I , by Method 2	83
	A.2.3 Calculation of X_I , by Method 3	84
	A.3 EXPERIMENTAL DATA OF SET 4	85
	A.3.1 Calculation of X_I , by Method 1	89
	A.3.2 Calculation of X_I , by Method 2	91
	A.3.3 Calculation of X_I , by Method 3	91
APPENDIX B	REVIEWED CALCULATIONS AND RESULTS OF EXPERIMENTS ON TANNERY WASTEWATER	94
	B.1 RE-CALCULATION OF SET 1 BY METHOD 1	94
	B.2 RE-CALCULATION OF SET 2 BY METHOD 1	95
	B.3 RE-CALCULATION OF SET 3 BY METHOD 1	96
	B.4 RE-CALCULATION OF SET 4 BY METHOD 1	97
APPENDIX C	CALCULATIONS AND RESULTS OF EXPERIMENTS ON DOMESTIC WASTEWATER	98
	C.1 EXPERIMENTAL DATA OF SET 1	98
	C.1.1 Calculation of X_I , by Method 1	100
	C.1.2 Calculation of S_I , by Method 3	102
	C.2 EXPERIMENTAL DATA OF SET 2	103
	C.2.1 Calculation of X_I , by Method 1	106
	C.2.2 Calculation of S_I , by Method 3	108
AUTOBIOGRAPHY		109

LIST OF SYMBOLS

b_H	: Herotrophic decay rate	$[T^{-1}]$
C_T	: Total COD	$[ML^{-3}]$
f_{EX}	: Inert fraction of the active biomass concentration	
K_H	: Hydrolysis rate constant	$[T^{-1}]$
K_s	: Half saturation constant	$[T^{-1}]$
Q	: Flow rate	$[L^3T^{-1}]$
Q_w	: Flow rate of the sludge wasted	$[L^3T^{-1}]$
S_I	: Soluble inert COD	$[ML^{-3}]$
S_P	: Soluble residual COD	$[ML^{-3}]$
S_R	: Soluble total residual COD	$[ML^{-3}]$
S_S	: Soluble biodegradable COD	$[ML^{-3}]$
S_T	: Total soluble COD	$[ML^{-3}]$
V	: Volume of the reactor	$[L^3]$
X_H	: Heterotrophic biomass	$[ML^{-3}]$
X_I	: Particulate inert COD	$[ML^{-3}]$
X_P	: Particulate residual COD	$[ML^{-3}]$
X_S	: Slowly biodegradable COD	$[ML^{-3}]$
X_T	: Total particulate COD	$[ML^{-3}]$
Y_H	: Yield coefficient	
Y_{SP}	: Residual soluble microbial products coefficient	

Y_{XP}	: Residual particulate microbial products coefficient	
α_D	: Growth associated product formation coefficient	
μ_{max}	: Maximum heterotrophic growth rate	$[T^{-1}]$
θ_H	: Hydraulic retention time	$[T]$
θ_X	: Sludge age	$[T]$



TABLE OF FIGURES

Figure 2.1 Conventional Activated Sludge Plant With Recycle.	5
Figure 2.2 Distribution of COD Fractions in Wastewaters.	9
Figure 2.3 Soluble COD Fractions in the Mixed Liquor.	10
Figure 2.4 Particulate COD Fractions in the Mixed Liquor.	10
Figure 2.5 Schematic Process Diagram for Multicomponent Modelling of Carbon Removal in a Single CSTR.	12
Figure 3.1 Schematic Representation of Raw Wastewater Reactor.	35
Figure 3.2 Schematic Representation of Raw and Filtered Wastewater Reactors.	37
Figure 3.3 Schematic Representation of Raw and Filtered Wastewater, and Glucose Reactors.	40
Figure 4.1 COD Profiles of Raw Wastewater Reactor of Set 1.	46
Figure 4.2 COD Profiles of Filtered Wastewater Reactor of Set 1.	46
Figure 4.3 COD Profile of Glucose Reactor of Set 1.	47
Figure 4.4 Particulate COD Profile of Raw Wastewater Reactor of Set 1.	48
Figure 4.5 Soluble COD Profiles of The Reactors of Set 1.	51
Figure 4.6 Total and Soluble COD Profiles of Filtered Wastewater.	56
Figure 4.7 Total and Soluble COD Profiles of Chemically Treated Wastewater Reactor.	57
Figure 4.8 Total and Soluble COD Profiles of Synthetic Reactor.	57
Figure 4.9 Total and Soluble COD Profiles of Synthetic Reactor Fed Five Times.	58
Figure A.1 COD Profiles of Raw Wastewater Reactor of Set 2.	72
Figure A.2 COD Profiles of Filtered Wastewater Reactor of Set 2.	73

Figure A.3 COD Profile of Glucose Reactor of Set 2.	74
Figure A.4 Particulate COD Profile of Raw Wastewater Reactor of Set 2.	75
Figure A.5 Soluble COD Profiles of The Reactors of Set 2.	78
Figure A.6 COD Profiles of Raw Wastewater Reactor of Set 3.	79
Figure A.7 COD Profiles of Filtered Wastewater Reactor of Set 3.	80
Figure A.8 COD Profile of Glucose Reactor of Set 3.	81
Figure A.9 Particulate COD Profile of Raw Wastewater Reactor of Set 3.	82
Figure A.10 Soluble COD Profiles of The Reactors of Set 3.	84
Figure A.11 COD Profiles of Raw Wastewater Reactor of Set 4.	86
Figure A.12 COD Profiles of Filtered Wastewater Reactor of Set 4.	87
Figure A.13 COD Profile of Glucose Reactor of Set 4.	88
Figure A.14 Particulate COD Profile of Raw Wastewater Reactor of Set 4.	90
Figure A.15 Soluble COD Profiles of The Reactors of Set 4.	92
Figure C.1 COD Profiles of Raw Wastewater Reactor of Set 1.	98
Figure C.2 COD Profiles of Filtered Wastewater Reactor of Set 1.	99
Figure C.3 COD Profile of Glucose Reactor of Set 1.	100
Figure C.4 Particulate COD Profile of Raw Wastewater Reactor of Set 1.	101
Figure C.5 Soluble COD Profiles of The Reactors of Set 1.	103
Figure C.6 COD Profiles of Raw Wastewater Reactor of Set 2.	104
Figure C.7 COD Profiles of Filtered Wastewater Reactor of Set 2.	105
Figure C.8 COD Profile of Glucose Reactor of Set 2.	106
Figure C.9 Particulate COD Profile of Raw Wastewater Reactor Set 2.	107

LIST OF TABLES

Table 2.1 Process Kinetics and Stoichiometry for Carbon Removal Involving Endogenous Decay	12
Table 3.1 Methods For Estimating Particulate Inert Organic Fraction in Wastewater	20
Table 4.1 Conventional Wastewater Characterization of Set 1	43
Table 4.2 Conventional Wastewater Characterization of Set 2	44
Table 4.3 Conventional Wastewater Characterization of Set 3	44
Table 4.4 Conventional Wastewater Characterization of Set 4	45
Table 4.5 Experimental Results of Set 1	52
Table 4.6 Experimental Results of Set 2	52
Table 4.7 Experimental Results of Set 3	53
Table 4.8 Experimental Results of Set 4	53
Table 4.9 The Comparison of Theoretical and Experimental Values of X_p	54
Table 4.10 The Contents of Synthetic Feed Solution	55
Table 4.11 The Experimental Data of f_{EX}	58
Table 4.12 Summary of The Experimentally Calculated Values of f_{EX}	62
Table 4.13 Re-calculated Experimental Results of Set 1	63
Table 4.14 Re-calculated Experimental Results of Set 2	63
Table 4.15 Re-calculated Experimental Results of Set 3	63
Table 4.16 Re-calculated Experimental Results of Set 4	63
Table 4.17 Conventional Wastewater Characterization of Moda Domestic Sewage	66
Table 4.18 Experimental Results of Set 1 and Set 2 of Domestic Wastewater	66

Table A.1 COD Data of Raw Wastewater Reactor of Set 2.	72
Table A.2 COD Data of Filtered Wastewater Reactor of Set 2.	73
Table A.3 COD Data of Glucose Reactor of Set 2.	74
Table A.4 Particulate COD Data of Raw Wastewater Reactor of Set 2.	75
Table A.5 Soluble COD Data of The Reactors of Set 2.	78
Table A.6 COD Data of Raw Wastewater Reactor of Set 3.	79
Table A.7 COD Data of Filtered Wastewater Reactor of Set 3.	80
Table A.8 COD Data of Glucose Reactor of Set 3.	81
Table A.9 Particulate COD Data of Raw Wastewater Reactor of Set 3.	82
Table A.10 Soluble COD Data of The Reactors of Set 3.	84
Table A.11 COD Data of Raw Wastewater Reactor of Set 4.	86
Table A.12 COD Data of Filtered Wastewater Reactor of Set 4.	87
Table A.13 COD Data of Glucose Reactor of Set 4.	88
Table A.14 Particulate COD Data of Raw Wastewater Reactor of Set 4.	89
Table A.15 Soluble COD Data of The Reactors of Set 4.	92
Table C.1 COD Data of Raw Wastewater Reactor of Set 1.	98
Table C.2 COD Data of Filtered Wastewater Reactor of Set 1.	99
Table C.3 COD Data of Glucose Reactor of Set 1.	100
Table C.4 Particulate COD Data of Raw Wastewater Reactor of Set 1.	101
Table C.5 Soluble COD Data of The Reactors of Set 1.	102
Table C.6 COD Data of Raw Wastewater Reactor of Set 2.	104
Table C.7 COD Data of Filtered Wastewater Reactor of Set 2.	105
Table C.8 COD Data of Glucose Reactor of Set 2.	106
Table C.9 Particulate COD Data of Raw Wastewater Reactor Set 2.	107

SUMMARY

Activated sludge systems and their multicomponent modelling is very important for the biological treatment of wastewaters. Wastewater characteristics, in the sense of organic content should be determined in detail for the accurate modelling and design considerations. COD is the collective analytical parameter accepted to be useful for modelling purposes but it has to be fractionated for the correct determination of organic fractions with different degradation characteristics.

COD first is divided into two, as inert and biodegradable COD, and the two general categories are further sub-divided to their soluble and particulate fractions. All the modelling calculations should be based on biodegradable COD, since the inert COD is not involved in any biochemical reaction occurring in the activated sludge and the soluble inert fraction by-passes the system while the particulate inert fraction is accumulated in the activated sludge. The determination of the initial inert COD of wastewaters, is therefore, very important as far as the effluent standards and sludge disposal are concerned.

There are many proposed methods in the literature to find the initial inert particulate COD of wastewaters, as summarized in the study, and the recently proposed three batch methods are experimentally evaluated. It is not possible to estimate initial inert COD without determining the particulate residual products generated by biomass decay, with the proposed methods. Two of the methods estimated this parameter experimentally and the third based on modelling.

So the study is extended in the sense that, literature survey and additional experimental procedure design, are performed for the determination of the particular residual products generated and the biologically inert fraction of the biomass. Experimental research is still recommended in this subject but as far as this study is concerned, the experiments, performed on tannery wastewater effluents and synthetic solution prepared, have shown that the inert fraction of biomass and the generation of residual inert products are wastewater specific, and should be determined experimentally.

Depending on the experimental results of tannery wastewater effluent and the evaluation of the three methods proposed, it is concluded that the best way for the determination of initial particulate inert COD is the proposed method based on modelling unless correct, experimentally determined value of the stoichiometric parameters, heterotrophic growth rate and inert fraction of biomass are used.

ATIKSULARDA PARTİKÜLER İNERT KOİ TAYİNİ

ÖZET

Aktif çamur biyolojik arıtma sistemleri, günümüzde en yaygın kullanım alanına sahip arıtma sistemidir. Aktif çamur sistemleri üzerine pek çok çalışma yapılmış, ve modelleme ve tasarım için pek çok deneysel veri elde edilmiştir. Çok bileşenli modelleme uygulamalarında kullanılan pek çok kinetik ve stoykiometrik parametre deneysel olarak tayin edilmiş ya da sabit olarak kabul görmüştür.

Çok bileşenli modelleme çalışmalarında en önemli olan, atıksu karakterizasyonunun belirlenmesidir. Burada bahsedilen karakterizasyon, atıksuyun organik madde içeriğine ve niteliğine göre yapılacak bir karakterizasyondur.

Atıksuların organik madde içeriği, uçucu askıda katı madde (UAKM), biyokimyasal oksijen ihtiyacı (BOİ), ve kimyasal oksijen ihtiyacı (KOİ) gibi konvansiyonel, kolektif parametrelerle ifade edilebilir. KOİ parametresi BOİ parametresinden daha yararlıdır, çünkü KOİ ile substrat, biyokütle ve çözünmüş oksijen arasında bir elektron alıcısı denklemi kurmak mümkün olur. Ancak KOİ, organik maddenin biyolojik olarak ayrışabilirliği konusunda bir belirleme yapamamaktadır. Bu yüzden KOİ, bileşenlerine ayrılarak incelenmelidir.

KOİ öncelikle, biyolojik olarak ayrışabilen ve inert KOİ olarak ikiye ayrılabilir. Daha sonra inert çözünürlük özelliklerine göre, çözünmüş ve partiküler olarak tekrar iki gruba ayrılmıştır. Biyolojik olarak ayrışabilen KOİ, ayrışma özelliklerine göre yavaş ve hızlı ayrışan KOİ olarak ele alınır.

Biyolojik olarak ayrışabilen KOİ çok önemlidir, çünkü bu KOİ fraksiyonu biyokimyasal süreçlere girer ve tüketilir. Tüm modelleme ve tasarım hesaplamalarının bu KOİ fraksiyonu kullanılarak yapılması gerekmektedir, aksi takdirde modelleme ve tasarım değerleri tam doğru ve kesin olmaz.

Biyolojik olarak ayrışabilen KOİ fraksiyonunun bulunabilmesi için inert KOİ fraksiyonunun saptanması gerekmektedir. Ancak atıksuların çözünmüş ve partiküler inert KOİ fraksiyonlarının belirlenmesi özellikle deşarj standartları ve işletme parametreleri açısından da büyük önem taşımaktadır.

Çözünmüş inert KOİ fraksiyonu hiç bir biyokimyasal reaksiyona katılmadan atıksu deşarjı ile dışarı atılır. Bu yüzden bu fraksiyon deşarj standartları açısından büyük önem taşımaktadır.

Partiküler inert KOİ fraksiyonu da hiç bir biyokimyasal reaksiyona katılmaz, ancak bu KOİ aktif çamur içinde birikir. Partiküler inert KOİ sistemden sadece fazla

çamur atılması ile çıktığı için sistemde çamur yaşına bağlı olarak birikir. Bu yüzden, özellikle yüksek partiküler inert fraksiyonuna sahip atıksular söz konusu olduğunda işletme parametreleri ve sistemin verimi çok iyi seçilmeli ve hesaplanmalıdır. Atıksularda partiküler inert KOİ fraksiyonunun varlığı, sistemden atılan çamur miktarını da büyük ölçüde etkileceği için çamur miktarının belirlenmesi ve çamur stabilizasyonu konularında tasarım açısından büyük önem taşır. Bu parametre dikkate alınmadığında havalandırma havuzundaki tüm askıda katı maddenin aktif çamur olduğu göze alınarak sistemin giderim verimi konusunda da yanlış yapılmış olacaktır. Tüm bu sebeplerle atıksuların partiküler inert KOİ fraksiyonunun belirlenmesi modelleme, tasarım, ve işletme açısından çok önemlidir.

Bu çalışmada, çok bileşenli modellerden, içdel solunum modeli incelenmiş, ve model detaylı olarak anlatılmıştır. İçsel solunum modelinin beş bileşen ve üç süreçli hali, karbon giderimi konusunda kullanılmıştır. Modeldeki süreçler, çoğalma, içsel solunum ve hidrolizdir. Model bileşenleri ise, biyolojik olarak hızlı ayrışan substrat, S_s , biyolojik olarak yavaş ayrışan substrat, X_s , heterotrofik biokütle, X_H , partiküler inert mikrobiyal ürünler, X_P , ve çözünmüş inert mikrobiyal ürünler, S_P 'dir. Model matrisinde inert KOİ bileşenleri X_I , ve S_I , de görülmekle beraber bu bileşenler hiçbir biyokimyasal reaksiyona girmeden sistemden çıkarlar.

İçsel solunum modeli kullanılarak kütle dengeleri yazılmış ve bu denklemler, kararlı denge koşulları için çözülmüştür. Partiküler inert KOİ hesaplamaları için bu çözümlerden yararlanılmıştır.

Atıksularda partiküler inert KOİ parametresinin tayini için şimdiye kadar pek çok method önerilmiştir. Bu methodlar, önerdikleri deney ve hesaplama yöntemleri, tez içerisinde, detaylı bir biçimde incelenmiştir. Önerilen methodların deney yöntemleri çeşitlilik göstermektedir. Partiküler inert KOİ parametresinin belirlenmesi için, sürekli ve kesikli deney yöntemlerinin yanı sıra model kalibrasyonu da öneriler arasındadır.

Bu çalışma çerçevesinde son olarak önerilen, üç kesikli deney yöntemi karşılaştırmalı olarak, Tuzla Organize Deri Sanayi atıksuyu kullanılarak yapılan deneylerle incelenmiştir. Bu üç yöntem, Method 1, Method 2, ve Method 3 olarak adlandırılmıştır.

Method 1, ham atıksu ile beslenmiş tek bir havalandırılmış kesikli reaktör kullanılarak yapılan bir deneydir. Bu deneyde çok az miktarda daha önceden atıksuya aklime edilmiş biyokütle kullanılmıştır. Ham atıksu reaktörüne aşılana biyokütle havalandırılır, ve tamamen mineralize olana dek deney sürdürülür.

Deney esnasında reaktördeki toplam ve çözünmüş KOİ bileşenleri ölçülerek, bunlar arasındaki farktan reaktörün partiküler KOİ profili elde edilir. Ölçümler hep aynı nihayi değerleri verdiğinde deney kesilir. Elde edilen nihayi partiküler KOİ, atıksudaki partiküler inert KOİ ve oluşan partiküler inert mikrobiyal ürünleri içerir. Oluşan inert mikrobiyal ürünlerin konsantrasyonu, model esaslı bir iterasyon yöntemi ile hesaplanarak atıksudaki partiküler inert KOİ bileşeni hesaplanır. Ancak bu deney yöntemi, çözünmüş inert KOİ, biyokütlenin inert fraksiyonu, ve heterotrofik dönüşüm

oranı gibi parametrelerin bilinmesini ya da deneysel olarak hesaplanmasını gerektirmektedir.

Method 2, bir ham atıksu bir de süzölmüş atıksu ile beslenen iki kesikli reaktör kullanılarak yapılan bir deneydir. Bu deneyde çok az miktarda daha önceden atıksuya aklime edilmiş biyokötle kullanılmıştır. Ham ve süzölmüş atıksu reaktörlerine aşıl原因 biyokötle havalandırılır, ve tamamen mineralize olana dek deney sürdürölmür.

Deney esnasında reaktörlerdeki toplam ve çözönmüş KOİ bileşenleri ölçölerek, reaktörlerin toplam ve çözönmüş KOİ profilleri elde edilir. Ölçölmler hep aynı nihayi değlerleri verdiğinde deney kesilir. Elde edilen nihayi toplam ve çözönmüş KOİ değlerleri kullanılarak, reaktörlerdeki toplam KOİ giderimleri hesaplanır. Reaktördeki KOİ giderimlerinin oranı, biyolojik olarak ayrışabilen giriş KOİ değlerlerinin ve dolayısıyla reaktörlerde oluşın inert mikrobiyal ürünlerin oranına eşittir. Süzölmüş atıksu reaktöründe oluşın nihayi partiköler KOİ, inert mikrobiyal ürünlerin KOİ konsantrasyonunu belirtir. Bu deney verisi ve belirtilen oran kullanılarak elde edilen hesaplar sonucu, partiköler inert KOİ parametresi belirlenmektedir.

Method 3, ham atıksu, süzölmüş atıksu ve süzölmüş atıksu ile aynı KOİ konsantrasyonuna sahip glikoz solösyonu ile beslenen üç kesikli reaktör kullanılarak yapılan bir deneydir. Bu deneyde çok az miktarda daha önceden atıksuya ve glikoza aklime edilmiş biyokötle kullanılmıştır. Ham ve süzölmüş atıksu, ve glikoz reaktörlerine aşıl原因 biyokötle havalandırılır, ve tamamen mineralize olana dek deney sürdürölmür. Deney esnasında reaktörlerdeki çözönmüş KOİ bileşenleri ölçölerek, reaktörlerin çözönmüş KOİ profilleri elde edilir. Ölçölmler hep aynı nihayi değlerleri verdiğinde deney kesilir.

Süzölmüş atıksu ve glikoz reaktörlerinden elde edilen nihayi çözönmüş KOİ değlerleri kullanılarak, atıksuyun çözönmüş inert KOİ bileşeni hesaplanır. Bu hesaplama glikoz reaktöründeki nihayi çözönmüş KOİ değlerinin sadece çözönmüş mikrobiyal ürönlere ait olduđu varsayımına dayanır. Biyolojik olarak ayrışabilen giriş KOİ değlerlerinin oranı, reaktörlerde oluşın çözönmüş inert mikrobiyal ürünlerin oranına eşittir. Süzölmüş atıksu reaktöründe oluşın nihayi çözönmüş KOİ, inert mikrobiyal ürünlerin KOİ konsantrasyonu ile girişteki çözönmüş inert KOİ değlerlerinin toplamından oluşur. Süzölmüş atıksu reaktörünün biyolojik olarak ayrışabilen KOİ fraksiyonu kullanılarak ham atıksu reaktöründeki biyolojik olarak ayrışabilen KOİ fraksiyonu bulunur. Bu deney verisi ve belirtilen oran kullanılarak elde edilen hesaplar sonucu, partiköler inert KOİ parametresi belirlenmektedir.

Bu üç method, deri atıksuyu ile yapılan deneylerle incelenmiş, ve Method 3'ün deneysel verilerle yapılan hesaplamalarda, kendi içörisinde tutarsız sonuçlar verdiğö görölmüştür. Method 1'in sonuçlarına bakıldığında ise, hesaplanan partiköler mikrobiyal biyokötle konsantrasyonunun, gerçöek değlerinin çok altında olduđu, hatta bu değerin süzölmüş atıksu reaktöründe oluşın ve miktarı deneysel olarak bulunan partiköler mikrobiyal biyokötle konsantrasyonunun da altında olduđu görölmüştür. Bunun sebepleri araştırıldığında ise, kullanılan biyokötle inert fraksiyonu, f_{EX} , parametresinin yanlış olduđu sonucuna varılmıştır.

Bu noktada çalışma bu stoykiometrik parametrenin, f_{EX} , daha yakından incelenmesine karar verilerek, kapsamlı bir literatür araştırması yapılmıştır. Literatürde bu parametrenin belirlenmesi için sentetik çözeltiler ile beslenen sürekli reaktörler ile yapılmış deneyler sonucu f_{EX} , parametresinin genel olarak 0.20 kabul edildiği görülmüştür. Model denklemleri ve yapılmış olan inert KOİ deneylerindeki süzölmüş atıksu reaktöründe oluşan partiküler KOİ parametresi kullanılarak yapılan hesaplarda f_{EX} , parametresinin 0.20 değerinin çok üzerinde olduğu sonucu elde edilmiştir.

Biyokütlenin inert fraksiyonunu temsil eden f_{EX} , parametresinin belirlenmesi için ayrıca yeni bir set deney tasarlanmıştır. Bu deneylerde deri atıksuyu ve sentetik çözelti ile beslenen kesikli reaktörler kullanılmıştır. Atıksu ve sentetik çözeltiye aklime edilen biyokütle ile az miktarda aşılana reaktörler, havalandırılarak, biyokütlenin tam mineralizasyonu sağlanana dek çalıştırılmıştır.

Bu deney seti için, süzölmüş atıksu reaktörü, kimyasal arıtılmış ve süzölmüş atıksu reaktörü, sentetik çözelti ile beslenmiş reaktör ve sentetik çözelti ile arka arkaya beş kez beslenmiş reaktör olmak üzere dört tane kesikli reaktör hazırlanmıştır. Reaktörlerin hepsine aynı biyokütle aşılana, ve reaktörler uzun bir süre numune alınmadan çalıştırılmıştır.

Deneylerde son dönemde alınan numunelerle toplam ve çözölmüş KOİ değerleri ölçölmüş ve deneylerin bittiğine reaktörlerdeki oksijen tüketim hızı (OTH) ölçölerek karar verilmiştir. Ölçölen nihayi toplam ve çözönmüş KOİ değerleri arasındaki fark ile reaktörlerde oluşan partiküler inert mikrobiyal ürünler hesaplanarak, bu sonuçlar ve model denklemleri yardımı ile deri atıksuyu ve sentetik çözelti üzerinde çoğalan biyokütlelerin inert fraksiyonları, f_{EX} , değerleri elde edilmiştir.

Elde edilen deneysel f_{EX} , değerleri ile Method 1 yeniden ele alındığında daha sağlıklı ve tutarlı sonuçlara varıldığı görölmüştür. Yeni Method 1 sonuçları ve Method 2'nin sonuçları karşılaştırıldığında sonuçların birbirine çok yakın olduğu görölmüştür. Ancak Method 2'nin hesaplama yöntemi deneysel verilerin oranlanmasına dayalı olduğu için deney verilerindeki küçük sapmalar, hesaplama sonuçlarında büyük oynamalara sebep olacağından, Method 2'nin hesaplama yöntemi önerilmemektedir.

Çalışmada ayrıca, Method 2 ve Method 3'te önerilen yöntemlerle çözönmüş inert KOİ parametresi de hesaplanmış ve her iki yönteminde birbirine çok yakın ve tutarlı sonuçlar verdiği görölmüştür.

Çözönmüş inert KOİ, S_I , deri atıksuyunun toplam KOİ'sinin %10-%14'ünü oluşturur. Çözönmüş inert KOİ, S_I , deri atıksuyunun çözönmüş KOİ'sinde %16-%28 arasında değişen oranlarda bulunmuştur.

Partiküler inert KOİ, X_I , deri atıksuyunun toplam KOİ'sinin %3 ile %19'u arasında değişen değerlere sahiptir. Deri atıksuyunun karmaşık yapısı ve değişken niteliğinden kaynaklanan bu çok farklı değerlerin ortalaması %11 olarak tespit edilmiştir.

Evsel atıksu ile yapılan deneylerde çözönmüş ve partiküler inert KOİ parametreleri hesaplanmıştır. Çözönmüş inert KOİ, S_I , evsel atıksuyun toplam KOİ'sinin %3-%5'ini

oluşturur. Çözünmüş inert KOİ, S_I , evsel atıksuyun çözünmüş KOİ'sinde %9-%22 arasında değişen oranlarda bulunmuştur. Partiküler inert KOİ, X_I , deri atıksuyunun toplam KOİ'sinin %10 ile %16'sı arasında değişen değerlere sahiptir.

