APPENDIX 2

Treatability Trial Report

(after first 3 months of project)

ANAEROBIC TREATMENT OF WOOL SCOURING EFFLUENT

Report No 1

PART II

TREATABILITY TRIAL

INITIAL LABORATORY FEASIBILITY STUDY ON THE ANAEROBIC TREATMENT OF EFFLUENT EMANATING FROM THE WOOL SCOURING PROCESS

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CONTENTS

1. INTRODUCTION

As to direct result of the properties of effluent emanating from wool scouring, anaerobic digestion was considered as the most appropriate remediation technology for the following reasons:-

- The process is capable of treating high strength wastes
- The end products of the process are useful gases
- Biochemical mechanisms under anaerobic conditions are known to impact on chemical species such as Lindane which are present in wool scouring effluent.

The commercial evaluation of the process requires that several key questions be answered. These include:-

- will the process impact on the target substrates
- what loading rates can be achieved and hence what are the reactor sizes required.
- can the process be easily controlled in practice
- can the biomass be contained within a reactor to render the system commercially feasible
- what are the concomitant economics.

In order to address these questions a lengthy study needs to be carried out which is the subject of this project.

This report details the work and results carried out over an initial three month period which assesses whether or not anaerobic digestion impacts on the target substrates and to indicate whether the system is capable of further development leading ultimately to full beneficial and economically attractive commercial application.

2. SUMMARY OF FINDINGS

The application of anaerobic processing to wool scouring effluent fulfilled all of our expectations with regard to its pollutive remediation capabilities.

Based on effluent provided by Haworth Scouring and on daily results the system was found to:-

- Remove up to 96.9% of the COD load
- Remove Lindane to a very low level (1 ppb)
- Reduction of COD appears to conform to a standard kinetic model
- The process has the potential for considerable improvement.

3. THE NEXT STEPS

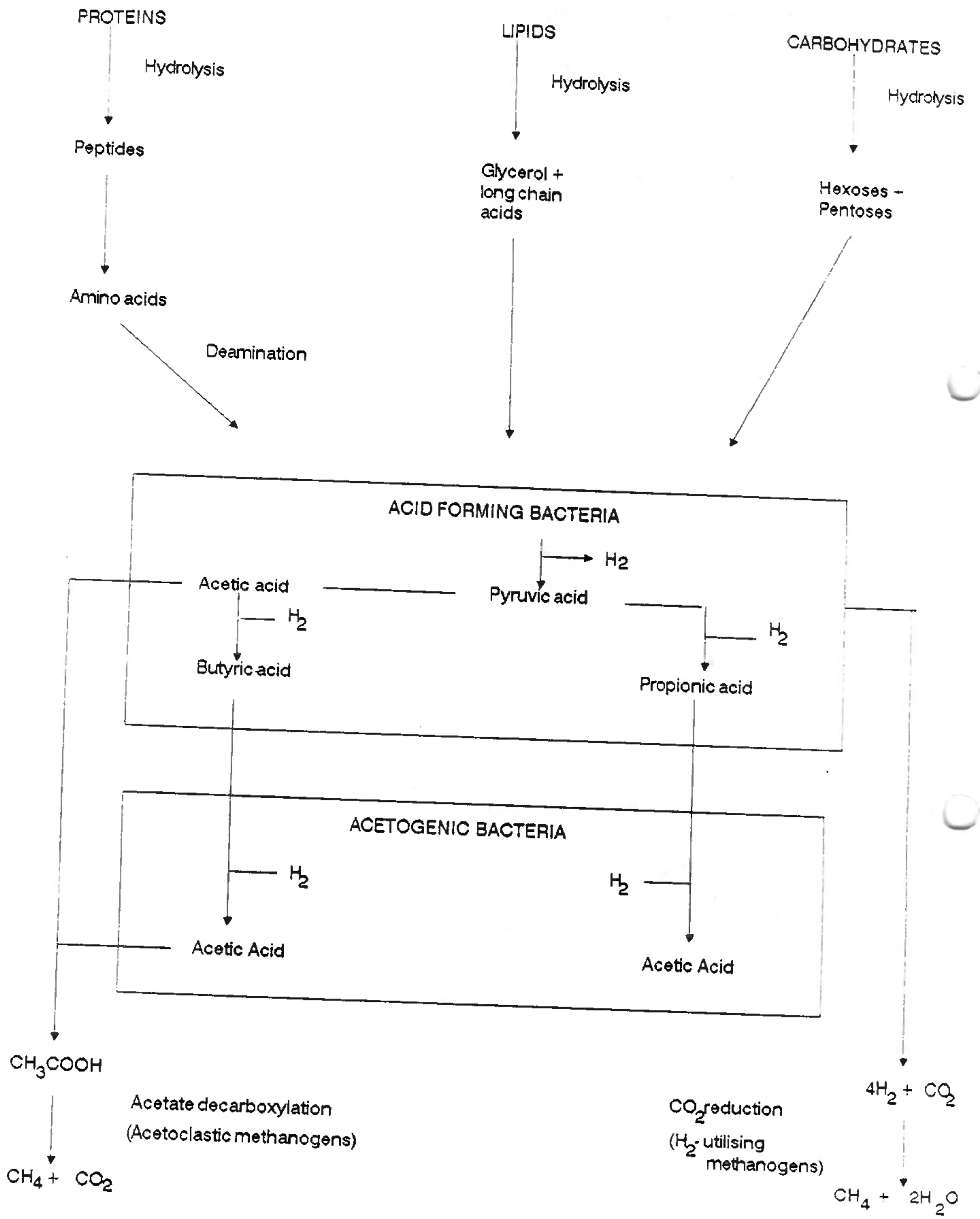
As outlined in the Introduction, this project has several distinct components with regard to developing adequate information for the design of a commercially attractive pollution remediation route for the wool scouring industry.