İki önemli stoykiometrik parametrenin, f_{EX} , ve Y_{XP} , bulunması için önerilen deneylerde deri atıksuyunda f_{EX} , için %42 ve Y_{XP} için 0.27 değerleri bulunmuştur.

Sentetik besleme çözeltisi ile yapılan deneylerde bu biyokütlenin inert fraksiyonunun %11 ve oluşan inert mikrobiyal ürünlerin fraksiyonunun, Y_{XP} , 0.07 olduğu görülmüştür.

Önceki çalışmalarda kabul edilmiş f_{EX} , değeri olan %20, burada çok farklılık göstermektedir. Bu konuda daha fazla deneysel çalışma yapılması gerekmektedir, ancak, bu çalışma göstermiştir ki, f_{EX} , parametresi, atıksuya bağlı bir parametredir ve sağlıklı modelleme ve tasarım çalışmalarının yürütülebilmesi için bu parametrenin deneysel olarak her atıksu için belirlenmesi gerekmektedir.

Sonuç olarak yapılan değerlendirmede, Method 1, deneysel olarak bulunan f_{EX} , ve Y_H , değerleri ile atıksulardaki partiküler inert KOİ fraksiyonunu en tutarlı ve sağlıklı şekilde tayin etmektedir. Method 2 ve Method 3, çözünmüş inert KOİ parametresinin belirlenmesinde kullanılmalıdır.

SECTION 1

INTRODUCTION

1.1 MEANING AND SIGNIFICANCE OF THE SUBJECT

Activated sludge is the most vital wastewater treatment process today. It has been used for carbon removal for almost a century as a conventional treatment system. Since it is widely applied, designing of activated sludge processes is an extremely important subject of environmental engineering. The success of the design however, depends on the agreement of the model with the real systems. The compatibility of the model is of great importance for designing efficient activated sludge systems.

The model is better off when the model parameters are well defined. A good model can be formed with accurate and reliable information about the wastewater to be treated and the biochemical reactions involved. The biochemical reactions are defined by various kinetic and stoichiometric coefficients. These are to be derived experimentally. An equally important subject to determine the process kinetics of activated sludge is, wastewater characteristics regarding the organic content. A number of experimental studies have been made to determine the model parameters of the activated sludge process in these fields.

The identification of wastewater characteristics with regard to the organic content is useful, both from the standpoint of process kinetics and prediction of effluent quality. Since wastewaters contain a number of organic matter, collective analytical parameters such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are used to determine the total organics.

COD is a more useful parameter than BOD since it is possible to correlate substrate, biomass and dissolved oxygen in terms of electron equivalence using COD. Although COD is a parameter that allows us to estimate the organic content of wastewaters at high accuracy, it is not possible to differentiate between the biodegradable and inert fractions of these organics with COD. Furthermore COD does not say anything about the rate of biodegradability of the organics, i.e., whether the substrate is readily or slowly degradable. Regarding this insufficiency of the collective parameter, COD should be separated into several fractions in order to be more precise about the design parameters.

The COD parameter involves different types of organic carbon that require further differentiation in terms of their biodegradation characteristics. In this context, raw wastewater has two major components: the total biodegradable COD, and the total non-biodegradable or inert COD. The inert fraction may be further divided into soluble inert COD, and particulate inert COD. The soluble inert COD by-passes the system without affecting the biochemical reactions in the system, but the particulate inert COD is accumulated in the activated sludge and leaves the system with sludge wastage. Thus the soluble inert fraction of the influent COD has an important role on the prediction of the effluent quality, whereas the particulate inert COD is to be taken into consideration in terms of operational parameters.

1.2 AIM AND SCOPE OF THE STUDY

The aim of the study is to examine the methods, proposed on the determination of initial inert particulate COD, and to present experimental data on the subject, to be used for purpose of design.

Scientific literature is searched and most of the data on the subject has been collected and presented in the study. Although several works are found in literature on the assessment of initial particulate inert COD, a universally accepted method is not present yet. In order to be able to make an evaluation of the methods, experimental data is obtained on the recently proposed ones.

The study is a detailed literature survey on the assessment of initial inert particulate COD and the generation of inert residual products, two very important parameters for the design of activated sludge systems operating under aerobic conditions. The study also provides experimental data on the subject and by the evaluation of the previously proposed methods, figures out the best way of determining initial inert particulate COD.



SECTION 2

THEORY AND MODEL

2.1 ACTIVATED SLUDGE SYSTEMS

Activated sludge treatment plants are built to remove organic matter from wastewater. The principle in activated sludge plants is that a mass of activated sludge is kept moving in water by stirring or aeration. Apart from the living biomass, the suspended solids contain inorganic as well as organic particles. Some of the organic particles can be degraded by subjecting them to hydrolysis whereas others are non-degradable.

The amount of suspended solids in the treatment plant is regulated through recycle of suspended solids and by removing so-called excess sludge. The handling and disposal of excess sludge is one of the environmentally difficult problems in wastewater treatment processes.

2.1.1 Conventional Activated Sludge Systems

A conventional activated sludge treatment plant with recycle, shown in Figure 2.1, has two units; the aeration tank and the settling tank. The influent wastewater enters the aeration tank after it is mixed with the recycled sludge. The purpose of the recycle is to increase the sludge concentration in the aeration tank. The result is an increased sludge age as the hydraulic retention time and the sludge age are separated. In this way it is possible to accumulate a biomass consisting of both rapid- and slow-growing micro-organisms. This is very important for settling and flocculation behavior of the sludge.

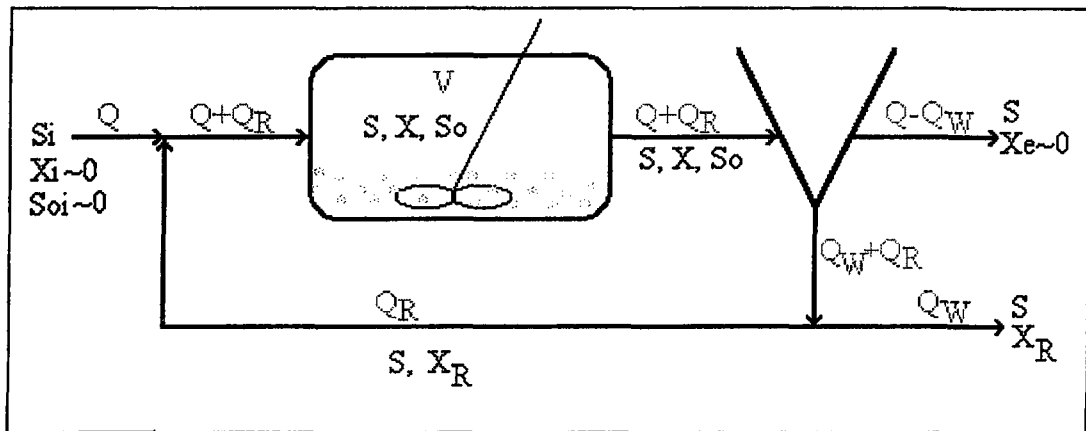


Figure 2.1 Conventional Activated Sludge Plant With Recycle.

The biochemical reactions occur in the aeration tank and as the process operates, the organic content of the wastewater, namely the substrate, decreases and the biomass in the reactor increases. The rate of the biochemical reactions of growth and decay occurring in the aeration tank are dependent on the kinetic parameters and the substrate, biomass, and oxygen concentrations.

The sludge must be concentrated prior to recycling which takes place in a settling tank. The settled sludge is then separated into two, where a portion is recycled and the remaining portion is disposed as excess sludge. The effluent from the upper part of the settling tank is supposed to be free of all the particulate matter, thus contains only the remaining soluble fraction of organic matter.

2.1.2 New Concepts in Activated Sludge Systems

The conventional activated sludge approach for carbon removal, has two major inadequacies for a fundamental understanding and interpretation of the process.

First, it is limited to only two components aside from dissolved oxygen, one defining the overall carbonaceous substrate, and the other, the total biomass in the reactor. Difficulties associated with the correct assessment of organic substrate and biomass have traditionally caused much inconvenience and confusion, perhaps to the extent of bringing some hindrance to the progress of activated sludge theory. The routine

collective analytical parameters like volatile suspended solids (VSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), etc. do not correspond to real system variables. VSS includes viable biomass together with non-viable particulate organic matter. As far as substrate is concerned, COD is estimated to be a more useful parameter than BOD, as it enables to make appropriate correlation among substrate, biomass and dissolved oxygen in terms of electron equivalence. However, COD can not identify the growth-limiting components directly related to corresponding process rate expressions especially in complex mediums. COD does not say anything about the rate of biodegradability of the organics, i.e., whether the substrate is readily or slowly degradable. Regarding this insufficiency of the collective parameter, COD should be separated into several fractions in order to be more precise about the design parameters.

Second, the two traditional process of growth and endogenous decay do not provide a complete and correct mechanistic description of the complex relationships and conversions among process components. Furthermore, the conceptual structure underlying the classical models is that growth is exclusively supported by the original substrate in the effluent, and that the residual organic material in the effluent, as measured by COD, is part of the original substrate itself. This concept leads to the practical result that the rate-limiting substrate concentration in the effluent of an activated sludge reactor is dependent on the influent concentration. A number of studies prove the opposite, with the explanation that the effluent COD mostly composed of organic matter released through microbial activities in the reactor. In this framework, introduction of necessary additional process components becomes a prerequisite for a more accurate modelling approach, and this needs a comprehensive wastewater characterization.

2.2 WASTEWATER CHARACTERIZATION

Wastewaters, in general, contain a number of different organic and inorganic components. Since the determination and analysis of these components one by one are time, energy, and money consuming it is more convenient to analyze wastewaters

by fractionating into some functional groups. The wastewater characterization to be analyzed, is restricted with the carbonaceous organic matter, and neither nitrogen nor phosphorus fractions of wastewater is to be considered in this context. The organic carbon contained in wastewater is expressed as COD for the reasons explained above.

2.2.1 Chemical Oxygen Demand (COD)

COD is a collective parameter that estimates the amount of organic matter present in the wastewater. The total COD of organic compounds in wastewater is measured by the dichromate COD test. A 2 hour reflux with concentrated sulfuric acid and potassium dichromate with silver sulfate and mercuric sulfate catalysts is adequate for complete oxidation of all but a few aromatic organic compounds. The measured COD value gives a good picture of the total content of the organic matter present in wastewaters.

2.2.2 COD Fractionation

Organic constituents of the wastewater are significant components of the activated sludge models. The main objective of wastewater characterization is to identify the organic fractions with different biodegradation properties. The COD value covers a number of organic materials of varying biological qualities. This provides the necessary experimental support to the model for the accurate prediction of the electron acceptor requirement and the activated sludge production.

The COD parameter embodies different forms of organic carbon that require further differentiation in terms of their biodegradation characteristics. In this context, the total influent COD, C_{T1} , has two major components: the total biodegradable COD, C_{S1} , and the total non-biodegradable or inert COD, C_{I1} .

$$C_{T1} = C_{S1} + C_{I1} \quad (2.1)$$

The inert fraction may be further subdivided into soluble inert COD, S_{II} , and particulate inert COD, X_{II} . The soluble inert COD concentration in the influent bypasses the system without affecting the biochemical reactions in the reactor, whereas the particulate inert COD is entrapped and accumulated in the activated sludge, and leaves the system through the sludge wastage system.

$$C_{II} = S_{II} + X_{II} \quad (2.2)$$

The subdivision of the biodegradable COD originally relates to the bi-substrate model of Dold and Marais [1], which identified two major fractions: readily biodegradable COD, S_{S1} , and slowly biodegradable COD, X_{S1} .

$$C_{S1} = S_{S1} + X_{S1} \quad (2.3)$$

The differentiation was based upon experimental observations showing a significant difference of approximately an order of magnitude between the rates of biodegradation of the two fractions. The slowly biodegradable fraction, originally defined as particulate organics in the model proposed by Dold and Marais [1], is now found to cover a wide range of particle size distribution from soluble to colloidal and larger organic particles of complex structure. The common feature of the particulate organics is that they can not pass through cell wall and need to undergo extracellular hydrolysis prior to adsorption. Hydrolysis is the rate limiting step for the utilization rate of the slowly biodegradable organic matter. Hydrolysis of organic matter occurs at various rates. Therefore the slowly biodegradable substrate is divided into further fractions, namely, rapidly hydrolyzable COD, S_{HI} , and slowly hydrolyzable COD, X_{S1} .

$$C_{S1} = S_{S1} + S_{HI} + X_{S1} \quad (2.4)$$

Figure 2.2 gives a schematical representation of different wastewater COD fractions.

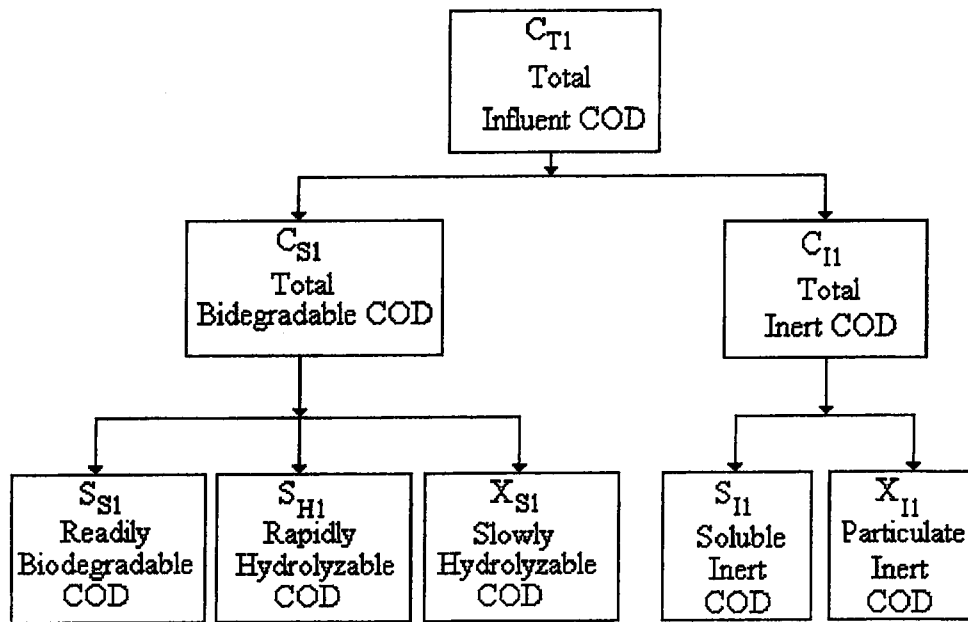


Figure 2.2 Distribution of COD Fractions in Wastewaters.

The mixed liquor and the process effluent exhibit a different COD structure from the wastewater. As far as soluble components are concerned, the quality of the process effluent is accepted to be the same as that of the mixed liquor, since process modelling generally includes the assumption that, no biological activity takes place in the settling phase. The total effluent soluble COD, S_T , includes the non-biodegradable organics originating from the wastewater and by-passing the reactor, S_{I1} , a small portion of the biodegradable COD remaining after biological oxidation ($S_S + S_H$), and soluble residual COD generated as metabolic products, S_P , as shown in Figure 2.3. Consequently, the effluent stream generally contains more soluble inert COD than the wastewater, since the effluent soluble residual COD, S_R , includes soluble residual products aside from the soluble inert COD of the wastewater by-passing the reactor.

$$S_R = S_{I1} + S_P \quad (2.5)$$

The generation of the soluble inert products have been incorporated into mathematical models by means of growth-associated or decay-associated processes [2]. In the models where soluble inert products are not included as a separate component, the entire residual COD, S_R , is measured and considered as a fictitious influent inert COD concentration.

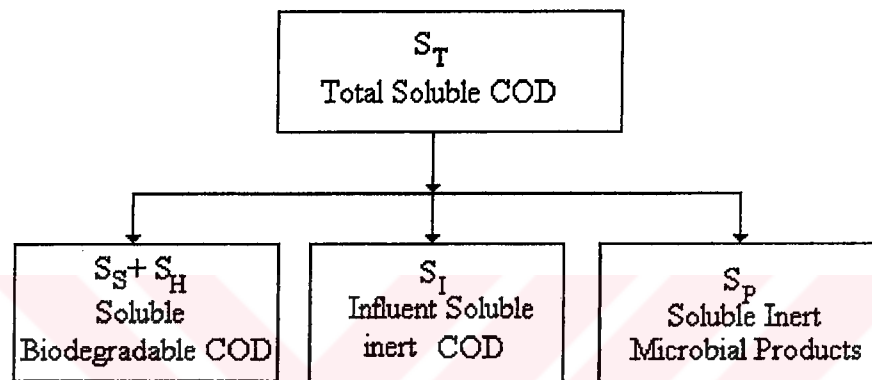


Figure 2.3 Soluble COD Fractions in the Mixed Liquor.

Similarly, the particulate COD in the mixed liquor and the process effluent has four fractions as shown in Figure 2.4.

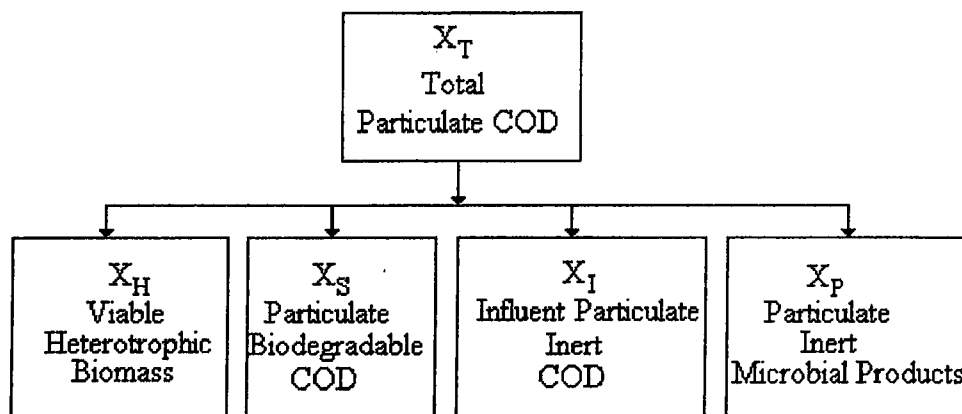


Figure 2.4 Particulate COD Fractions in the Mixed Liquor.

The major component is the active biomass, X_H , that is sustained in the reactor using the biodegradable COD as the energy and the carbon source. The other component may be a small fraction of the particulate slowly biodegradable organics, X_S , remaining after hydrolysis and subsequent utilization. The mixed liquor also contains particulate inert COD of influent origin, X_I , that is enmeshed in the sludge and accumulated in the reactor. This is not the only particulate non-biodegradable COD fraction: particulate inert organic products, X_P , are generated as a result of the microbial metabolic activity, during the endogenous decay phase. This spectrum accounts only for the organic structure of the activated sludge, also expressed in terms of the VSS parameter. The inorganic fraction of the activated sludge is also important in the process design, it is quantified as the difference between the mixed liquor suspended solids (SS), and the volatile suspended solids (VSS), concentrations.

2.3 MULTICOMPONENT MODELLING OF CARBON REMOVAL IN COMPLETELY MIXED SYSTEMS

A multicomponent approach to the modelling of activated sludge provides the necessary clarification to the composition of the activated sludge as far as the viable and particulate inert fractions are concerned, based upon improved process kinetics and stoichiometry. This information is of great significance for the correct assessment of the viable biomass in the reactor, and for the evaluation of the amount of sludge to be wasted from the system. The model also yields an accurate picture of the distribution of the soluble COD fractions in the effluent stream.

The relationships between the process components and the model parameters are derived on the basis of continuity equations defining mass balance around the influent and the effluent streams. The schematic process diagram shown in Figure 2.5 is used to define a steady-state kinetic model with the same simplifying assumptions as the traditional approach: no biomass and biochemical reactions in the settling tank and in the influent; complete settling.

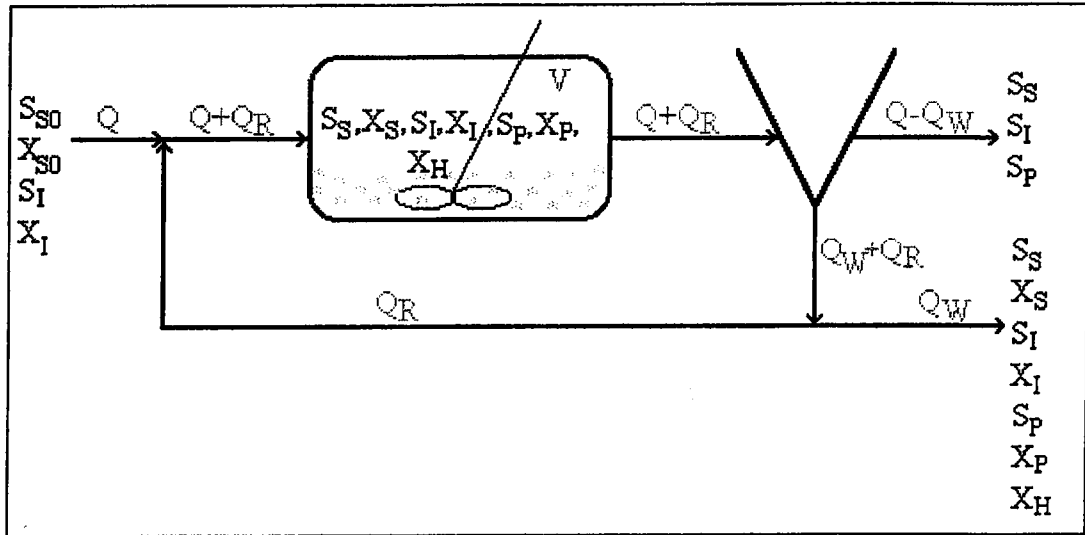


Figure 2.5 Schematic Process Diagram for Multicomponent Modelling of Carbon Removal in a Single CSTR.

2.3.1 Endogenous Decay Model

The Endogenous decay model is structured upon three processes: growth, decay, and hydrolysis. Table 2.1 gives the matrix representation of the process kinetics and the

Table 2.1 Process Kinetics and Stoichiometry for Carbon Removal Involving Endogenous Decay

Component Process	S_S	X_S	X_H	S_P	X_P	S_I	X_I	Reaction Rate
Growth	$\frac{1}{Y_H}$		1	α_D				$\mu_{max} \cdot \frac{S_S}{K_S + S_S} \cdot X_H$
Decay			-1	f_{ES}	f_{EX}			$b_H \cdot X_H$
Hydrolysis	1	-1						$K_H \cdot X_S$
Parameters, ML^{-3}	COD	COD	cell COD	COD	COD	COD	COD	

stoichiometry of the model based upon the concept of endogenous decay. It reflects the basic stoichiometric relationships affecting individual components. Influent inert COD fractions S_I and X_I do not include any stoichiometric coefficient, since they do not participate in biochemical processes.

On the basis of the process kinetics and stoichiometry outlined in Table 2.1, the continuity expression for the readily biodegradable substrate, S_S , defining the steady-state operation of a completely mixed reactor is given as:

$$\frac{dS_S}{dt} = Q \cdot S_{S0} - Q \cdot S_S - V \cdot \frac{\mu_{max}}{Y_H} \frac{S_S}{K_S + S_S} X_H + V \cdot K_H \cdot X_S = 0 \quad (2.6)$$

where,

μ_{max} is the maximum heterotrophic growth rate,

Y_H is the yield coefficient,

K_S is the half saturation constant,

K_H is the hydrolysis rate constant,

Q is the flow rate,

V is the volume of the reactor, and

X_H is the heterotrophic biomass.

A similar mass balance for the heterotrophic biomass, , yields:

$$\frac{dX_H}{dt} = -Q_w \cdot X_H + V \cdot \mu_{max} \frac{S_S}{K_S + S_S} X_H - V \cdot b_H \cdot X_H = 0 \quad (2.7)$$

where,

Q_w , is the flow rate of the sludge wasted.

The fundamental Monod equation is as follows:

$$\mu = \mu_{\max} \frac{S_s}{K_s + S_s} \quad (2.8)$$

The basic definition of the sludge age, θ_x , is:

$$\theta_x = \frac{V \cdot X_H}{Q_w \cdot X_H} \quad (2.9)$$

Hence,

$$\frac{1}{\theta_x} = \mu_H - b_H \quad (2.10)$$

where,

b_H is the heterotrophic decay rate.

The value of the readily biodegradable substrate concentration, S_s , in the mixed liquor is defined by combining Equation (2.10) with the fundamental Monod expression, formulated as Equation (2.8) :

$$S_s = \frac{K_s \cdot (1 + \theta_x \cdot b_H)}{\mu_{\max} \cdot \theta_x - (1 + \theta_x \cdot b_H)} \quad (2.11)$$

The slowly biodegradable COD, X_s , is the other component related to substrate utilization and microbial growth. The hydrolysis step associated with this fraction does not necessarily indicate that it should be considered as particulate material. The fate

of some soluble and colloidal organic compounds with large molecular weight can best be interpreted if they are included in this group. The type of expression to be derived depends upon the particle size distribution adopted for this fraction.

If the slowly biodegradable COD is assumed to be of particulate nature, the part that is not hydrolyzed is entrapped in activated sludge and discharged with the waste stream in accordance with the following equation:

$$\frac{dX_S}{dt} = Q \cdot X_{S0} - Q_W \cdot X_S - V \cdot K_H \cdot X_S = 0 \quad (2.12)$$

The hydraulic retention time, θ_h , is expressed as:

$$\theta_h = \frac{V}{Q} \quad (2.13)$$

Equation (2.12) may be rearranged as:

$$Q \cdot X_{S0} - Q \frac{\theta_h}{\theta_X} \cdot X_S - V \cdot K_H \cdot X_S = 0 \quad (2.14)$$

From Equation (2.14), X_S , may be calculated as:

$$X_S = \frac{\theta_X / \theta_h}{1 + K_H \cdot \theta_X} \cdot X_{S0} \quad (2.15)$$

Using the mass balance of readily biodegradable substrate under steady state conditions, i.e., Equation (2.6), the viable biomass concentration can be expressed as follows:

$$X_H = \frac{Y_H}{1 + \theta_X \cdot b_H} \cdot (C_{S0} - C_S) \cdot \frac{\theta_X}{\theta_h} \quad (2.16)$$

A practical approach for the assessment of the soluble inert products is to consider only the predominant mechanism compatible with the selected process operation, and to neglect the other. If growth-associated mechanism is estimated to be significant, the corresponding mass balance equation becomes:

$$\frac{dS_P}{dt} = -Q \cdot S_P + V \cdot \alpha_D \cdot \mu_{\max} \cdot \frac{S_S}{K_S + S_S} X_H = 0 \quad (2.17)$$

where,

α_D is the growth associated product formation coefficient.

The soluble microbial products, S_P , generated by the process can be estimated by:

$$S_P = \alpha_D \cdot Y_H \cdot (C_{S0} - C_S) \quad (2.18)$$

where, the fraction of biodegradable substrate that is converted to soluble microbial products, Y_{SP} , is defined as:

$$Y_{SP} = \alpha_D \cdot Y_H \quad (2.19)$$

The release of particulate inert products is described by the following mass balance equation:

$$\frac{dX_P}{dt} = -Q_W X_P + V \cdot f_{EX} \cdot b_H \cdot X_H = 0 \quad (2.20)$$

where,

f_{EX} is the inert fraction of the active biomass concentration.