This initial overview of anaerobic treatment of wool scouring effluent demonstrated that the process has good potential for the solution of wool scouring environmental problems. It has identified that the process efficiency not only demonstrates a high remediation capability but the manner in which those efficiencies are achieved would appear to obey classical scientific theory.

The next step is to carry out detailed microbiological research in order to achieve the following:

- To optimise the biological consortia in terms of community dynamics with regard to the target functions
- To determine the most favourable processing parameters in the interest of process efficiency (eg. temp, pH, etc.)
- To determine the properties of that developed consortia. We refer in particular to loading rates, reaction kinetics etc. so that a meaningful plant design criteria may be produced
- To identify the technology required for the containment of the microbiological consortia so that effective reactor internals may be applied
- To commence process engineering research and in particular process modelling using Computational Fluid Dynamics simulation software.
- To design a suitable pilot plant to demonstrate the process on-line and to allow particular engineering problems to be addressed facilitating the full scale implementation of the process.

BIOCHEMICAL SCHEMATIC OF ANAEROBIC DIGESTION



4. LABORATORY METHODOLOGY

4.1 Objectives

To acclimate a broad spectrum anaerobic biomass to wool scouring effluent and then to overview its properties. In the first instance those of specific interest were COD and Lindane removal.

4.2 Theory

A very simple description of the anaerobic process is offered in schematic form on the opposite page.

This diagram broadly describes the process at the molecular level and demonstrates the close relationship between the various bacteria responsible for the conversion of complex organic molecules to smaller molecular weight gaseous products Carbon Dioxide and Methane. The process is complex but may be broadly classified as follows:

- Macro molecules are converted to smaller soluble chemical species
- These small molecules are utilised by acid forming bacteria to produce acetic acid or higher molecular weight fatty acids eg. Butyric and Propionic
- Acetogenic bacteria convert the higher fatty acids to acetic acid
- The Methanogenic bacteria then utilise the acetic acid to produce Methane. Methane is also produced from hydrogen and Carbon Dioxide.

In our experience, the most susceptible group of organisms to process shocks are the Methanogens and it becomes clear from the diagram opposite that in the event of a sudden feed overload that an excess of substrate is presented to the hydrolytic and acid forming bacteria resulting in a rapid increase in volatile acid levels in the fermenter. This is because the slower to respond Methanogens are unable to metabolise the increase substrate levels fast enough. This results in a lowering of pH because of the build up of volatile acids and brings about feed back inhibition of the Methanogens and ultimately system failure.

Because of the short time period given to the initial phase of this study the anaerobic process components cannot be fully elucidated. Such important issues as to whether a particular step is rate limiting when the biomass is confronted with wool scouring effluent, whether there are any major inhibitory chemicals present etc. will be addressed later in the work programme.

At this point we are evaluating whether or not the anaerobic process offers any potential for subsequent process development so the consortia has to be protected against process excursions in order to get a proper view of the biomass's potential.

To this end the experiments were carried out in a manner to avoid such problems. We refer to maintaining the alkalinity levels to buffer the system against pH excursions which may inhibit Methanogensis, applying substrate load rates at a level that produces low, volatile acids in order to ensure that the newly acclimated biomass is maintained in balance.

This approach will answer the key questions which include:

- Is COD removed?
- What is the expected maximum removal rate?
- Is the removal mechanism understood?
- Is Lindane removed?

4.3 Apparatus

The apparatus used for this work was an enclosed 5 litre glass vessel fitted with continuous stirring, level and temperature controls a calibrated feed pump and a simple sludge recycle system. Gas monitoring was carried out using a W.R.C. gas meter connected to the reaction vessel.

4.4 Method

Biomass was added to the reaction vessel so that approximately 4.5 litres of liquid contained 10 g/l mixed liquor Suspended Solids. The system was continuously stirred and maintained at a temperature of 35°C wool scouring effluent was fed to the reaction vessel via calibrated feed pump at a rate that maintained stable process conditions. Liquid overflowing from this vessel was passed to a small glass container where the biomass was allowed to settle and subsequently be returned to the reaction vessel.

During the study period the following parameters were monitored:-

- ph in and out
- COD in and out
- Gas production
- Gas methane content
- Suspended Solids in and out
- Reactor contents alkalinity
- Reactor contents total volatile acids
- Lindane in and out

pH was not controlled since the effluent samples received were already very alkaline. On dilution, necessary because of the very high COD concentration, the pH fell to a level reasonably suitable for this process.

The alkalinity of the reactor contents were maintained at approximately 1000 ppm and wool scouring effluent feed rates controlled to maintain volatile acid levels at below 200 ppm.

At the loading rates experienced no major problems were observed with the process so nutrients were not evaluated at this stage, it appeared that the effluent source contained adequate nutrients for this part of the project.

5. INTERPRETATION OF RESULTS

The raw data obtained during the trial is included in Appendix I in both graphical and tabular form. In order to obtain a clear picture of the process capability the raw data has been analysed in some depth to produce a predictive performance model. This analysis relates to the COD removal efficiency where enough raw data exists to render it meaningful.

Theory:

The scientific theory that is relevant to biological processes is that shown below which is the Michaelis Menton equation. This demonstrates a clear relationship between substrate concentration and reaction velocity in enzyme related systems.

$$v = \frac{Vmax\,[s]}{Km + [s]}$$

Where			
	v	=	**The rate of the reaction**
	Vmax	=	**The limiting rate**
	[s]	=	**The substrate concentration**
	Km	=	**The Michaelis constant**

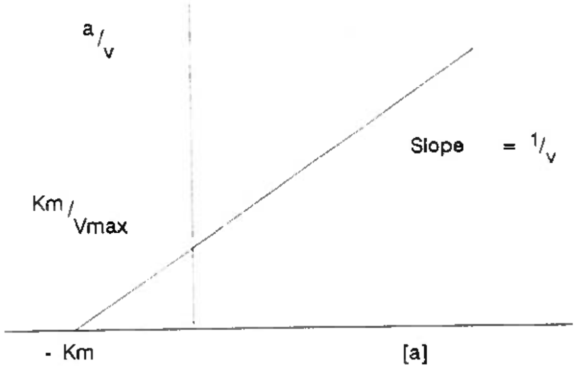
Whilst this relationship is determined classically for molar concentrations of discrete substrates and known enzyme systems the model should still relate to more complex situations that are biological in nature even though interpretation of Vmax and Km may be less easily understood.

In applying this to the current study where molar concentrations are not known [s] has been replaced by [a] which is the COD concentration in mg/l and the units of Km will also be in mg/l.

Rearranging the equation and incorporating [a] in place of [s] to a more convenient form we have

$$\frac{[a]}{v} = \frac{[a]}{Vmax} + \frac{Km}{Vmax}$$

If [a] is plotted against a/v for an enzyme system the following should be the result.



An additional problem in using the Michaelis Menton equation to analyse the study results is the measurement of velocity.

During the study different loads were applied to the laboratory unit and removal rates measured daily. In order to overcome this problem the results obtained were all converted to unit COD removed per unit applied for each of the COD concentrations applied.

This approach was thought to be satisfactory because it was clear that the biomass volume in the digestor was in a steady state condition ie. constant mixing etc and that the system was not loaded to its maximum with regard to load of COD applied per day, implying that excess catalytic capacity was always available (ie. appropriate enzymes).

Process Analysis:

The first step in analysing the process data was to calculate the required parameters for incorporation into the model discussed above. This has been carried out and is tabulated in Appendix II ie. COD removed by the system in grams per day.

On obtaining the COD removal data it was transformed into grammes per day removed divided by grammes per day applied to give the required [v] value discussed above. This was tabulated against the associated concentrations of COD applied figure which was [a] above. a/v was then calculated and the data arranged in ascending order of COD concentration applied. The table of this data is offered in Appendix II but a/v has been multiplied by 100 which corresponds to percentage removal in the final result.

Utilising the resulting regression equation a/v x 100 was estimated for the varying input COD concentrations [a] and the predicted v x 100 figure computed. As this figure also corresponds to percent removal of COD per day, a plot of applied COD concentration against COD removed was carried out and is offered in Appendix II. It clearly demonstrates the process performance.

The data generated by the study and its subsequent incorporation into the Michaelis Menton based model also allows the computation of Vmax, the maximum potential velocity of the process given the defined conditions. This was estimated to be 0.9691.

Additionally a value corresponding to Km was calculated for this system yielding a mathematical model that described very well the systems performance at the time of the study. It was found to be 1160.

The resulting mathematical process model was:-

$$\textbf{\% COD removal (g/g)} = \frac{\text{COD mg/l} \times 0.9691}{\textbf{1160} + \textbf{COD mg/l}}$$

6. CONCLUSIONS

The conclusions of this brief initial study may be concisely stated as follows:-

COD removal

COD was effectively removed by the acclimated biomass without major difficulty at the loading rates applied. The maximum removal rate expected was 96.9% each day.

The removal rates experienced during the study were related to concentration of substrate applied as predicted by a classical kinetic model.