Endogenous decay is conveniently described as an overall decrease in the mixed liquor VSS concentration in the conventional models by means a decay coefficient. When the concept of viability is considered, the decay of active biomass is coupled with the generation of inert endogenous mass or particulate inert products. During endogenous respiration, a fraction f_{EX} , of the active biomass does not undergo any further reaction and accumulates in the activated sludge. The only way this fraction can be removed from the system is sludge wastage.

As originally defined by McKinney [3], the rate of decrease in total biomass is the sum of the endogenous decay rate of the active biomass and the generation rate of the particulate inert products. A value of 0.2 is universally accepted to characterize f_{EX} , based upon earlier observations [4], [5], [6]. This residual fraction is said to be a complex polysaccharide by McKinney [3].

Using the above equation, particulate microbial products may be expressed as:

$$X_P = f_{EX} \cdot \theta_X \cdot b_H \cdot X_H \quad (2.21)$$

Although the influent inert COD fractions, S_I , and X_I , do not participate in the biochemical reactions, and the soluble inert COD, S_I , by-passes the system, the influent particulate inert COD, X_I , is entrapped and accumulated in the activated

sludge by the ratio of the sludge age to the hydraulic retention time maintained in the system, due to the sludge recycle. The corresponding mass balance is written as:

$$\frac{dX_I}{dt} = Q \cdot X_{I0} - Q_w \cdot X_I = 0 \quad (2.22)$$

The concentration of the influent particulate inert COD, X_I , may be expressed as:

$$X_I = X_{I0} \frac{\theta_x}{\theta_h} \quad (2.23)$$

The equation above indicates that activated sludge systems operated at long sludge ages face the problem of high rate of accumulation of biologically inert particulate organic matter. Therefore systems with long sludge ages end up with greater amount of influent particulate inert COD, in addition to the particulate inert microbial products generated, within the system. Thus the fraction of the viable biomass in the reactor decreases. If the influent particulate inert COD, and the inert particulate microbial products generated, are not taken into account when designing the process, both the efficiency and the amount of sludge production of the system will be underestimated.

The new concept of multicomponent activated sludge systems, guides the environmental engineer for an accurate system design. As far as the inert particulate material - either influent origin, or generated by the system-, is concerned, the sludge production is to be inspected carefully for the efficient and accurate design of any completely mixed activated sludge system with sludge recycle. In view of these concepts the assessment of the initial particulate inert COD, X_I , has gained great importance in wastewater characterization, and process modelling and design.

SECTION 3

ASSESSMENT OF INITIAL PARTICULATE INERT CHEMICAL OXYGEN DEMAND OF WASTEWATER

3.1 FORMERLY PROPOSED METHODS FOR THE ESTIMATION OF INITIAL INERT PARTICULATE COD

The initial inert particulate COD, was traditionally overlooked in the rational description of the activated sludge process mainly because of the structural inadequacy of the classical modelling approach based on only two parameters (overall substrate and biomass) and two processes, namely, bacterial growth and decay [7]. However the traditional modelling approach has been expanded [8], and modified [2],[9], to include eight components and three processes for carbonaceous compounds.

Assessment of the inert fraction of the organic matter is very important because it indicates indirectly, the other main fraction, which is biodegradable organic matter, i.e., substrate available for microbial growth and electron acceptor utilization. A number of methods have so far been proposed for the estimation of particulate inert fraction of wastewater, as listed in Table 3.1 [10].

Procedures generally suggested for the assessment of initial particulate inert COD, involve the kinetic analysis of a laboratory-scale completely mixed activated sludge unit operated at steady-state or laboratory-scale batch tests. The proposed procedures will be examined one by one in the succeeding items.

Table 3.1 Methods For Estimating Particulate Inert Organic Fraction in Wastewater

Test Methods	Reference
Continuous + model calculation	Ekama et al. [11]
Calibrated with sludge production	Henze et al. [8]
Batch	Orhon et al. [12]
Batch	Kappler and Gujer [13]
Batch	Lesouef et al. [14]
Batch	Germirli et al. [15]
Batch	Orhon et al. [7]

3.1.1 Experimental Method Proposed by Ekama et al. [11]

Two laboratory-scale completely mixed aerobic reactor systems are operated two different sludge ages longer than 5 days - say 10 and 20 days. Each of the units are fed a constant mass of COD each day at a constant flow rate over the day. The influent waste flow is collected in large batches sufficient for one to two weeks feed. The sludge age is set by hydraulic control. In this control procedure, there is no attempt to control MLVSS concentration in the reactor to some selected value; instead, a fixed volume of mixed liquor is abstracted daily directly from the reactor; e.g. at 10 and 20 days sludge age, every day 1/10th and 1/20th of the reactor volume respectively is abstracted. In time, the reactor MLVSS concentration will reach a steady-state value and corresponding to the set sludge age.

Once at steady-state the following parameters are measured regularly over 2 or 3 sludge ages; influent COD unfiltered; effluent COD filtered and unfiltered; reactor MLSS and MLVSS, the COD/VSS ratio of the VSS and the oxygen utilization rate (OUR) in the reactor.

The influent unbiodegradable particulate COD (X_{fi}), is calculated by calibration against the hypothesized model describing the activated sludge process. The mass of VSS in the system is calculated for the two sludge ages according to the below relationship: Mass of VSS in the system is equal to the sum of active organism mass

in the system, endogenous residue mass in the system, and inert VSS mass from unbiodegradable particulate COD accumulated in the system.

The value of reactor VSS is dependent on the kinetic and stoichiometric values of Y_H , b_H , f_{EX} , the COD/VSS ratio of the sludge and the ratio of the particulate inerts to the influent COD concentration (f_{UP}). The values of these constants are used as they are generally accepted. So the reactor VSS is calculated with these constants for a range of f_{UP} values; the f_{UP} value which gives the closest mass of VSS to that measured in the system for both sludge ages, is estimated as the ratio of the particulate inerts to the influent COD concentration (f_{UP}). This ratio of the particulate inerts to the influent COD concentration (f_{UP}) is checked by using this value in the calculation of the daily carbonaceous oxygen demand and comparing this with the measured carbonaceous oxygen demand.

The Task Group [8] recommends a similar approach based upon the comparison of the of observed and calculated sludge production. These procedures require that two kinetic constants, namely the heterotrophic yield, Y_H , the endogenous decay rate, b_H , and the inert fraction of the biomass, f_{EX} , be correctly determined by independent experimental methods.

3.1.2 Experimental Method Proposed by Orhon et al. [12]

This method is defined as a modification of that previously proposed by Germirli et al. [16] to access S_I . Basically, the method involves running three batch reactors, two with the wastewater to be studied and the third with glucose. The first wastewater reactor is started with raw wastewater, total COD, C_{T0} , and the second, with the total soluble COD, S_{T0} , whereas the initial COD in the glucose reactor is adjusted to equal S_{T0} . In the reactors, minimal amount of wastewater and glucose acclimated seed of activated sludge is used and the changes in the soluble COD profiles are observed for a period during which all degradable COD is entirely depleted.

The soluble COD in the glucose reactor reaches a level characterizing the soluble residual microbial products, S_P , alone, as glucose contains no initially inert fraction. This concentration of the soluble residual microbial products, S_P , is assumed to be the same as the reactor started with soluble wastewater. This assumption is justifiable as the two reactors are operated with approximately the same S_{S0} .

In the wastewater reactor started with soluble wastewater, S_{T0} , the COD is reduced to a minimum level equal to the sum of initial soluble inert COD, S_I , and soluble residual microbial products, S_P . Consequently the soluble inert fraction, S_I of the wastewater can be calculated and this is used to calculate the soluble residual microbial products, S_P , of the raw wastewater reactor, by subtracting the inert fraction from the final soluble COD. The ratio of the two the soluble residual microbial products, S_P , is equal to the ratio of the initial total biodegradable COD to initial soluble biodegradable COD. Since initial soluble biodegradable COD is the difference of the initial total soluble COD and the inert fraction, the initial total biodegradable COD can be estimated. The initial particulate inert COD, X_I , is calculated by subtracting the soluble inert fraction and the initial total biodegradable COD, from the initial total COD of the wastewater.

3.1.3 Experimental Method Proposed by Kappler and Gujer [13]

Kappler and Gujer [13] have proposed a batch test, instead of the comparison method of Task Group. The batch test is carried out just with wastewater. Because in such a batch reactor the initial concentrations of readily biodegradable substrate, S_{S0} , slowly biodegradable substrate, X_{S0} , and the heterotrophic biomass, X_{H0} , can be determined by curve fitting and the soluble inert COD, S_{I0} , as well as the total COD by simple measuring, the inert suspended organic matter, X_{I0} can be obtained by subtracting all of the four initial COD fractions from the total initial COD.

3.1.4 Experimental Method Proposed by Lesouef et al. [14]

Two parallel batch tests are carried out with filtered and non-filtered samples of wastewater, aerated continuously. The inert particulate matter, X_I , can be estimated by the difference between the total COD of the aerated non-filtered sample, minus the created biomass, and the soluble inert COD, S_I .

The particulate mass generated by the biodegradation of the remaining matter in the filtrate is calculated as the difference between the final total COD of the filtered sample minus the final soluble COD of the experiment with the filtered sample, S_I . The observed yield of biomass production per degraded COD can then be calculated by putting the mass created into relation with the COD degraded.

The calculation of the biomass formed by the removal of the degradable particulate matter is based on the non-filtered sample: the difference of initial total COD and the soluble final COD corresponds to the converted substrate. Multiplied by the yield, this gives the created biomass.

The inert particulate matter is the difference between the final total COD of the non-filtered sample, from which the soluble inert fraction is reduced, X_I , and the produced biomass.

3.1.5 Experimental Method Proposed by Germirli et al. [15]

Two aerated batch reactors, one fed with unfiltered wastewater, C_{T0} , and the other with filtered wastewater, S_{T0} , seeded with a minimal amount of biomass previously acclimated to the same sample are run and the final threshold values of the total and soluble COD are measured after a period in which all biological activity has been completed. The relationships between the different COD concentrations measured allow for the direct assessment of the initial particulate inert COD, X_I .

The ratio of the amount of total COD removed from raw wastewater reactor to the amount of total COD removed from filtered wastewater reactor, is equal to the ratio of the initial total biodegradable COD to initial soluble biodegradable COD. The particulate COD generated in the filtered wastewater reactor, is equal to the particulate microbial products, X_P , and the particulate microbial products, X_P , of the raw wastewater reactor is estimated by using the ratio of the initial total biodegradable COD to initial soluble biodegradable COD. The initial particulate COD, X_I , is then calculated by the difference of the final particulate COD and the particulate microbial products generated in the raw wastewater reactor.

3.1.6 Experimental Method Proposed by Orhon et al. [7]

This method involves the monitoring of the particulate COD. The method relies on the measurement of the final threshold value of this parameter in an aerated batch reactor fed by the initial total COD, C_{T0} , of the wastewater to be tested and seeded by a minimal amount of biomass previously acclimated to the wastewater, to avoid possible interference. The threshold measurement is made after a reaction time long enough to ensure the depletion of all biodegradable substrate and the mineralization of all biomass, so that the measured particulate COD is the sum of the initial inert particulate COD and the residual particulate product generated by the biomass decay. The residual particulate product generated, X_P , is calculated theoretically and thus the initial inert particulate COD, X_I , is then calculated by using an iterative procedure. The procedure also requires if initial soluble inert COD, S_I , is present this would be experimentally measured and accounted for, using one of the previously suggested methods [16].

3.2 LITERATURE SURVEY ON THE PARTICULATE MICROBIAL PRODUCTS

Previous studies on the activated sludge systems, lead scientists to the idea of operating the conventional activated sludge systems with no sludge wastage. Total oxidation of the organic influent substrate was first proposed by Porges, Jasewicz, and Hoover [17], in 1953. They developed the theory of the substrate being removed and assimilated into new cells as Phase I, and the entire flora of the cells being self-oxidized (endogenous respiration) in what was called Phase II. It was claimed that in Phase I, 52% of the substrate reappeared as new cells (activated sludge). In Phase II, Porges et al., measured an endogenous rate of 1% per hour, or a total time of 460 hr for 99% endogenous oxidation of a unit mass of newly created cells.

These data indicated that there should exist an equilibrium between the weight of new sludge created and the weight of sludge lost by self-oxidation. This suggests that there could result a system in which the entire influent was eventually oxidized, and thus there would be no sludge removal required.

To investigate this theory, small industrial waste and sanitary sewage treatment plants were constructed embodying these proposed principles. However the lack of complete operating data and erratic quantities and qualities of influent limited the accumulation of usable data. It was suspected that these systems regularly discharged low concentrations of activated sludge and thus produced a pseudo-equilibrium.

Symons and McKinney [18] showed that the total oxidation of such flora was not possible and that a small amount of non-oxidizable polysaccharide material remained. Some theories were proposed that alternate feeding and starving of a culture produced atypical data.

3.2.1 The Study of Kountz and Forney [4]

Kountz and Forney [4] suggested that the accurate evaluation of such an entire system could best be demonstrated by a continuous operation with a uniform concentration of influent having a known chemical composition, and with measurement of the system effluents.

The experimental system consisted of a series of six aeration tanks, a substrate dispenser, and a substrate dispenser, and a clarifier. The influent was formed by adding 0.2 gpm of skim milk powder solution by means of a positive displacement pump, the strength of the solution being prepared so as to feed 1.65 lb. of dry milk solids per 24 hr.

Skim milk powder (52% lactose, 37% casein, and 11% ash) was used because of its uniformity in chemical composition, its economy in bulk and in cost, its easy solubility, its desirable C-N ratio, and most important its similarity in chemical components to those of sanitary sewage.

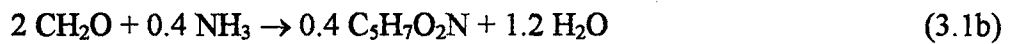
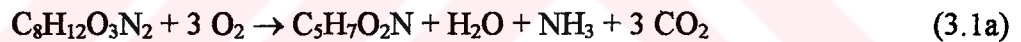
The system originally inoculated with a mixture of activated sludge from a domestic sewage treatment plant and a water extraction of top soil, was in continuous operation for approximately six months prior to the collection of any data reported.

Essentially the system had a detention time of seven and one-half hours: one hour of sludge aeration prior to substrate addition, five hours of aeration following substrate addition, and one and a half hours of clarification and sludge return. The system design also provided for changing the point of influent addition to any of the six aeration tanks, as desired; however, during the period of this study the influent was added to the second aeration tank. Preceding the series of observations the following average characteristics of the system were determined as; pH: 7.2, temperature: 75 °F, and oxygen supply: ≥ 2 ppm.

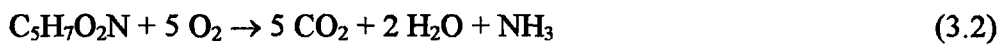
Also it was found that the removal of the skim milk solids from solution as measured by the COD and lactose tests was so rapid that none of the components could be detected in the substrate after 30 minutes, which was the shortest sampling time available.

The weight of suspended solids (in the system and lost in the effluent) was determined by the membrane filter method described by Engelbrecht and McKinney [19]. Effluent solids determinations were made on a composite sample collected over a 24 hour period by means of the pump. The first solids balance was maintained for a period of 44 days, during which the total weight of solids in the aeration system remained constant but there was a discharge of 0.122 lb. of sludge in the effluent each day. The second solids balance was attempted with no discharge of sludge for a period of 80 days, but this resulted in a uniform increase of solids in the system of 0.122 lb./day.

New Sludge Formation:



Endogenous Oxidation:



To evaluate the sludge produced and oxidized in the system, attention is directed to the two sludge formation Equations (3.1a) and (3.1b) which would indicate the creation of 0.515 lb./day of new sludge instead of the value of 0.75 lb./day proposed by Porges et al[20], from the same initial constituents. When the system was operating at an internal solids balance there was an effluent discharge of 50 mg/l. of activated sludge, equivalent to 0.12 lb./day. The effluent solids discharge was eliminated with the result of daily increase in the total system weight of activated

sludge equal to 0.12 lb./day. This would indicate that 23% of the sludge is non-oxidizable (polysaccharide material).

From the results of studies on metabolic energy balances in a multiple-unit total oxidation system using dry skim milk as a source of organic matter, the following conclusion is reached: Total endogenous oxidation is not possible within reasonable times and sizes of treatment systems, as there is a residual material remaining equivalent to 20 to 25% by weight of the new activated sludge produced.

3.2.2 The Study of McKinney [3]

The key to understanding the complete mixing activated sludge process lies in understanding the fundamental biochemistry of aerobic biological metabolism. The stabilization of organic matter in wastes is brought about by the metabolic reactions of the microorganisms that live within the aeration tank.

Bacteria metabolize organic matter to produce protoplasm for the creation of new bacteria. Protoplasm is not a single chemical substance but a mixture of hundreds of different chemical molecules from a single organic compound and simple mineral salts. To do this bacteria must be able to break down the organic molecule being metabolized and synthesize all the molecules for protoplasm. The synthesis requires energy, which the bacteria obtain by oxidizing a portion of the organic molecules being metabolized.

Bacteria require a small amount of energy to maintain normal functions such as motion and enzyme activation. The basal-energy requirement of the bacteria has been designated as endogenous respiration. It has been shown that the endogenous respiration reaction is a continuous reaction that results in the metabolism of certain components of protoplasm. Even when excess nutrients are available, endogenous metabolism proceeds with the breakdown of protoplasm. The significance of this is simply that all the organic matter metabolized enters into the synthesis reactions, with

the net protoplasm or sludge accumulation being the difference between the synthesis reaction and the endogenous reaction.

The endogenous metabolism is a function of the living or active portion of the bacterial mass. As endogenous metabolism proceeds, the bacteria reach a point at which they can no longer sustain life and die. A portion of the dead bacteria undergoes lysing with a release of the remaining nutrients into the outer environment where other bacteria can utilize these nutrients as food. A residual organic fraction of bacteria remains, which is insoluble and not metabolizable by other bacteria. This residual fraction was believed by Symons and McKinney [18] to be complex polysaccharide. In the activated sludge, the endogenous reaction can be assumed as a continuous reaction in which the residual, inert organic matter accumulates in proportion to the endogenous metabolism.

The rate of formation of residual, inert organic matter, is reported as 0.0015 /hr. or 0.036 /day. This rate is proportional to endogenous respiration rate which is found to be 0.007 /hr. The proportionality constant of the two rates reflects the inert fraction of the biomass, f_{EX} , which can be calculated to be 21% with these results of McKinney.

3.2.3 The Study of Washington and Symons [6]

In order to determine the accumulation of sludge at equilibrium, it was important to choose laboratory models which would closely duplicate biological conditions occurring in the extended sludge aeration activated sludge plants. These plants could be classified in two general groups depending on their loading procedures. The first type operates over a wide range of biological growth curve as a result of a continually varying organic substrate concentration. The second type operates at a constant organic substrate concentration which results in a more stable biological system.

The pilot plants chosen for this investigation were 1.5 l. rectangular tanks. A batch-fed basin was used to simulate the conventional activated sludge system. A

continuously fed basin was used to represent the complete mixing activated sludge systems.

The study is concerned with the relative degradability of the equilibrium sludge components under endogenous respiration. The investigation was undertaken to determine whether the various cell fractions were degraded at the same relative rate at which they are synthesized. It was felt this information would aid in determining the general composition of any biologically inert organic sludge accumulation.

The activated sludge remaining in the basins after the synthesis study was allowed to aerate without subsequent substrate addition. Samples of the endogenous state were analyzed for their content of volatile solids and major cell components.

Over the period of no sludge wasting, the complete mixing acetate fed systems showed an average volatile accumulation of 11.5% of the ultimate BOD removed. A similar conventional system showed 14.5% accumulation of the ultimate BOD removed. The data are sufficient to show that during stabilization in the equilibrium phase the systems continued to accumulate solids. The rate of buildup in the 16 basins ranged from about 4 to 15% of the ultimate BOD removed as new sludge.

These findings are in agreement with that of Kountz and Forney [4], where from 11.6 to 14.5% of the substrate ultimate BOD fed to their system appeared as solids accumulation.

3.3 EXPERIMENTAL PROCEDURES CARRIED OUT IN THIS STUDY FOR THE ESTIMATION OF INITIAL INERT PARTICULATE COD

In this study, three of the proposed experimental methods, [7], [12], and [15], are experimentally tested to determine the initial inert particulate COD, X_I . The methods were defined by applying concepts of current mathematical models so that similar fractions, initially present in the input stream and generated later as microbial products, could be separately identified.

All of the three methods studied are conducted as batch tests and have similarities which enable the experimentalist examine the methods in parallel.

3.3.1 Conceptual Approach

The assessment of initial particulate inert COD depends on differentiating it from the residual microbial products. In order to differentiate between the initial particulate inert COD and residual microbial products, the latter should be expressed in terms of the total biodegradable COD. These expressions may be derived by means of the model equations which describe the performance of the activated sludge system operated at steady state [9].

Using the mass balance equations on readily biodegradable COD, Equation (2.6), on the slowly biodegradable COD, Equation (2.12), on the heterotrophic biomass, Equation (2.7), on the soluble residual products, Equation (2.17), and on the particulate residual products, Equation (2.20), and substituting the steady-state solutions of these equations, i.e., Equation (2.11), defining the readily biodegradable COD, Equation (2.15), defining the slowly biodegradable COD, Equation (2.16), and defining the heterotrophic biomass, into the expressions defining the soluble residual products, Equation (2.18), and the particulate residual products, Equation (2.21), the following model equations are obtained for the residual microbial products;

Soluble residual products:

$$S_P = \alpha_D \cdot Y_H \cdot (C_{S0} - C_S) \quad (3.3)$$

If the residual soluble microbial products coefficient is defined as Equation (2.19):

$$S_P = Y_{SP} \cdot (C_{S0} - C_S) \quad (3.4)$$

Particulate residual products:

$$X_P = f_{EX} \cdot \theta_X \cdot b_H \frac{Y_H}{1 + \theta_X \cdot b_H} (C_{S0} - C_S) \frac{\theta_X}{\theta_H} \quad (3.5)$$

If the residual soluble microbial products coefficient is defined as:

$$Y_{XP} = f_{EX} \cdot \theta_X \cdot b_H \frac{Y_H}{1 + \theta_X \cdot b_H} \cdot \frac{\theta_X}{\theta_H} \quad (3.6)$$

Substituting the above expression into Equation (3.3), the particulate residual products are defined by:

$$X_P = Y_{XP} \cdot (C_{S0} - C_S) \quad (3.7)$$

In an experimental study long enough for all biological reactions to be completed:

$$\theta_X \approx \infty, \theta_H \approx \infty, \text{ and } \theta_X = \theta_H, \quad (3.8)$$

$$\left. \begin{array}{l} S_S \approx 0 \\ X_S \approx 0 \end{array} \right\} \Rightarrow C_S \approx 0, \text{ and } X_H \approx 0 \quad (3.9)$$

Under these experimental conditions summarized by Equation (3.8) and (3.9), the model equations used in this study can be defined by:

$$S_P = \alpha_D \cdot Y_H \cdot C_{S0} \quad (3.3)$$

and,

$$Y_{SP} = \alpha_D \cdot Y_H \quad (2.19)$$

so the soluble residual products are expressed as:

$$S_P = Y_{SP} \cdot C_{S0} \quad (3.4)$$

When the limits of the experimental conditions are adopted to Equation (3.5):

$$X_P = f_{EX} \cdot Y_H \cdot C_{S0} \quad (3.10)$$

and, Equation (3.6) becomes:

$$Y_{XP} = f_{EX} \cdot Y_H \quad (3.11)$$

so the particulate residual products are expressed as:

$$X_P = Y_{XP} \cdot C_{S0} \quad (3.12)$$

3.3.2 Experimental Procedure

Three batch aerated reactors were prepared for this study. The first reactor was fed with raw wastewater, the second, with filtered wastewater, and the third with glucose. The same acclimated seed was used in all the three reactors.

3.3.2.1 Acclimation

Some activated sludge seed was taken and fed with fresh wastewater and glucose solution mixture in an aerated fill and draw reactor. The hydraulic detention time was set at one day, and the aeration of the reactor was withdrawn after 23 hours to allow one hour of settling. The aqueous upper portion of the reactor was wasted and the

reactor was fed with fresh wastewater and glucose solution. The wastewater and the glucose solution mixture was previously prepared to have equal COD concentrations.

After the mixed liquor VSS concentration reached at a desired level, the daily VSS concentrations were observed and the amount of excess sludge produced, was wasted. When the amount of excess sludge was approximately constant, the fill and draw system is said to reach steady-state with definite sludge age, hydraulic detention time and F/M ratio. The F/M ratio was chosen to be greater than 1 to sustain the activity of the biomass in the reactor and to reduce the accumulation of inert particulate residual products in the activated sludge.

3.3.2.2 Experiments

As explained above, three batch reactors were prepared. Tannery wastewater, from Tuzla leather industry complex, was used in the experiments. The reactor volumes were chosen as two liters. The first reactor was fed with raw wastewater. The wastewater used in the second reactor was the filtrate from the AP40 filter paper. The initial total and soluble COD of the wastewater was exactly determined, and the third reactor was fed with a glucose solution having the same COD of that of the filtered wastewater. After the nutrient solutions were added the pH was adjusted if necessary. All the three reactors were seeded with the wastewater-glucose acclimated activated sludge, by using the minimum amount of biomass, about 30–40 mg/l VSS, in order to prevent the effect of external particulate inert interference. The reactors were aerated vigorously so that oxygen is not a rate limiting parameter.

The total and soluble COD profiles of the two wastewater reactors and the soluble COD profile of the glucose reactor were observed for a period long enough to ensure the depletion of all the biodegradable substrate and the mineralization of all biomass, i.e., until the final COD values were constant. The oxygen uptake rates (OUR) of the reactors were checked before the experiments were ended. The experimental data obtained in this way from parallel reactors were used to evaluate the initial particulate COD with the three proposed methods explained below.

3.3.3 Evaluation Procedure

The three methods proposed were explained previously. The coming sections will present their calculation procedures.

3.3.3.1 Method 1 [7]

The experimental pathway and calculations are explained below:

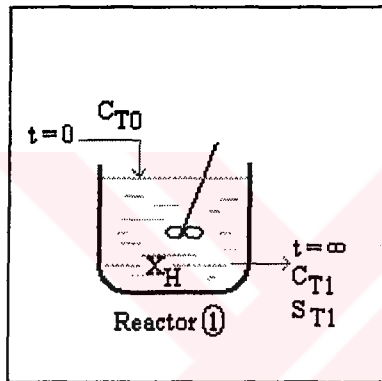


Figure 3.1 Schematic Representation of Raw Wastewater Reactor

The influent used in Reactor 1 is raw wastewater, C_{T0} , composed of readily, S_{S0} , and slowly, X_{S0} , biodegradable COD and the soluble, S_I , and particulate, X_I , inert COD as below:

$$C_{T0} = S_{S0} + X_{S0} + S_I + X_I \quad (3.13)$$

The effluent total COD, C_{T1} , is composed of the soluble, S_I , and particulate, X_I , inert COD and the soluble, S_{P1} , and particulate, X_{P1} , residual products as below:

$$C_{T1} = S_I + X_I + S_{P1} + X_{P1} \quad (3.14)$$

The effluent soluble COD, S_{T1} , is composed of the soluble inert COD, S_I , and the soluble residual products, S_{P1} , as below:

$$S_{T1} = S_I + S_{P1} \quad (3.15)$$

The calculation procedure is based on simple iteration.