No serious inhibition of the process under the study conditions was experienced.

Gas Production

The gas production predicted by theory was not often observed during the study. The equipment used at this stage was fairly basic and resulted in gas losses. As this was not a major issue at this stage it was not seen as important. However, this will be addressed in the next stage when mass balances will be produced but using far more sophisticated equipment.

Lindane Removal

The process removed Lindane effectively demonstrating that Lindane biodegraders were present in the consortium This aspect of the process was not studied in any depth. It will be a major element in the next stage of the research, when the detailed microbiology of the system is described.

Suspended Solids

During the study the Suspended Solids built up in the reactor at a rate that exceeded expectations. At this stage it is suspected that this excess material is the result of inorganic debris entering the system and is not due to biological growth.

7. DEFINITION OF STAGE II LABORATORY RESEARCH TRIALS

As outlined in Section 1 this project has several distinct components with regard to developing adequate information for the design of a commercially attractive pollution remediation route for the Wool Scouring Industry.

This initial overview of anaerobic treatment of wool scouring effluent demonstrated that the process has enormous potential for the solution of wool scouring environmental problems. It has identified that the process efficiency not only demonstrates high remediation efficiencies but the manner in which those efficiencies are achieved would appear to obey classical scientific theories.

The next step is to carry out detailed microbiological research in order to achieve the following:

- to optimise the biological consortia in terms of community dynamics with regard to the target functions
- to determine the most favourable processing parameters in the interest of process efficiency (e.g. temp, pH, etc)
- to determine the properties of that developed consortia. We refer in particular to loading rates, reaction kinetics, etc., so that a meaningful plant design criteria may be produced
- to identify the technology required for the containment of the microbiological consortia so that effective reactor internals may be applied
- to design a suitable pilot plant to demonstrate the process on-line and to allow particular engineering problems to be addressed facilitating the full scale implementation of the process.

Activities 1 and 2 above will be carried out in the laboratory using conventional microbiological research techniques, e.g. enrichment, isolation, identification and elucidation of properties.

This will result in a detailed understanding of the process parameters and the modification in population dynamics required to optimise the final process efficiency.

The target substrates in the main will be fats and specific chemical degradations.

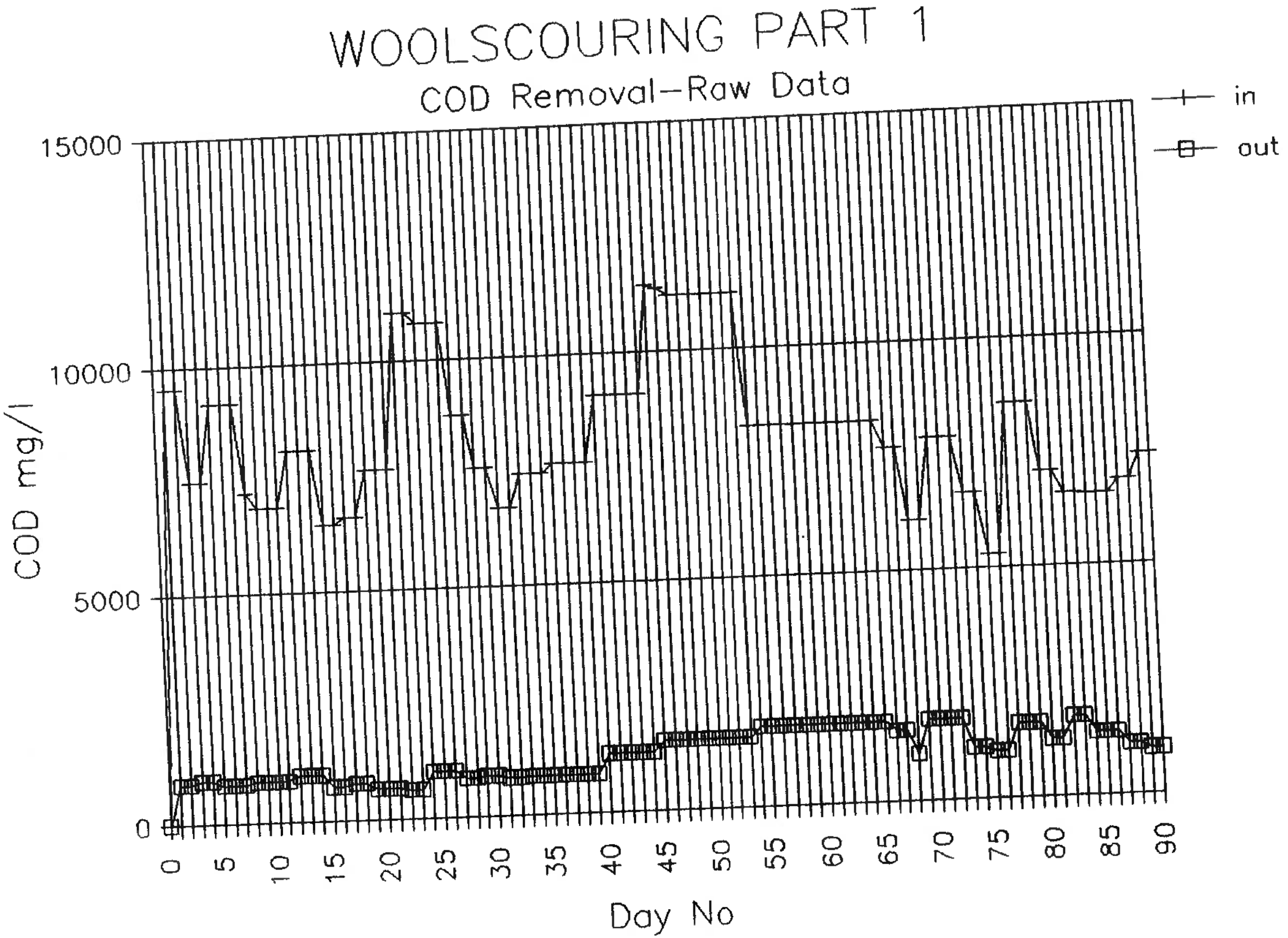
Activities 2 to 4 will be addressed using laboratory fermenters operated under continuous flow conditions. By observation of the enclosed anaerobic schematic it becomes clear that the key stage of interest is that which may be broadly defined as acidogenic. In order to study this in some detail the following fermenters will be commissioned.