1. Final Particulate COD, X_T , is defined as:

$$X_T = C_{T1} - S_{T1} \quad (3.16)$$

2. The first estimation of the particulate products, X_{P1} , is given by using initial total COD, C_{T0} , instead of C_{S0} :

$$X_{P1} = Y_{XP} \cdot C_{S0} = f_{EX} \cdot Y_H \cdot C_{S0} \quad (3.17)$$

3. The first estimation of the initial inert particulate COD, X_I , is defined by:

$$X_I = X_{T1} - X_{P1} \quad (3.18)$$

4. The biodegradable COD, C_{S0} , is calculated as:

$$C_{S0} = C_{T0} - X_I - S_I \quad (3.19)$$

The procedure returns back to step 3 until the same result for X_I is obtained.

3.3.3.2 Method 2 [15]

The experimental pathway and calculations are explained below:

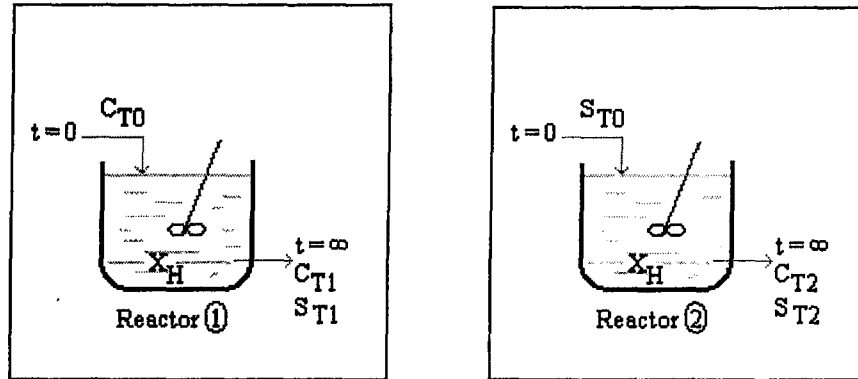


Figure 3.2 Schematic Representation of Raw and Filtered Wastewater Reactors

The influent used in Reactor 1 is raw wastewater, C_{T0} , composed of readily, S_{S0} , and slowly, X_{S0} , biodegradable COD and the soluble, S_I , and particulate, X_I , inert COD as below:

$$C_{T0} = S_{S0} + X_{S0} + S_I + X_I \quad (3.13)$$

The effluent total COD, C_{T1} , is composed of the soluble, S_I , and particulate, X_I , inert COD and the soluble, S_{P1} , and particulate, X_{P1} , residual products as below:

$$C_{T1} = S_I + X_I + S_{P1} + X_{P1} \quad (3.14)$$

The effluent soluble COD, S_{T1} , is composed of the soluble inert COD, S_I , and the soluble residual products, S_{P1} , as below:

$$S_{T1} = S_I + S_{P1} \quad (3.15)$$

The influent used in Reactor 2 is filtered wastewater, S_{T0} , composed of readily, S_{S0} , and the soluble inert COD, S_I , as below:

$$S_{T0} = S_{S0} + S_I \quad (3.20)$$

The effluent total COD, C_{T2} , is composed of the soluble inert COD, S_I , and the soluble, S_{P2} , and particulate, X_{P2} , residual products as below:

$$C_{T2} = S_I + S_{P2} + X_{P2} \quad (3.21)$$

The effluent soluble COD, S_{T2} , is composed of the soluble inert COD, S_I , and the soluble residual products, S_{P2} , as below:

$$S_{T2} = S_I + S_{P2} \quad (3.22)$$

The calculation procedure is as follows:

1. Total COD removed from raw wastewater reactor, ΔC_{T1} , is defined by:

$$\Delta C_{T1} = C_{T0} - C_{T1} = C_{S0} - S_{P1} - X_{P1} = (1 - Y_{SP} - Y_{XP}) C_{S0} \quad (3.23)$$

2. Total COD removed from filtered wastewater reactor, ΔC_{T2} , is defined by:

$$\Delta C_{T2} = S_{T0} - C_{T2} = S_{S0} - S_{P2} - X_{P2} = (1 - Y_{SP} - Y_{XP}) S_{S0} \quad (3.24)$$

3. The particulate COD generated in the filtered wastewater reactor, is equal to the particulate microbial products, X_{P2} :

$$X_{P2} = C_{T2} - S_{T2} \quad (3.25)$$

4. The particulate microbial products, X_{P1} , of the raw wastewater reactor is estimated by:

$$X_{P1} = X_{P2} \frac{\Delta C_{T1}}{\Delta C_{T2}} \quad (3.26)$$

5. The initial particulate inert COD, X_I , is calculated by:

$$X_I = C_{T1} - S_{T1} - X_{P1} \quad (3.27)$$

This method can also be used to calculate S_{P1} , as below:

$$S_{P1} = \frac{S_{T1} - S_{T2}}{1 - \frac{\Delta C_{T2}}{\Delta C_{T1}}} \quad (3.28)$$

The initial inert soluble COD, S_I , is defined by:

$$S_I = S_{T1} - S_{P1} \quad (3.29)$$

Soluble biodegradable COD, S_{S0} , can then be calculated by:

$$S_{S0} = S_{T0} - S_I \quad (3.30)$$

3.3.3.3 Method 3 [12]

The experimental pathway and calculations are explained below:

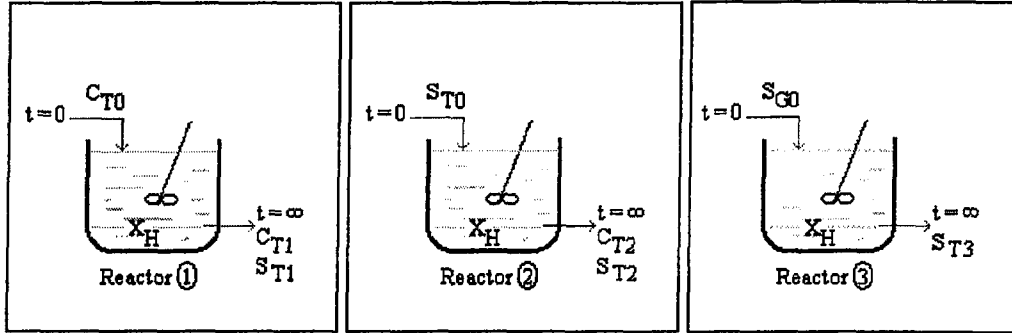


Figure 3.3 Schematic Representation of Raw and Filtered Wastewater, and Glucose Reactors

The influent used in Reactor 1 is raw wastewater, C_{T0} , composed of readily, S_{S0} , and slowly, X_{S0} , biodegradable COD and the soluble, S_I , and particulate, X_I , inert COD as below:

$$C_{T0} = S_{S0} + X_{S0} + S_I + X_I \quad (3.13)$$

The effluent soluble COD, S_{T1} , is composed of the soluble inert COD, S_I , and the soluble residual products, S_{P1} , as below:

$$S_{T1} = S_I + S_{P1} \quad (3.15)$$

The influent used in Reactor 2 is filtered wastewater, S_{T0} , composed of readily, S_{S0} , and the soluble inert COD, S_I , as below:

$$S_{T0} = S_{S0} + S_I \quad (3.20)$$

The effluent soluble COD, S_{T2} , is composed of the soluble inert COD, S_I , and the soluble residual products, S_{P2} , as below:

$$S_{T2} = S_I + S_{P2} \quad (3.22)$$

The influent used in Reactor 3 is glucose solution with the same COD, S_{G0} , of the filtered wastewater reactor, S_{T0} :

$$S_{G0} = S_{T0} \quad (3.31)$$

The effluent soluble COD, S_{T3} , is composed of soluble residual products, S_{P3} :

$$S_{T3} = S_{P3} \quad (3.32)$$

The calculation procedure is as follows:

1. The fraction of biodegradable COD that is converted into soluble residual products, Y_{SP} , is calculated as:

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} \quad (3.33)$$

2. The soluble inert COD, S_I , is calculated as:

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} \quad (3.34)$$

3. The soluble microbial products generated by the raw wastewater reactor, S_{P1} , is calculated as:

$$S_{P1} = S_{T1} - S_I \quad (3.35)$$

4. The soluble microbial products generated by the filtered wastewater reactor, S_{P2} , is calculated as:

$$S_{P2} = S_{T2} - S_I \quad (3.36)$$

5. The soluble biodegradable COD of the filtered wastewater reactor, S_{S0} , is:

$$S_{S0} = S_{T0} - S_I \quad (3.37)$$

6. The total biodegradable COD of the raw wastewater reactor, C_{S0} , is defined by:

$$C_{S0} = \frac{S_{P1}}{S_{P2}} S_{S0} \quad (3.38)$$

7. The initial particulate inert COD, X_I , is calculated by:

$$X_I = C_{T0} - C_{S0} - S_I \quad (3.39)$$

SECTION 4

EXPERIMENTAL RESULTS

4.1 CONDUCTED EXPERIMENTS

Four sets of experiments were conducted with tannery wastewater, for the assessment of initial particulate inert COD, X_I . The three proposed methods were evaluated for all the four sets of experiments, for which three batch reactors of 2 lt. were used, fed with raw, filtered wastewater, and glucose solution. The first three sets were conducted in the way explained in Section 3.3.2.2, whereas in the fourth set the filtration is done by membrane filters of $0.45\mu\text{m}$.

Experimental Set 1 is conducted with the tannery wastewater sample of 7/10/1996, with the conventional characterization given in Table 4.1.

Table 4.1 Conventional Wastewater Characterization of Set 1

Parameter	Value
pH	8.5
SS	1100 mg/l.
VSS	680 mg/l.
COD _{TOTAL}	1930 mg/l.
COD _{SOLUBLE}	1260 mg/l.
TKN	193 mg/l.
TKN _{SOLUBLE}	160 mg/l.
NH ₃ -N	160 mg/l.
TP	6.4 mg/l.
P _{SOLUBLE}	6.1 mg/l.
Alkalinity	1875 mg/l.
Cl ⁻	8095 mg/l.
Sulfur	20 mg/l.
Cr _{TOTAL}	30 mg/l.

Experimental Set 2 is conducted with the tannery wastewater sample of 11/11/1996, with the conventional characterization given in Table 4.2.

Table 4.2 Conventional Wastewater Characterization of Set 2

Parameter	Value
pH	7.5
SS	1480 mg/l.
VSS	940 mg/l.
COD _{TOTAL}	2030 mg/l.
COD _{SOLUBLE}	1000 mg/l.
TKN	210 mg/l.
TKN _{SOLUBLE}	160 mg/l.
NH ₃ -N	145 mg/l.
TP	1.3 mg/l.
P _{SOLUBLE}	1.2 mg/l.
Alkalinity	1075 mg/l.
Cl ⁻	8195 mg/l.
Sulfur	10 mg/l.
Cr _{TOTAL}	55 mg/l.

Experimental Set 3 is conducted with the tannery wastewater sample of 2/12/1996, with the conventional characterization given in Table 4.3.

Table 4.3 Conventional Wastewater Characterization of Set 3

Parameter	Value
pH	8.5
SS	825 mg/l.
VSS	440 mg/l.
COD _{TOTAL}	2445 mg/l.
COD _{SOLUBLE}	1435 mg/l.
TKN	195 mg/l.
TKN _{SOLUBLE}	170 mg/l.
NH ₃ -N	165 mg/l.
TP	3.6 mg/l.
P _{SOLUBLE}	3.1 mg/l.
Alkalinity	905 mg/l.
Cl ⁻	5550 mg/l.
Sulfur	30 mg/l.
Cr _{TOTAL}	46 mg/l.

Experimental Set 4 is conducted with the tannery wastewater sample of 3/03/1997, with the conventional characterization given in Table 4.4.

Table 4.4 Conventional Wastewater Characterization of Set 4

Parameter	Raw Wastewater	Chem. Treated WW.
pH	7.72	8.40
SS	530 mg/l.	285 mg/l.
VSS	315 mg/l.	155 mg/l.
COD _{TOTAL}	1710 mg/l.	865 mg/l.
COD _{SOLUBLE}	810 mg/l.	810 mg/l.
TKN	308 mg/l.	230 mg/l.*
TKN _{SOLUBLE}	255 mg/l.	220 mg/l.*
NH ₃ -N	250 mg/l.	205 mg/l.*
TP	5.7 mg/l.	3.2 mg/l.
P _{SOLUBLE}	3.9 mg/l.	2.3 mg/l.
Alkalinity	875 mg/l.	825 mg/l.
Cl ⁻	6600 mg/l.	6600 mg/l.
Sulfur	10 mg/l.	6 mg/l.
Cr _{TOTAL}	23 mg/l.	1.35 mg/l.

* Measurements made on 06.03.1997

4.2 EXPERIMENTAL DATA AND CALCULATIONS

The experimental data and calculation of Set 1, according to all three methods is shown below. The relevant calculations for Set 2, Set 3 and Set 4 will be presented in Appendix A.

4.2.1 Experimental Data of Set 1

The initial total and soluble COD are, 1930 mg/l. and 1260 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure 4.1. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure 4.2. The soluble COD profile of the glucose reactor is given in Figure 4.3.

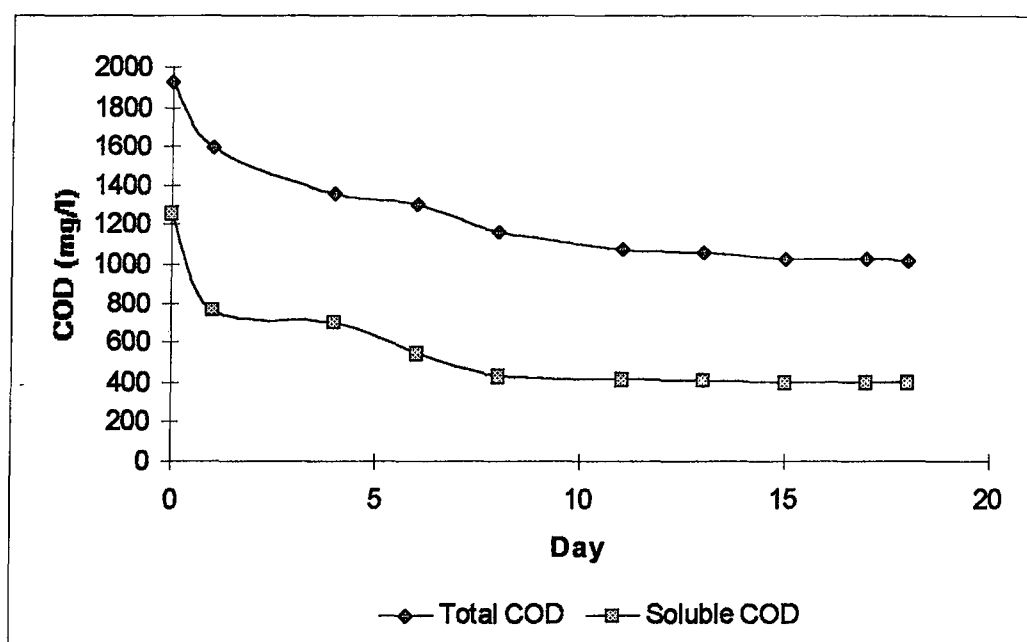


Figure 4.1 COD Profiles of Raw Wastewater Reactor of Set 1.

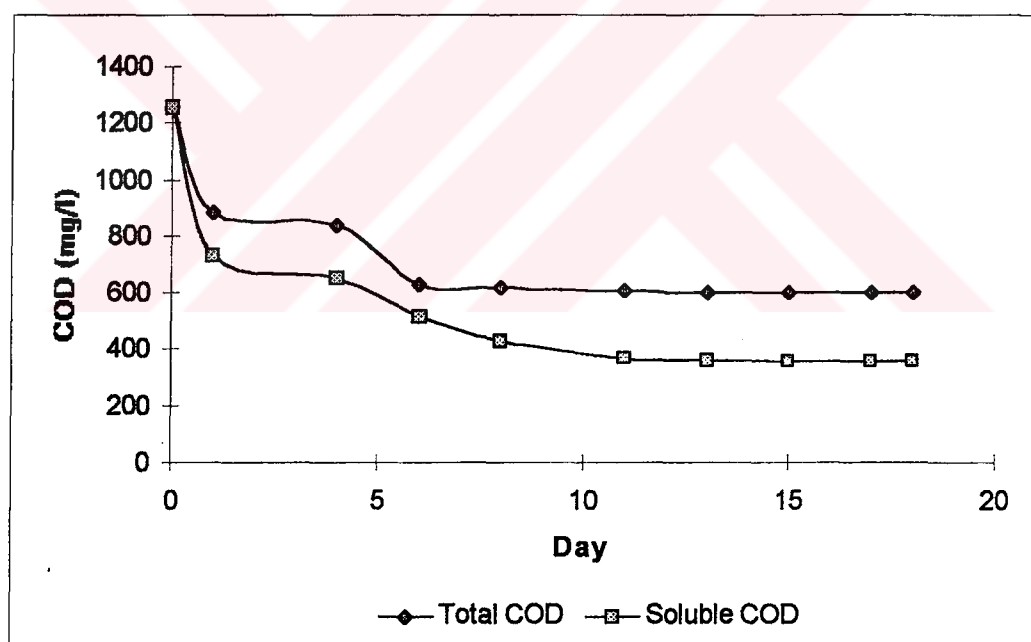


Figure 4.2 COD Profiles of Filtered Wastewater Reactor of Set 1.

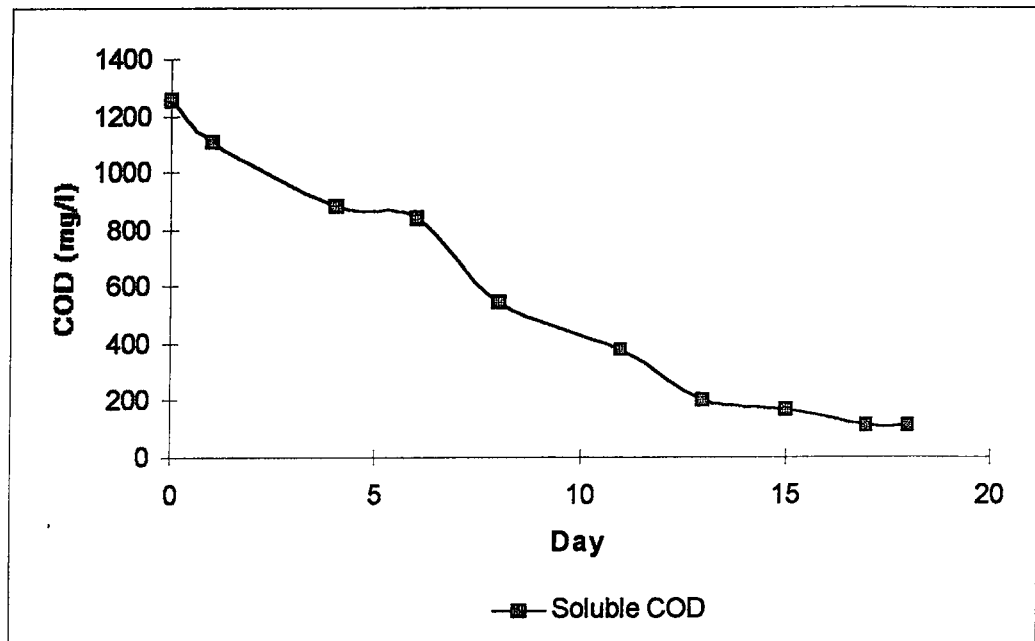


Figure 4.3 COD Profile of Glucose Reactor of Set 1.

The experimental data in graphical presentation above can be summarized by:

$$C_{T0} = 1930 \text{ mg/l. COD}, \quad S_{T0} = 1260 \text{ mg/l. COD},$$

$$C_{T1} = 1020 \text{ mg/l. COD}, \quad S_{T1} = 400 \text{ mg/l. COD},$$

$$C_{T2} = 600 \text{ mg/l. COD}, \quad S_{T2} = 355 \text{ mg/l. COD},$$

$$S_{G0} = 1260 \text{ mg/l. COD}, \quad S_{T3} = 115 \text{ mg/l. COD}.$$

4.2.2 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.64 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 265 mg/l.

The reactor particulate COD profile is given in Figure 4.4.

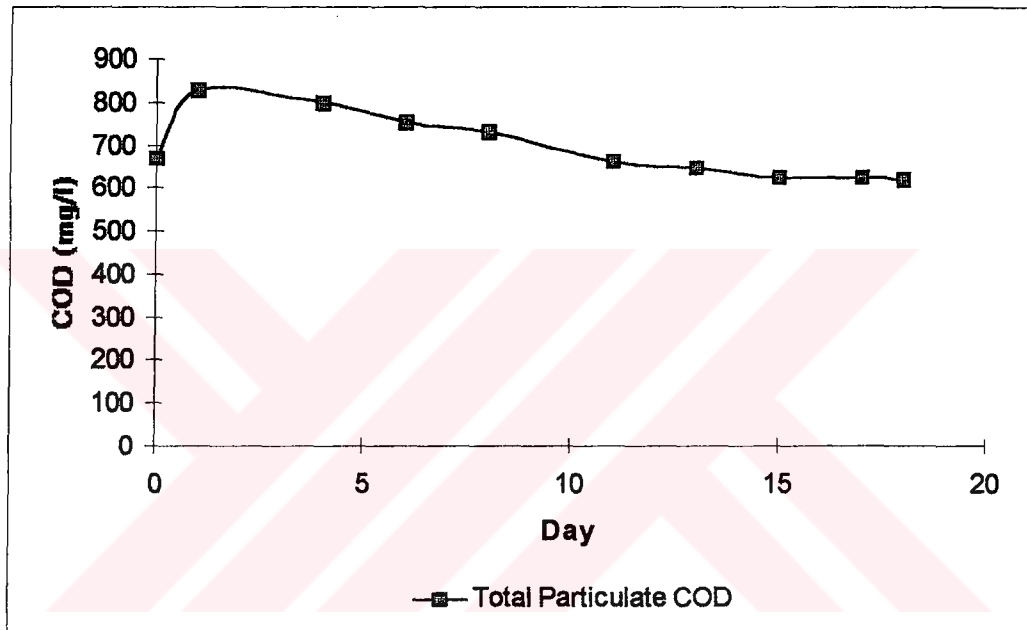


Figure 4.4 Particulate COD Profile of Raw Wastewater Reactor of Set 1.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 1020 - 400 = 620 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.64 = 0.128$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 1930 = 247 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 247 = 373 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 373 - 265 = 1292 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1292 = 165 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 165 = 455 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 455 - 265 = 1210 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1210 = 155 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 155 = 465 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 465 - 265 = 1200 \text{ mg/l. COD.}$$

4.2.3 Calculation of X_I , by Method 2

The total and soluble COD profiles used in this calculation were given above as Figure 4.1 and Figure 4.2.

$$\Delta C_{T1} = C_{T0} - C_{T1} = 1930 - 1020 = 910 \text{ mg/l. COD.}$$

$$\Delta C_{T2} = S_{T0} - C_{T2} = 1260 - 600 = 660 \text{ mg/l. COD.}$$

$$X_{P2} = C_{T2} - S_{T2} = 600 - 355 = 245 \text{ mg/l. COD.}$$

$$X_{P1} = X_{P2} \frac{\Delta C_{T1}}{\Delta C_{T2}} = 245 \frac{910}{660} = 340 \text{ mg/l. COD.}$$

$$X_I = C_{T1} - S_{T1} - X_{P1} = 1020 - 400 - 340 = 280 \text{ mg/l. COD.}$$

$$S_{P1} = \frac{S_{T1} - S_{T2}}{1 - \frac{\Delta C_{T2}}{\Delta C_{T1}}} = \frac{400 - 355}{1 - \frac{660}{910}} = 165 \text{ mg/l. COD.}$$

$$S_I = S_{T1} - S_{P1} = 400 - 165 = 235 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1260 - 235 = 1025 \text{ mg/l. COD.}$$

4.2.4 Calculation of X_I , by Method 3

The three soluble COD profiles from the three reactors, as shown in Figure 4.5, helps understanding the calculation.

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{115}{1260} = 0.09$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{355 - 0.09 \times 1260}{(1 - 0.09)} = 265 \text{ mg/l. COD.}$$

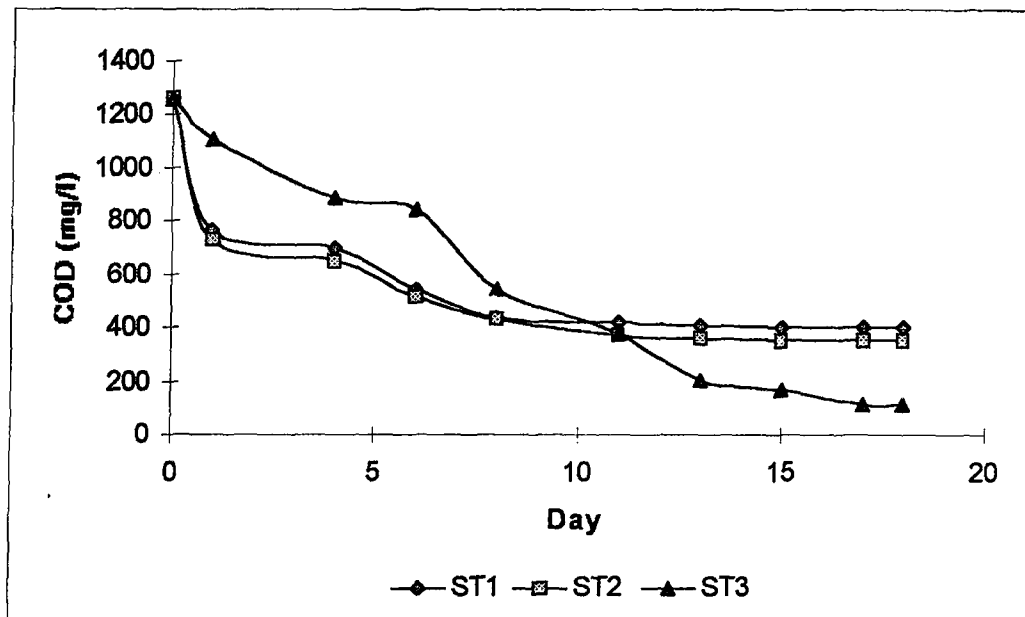


Figure 4.5 Soluble COD Profiles of The Reactors of Set 1.

$$S_{P1} = S_{T1} - S_I = 400 - 265 = 135 \text{ mg/l. COD.}$$

$$S_{P2} = S_{T2} - S_I = 355 - 265 = 90 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1260 - 265 = 995 \text{ mg/l. COD.}$$

$$C_{S0} = \frac{S_{P1}}{S_{P2}} S_{S0} = \frac{135}{90} 995 = 1495 \text{ mg/l. COD.}$$

$$X_I = C_{T0} - C_{S0} - S_I = 1930 - 1495 - 265 = 170 \text{ mg/l. COD.}$$

4.3 EXPERIMENTAL RESULTS AND DISCUSSION

4.3.1 Results of Experiments Performed With Tannery Wastewater

The four set of experiments performed, have provided data for the assessment of particulate inert COD, X_I . However, as it may be noticed from the calculations in Section 4.2 and Appendix A, the soluble inert COD, S_I , and the soluble and particulate residual products were also estimated for this purpose. This is, of course, expected since the way of the determination of the initial inert COD fractions is to determine the biodegradable fraction of COD, from which the residual products are generated.