Two prehydrolysis reactors, one fully mixed and the other partially packed followed by three methanogenic second stage reactors. At this point in time these will consist of upward flow sludge blanket, fluidised bed and partially packed reaction vessels. The performance of each stage of the process will be optimised as the scientific work and data production proceeds.

APPENDIX I

RAW DATA FROM TRIAL

(Graphs and Tabulations)


WOOLSCOURING PART 1
COD Removal-Raw Data
in
out
15000
10000
5000
0
COD mg/l
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Day No

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

COD conc. effect.

Day No	COD mg/l in	COD mg/l out
0	0	0
	9530	868
	9530	868
	7480	944
	7480	944
5	9190	844
	9190	844
	9190	844
	7210	900
	6880	900
10	6880	900
	6880	900
	8110	1010
	8110	1010
	8110	1010
15	6470	744
	6470	744
	6610	803
	6610	803
	7640	674
20	7640	674
	7640	674
	11040	628
	11048	628
	10810	1014
25	10810	1014
	10810	1014
	8760	844
	8760	844
	7590	876
30	7590	876
	6710	824
	6710	824
	7430	844
	7430	844
35	7430	844
	7640	840
	7640	840
	7640	840
	7640	840
40	9080	1276
	9080	1276
	9080	1276
	9080	1276
	9080	1276

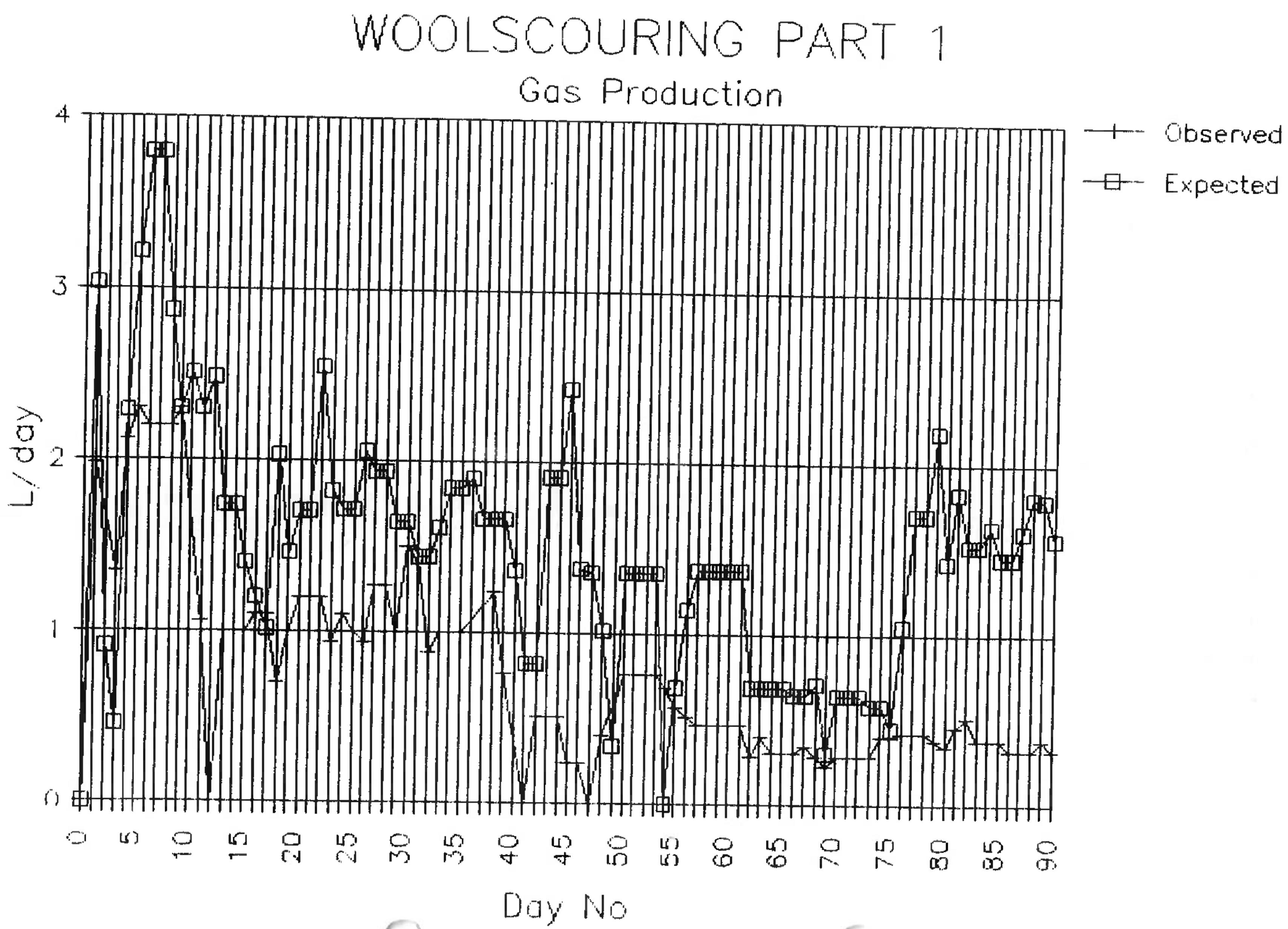
WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

COD conc. effect cont.

Day No	COD mg/l in	COD mg/l out
45	11440	1520
	11370	1520
	11210	1520
	11210	1520
	11210	1520
50	11210	1520
	11210	1520
	11210	1520
	11210	1520
	8280	1736
55	8280	1736
	8280	1736
	8280	1736
	8280	1736
	8280	1736
60	8280	1736
	8280	1736
	8280	1736
	8280	1736
	8280	1736
65	8280	1736
	7690	1536
	7690	1536
	6090	1016
	6090	1756
70	7870	1756
	7870	1756
	7870	1756
	6650	1112
	6650	1112
75	5300	1020
	5300	1020
	8560	1608
	8560	1608
	8560	1608
80	7060	1246
	7060	1246
	6570	1732
	6570	1732
	6550	1364
85	6550	1364
	6550	1364
	6840	1100
	6840	1100
	7380	984
90	7380	984


WOOLSCOURING PART 1
Gas Production
L/day
0
1
2
3
4
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Day No
Observed
Expected

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Gas Production

Day No	Gas Yield L/day	Expected yield	Methane%
0	0	0	
	1.98	3.0317	
		.90951	
	1.35	.45752	
	2.12	2.2876	
5	2.3	3.21321	
	2.2	3.79743	
	2.2	3.79743	
	2.2	2.87105	
	2.3	2.3023	
10		2.5116	
	1.06	2.3023	
	0	2.485	
	1	1.7395	
	1	1.7395	
15	1	1.40287	
	1.1	1.20246	
	1.1	1.016225	
	.7	2.03245	
	1	1.46286	85
20	1.2	1.70667	
	1.2	1.70667	
	1.2	2.55094	
	.94	1.8235	
	1.1	1.7143	
25	1	1.7143	
	.94	2.05716	
	1.27	1.93942	
	1.27	1.93942	
	1	1.64493	
30	1.5	1.64493	
	1.4	1.44207	
	.88	1.44207	
	1	1.61357	75
	1	1.84408	
35	1	1.84408	
		1.904	
		1.666	
	1.24	1.666	
	.76	1.666	
40		1.3657	
	0	.81942	
	.511	.81942	
	.511	1.91198	
	.511	1.91198	