The fourth set of experiments were handled with extra care; filtration is done by membrane filters of 0.45 μm . pore size, and the experiment period is extended to 60 days. This was done to see whether the definition of the particulate matter effected the results of the experiments. Although the effect of filtration pore size on the experimental results was in the acceptable limits it is recommended that 0.45 μm . pore sized membrane filters are used in these experiments to be on the safe side.

The results are summarized in Table 4.5, Table 4.6, Table 4.7, and Table 4.8.

Table 4.5 Experimental Results of Set 1

Method	X_I	S_I	C_{S0}	S_{S0}	S_{P1}	S_{P2}	X_{P1}	X_{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	465		1200				155		24%		
2	280	235	1415	1025	165	120	340	245	15%	12%	19%
3	170	265	1495	995	135	90	450		9%	14%	21%

Table 4.6 Experimental Results of Set 2

Method	X_I	S_I	C_{S0}	S_{S0}	S_{P1}	S_{P2}	X_{P1}	X_{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	625		1135				145		31%		
2	395	275	1360	725	85	45	375	200	20%	14%	28%
3	445	270	1315	730	90	50	325		22%	13%	27%

Table 4.7 Experimental Results of Set 3

Method	X_I	S_I	C_{S0}	S_{S0}	S_{P1}	S_{P2}	X_{P1}	X_{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	415		1795				230		17%		
2	85	245	2115	1190	55	30	560	315	4%	10%	17%
3	260	235	1950	1200	65	40	385		11%	10%	16%

Table 4.8 Experimental Results of Set 4

Method	X_I	S_I	C_{S0}	S_{S0}	S_{P1}	S_{P2}	X_{P1}	X_{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	325		1170				150		19%		
2	120	190	1370	600	35	15	355	155	7%	11%	24%
3	285	185	1210	605	40	20	190		17%	11%	23%

The results show that the two methods are in agreement for the soluble COD fractions, and the first method does not consider the soluble fractions. The initial soluble inert COD, S_I , the initial soluble biodegradable COD, S_{S0} , the soluble residual products, S_{P1} , and S_{P2} , in raw and filtered wastewater reactors, respectively, have similar calculated values. So either of the two methods can be used successfully to determine the soluble COD fractions.

The soluble inert COD, S_I , makes up 10 - 14 % of the total COD of the tannery wastewater. The percent of S_I , present in the soluble COD tannery wastewater is between 16% and 28%, due to the variable characteristics of tannery effluents.

When the results of the particulate COD fractions are examined, a great difference can easily be noticed between the three methods. If the calculational procedures are inspected, it is seen that the first two methods, calculate the particulate residual products generated, and the third calculates the total biodegradable COD, in order to get to the value of X_I . The first method estimates the particulate residual products generated, by using the model. The second, however, uses the experimental data and the ratio of degraded COD of the two wastewater reactors. The third method uses the ratio of soluble products generated to calculate the total biodegradable COD.

As far as the initial inert particulate COD, X_I , is concerned, the highest values are obtained by Method 1. When the particulate products, X_{P1} , are examined the lowest value is achieved by the calculation procedure of Method 1. These X_{P1} values are even lower than the value of X_{P2} calculated in Method 2, as summarized in Table 4.9.

Table 4.9 The Comparison of Theoretical and Experimental Values of X_P .

C_{T0} (mg/l.)	Calculated value of X_{P1} by Method 1	S_{T0} (mg/l.)	Experimental value of X_{P2} by Method 2
1930	155 mg/l.	1260	245 mg/l.
2030	145 mg/l.	1000	200 mg/l.
2445	230 mg/l.	1435	315 mg/l.
1680	150 mg/l.	790	155 mg/l.

The X_{P2} values calculated in Method 2 are, in fact raw experimental data of the final particulate COD of the filtered wastewater reactor. Since there is no interference of initial inert particulate COD, X_I , in the filtered wastewater reactor this particulate COD, shows the amount of particulate products generated by the soluble fraction of the biodegradable COD, S_{S0} . It is not possible that the total biodegradable COD, C_{S0} , generates less amount of particulate products. Therefore it can be concluded that, the values particulate residual products, X_{P1} , calculated by Method 1 do not reflect the actual case.

4.3.2 Determination of The Inert Fraction of Biomass, f_{EX}

If the calculation procedure of Method 1 in Section 3.2.3.1, is reviewed; the particulate products are calculated as:

$$X_{P1} = Y_{XP} \cdot C_{S0} = f_{EX} \cdot Y_H \cdot C_{S0} \quad (3.15)$$

The heterotrophic yield coefficient, Y_H , used in the calculations is found experimentally so the only parameter is f_{EX} , which is underestimated. So experimental calculation of f_{EX} , was essential.

According to Equation (3.15), Y_{XP} can be defined as the ratio of the particulate products generated over the biodegradable COD in the reactor:

$$Y_{XP} = \frac{X_{P1}}{C_{S0}} = \frac{X_{P2}}{S_{S0}} \quad (4.1)$$

and f_{EX} can be calculated as:

$$f_{EX} = \frac{Y_{XP}}{Y_H} \quad (4.2)$$

In order to calculate the value of f_{EX} , a new set of experiments are designed, with filtered and chemically treated tannery wastewater, and a synthetic feed solution. Four batch, aerated reactors of 2 lt. volume are prepared. The first reactor is fed with filtered wastewater and the second fed with chemically treated and filtered wastewater. Tannery wastewater used is the same as the one used in Set 4. The chemical treatment is a coagulation, flocculation process. Aluminum sulfate is used as the coagulant. Alum is used at a dosage of 300 mg/l. with 2 mg/l. of polyelectrolyte addition. Coagulation process is done with rapid mixing after pH is adjusted to 9.5. Flocculation is done by slow mixing and chromium is precipitated. The wastewater is filtered after precipitation. All the filtration operations are performed with 0.45 μm . membrane filters. The third and the fourth reactors are fed with a synthetic feed solution, whose contents are presented in Table 4.10.

Table 4.10 The Contents of Synthetic Feed Solution

Chemical Substance	Amount	Approximate COD
Acetic Acid	10 ml.	10,000 mg
Propionic Acid	3.1 ml.	4,000 mg
Ethanol	1.68 ml.	2,000 mg
Glutamic Acid	3.62 g.	4,000 mg
Glucose	4.54 g.	4,000 mg.

The filtered and chemically treated wastewater reactors have initial soluble COD, S_{T0} , of 790 mg/l. The third reactor of synthetic solution is started with 800 mg/l. COD. The fourth reactor is fed with the synthetic solution prepared, repeatedly, to have a total COD of 3820 mg/l.

All of the reactors were seeded with the same acclimated biomass of the experimental sets. Biomass is seeded to be 75 mg VSS, in each reactor. The reactors are aerated vigorously and left without sampling, in order to prevent any loss of biomass or substrate. Sampling is started after 35 days, and the experiment are ended after a period of 70 days. The threshold values of the total and soluble COD are measured. The COD profiles of the four reactors are given in Figure 4.6, Figure 4.7, Figure 4.8, and Figure 4.9.

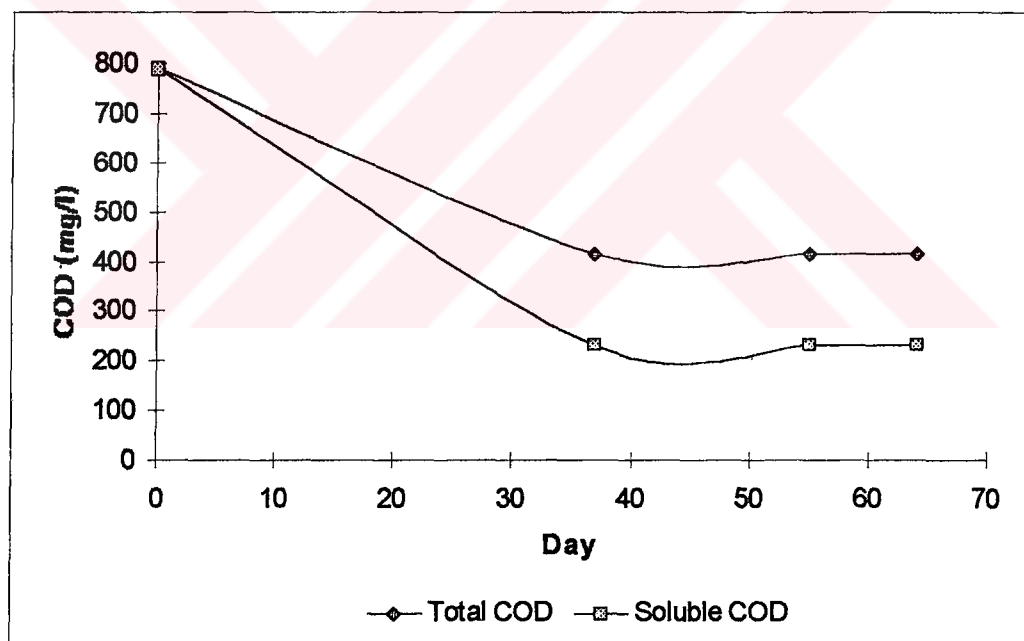


Figure 4.6 Total and Soluble COD Profiles of Filtered Wastewater Reactor.

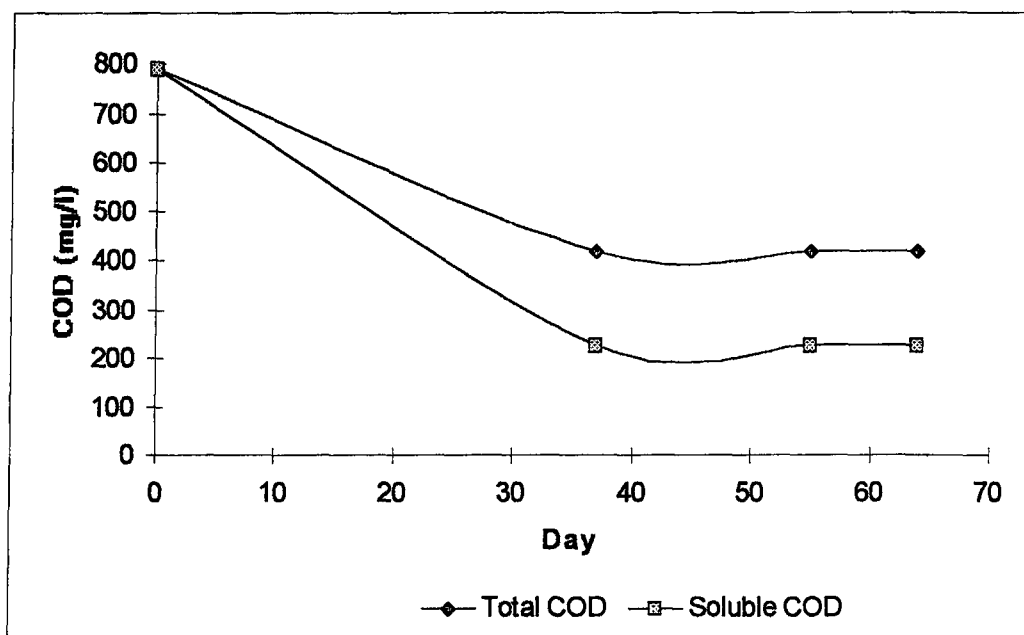


Figure 4.7 Total and Soluble COD Profiles of Chemically Treated Wastewater Reactor.

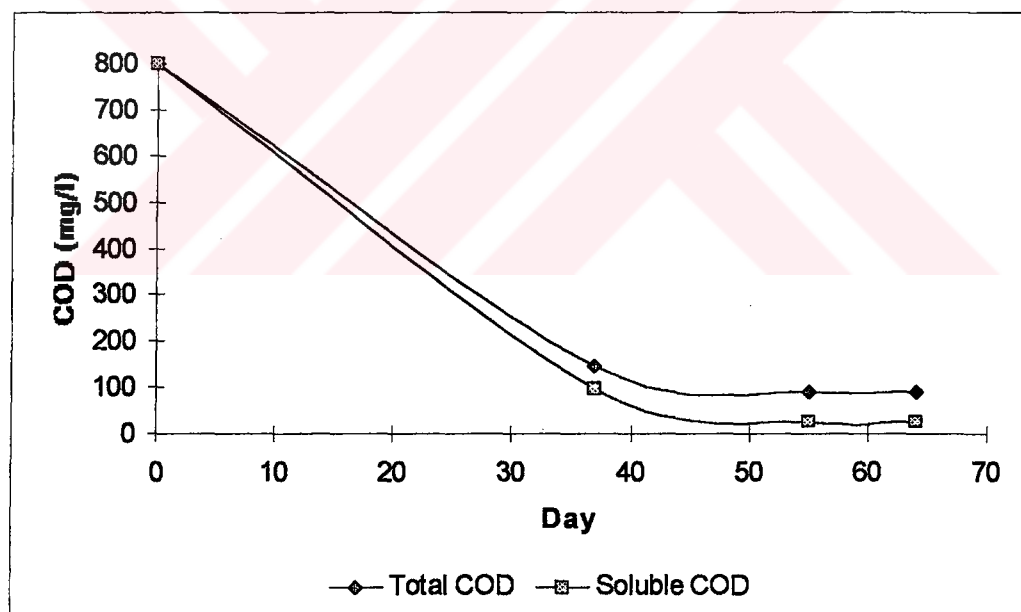


Figure 4.8 Total and Soluble COD Profiles of Synthetic Reactor.

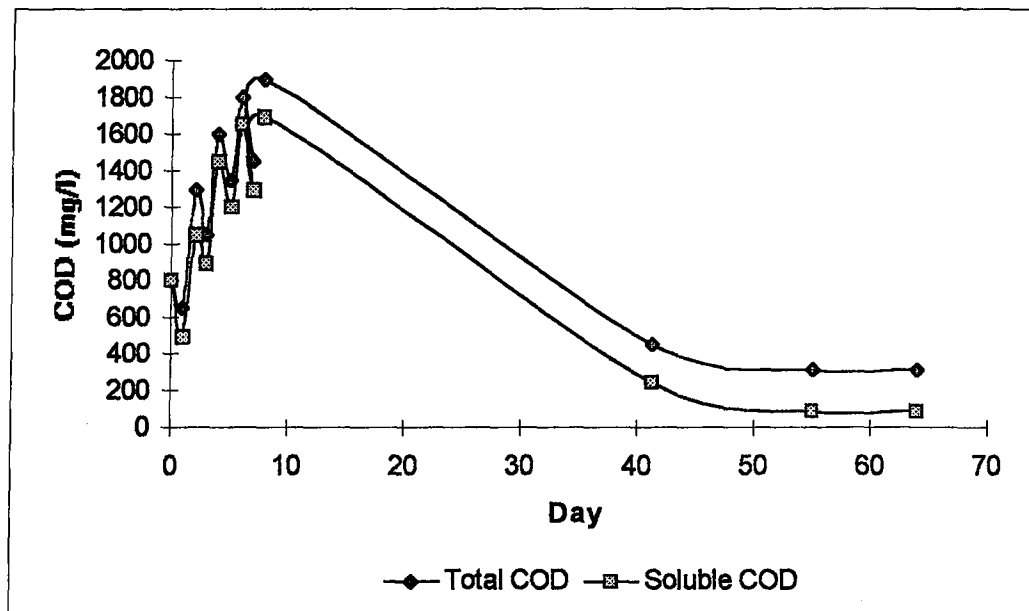


Figure 4.9 Total and Soluble COD Profiles of Synthetic Reactor Fed Five Times.

The experimental data obtained is summarized in Table 4.11.

Table 4.11 The Experimental Data of f_{EX}

Reactor Feed	S_{T0}	C_{T1}	S_{T1}
Filtered WW.	790 mg/l. COD	415 mg/l. COD	230 mg/l. COD
Chem. Treat. WW.	790 mg/l. COD	415 mg/l. COD	230 mg/l. COD
Synthetic Sln.	800 mg/l. COD	90 mg/l. COD	25 mg/l. COD
Synthetic Sln. x 5	3820 mg/l. COD	310 mg/l. COD	90 mg/l. COD

The soluble inert fraction of the initial COD, S_I , is accepted as 185 mg/l. and the heterotrophic yield coefficient, Y_H , is 0.64 mg COD/mg COD. Calculation of the stoichiometric coefficients Y_{XP} , and f_{EX} , for the four types of feed is as follows;

For Reactor 1:

$$X_{P2} = C_{T1} - S_{T1} = 415 - 230 = 185 \text{ mg/l. COD}$$

$$S_{S0} = S_{T0} - S_I = 790 - 185 = 605 \text{ mg/l. COD}$$

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{185}{605} = 0.306$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.306}{0.64} = 0.478$$

For Reactor 2:

$$X_{P2} = C_{T1} - S_{T1} = 415 - 230 = 185 \text{ mg/l. COD}$$

$$S_{S0} = S_{T0} - S_I = 790 - 185 = 605 \text{ mg/l. COD}$$

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{185}{605} = 0.306$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.306}{0.64} = 0.478$$

For Reactor 3:

$$X_{P2} = C_{T1} - S_{T1} = 90 - 25 = 65 \text{ mg/l. COD}$$

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{65}{800} = 0.081$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.081}{0.64} = 0.127$$

For Reactor 4:

$$X_{P2} = C_{T1} - S_{T1} = 310 - 90 = 220 \text{ mg/l. COD}$$

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{220}{3820} = 0.058$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.058}{0.64} = 0.091$$

The results of the filtered and chemically treated wastewater are the same, simply because just by chance, the initial soluble COD of the two reactors were equal, but this shows that the chromium salts present in tannery wastewaters do not effect the inert fraction of the biomass, f_{EX} .

The two synthetic reactors gave close but different f_{EX} values due to the possible experimentation errors done when determining COD concentrations.

Calculation the stoichiometric coefficients Y_{XP} , and f_{EX} , for the four sets of experiments done for the assessment of X_I , is as follows;

For Set 1:

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{245}{1025} = 0.239$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.239}{0.64} = 0.373$$

For Set 2:

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{200}{725} = 0.276$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.276}{0.64} = 0.431$$

For Set 3:

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{315}{1190} = 0.265$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.265}{0.64} = 0.414$$

For Set 4:

$$Y_{XP} = \frac{X_{P2}}{S_{S0}} = \frac{155}{600} = 0.258$$

$$f_{EX} = \frac{Y_{XP}}{Y_H} = \frac{0.258}{0.64} = 0.404$$

Table 4.12 Summary of The Experimentally Calculated Values of f_{EX}

Tannery WW.	Y_{XP}	f_{EX}	Synthetic Sln.	Y_{XP}	f_{EX}
Set 1	0.239	0.373	f_{EX} Experiment	0.081	0.127
Set 2	0.276	0.431			
Set 3	0.265	0.414	f_{EX} Experiment		
Set 4	0.258	0.404	with 5 feedings	0.058	0.091
f_{EX} Experiment	0.306	0.478			
Average	0.269	0.420	Average	0.070	0.109

As summarized in Table 4.12, the biomass fed with tannery wastewater has 42% inerts by mass, and the biomass fed with synthetic solution has 11% inerts by mass. This result shows that the inert fraction of the biomass, and in parallel the particulate inert products generated, are wastewater specific, as all other stoichiometric parameters. This fraction may have very high values, like in the case of tannery wastewater, and the complicity of the wastewater may effect the formation of the inert fraction of biomass.

4.3.3 The Results With Experimentally Determined f_{EX}

The results of Method 1 are re-estimated with the experimentally calculated f_{EX} values, as shown in Appendix B. With the new calculations, the results of the four set of experiments are summarized in Table 4.13, Table 4.14, Table 4.15, and Table 4.16.

Table 4.13 Re-calculated Experimental Results of Set 1

Method	X _I	S _I	C _{S0}	S _{S0}	S _{P1}	S _{P2}	X _{P1}	X _{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	290		1375				330		15%		
2	280	235	1415	1025	165	120	340	245	15%	12%	19%
3	170	265	1495	995	135	90	450		9%	14%	21%

Table 4.14 Re-calculated Experimental Results of Set 2

Method	X _I	S _I	C _{S0}	S _{S0}	S _{P1}	S _{P2}	X _{P1}	X _{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	390		1370				380		19%		
2	395	275	1360	725	85	45	375	200	20%	14%	28%
3	445	270	1315	730	90	50	325		22%	13%	27%

Table 4.15 Re-calculated Experimental Results of Set 3

Method	X _I	S _I	C _{S0}	S _{S0}	S _{P1}	S _{P2}	X _{P1}	X _{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	80		2130				565		3%		
2	85	245	2115	1190	55	30	560	315	4%	10%	17%
3	260	235	1950	1200	65	40	385		11%	10%	16%

Table 4.16 Re-calculated Experimental Results of Set 4

Method	X _I	S _I	C _{S0}	S _{S0}	S _{P1}	S _{P2}	X _{P1}	X _{P2}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	120		1375				355		7%		
2	120	190	1370	600	35	15	355	155	7%	11%	24%
3	285	185	1210	605	40	20	190		17%	11%	23%

4.3.4 Evaluation of The Three Proposed Methods

The re-calculated experimental results of Method 1, shows similarities with that of Method 2. The results of Method 3, vary from the others, over the acceptable limits. This is because Method 3, is inconsistent, within its calculational procedure. This inconsistency can be shown by going over the calculations of Set 1 as an example.

The ratio of the soluble products generated are equal to the ratio of the biodegradable substrate as shown:

$$\frac{C_{S0}}{S_{S0}} = \frac{S_{P1}}{S_{P2}} \quad (4.3)$$

This ratio also holds for the particulate products generated:

$$\frac{C_{S0}}{S_{S0}} = \frac{X_{P1}}{X_{P2}} \quad (4.4)$$

By combining Equation (4.3) and (4.4), we get:

$$\frac{C_{S0}}{S_{S0}} = \frac{S_{P1}}{S_{P2}} = \frac{X_{P1}}{X_{P2}} \quad (4.5)$$

Method 3 calculates X_I , using this ratio as :

$$X_I = C_{T0} - C_{S0} - S_I = 1930 - 1495 - 265 = 170 \text{ mg/l. COD.}$$

If X_{P1} , is calculated as:

$$X_{P1} = X_{T1} - X_I = 620 - 170 = 450 \text{ mg/l. COD.}$$

If X_{P1} , is calculated using the experimental data of X_{P2} , and the above ratio:

$$X_{P1} = \frac{S_{P1}}{S_{P2}} X_{P2} = \frac{135}{90} \times 245 = 370 \text{ mg/l. COD.}$$

These results show the inconsistency of Method 3. It can be concluded that, although Method 3, is an acceptable and highly accurate method for the calculation of S_I , it is not a reliable method for the assessment of X_I .

Method 1 and Method 2 have given similar results, but if the calculational procedures are carefully examined, it can easily be seen that Method 2 has accuracy defects. The accuracy of Method 2 is strictly dependent on the accuracy of the experimental data. Any acceptable experimental error may cause great variances in the results presented by Method 2, due to the ratios used in the calculation procedure. The random experimental errors made in the determination of the threshold COD values, coupled with the division operation, would diverge and lower the accuracy at a great extend. So Method 2 may not be reliable at a great extend, when careless routine experimentation is concerned.

With the assessment of the stoichiometric parameters of Y_H , and f_{EX} , Method 1 is an accurate and reliable experimental method for the assessment of the initial particulate inert COD, X_I .

4.4 INITIAL INERT PARTICULATE COD OF DOMESTIC WASTEWATER

Two additional sets of experiments were done with domestic wastewater of Moda, to present more data on the parameter X_I . The estimation of S_I , is done by Method 3, and Method 1 is used for the determination of X_I .

The first set of experiments are done with 19/11/1996 sample of Moda domestic sewage, and the second set is performed with 10/03/1997 sample.

Filtration is done by AP40 filters in Set 1 and 0.45 μm . membrane filters in Set 2. The Experimental data and calculations are shown in Appendix C. The experimental data obtained for X_I of domestic wastewater is given in Table 4.18.

Table 4.17 Conventional Wastewater Characterization of Moda Domestic Sewage

Parameter	Set 1	Set 2
pH	7.43	7.22
SS	430 mg/l.	445 mg/l.
VSS	315 mg/l.	305 mg/l.
COD _{TOTAL}	650 mg/l.	650 mg/l.
COD _{SOLUBLE}	230 mg/l.	135 mg/l.
TKN	60 mg/l.	75 mg/l.
TKN _{SOLUBLE}	45 mg/l.	50 mg/l.
NH ₃ -N	40 mg/l.	40 mg/l.
TP	10.2 mg/l.	12.6 mg/l.
P _{SOLUBLE}	9.1 mg/l.	11.4 mg/l.
Alkalinity	410 mg/l.	375 mg/l.

Table 4.18 Experimental Results of Set 1 and Set 2 of Domestic Wastewater

Set	X _I	S _I	C _{S0}	S _{S0}	X _{P1}	$\frac{X_I}{C_{T0}}$	$\frac{S_I}{C_{T0}}$	$\frac{S_I}{S_{T0}}$
1	65	20	565	210	75	10%	3%	9%
2	105	30	515	105	65	16%	5%	22%

RESULTS AND RECOMMENDATIONS

The multicomponent modelling approach should be used in the design of activated sludge systems. In order to make accurate design calculations, assessment of initial inert particulate and soluble fractions of wastewater. This study presents experimental data obtained for the initial inert particulate COD with a new method proposed by Orhon et al.[7].

The initial soluble inert COD, S_I , makes up 10 - 14 % of the total COD of the tannery wastewater. The percent of S_I , present in the soluble COD tannery wastewater is between 16% and 28%.

The initial particulate inert COD, X_I , varies from 3 to 19% of the total COD of tannery wastewater, being 11% on the average, due to the variable characteristics of tannery effluents.

Experimental data is obtained for the initial particulate and soluble inert fractions of domestic sewage. The initial soluble inert COD, S_I , makes up 3-5% of the total COD of the domestic wastewater. The percent of S_I , present in the soluble COD domestic wastewater is 9% and 22%. The initial particulate inert COD, X_I , varies from 10 to 16% of the total COD of domestic wastewater.

Useful data is obtained for the two stoichiometric parameters, f_{EX} , and Y_{XP} , by the proposed experimental procedure. The experiments performed with tannery wastewater gave an average value of 42% for f_{EX} , and 0.27 for Y_{XP} , by mass. These results defer very much from the stated values in literature but the previous studies were conducted with easily degradable synthetic feeds in continuous systems. The tannery wastewater is a very complex feed composed of many types organic matter, with a variety of degradation characteristics.

The batch tests done by synthetic feed, resulted that the biomass had 11% particulate inert fraction and the fraction of biomass generated as inert residual products, Y_{XP} , is found to be 0.07.

The previous accepted value of f_{EX} , was 20%, and the experimental results found here present different values for this parameter, so additional experimental data should be obtained to have a better understanding of the subject. However these results certainly lead us to the idea that the stoichiometric parameter, f_{EX} , is dependent on the wastewater degraded by biomass.

The inert fraction of biomass, f_{EX} , and the fraction of biomass generated as inert residual products, Y_{XP} , are wastewater specific, and these stoichiometric parameters need to be determined experimentally for modelling and design purposes of activated sludge systems.

The new method proposed by Orhon et al.[7], for the assessment of initial inert particulate COD, X_I , is modified by the experimental determination of f_{EX} . The method when compared with the others in the light of the experimental data obtained, is accepted as a reliable and consistent method.

REFERENCES

- [1] Dold, P. L. and Marais, G. v. R., Evaluation of the general activated sludge model proposed by IAWPRC Task Group. *Wat. Sci. Tech.*, 18(6) (1986) 63-90.
- [2] Orhon, D., Artan, N. and Cimpit, Y., The concept of soluble residual product formation in the modelling of activated sludge. *Wat. Sci. Tech.*, 21(4-5) (1989) 339-50.
- [3] McKinney, R. E., Mathematics of complete-mixing activated sludge. *J. Sed. Proc. ASCE*, 88(SA 3) (1962) 87-113.
- [4] Kountz, R. R., and Forney, C., Jr., Metabolic energy balances in a total oxidation activated sludge system. *Sewage and Industrial Wastes*, 31, 8 (1959) 819-826
- [5] McCarty, P. L., and Broderson, C. F., Theory of extended aeration activated sludge. *J. Wat. Pollut. Control Fed.*, 34 (1962):1095
- [6] Washington, D. R., and Symons, J. M., Volatile sludge accumulation in activated sludge systems. *J. Wat. Pollut. Control Fed.*, 34, 8 (1962):767
- [7] Orhon, D., Artan, N. and Ateş, E., A description of the three methods for the determination of the initial inert particulate chemical oxygen demand of wastewater. *J. Chem. Tech. Biotech.*, 61 (1994) 73-80.
- [8] Henze, M., Grady, C. P. L. Jr., Gujer, W., Marais, G. V. R. and Matsuo, T., Activated Sludge Model No. 1, IAWPRC Scientific and Technical Report No. 1, 1987.
- [9] Orhon, D., Artan, N. and Baykal, B. B., Implication of the Task Group Model, I. The effect of initial substrate concentration. *Wat. Res.*, 24(10) (1990) 1251-8.
- [10] Orhon, D., and Çokgör, E. U., COD fractionation in wastewater characterization-The state of the art. *J. Chem. Tech. Biotech.*, 68 (1997) 283-293.
- [11] Ekama, G. A., Dold, P. L. and Marais, G. v. R., Procedures for determining COD fractions and maximum specific growth rate of heterotrophs in activated sludge systems. *Wat. Sci. Tech.*, 18(6) (1986) 91-114.
- [12] Orhon, D., Artan, N., Büyükmurat, M. and Görgün, E., The effect of residual COD on the biological treatability of textile wastewater. *Wat. Sci. Tech.*, 26(3-4) (1992) 815-25.

- [13] Kappler, J. and Gujer, W., Estimation of kinetic parameters of heterotrophic biomass under aerobic conditions and characterization of wastewater for activated sludge modelling. *Wat. Sci. Tech.*, 25(6) (1992) 125-40.
- [14] Lesouef, A., Payrandeau, A., Rogalla, F. and Kleiber, B., Optimizing nitrogen removal reactor configurations by on-site calibration of the IAWPRC Activated Sludge Model. *Wat. Sci. Tech.*, 25(6) (1992) 105-20.
- [15] Germirli, F., Orhon, D., Artan, N., Ubay, E. and Görgün, E., Effect of two-stage treatment on the biological treatability of strong industrial wastewaters. *Wat. Sci. Tech.*, 28(2) (1993) 145-54.
- [16] Germirli, F., Orhon, D., and Artan, N., Assessment of the initial inert soluble COD in industrial wastewater. *Wat. Sci. Tech.*, 23 (1991) 1077-86.
- [17] Porges, N., Jasewicz, L., and Hoover, S. R., Aerobic treatment of dairy wastes. *Applied Microbiol.*, 1 (1953) 262.
- [18] Symons, J. M., and McKinney, R. E., The biochemistry of nitrogen in the synthesis of activated sludge. *Sewage and Industrial Wastes*, 30, 7 (1958) 874.
- [19] Engelbrecht, R. S., and McKinney, R. E., Membrane filter method applied to activated sludge suspended solids determinations. *Sewage and Industrial Wastes*, 28, 11 (1956) 1321.
- [20] Porges, N., Jasewicz, L., and Hoover, S. R., Biological oxidation of dairy wastes. VII Purification, oxidation, synthesis, and storage. *Proc. 10th Ind. Waste Conf. Purdue Univ.*, 89 (1956) 135.

APPENDICES

- APPENDIX A CALCULATIONS AND RESULTS OF EXPERIMENTS ON
TANNERY WASTEWATER**
- APPENDIX B REVIEWED CALCULATIONS AND RESULTS OF
EXPERIMENTS ON TANNERY WASTEWATER**
- APPENDIX C CALCULATIONS AND RESULTS OF EXPERIMENTS ON
DOMESTIC WASTEWATER**

APPENDIX A

A.1 EXPERIMENTAL DATA OF SET 2

The initial total and soluble COD are, 2030 mg/l. and 1000 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure A.1. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure A.2. The soluble COD profile of the glucose reactor is given in Figure A.3.

Table A.1 COD Data of Raw Wastewater Reactor of Set 2.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	2030	1000
1	1585	668
3	1540	612
6	1465	395
8	1130	383
10	1140	419
13	1142	372
15	1192	387
17	1162	434
20	1130	360
25	1130	360

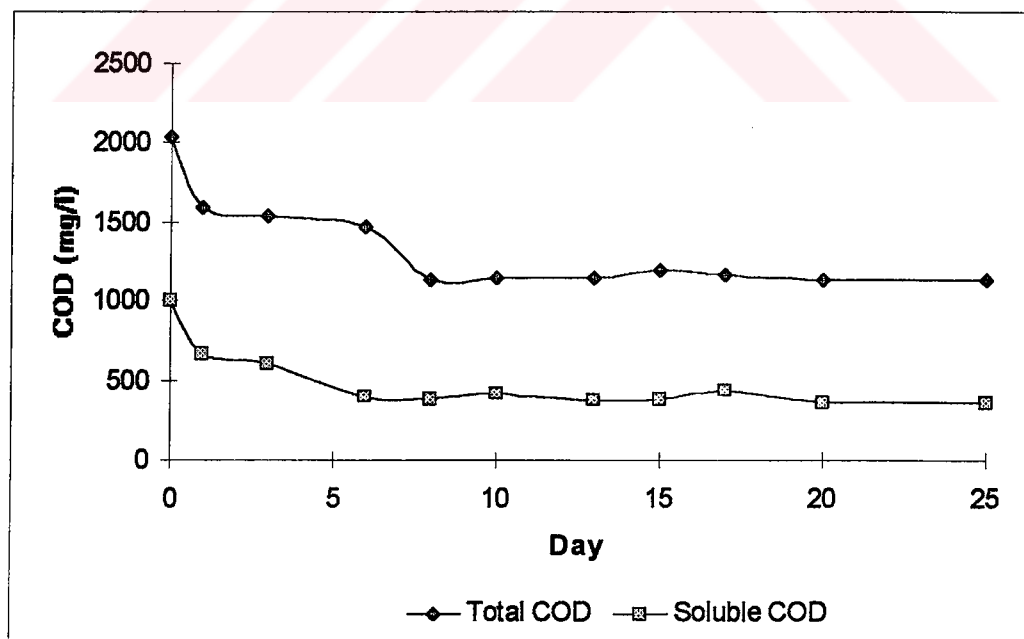


Figure A.1 COD Profiles of Raw Wastewater Reactor of Set 2.

Table A.2 COD Data of Filtered Wastewater Reactor of Set 2.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	1000	1000
1	933	781
3	770	431
6	609	355
8	634	317
10	543	317
13	521	283
15	571	364
17	536	362
20	520	320
25	520	320

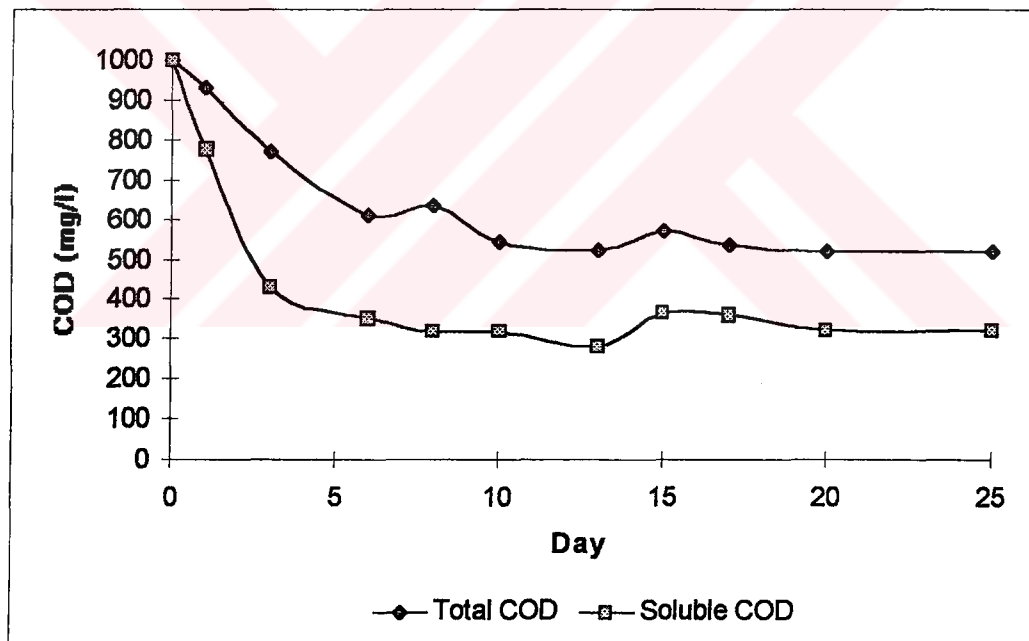


Figure A.2 COD Profiles of Filtered Wastewater Reactor of Set 2.

Table A.3 COD Data of Glucose Reactor of Set 2.

Day	Soluble COD (mg/l)
0	1000
1	856
3	684
6	280
8	114
10	188
13	89
15	70
17	70
20	70
25	70

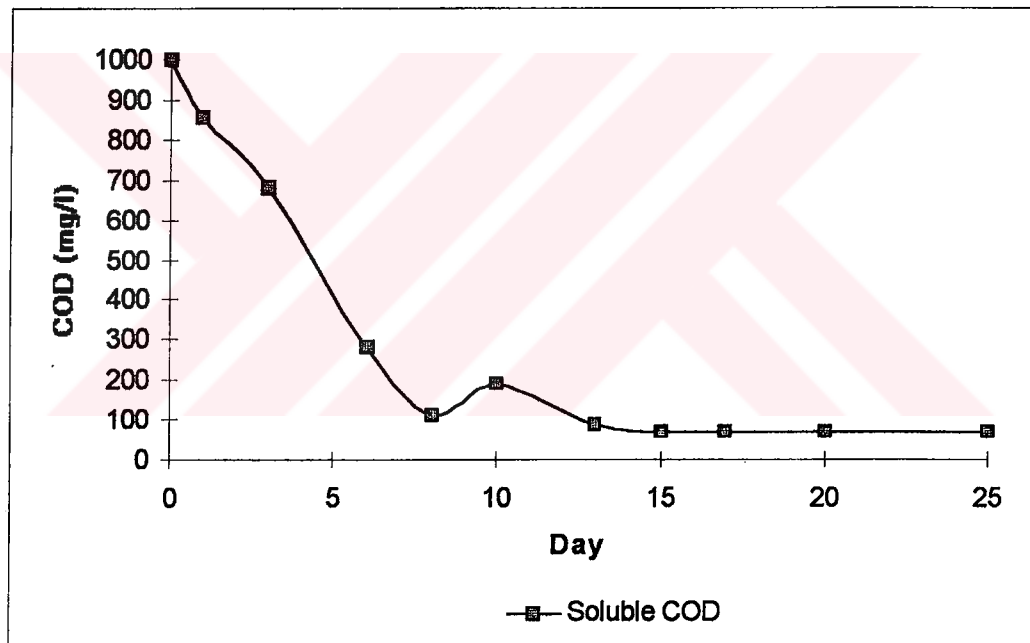


Figure A.3 COD Profile of Glucose Reactor of Set 2.

The experimental data in graphical presentation above can be summarized by:

$$C_{T0} = 2030 \text{ mg/l. COD}, \quad S_{T0} = 1000 \text{ mg/l. COD},$$

$$C_{T1} = 1130 \text{ mg/l. COD}, \quad S_{T1} = 360 \text{ mg/l. COD},$$

$$C_{T2} = 520 \text{ mg/l. COD}, \quad S_{T2} = 320 \text{ mg/l. COD},$$

$$S_{G0} = 1000 \text{ mg/l. COD}, \quad S_{T3} = 70 \text{ mg/l. COD}.$$

A.1.1 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.64 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 270 mg/l.

Table A.4 Particulate COD Data of Raw Wastewater Reactor of Set 2.

Day	Total Particulate COD
0	1030
1	1040
6	1070
8	827
13	770
20	750
25	750

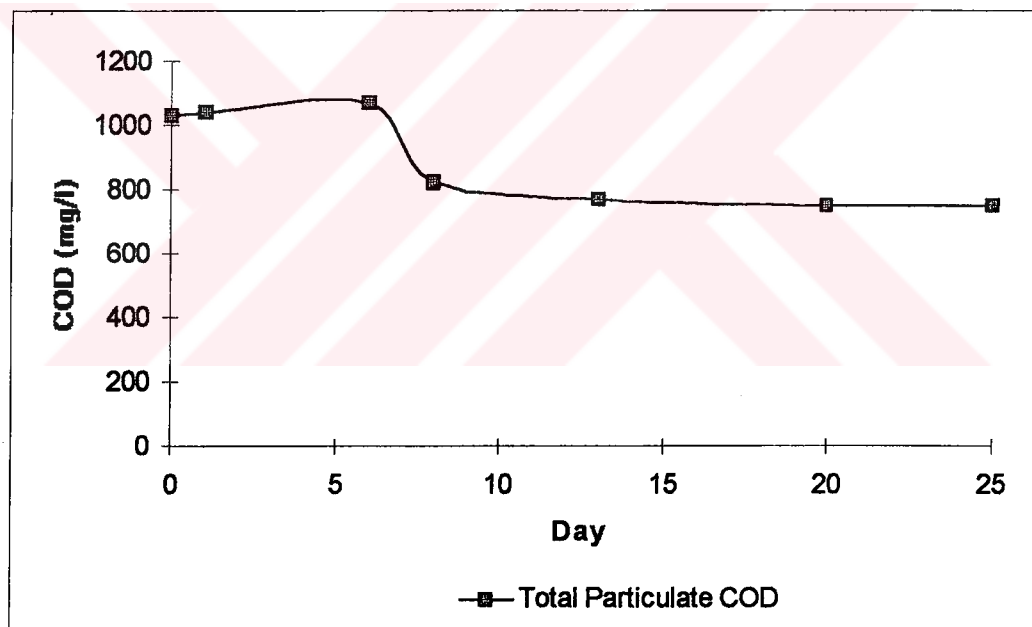


Figure A.4 Particulate COD Profile of Raw Wastewater Reactor of Set 2.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 1130 - 360 = 770 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.64 = 0.128$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 2030 = 260 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 260 = 510 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 510 - 270 = 1250 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1250 = 160 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 160 = 610 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 610 - 270 = 1150 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1150 = 147 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 147 = 623 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 623 - 270 = 1137 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1137 = 146 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 146 = 624 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 624 - 270 = 1136 \text{ mg/l. COD.}$$

Iteration 5:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1136 = 145 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 145 = 625 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 625 - 270 = 1135 \text{ mg/l. COD.}$$

A.1.2 Calculation of X_I , by Method 2

The total and soluble COD profiles used in this calculation were given above as Figure A.1 and Figure A.2.

$$\Delta C_{T1} = C_{T0} - C_{T1} = 2030 - 1130 = 900 \text{ mg/l. COD.}$$

$$\Delta C_{T2} = S_{T0} - C_{T2} = 1000 - 520 = 480 \text{ mg/l. COD.}$$

$$X_{P2} = C_{T2} - S_{T2} = 520 - 320 = 200 \text{ mg/l. COD.}$$

$$X_{P1} = X_{P2} \frac{\Delta C_{T1}}{\Delta C_{T2}} = 200 \frac{900}{480} = 375 \text{ mg/l. COD.}$$

$$X_I = C_{T1} - S_{T1} - X_{P1} = 1130 - 360 - 375 = 395 \text{ mg/l. COD.}$$

$$S_{P1} = \frac{S_{T1} - S_{T2}}{\Delta C_{T2}} \frac{\Delta C_{T1}}{1 - \frac{\Delta C_{T2}}{\Delta C_{T1}}} = \frac{360 - 320}{480} \frac{900}{1 - \frac{480}{900}} = 85 \text{ mg/l. COD.}$$

$$S_I = S_{T1} - S_{P1} = 360 - 85 = 275 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1000 - 275 = 725 \text{ mg/l. COD.}$$

A.1.3 Calculation of X_I , by Method 3

The three soluble COD profiles from the three reactors, as shown in Figure A.5, helps understanding the calculation.

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{70}{1000} = 0.07$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{320 - 0.07 \times 1000}{(1 - 0.07)} = 270 \text{ mg/l. COD.}$$

$$S_{P1} = S_{T1} - S_I = 360 - 270 = 90 \text{ mg/l. COD.}$$

$$S_{P2} = S_{T2} - S_I = 320 - 270 = 50 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1000 - 270 = 730 \text{ mg/l. COD.}$$

Table A.5 Soluble COD Data of The Reactors of Set 2.

Day	ST1 (mg/l)	ST2 (mg/l)	ST3(mg/l)
0	1000	1000	1000
1	668	781	856
3	612	431	684
6	395	355	280
8	383	317	114
10	419	317	188
13	372	283	89
15	387	364	70
17	434	362	70
20	360	320	70
25	360	320	70

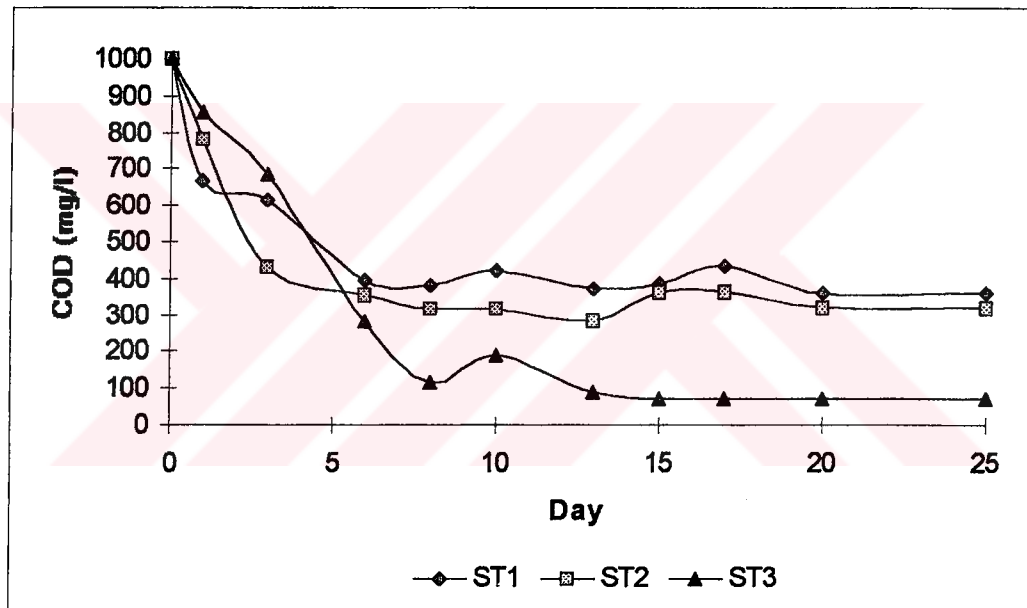


Figure A.5 Soluble COD Profiles of The Reactors of Set 2.

$$C_{S0} = \frac{S_{P1}}{S_{P2}} S_{S0} = \frac{90}{50} 730 = 1315 \text{ mg/l. COD.}$$

$$X_I = C_{T0} - C_{S0} - S_I = 2030 - 1314 - 270 = 445 \text{ mg/l. COD.}$$

A.2 EXPERIMENTAL DATA OF SET 3

The initial total and soluble COD are, 2030 mg/l. and 1000 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure A.6. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure A.7. The soluble COD profile of the glucose reactor is given in Figure A.8.

The experimental data in graphical presentation above can be summarized by:

$$C_{T0} = 2445 \text{ mg/l. COD}, \quad S_{T0} = 1435 \text{ mg/l. COD},$$

$$C_{T1} = 945 \text{ mg/l. COD}, \quad S_{T1} = 300 \text{ mg/l. COD},$$

$$C_{T2} = 590 \text{ mg/l. COD}, \quad S_{T2} = 275 \text{ mg/l. COD},$$

$$S_{G0} = 1435 \text{ mg/l. COD}, \quad S_{T3} = 50 \text{ mg/l. COD}.$$

Table A.6 COD Data of Raw Wastewater Reactor of Set 3.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	2445	1435
2	2089	427
5	1119	396
7	1404	385
9	1235	373
12	1408	350
15	1136	302
19	1120	297
21	1154	300
23	945	300
26	945	300
30	945	300

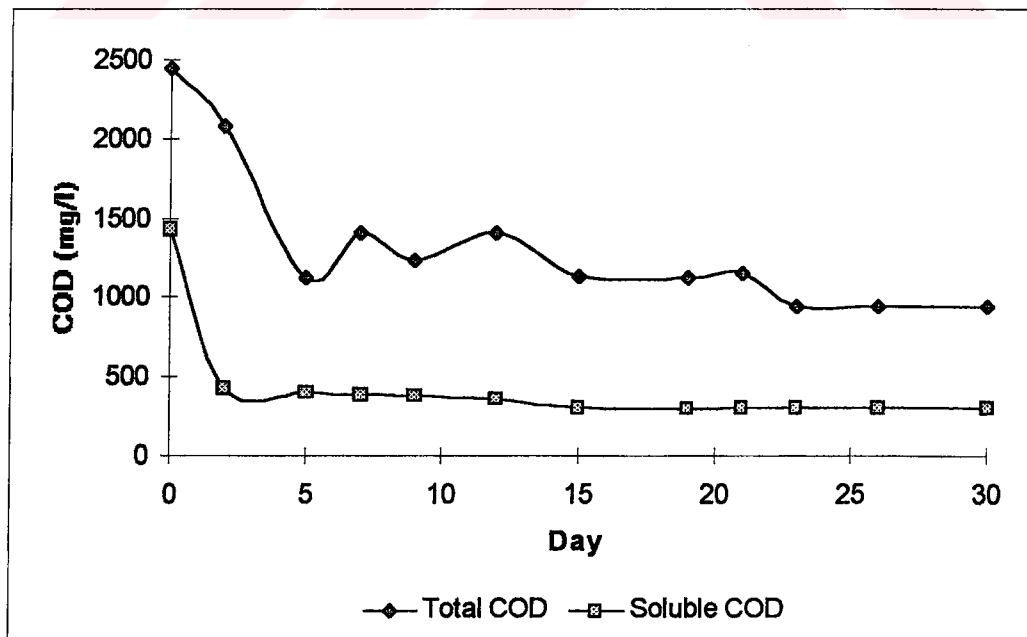


Figure A.6 COD Profiles of Raw Wastewater Reactor of Set 3.

Table A.7 COD Data of Filtered Wastewater Reactor of Set 3.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	1435	1435
2	1039	554
5	746	443
7	634	261
9	746	350
12	669	346
15	626	290
19	606	286
21	600	300
23	600	346
26	590	275
30	590	275

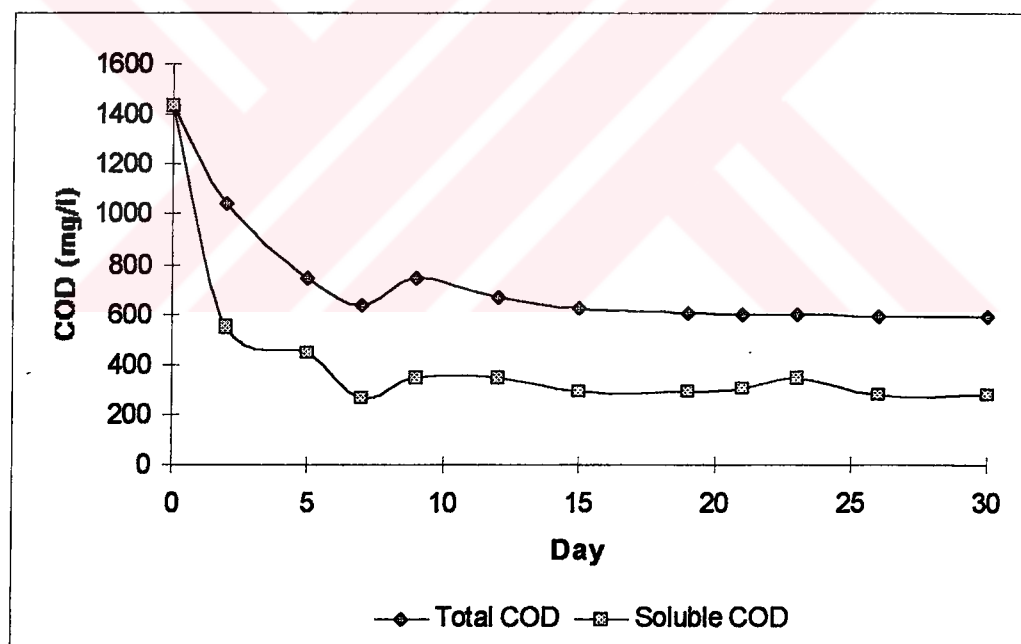


Figure A.7 COD Profiles of Filtered Wastewater Reactor of Set 3.

Table A.8 COD Data of Glucose Reactor of Set 3.