WOOLSCOURING PART 1

Effluent source:Haworth Scouring

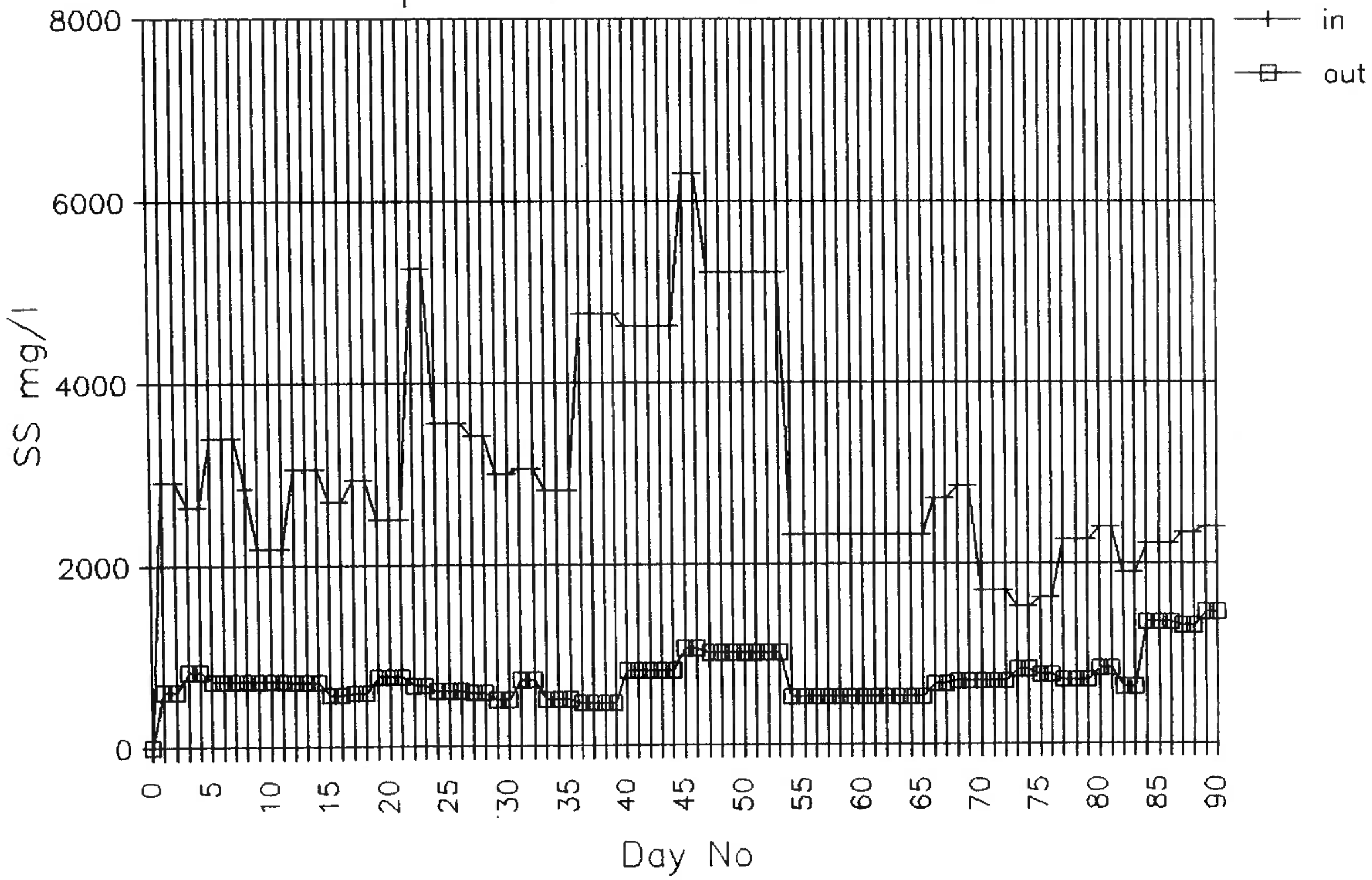
Single Stage Anaerobic Digester

Gas Production cont.

Day No	Gas Yield L/day	Expected yield	Methane%
45	.236	2.4304	
	.236	1.379	
	0	1.3566	80
	.399	1.01745	
		.33915	
50	.76	1.3566	
	.76	1.3566	
	.76	1.3566	
	.76	1.3566	
	.684	0	
55	.57	.68712	
	.513	1.1452	
	.467	1.37424	
	.467	1.37424	
	.467	1.37424	
60	.467	1.37424	
	.467	1.37424	
	.285	.68712	
	.399	.68712	
	.304	.68712	
65	.304	.68712	
	.304	.64617	
	.342	.64617	
	.285	.71036	
	.228	.30338	
70	.285	.64197	
	.285	.64197	
	.285	.64197	
	.285	.58149	
	.399	.58149	
75	.399	.4494	
	.42	1.0486	
	.42	1.70324	
	.42	1.70324	
	.38	2.18988	
80	.342	1.42443	
	.456	1.83141	
	.513	1.52397	
	.38	1.52397	
	.38	1.63359	
85	.38	1.45208	
	.32	1.45208	
	.32	1.6072	
	.32	1.8081	
	.38	1.79088	
90	.32	1.56702	

WOOLSCOURING PART 1

Suspended Solids Removal-Raw Data



WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Suspended Solids conc. effect.