Day	Soluble COD (mg/l)
0	1435
2	900
5	149
7	136
9	138
12	153
15	142
19	85
21	70
23	65
26	50
30	50

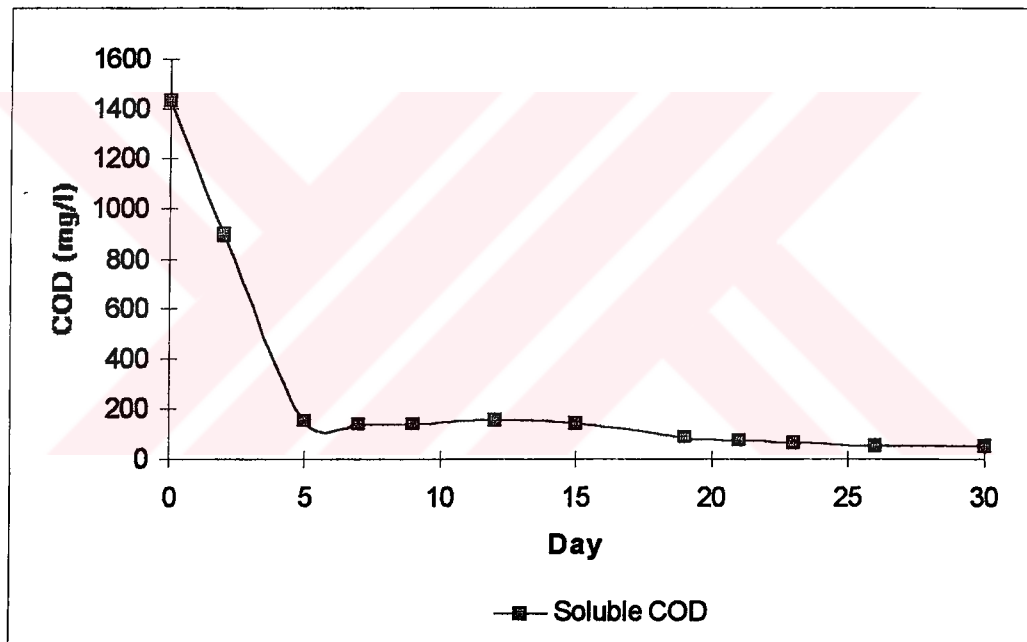


Figure A.8 COD Profile of Glucose Reactor of Set 3.

A.2.1 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.64 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 235 mg/l.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 945 - 300 = 645 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.64 = 0.128$$

Table A.9 Particulate COD Data of Raw Wastewater Reactor Set 3.

Day	Total Particulate COD (mg/l)
0	1010
2	1662
7	1019
9	862
12	762
15	734
19	723
21	654
23	650
26	637
30	645

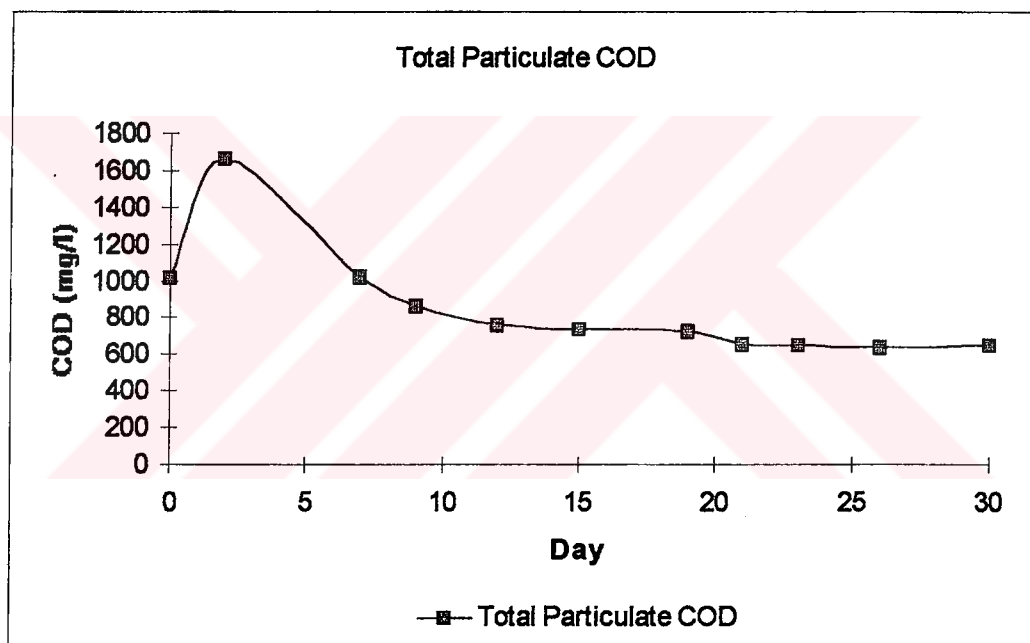


Figure A.9 Particulate COD Profile of Raw Wastewater Reactor Set 3.

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 2445 = 313 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 313 = 332 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 332 - 235 = 1878 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1878 = 240 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 240 = 405 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 405 - 235 = 1805 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1805 = 231 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 231 = 414 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 414 - 235 = 1796 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.128 \times 1796 = 230 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 230 = 415 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 415 - 235 = 1795 \text{ mg/l. COD.}$$

A.2.2 Calculation of X_I , by Method 2

The total and soluble COD profiles used in this calculation were given above as Figure A.6 and Figure A.7.

$$\Delta C_{T1} = C_{T0} - C_{T1} = 2445 - 945 = 1500 \text{ mg/l. COD.}$$

$$\Delta C_{T2} = S_{T0} - C_{T2} = 1435 - 590 = 845 \text{ mg/l. COD.}$$

$$X_{P2} = C_{T2} - S_{T2} = 590 - 275 = 315 \text{ mg/l. COD.}$$

$$X_{P1} = X_{P2} \frac{\Delta C_{T1}}{\Delta C_{T2}} = 315 \frac{1500}{845} = 560 \text{ mg/l. COD.}$$

$$X_I = C_{T1} - S_{T1} - X_{P1} = 945 - 300 - 560 = 85 \text{ mg/l. COD.}$$

$$S_{P1} = \frac{S_{T1} - S_{T2}}{1 - \frac{\Delta C_{T2}}{\Delta C_{T1}}} = \frac{300 - 275}{1 - \frac{845}{1500}} = 55 \text{ mg/l. COD.}$$

$$S_I = S_{T1} - S_{P1} = 300 - 55 = 245 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1435 - 245 = 1190 \text{ mg/l. COD.}$$

A.2.3 Calculation of X_I , by Method 3

The three soluble COD profiles from the three reactors, as shown in Figure A.10, helps understanding the calculation.

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{50}{1435} = 0.04$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{275 - 0.04 \times 1435}{(1 - 0.04)} = 235 \text{ mg/l. COD.}$$

Table A.10 Soluble COD Data of The Reactors of Set 3.

Day	ST1 (mg/l)	ST2 (mg/l)	ST3 (mg/l)
0	1435	1435	1435
2	427	554	900
5	396	443	149
7	385	261	136
9	373	350	138
15	302	290	142
19	297	286	85
21	300	300	70
23	300	346	65
26	300	275	50
30	300	275	50

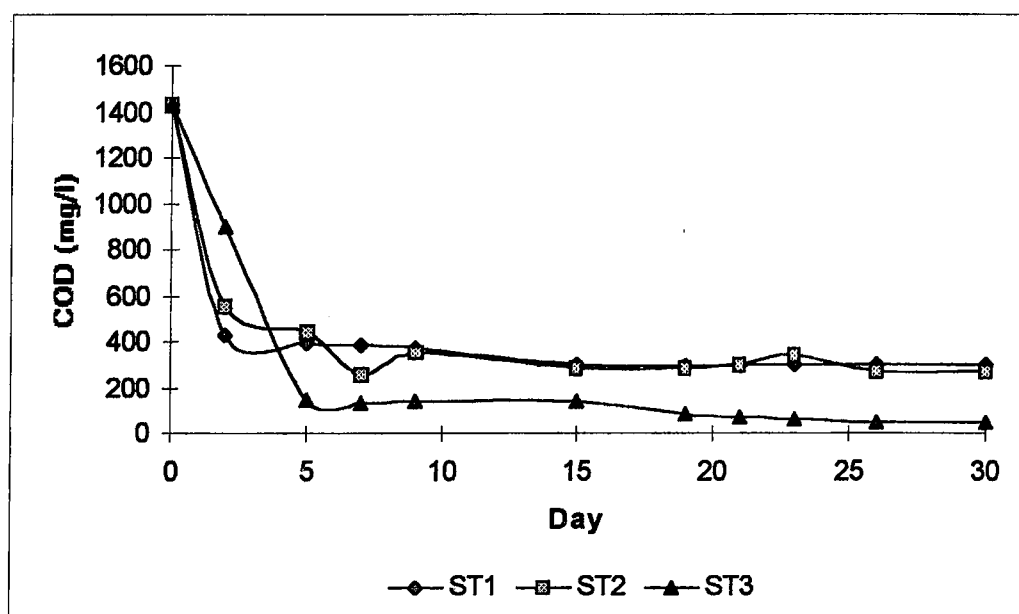


Figure A.10 Soluble COD Profiles of The Reactors of Set 3.

$$S_{P1} = S_{T1} - S_I = 300 - 235 = 65 \text{ mg/l. COD.}$$

$$S_{P2} = S_{T2} - S_I = 275 - 235 = 40 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 1435 - 235 = 1200 \text{ mg/l. COD.}$$

$$C_{S0} = \frac{S_{P1}}{S_{P2}} S_{S0} = \frac{65}{40} 1200 = 1950 \text{ mg/l. COD.}$$

$$X_I = C_{T0} - C_{S0} - S_I = 2445 - 1950 - 235 = 260 \text{ mg/l. COD.}$$

A.3 EXPERIMENTAL DATA OF SET 4

The initial total and soluble COD are, 1680 mg/l. and 790 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure A.11. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure A.12. The soluble COD profile of the glucose reactor is given in Figure A.13. The difference between Set 4 and others is that in all the filtration operations of Set 4 membrane filters of 0.45 μm . pore size are used and the period of experimentation is extended to 70 days. But as it is seen from the Graphs presented below the reactors stabilized after approximately 30 days.

Table A.11 COD Data of Raw Wastewater Reactor of Set 4.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	1680	790
2	1352	419
6	1060	625
9	1030	300
14	891	229
20	845	205
23	815	256
27	792	256
29	808	280
33	796	225
35	700	225
37	700	225
41	700	225
55	700	225
69	700	225

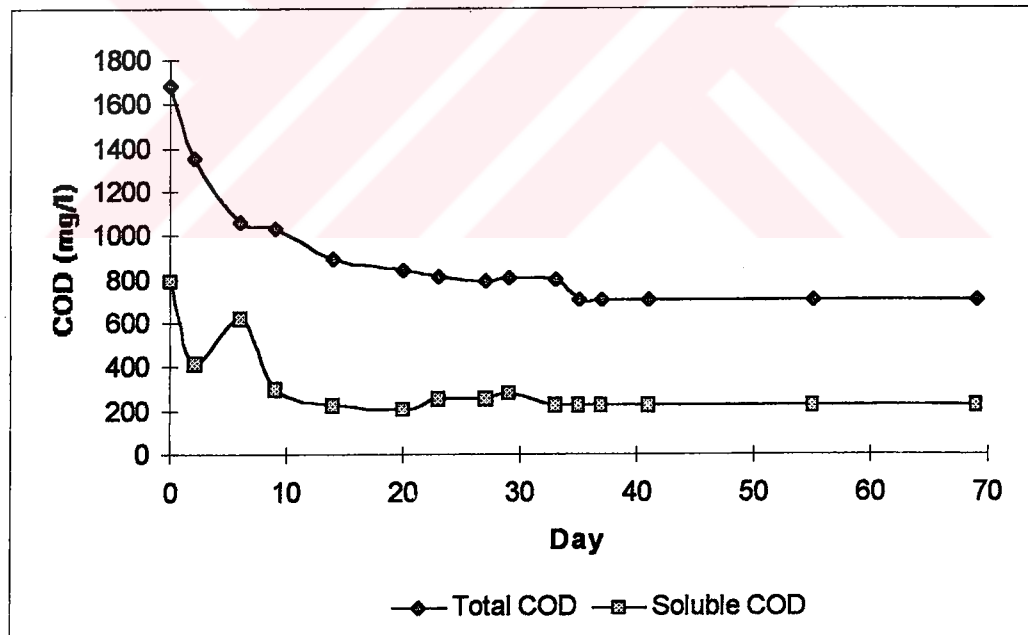


Figure A.11 COD Profiles of Raw Wastewater Reactor of Set 4.

Table A.12 COD Data of Filtered Wastewater Reactor of Set 4.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	790	790
2	606	419
6	530	230
9	526	320
14	502	206
20	365	205
23	370	186
27	361	117
29	396	210
33	387	114
35	405	205
37	405	205
41	360	205
55	360	205
69	360	205

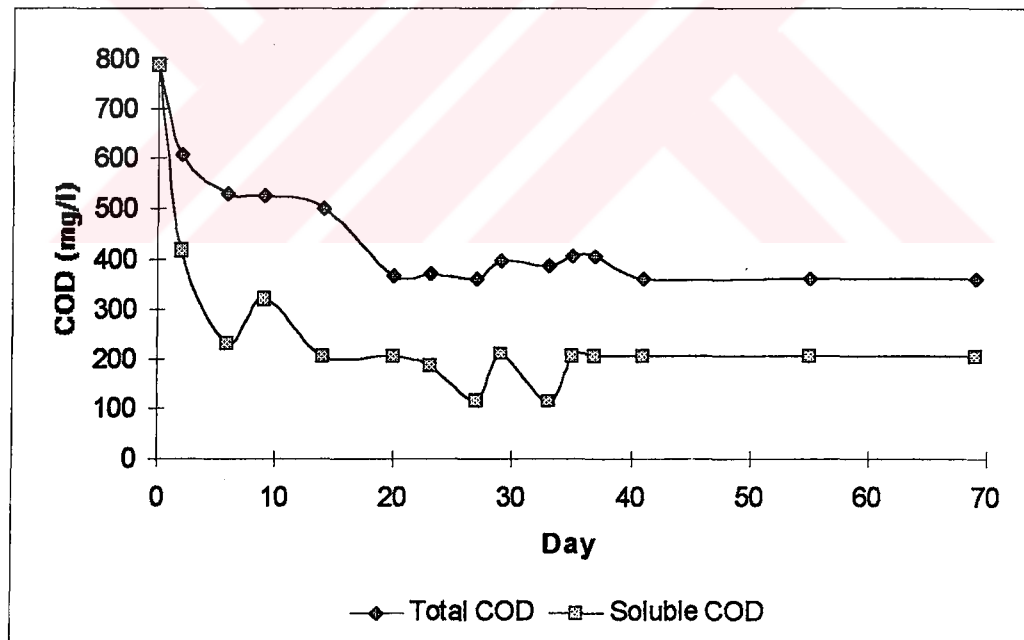


Figure A.12 COD Profiles of Filtered Wastewater Reactor of Set 4.

Table A.13 COD Data of Glucose Reactor of Set 4.

Day	Soluble COD (mg/l)
0	795
2	93
6	80
9	90
14	70
20	50
23	23
27	37
29	33
33	23
35	25
37	25
41	25
55	25

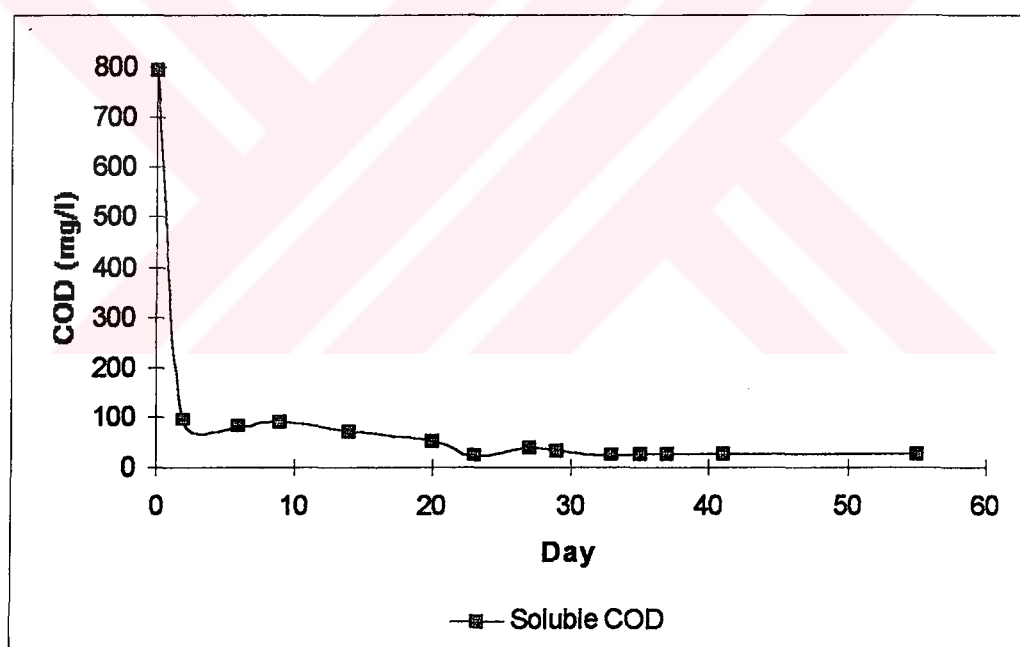


Figure A.13 COD Profile of Glucose Reactor of Set 4.

The experimental data in graphical presentation above can be summarized by:

$$C_{T0} = 1680 \text{ mg/l. COD}, \quad S_{T0} = 790 \text{ mg/l. COD},$$

$$C_{T1} = 700 \text{ mg/l. COD}, \quad S_{T1} = 225 \text{ mg/l. COD},$$

$$C_{T2} = 360 \text{ mg/l. COD}, \quad S_{T2} = 205 \text{ mg/l. COD},$$

$$S_{G0} = 795 \text{ mg/l. COD}, \quad S_{T3} = 25 \text{ mg/l. COD}.$$

A.3.1 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.64 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 185 mg/l.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 700 - 225 = 475 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.64 = 0.128$$

Table A.14 Particulate COD Data of Raw Wastewater Reactor Set 4.

Day	Total Particulate COD (mg/l)
0	890
2	933
6	835
9	730
14	662
20	640
23	559
27	536
29	528
33	521
35	475
37	475
41	475
55	475
69	475

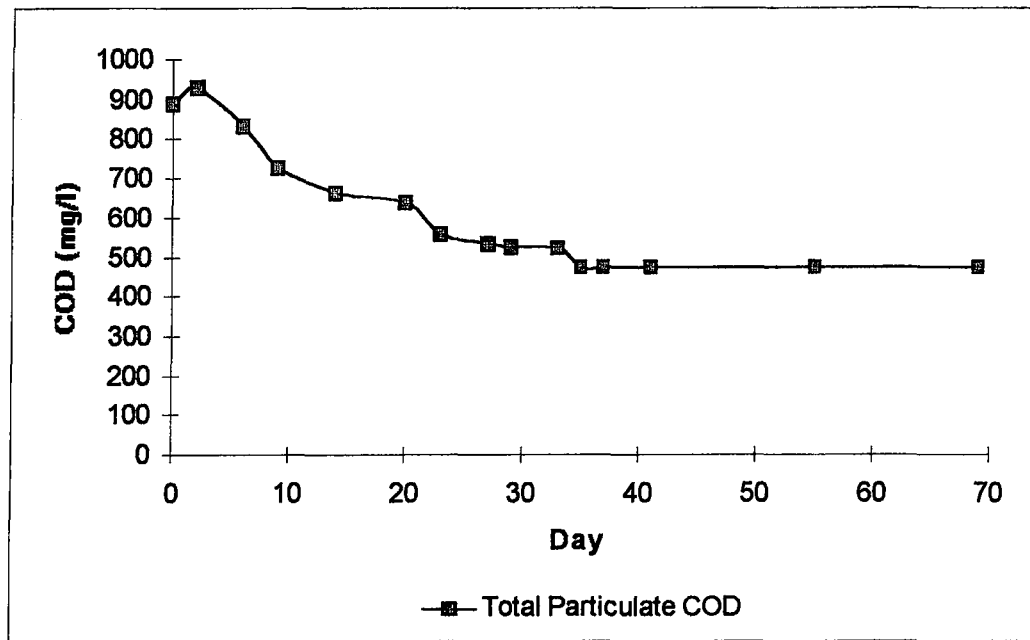


Figure A.14 Particulate COD Profile of Raw Wastewater Reactor Set 4.

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 1680 = 215 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 215 = 260 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 260 - 185 = 1235 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 1235 = 158 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 158 = 317 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 317 - 185 = 1178 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 1178 = 151 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 151 = 324 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 324 - 185 = 1171 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.128 \times 1171 = 150 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 150 = 325 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 325 - 185 = 1170 \text{ mg/l. COD.}$$

A.3.2 Calculation of X_I , by Method 2

The total and soluble COD profiles used in this calculation were given above as Figure A.11 and Figure A.12.

$$\Delta C_{T1} = C_{T0} - C_{T1} = 1680 - 700 = 980 \text{ mg/l. COD.}$$

$$\Delta C_{T2} = S_{T0} - C_{T2} = 790 - 360 = 430 \text{ mg/l. COD.}$$

$$X_{P2} = C_{T2} - S_{T2} = 360 - 205 = 155 \text{ mg/l. COD.}$$

$$X_{P1} = X_{P2} \frac{\Delta C_{T1}}{\Delta C_{T2}} = 155 \frac{980}{430} = 355 \text{ mg/l. COD.}$$

$$X_I = C_{T1} - S_{T1} - X_{P1} = 700 - 225 - 355 = 120 \text{ mg/l. COD.}$$

$$S_{P1} = \frac{S_{T1} - S_{T2}}{\Delta C_{T2}} = \frac{225 - 205}{430} = 35 \text{ mg/l. COD.}$$

$$1 - \frac{\Delta C_{T2}}{\Delta C_{T1}} = 1 - \frac{430}{980}$$

$$S_I = S_{T1} - S_{P1} = 225 - 35 = 190 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 790 - 190 = 600 \text{ mg/l. COD.}$$

A.3.3 Calculation of X_I , by Method 3

The three soluble COD profiles from the three reactors, as shown in Figure A.15, helps understanding the calculation.

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{25}{795} = 0.03$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{205 - 0.3 \times 795}{(1 - 0.03)} = 185 \text{ mg/l. COD.}$$

Table A.15 Soluble COD Data of The Reactors of Set 4.

Day	ST1 (mg/l)	ST2 (mg/l)	ST3 (mg/l)
0	790	790	795
2	419	419	93
6	625	230	80
9	300	320	90
14	229	206	70
20	205	205	50
23	256	186	23
27	256	117	37
29	280	210	33
33	225	114	23
35	225	205	25
37	225	205	25
41	225	205	25
55	225	205	25
69	225	205	25

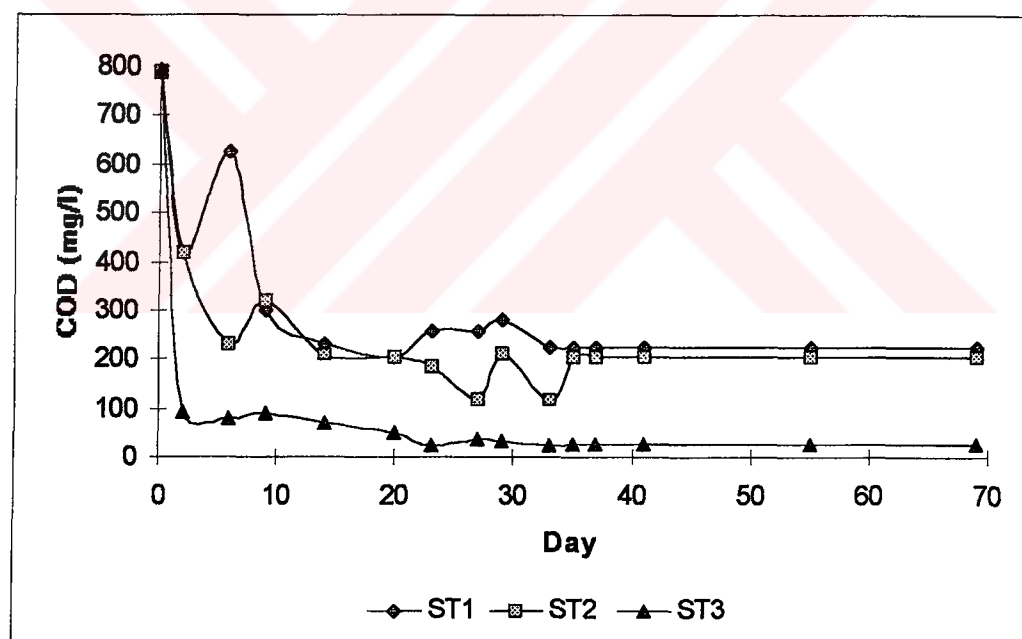


Figure A.15 Soluble COD Profiles of The Reactors of Set 4.

$$S_{P1} = S_{T1} - S_I = 225 - 185 = 40 \text{ mg/l. COD.}$$

$$S_{P2} = S_{T2} - S_I = 205 - 185 = 20 \text{ mg/l. COD.}$$

$$S_{S0} = S_{T0} - S_I = 790 - 185 = 605 \text{ mg/l. COD.}$$

$$C_{S0} = \frac{S_{P1}}{S_{P2}} S_{S0} = \frac{40}{20} 605 = 1210 \text{ mg/l. COD.}$$

$$X_I = C_{T0} - C_{S0} - S_I = 1680 - 1210 - 185 = 285 \text{ mg/l. COD.}$$



APPENDIX B

B.1 RE-CALCULATION OF SET 1 BY METHOD 1

The initial total and soluble COD are, 1930 mg/l. and 1260 mg/l., respectively.

$$X_{T1} = C_{T1} - S_{T1} = 1020 - 400 = 620 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.373 \times 0.64 = 0.239$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.239 \times 1930 = 461 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 461 = 159 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 159 - 265 = 1506 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.239 \times 1506 = 360 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 360 = 260 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 260 - 265 = 1405 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.239 \times 1405 = 336 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 336 = 284 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 284 - 265 = 1381 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.239 \times 1381 = 330 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 620 - 330 = 290 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1930 - 290 - 265 = 1375 \text{ mg/l. COD.}$$

B.2 RE-CALCULATION OF SET 2 BY METHOD 1

$$X_{T1} = C_{T1} - S_{T1} = 1130 - 360 = 770 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.431 \times 0.64 = 0.276$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.276 \times 2030 = 560 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 560 = 210 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 210 - 270 = 1550 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.276 \times 1550 = 428 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 428 = 342 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 342 - 270 = 1418 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.276 \times 1418 = 391 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 391 = 379 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 379 - 270 = 1381 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.276 \times 1381 = 381 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 381 = 389 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 389 - 270 = 1371 \text{ mg/l. COD.}$$

Iteration 5:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.276 \times 1371 = 380 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 770 - 380 = 390 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2030 - 390 - 270 = 1370 \text{ mg/l. COD.}$$

B.3 RE-CALCULATION OF SET 3 BY METHOD 1

$$X_{T1} = C_{T1} - S_{T1} = 945 - 300 = 645 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.414 \times 0.64 = 0.265$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.265 \times 2445 = 648 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 648 \cong 0 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 0 - 235 = 2210 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.265 \times 2210 = 586 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 586 = 59 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 59 - 235 = 2151 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.265 \times 2151 = 570 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 570 = 75 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 75 - 235 = 2135 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.265 \times 2135 = 566 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 566 = 79 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 79 - 235 = 2131 \text{ mg/l. COD.}$$

Iteration 5:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.265 \times 2131 = 565 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 645 - 565 = 80 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 2445 - 80 - 235 = 2130 \text{ mg/l. COD.}$$

B.4 RE-CALCULATION OF SET 4 BY METHOD 1

$$X_{T1} = C_{T1} - S_{T1} = 700 - 225 = 475 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.404 \times 0.64 = 0.258$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.258 \times 1680 = 433 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 433 = 42 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 42 - 185 = 1453 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.258 \times 1453 = 375 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 375 = 100 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 100 - 185 = 1395 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.258 \times 1395 = 360 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 360 = 115 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 115 - 185 = 1380 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.258 \times 1380 = 356 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 356 = 119 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 119 - 185 = 1376 \text{ mg/l. COD.}$$

Iteration 5:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.258 \times 1376 = 355 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 475 - 355 = 120 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 1680 - 120 - 185 = 1375 \text{ mg/l. COD.}$$

APPENDIX C

C.1 EXPERIMENTAL DATA OF SET 1

The initial total and soluble COD are, 650 mg/l. and 230 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure C.1. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure C.2. The soluble COD profile of the glucose reactor is given in Figure C.3.

Table C.1 COD Data of Raw Wastewater Reactor of Set 1.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	650	230
1	478	126
5	226	66
7	218	66
9	201	42
13	221	73
15	245	60
20	218	65
21	208	61
22	204	59
26	200	60

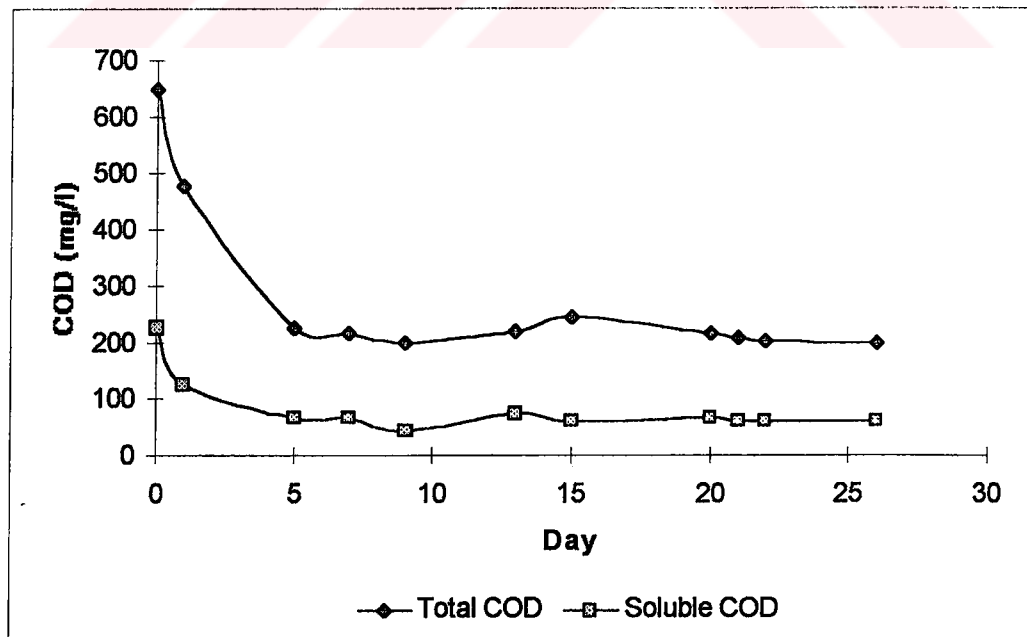


Figure C.1 COD Profiles of Raw Wastewater Reactor of Set 1.

Table C.2 COD Data of Filtered Wastewater Reactor of Set 1.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	230	230
1	225	88
5	136	73
7	137	64
9	128	44
13	153	58
15	134	55
20	128	54
21	131	49
22	134	54
26	130	50

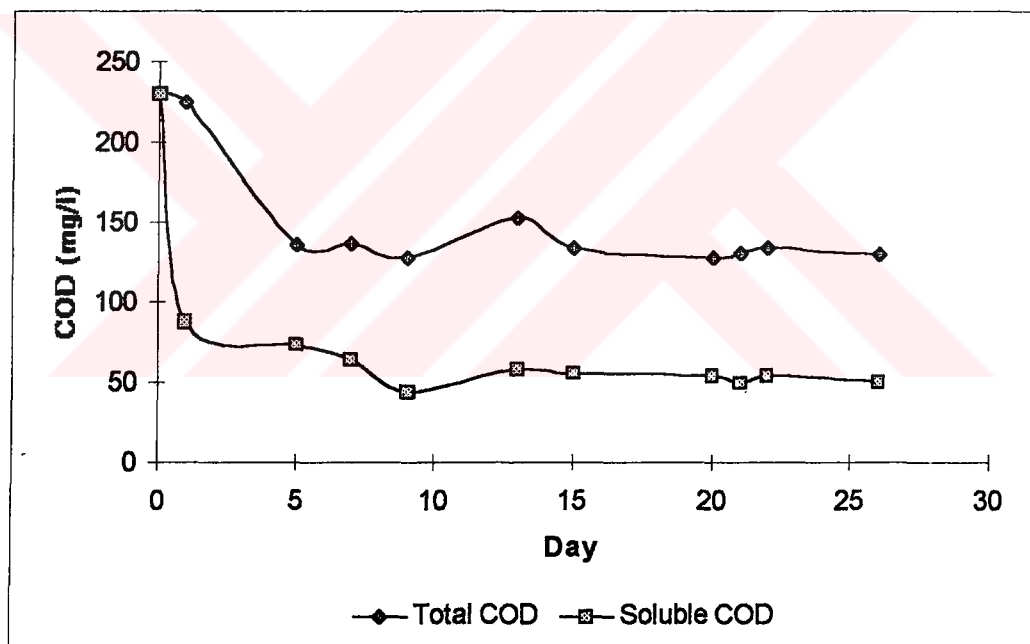


Figure C.2 COD Profiles of Filtered Wastewater Reactor of Set 1.

Table C.3 COD Data of Glucose Reactor of Set 1.

Day	Soluble COD (mg/l)
0	230
1	81
5	23
15	35
22	35
26	35

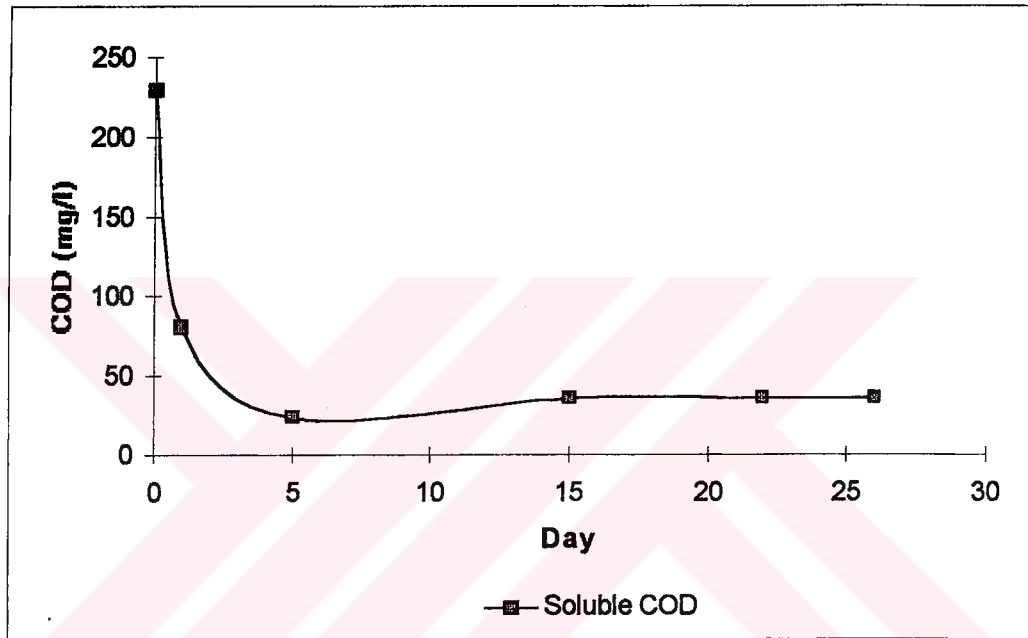


Figure C.3 COD Profile of Glucose Reactor of Set 1.

The experimental data in graphical presentation above can be summarized by:

$$C_{T0} = 650 \text{ mg/l. COD}, \quad S_{T0} = 230 \text{ mg/l. COD},$$

$$C_{T1} = 200 \text{ mg/l. COD}, \quad S_{T1} = 60 \text{ mg/l. COD},$$

$$C_{T2} = 130 \text{ mg/l. COD}, \quad S_{T2} = 50 \text{ mg/l. COD},$$

$$S_{G0} = 230 \text{ mg/l. COD}, \quad S_{T3} = 35 \text{ mg/l. COD}.$$

C.1.1 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.65 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 20 mg/l.

Table C.4 Particulate COD Data of Raw Wastewater Reactor Set 1.

Day	Total Particulate COD (mg/l)
0	420
1	352
5	160
7	152
9	159
13	148
15	185
20	153
21	147
22	145
26	140

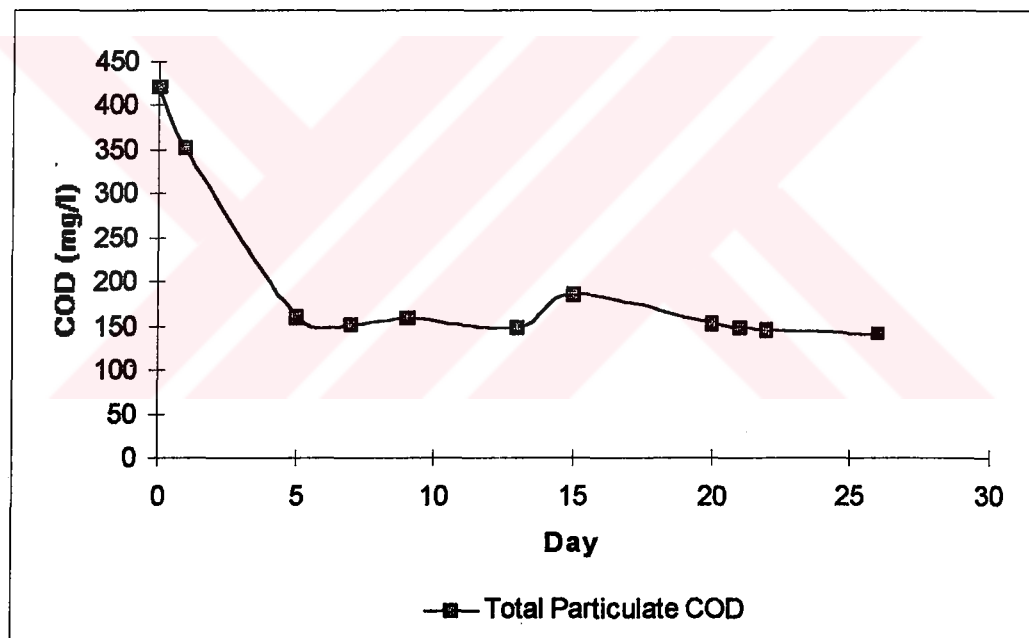


Figure C.4 Particulate COD Profile of Raw Wastewater Reactor Set 1.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 200 - 60 = 140 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.65 = 0.13$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.13 \times 650 = 85 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 140 - 85 = 55 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 55 - 20 = 575 \text{ mg/l. COD.}$$

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.13 \times 575 = 75 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 140 - 75 = 65 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 65 - 20 = 565 \text{ mg/l. COD.}$$

C.1.2 Calculation of S_I , by Method 3

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{35}{230} = 0.15$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{50 - 0.15 \times 230}{(1 - 0.22)} = 20 \text{ mg/l. COD.}$$

Table C.5 Soluble COD Data of The Reactors of Set 1.

Day	ST1 (mg/l)	ST2 (mg/l)	ST3 (mg/l)
0	230	230	230
1	126	88	81
5	66	73	23
7	66	64	25
9	42	44	30
13	73	58	32
15	60	55	35
20	65	54	35
21	61	49	35
22	59	54	35
26	60	50	35

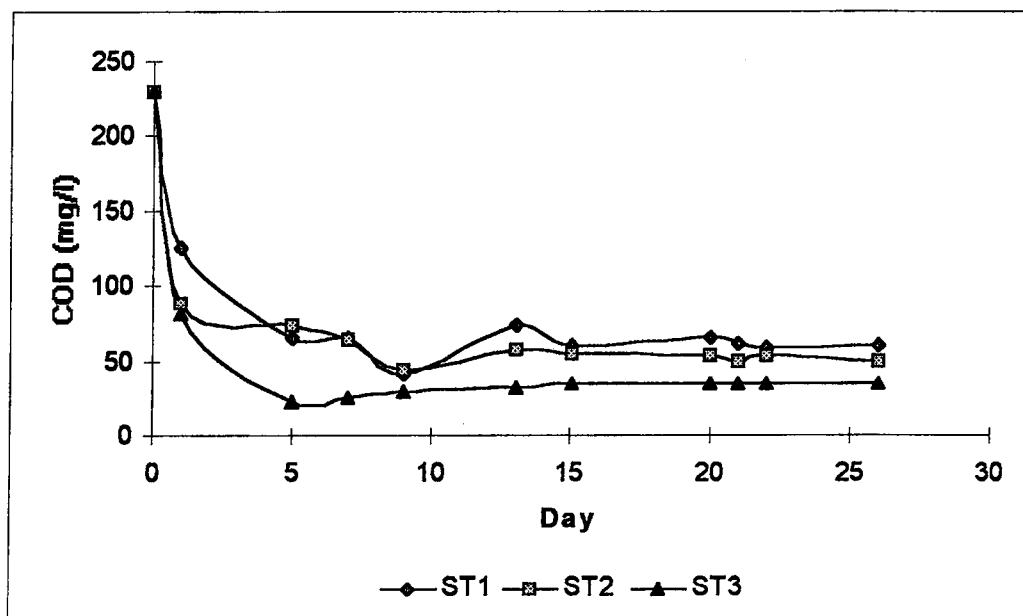


Figure C.5 Soluble COD Profiles of The Reactors of Set 1.

C.2 EXPERIMENTAL DATA OF SET 2

The initial total and soluble COD are, 650 mg/l. and 135 mg/l., respectively. The total and soluble COD profiles of the raw wastewater reactor is given in Figure C.6. The total and soluble COD profiles of the filtered wastewater reactor is given in Figure C.7. The soluble COD profile of the glucose reactor is given in Figure C.8.

The experimental data in graphical presentation below can be summarized by:

$$\dot{C}_{T0} = 650 \text{ mg/l. COD}, \quad S_{T0} = 135 \text{ mg/l. COD},$$

$$C_{T1} = 225 \text{ mg/l. COD}, \quad S_{T1} = 55 \text{ mg/l. COD},$$

$$C_{T2} = 75 \text{ mg/l. COD}, \quad S_{T2} = 37 \text{ mg/l. COD},$$

$$S_{G0} = 135 \text{ mg/l. COD}, \quad S_{T3} = 10 \text{ mg/l. COD}.$$

Table C.6 COD Data of Raw Wastewater Reactor of Set 2.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	650	135
2	603	96
6	470	65
10	374	55
15	306	55
20	280	56
23	260	51
28	254	51
36	225	55
50	225	55
56	225	55

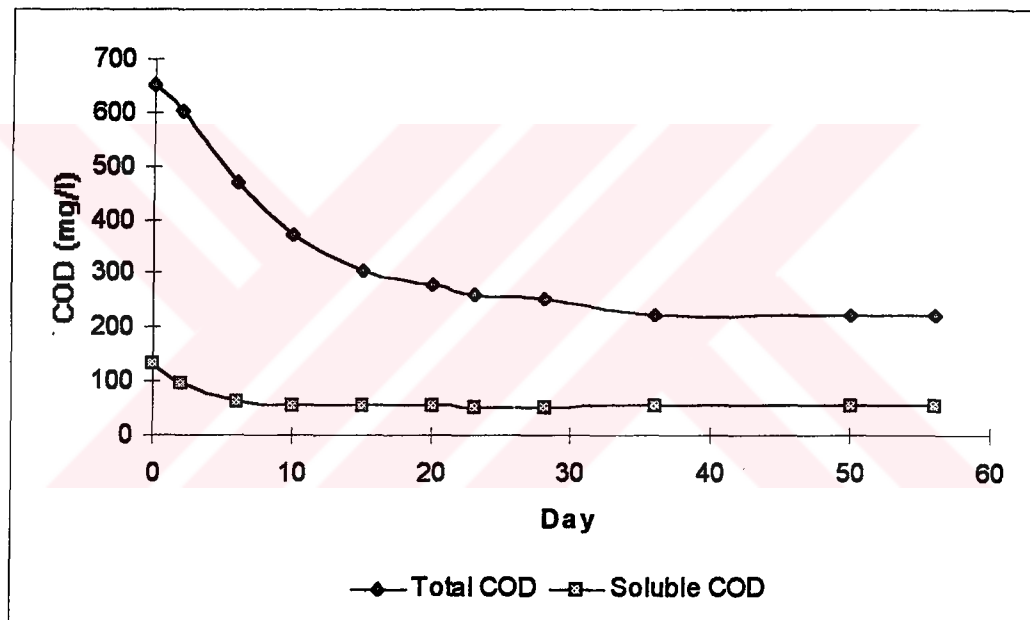


Figure C.6 COD Profiles of Raw Wastewater Reactor of Set 2.

Table C.7 COD Data of Filtered Wastewater Reactor of Set 2.

Day	Total COD (mg/l)	Soluble COD (mg/l)
0	135	135
2	146	87
6	130	50
10	97	42
15	91	46
20	86	47
23	84	46
28	74	37
36	73	37
50	73	37
56	73	37

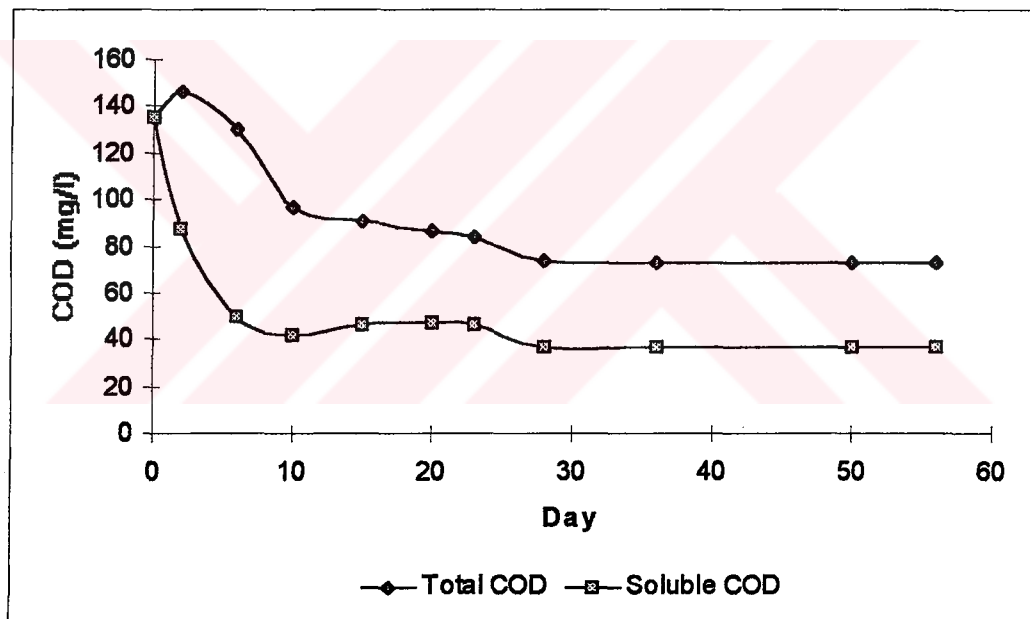


Figure C.7 COD Profiles of Filtered Wastewater Reactor of Set 2.

Table C.8 COD Data of Glucose Reactor of Set 2.

Day	Soluble COD (mg/l)
0	135
2	32
6	28
15	18
20	33
23	5
28	5
36	12
50	12
56	12

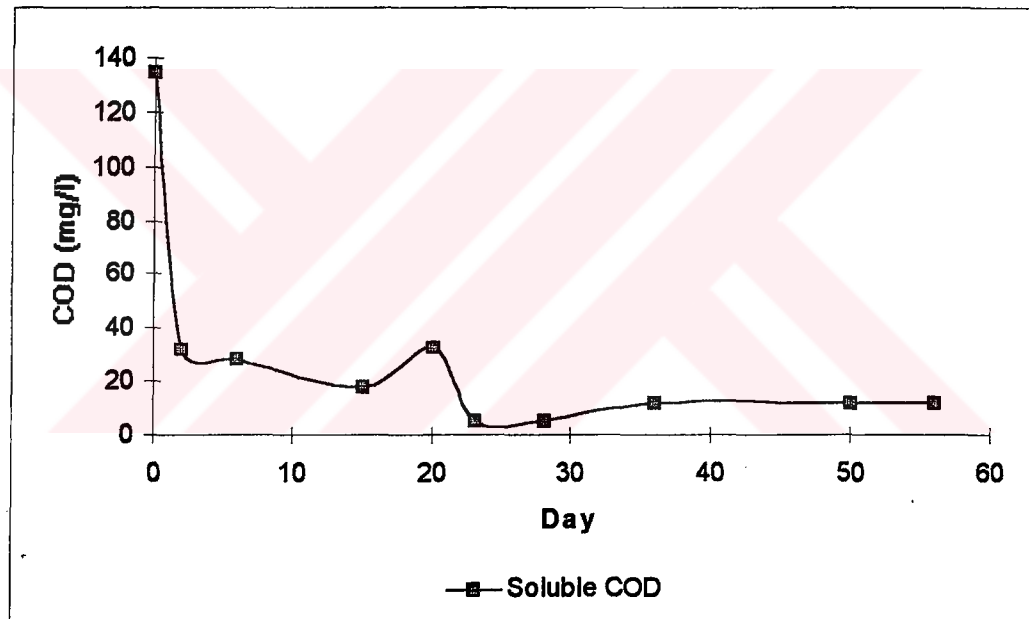


Figure C.8 COD Profile of Glucose Reactor of Set 2.

C.2.1 Calculation of X_I , by Method 1

The heterotrophic yield coefficient, Y_H , is taken as 0.65 mg COD/mg COD. The inert fraction of the biomass, f_{EX} , is assumed to be 0.20. Soluble inert COD is accepted as 30 mg/l.

The threshold value of the particulate COD is used to calculate X_I .

$$X_{T1} = C_{T1} - S_{T1} = 225 - 55 = 170 \text{ mg/l. COD.}$$

$$Y_{XP} = f_{EX} \cdot Y_H = 0.20 \times 0.65 = 0.13$$

Iteration 1:

$$X_{P1} = Y_{XP} \cdot C_{T0} = 0.13 \times 650 = 85 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 170 - 85 = 85 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 85 - 30 = 535 \text{ mg/l. COD.}$$

Table C.9 Particulate COD Data of Raw Wastewater Reactor Set 2.

Day	Total Particulate COD (mg/l)
0	515
2	507
6	405
10	319
15	251
20	224
23	209
28	203
36	170
50	170
56	170

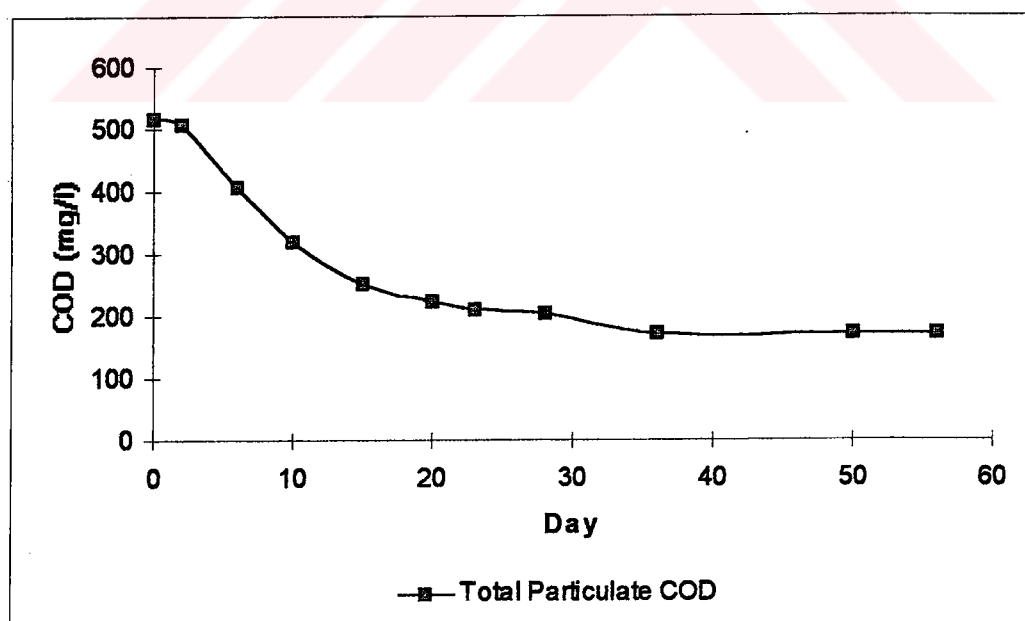


Figure C.9 Particulate COD Profile of Raw Wastewater Reactor Set 2.

Iteration 2:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.13 \times 535 = 70 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 170 - 70 = 100 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 100 - 30 = 520 \text{ mg/l. COD.}$$

Iteration 3:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.13 \times 520 = 68 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 170 - 68 = 102 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 102 - 30 = 518 \text{ mg/l. COD.}$$

Iteration 4:

$$X_{P1} = Y_{XP} \cdot C_{S0} = 0.13 \times 518 = 65 \text{ mg/l. COD.}$$

$$X_I = X_{T1} - X_{P1} = 170 - 65 = 105 \text{ mg/l. COD.}$$

$$C_{S0} = C_{T0} - X_I - S_I = 650 - 105 - 30 = 515 \text{ mg/l. COD.}$$

C.2.2 Calculation of S_I , by Method 3

$$Y_{SP} = \frac{S_{P3}}{S_{G0}} = \frac{10}{135} = 0.07$$

$$S_I = \frac{S_{T2} - S_{T0} Y_{SP}}{(1 - Y_{SP})} = \frac{37 - 0.07 \times 135}{(1 - 0.07)} = 30 \text{ mg/l. COD.}$$

AUTOBIOGRAPHY

Özlem KARAHAN, was born in İstanbul, on 20/01/1972. She graduated from Kadıköy Anadolu Lisesi, in June, 1989 and received her B.S. degree in chemical engineering from Boğaziçi University, Faculty of Engineering, Chemical Engineering department, in July, 1995.