Day No	SS mg/l in	SS mg/l out
0	0	0
	2920	610
	2920	610
	2640	830
	2640	830
5	3400	720
	3400	720
	3400	720
	2850	720
	2180	720
10	2180	720
	2180	720
	3060	710
	3060	710
	3060	710
15	2700	570
	2700	570
	2940	590
	2940	590
	2500	770
20	2500	770
	2500	770
	5260	670
	5260	670
	3560	610
25	3560	610
	3560	610
	3420	590
	3420	590
	3000	510
30	3000	510
	3060	730
	3060	730
	2820	510
	2820	510
35	2820	510
	4760	470
	4760	470
	4760	470
	4760	470
40	4620	830
	4620	830
	4620	830
	4620	830
	4620	830

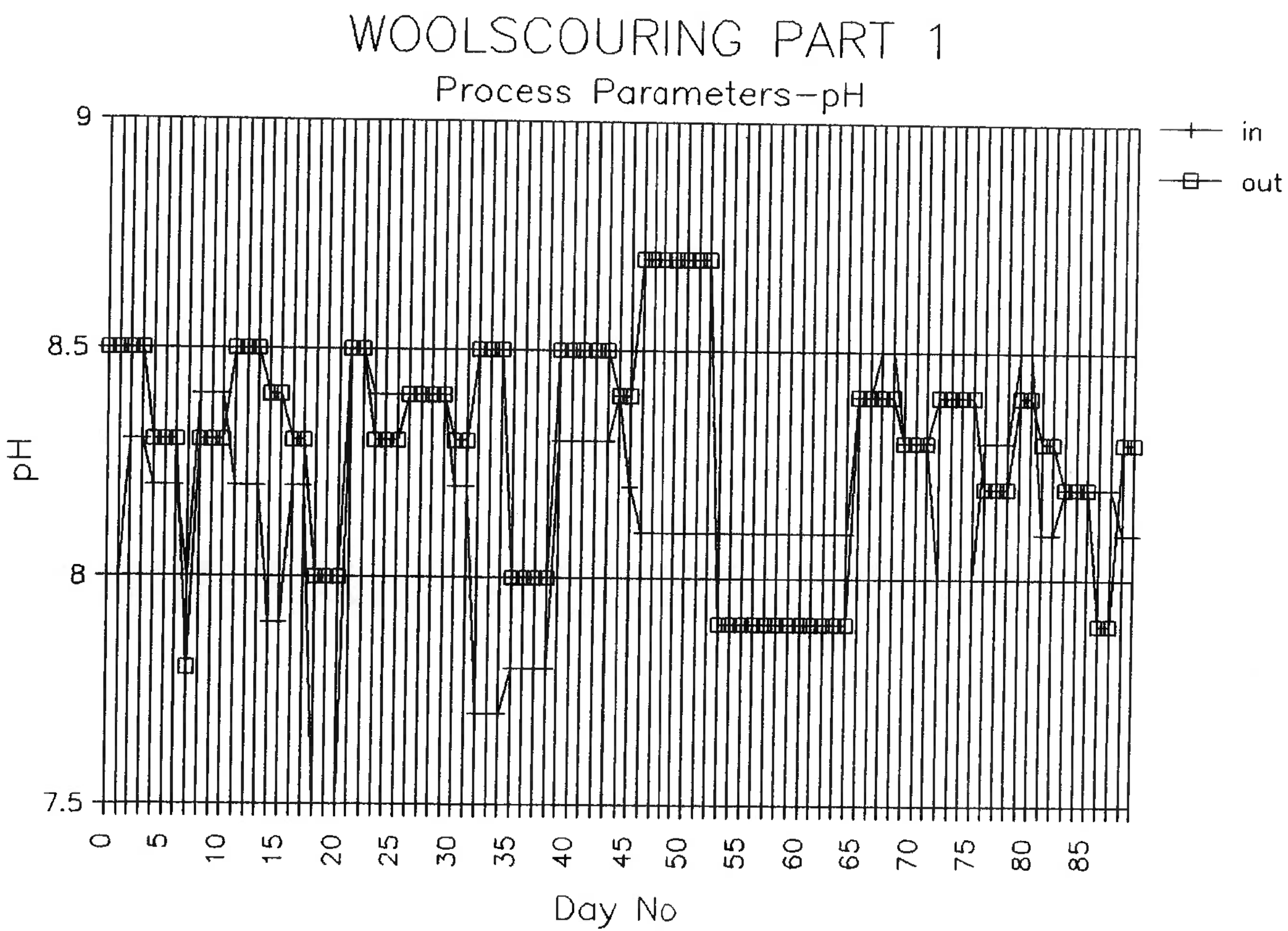
WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Suspended Solids conc. effect cont.

Day No	SS mg/l in	SS mg/l out
45	6300	1070
	6300	1070
	5220	1020
	5220	1020
	5220	1020
50	5220	1020
	5220	1020
	5220	1020
	5220	1020
	2320	530
55	2320	530
	2320	530
	2320	530
	2320	530
	2320	530
60	2320	530
	2320	530
	2320	530
	2320	530
	2320	530
65	2320	530
	2720	670
	2720	670
	2860	700
	2860	700
70	1700	700
	1700	700
	1700	700
	1520	830
	1520	830
75	1620	770
	1620	770
	2260	710
	2260	710
	2260	710
80	2400	840
	2400	840
	1900	630
	1900	630
	2220	1350
85	2220	1350
	2220	1350
	2340	1310
	2340	1310
	2400	1460
90	2400	1460


WOOLSCOURING PART 1
Process Parameters-pH
pH
9
8.5
8
7.5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Day No
in
out

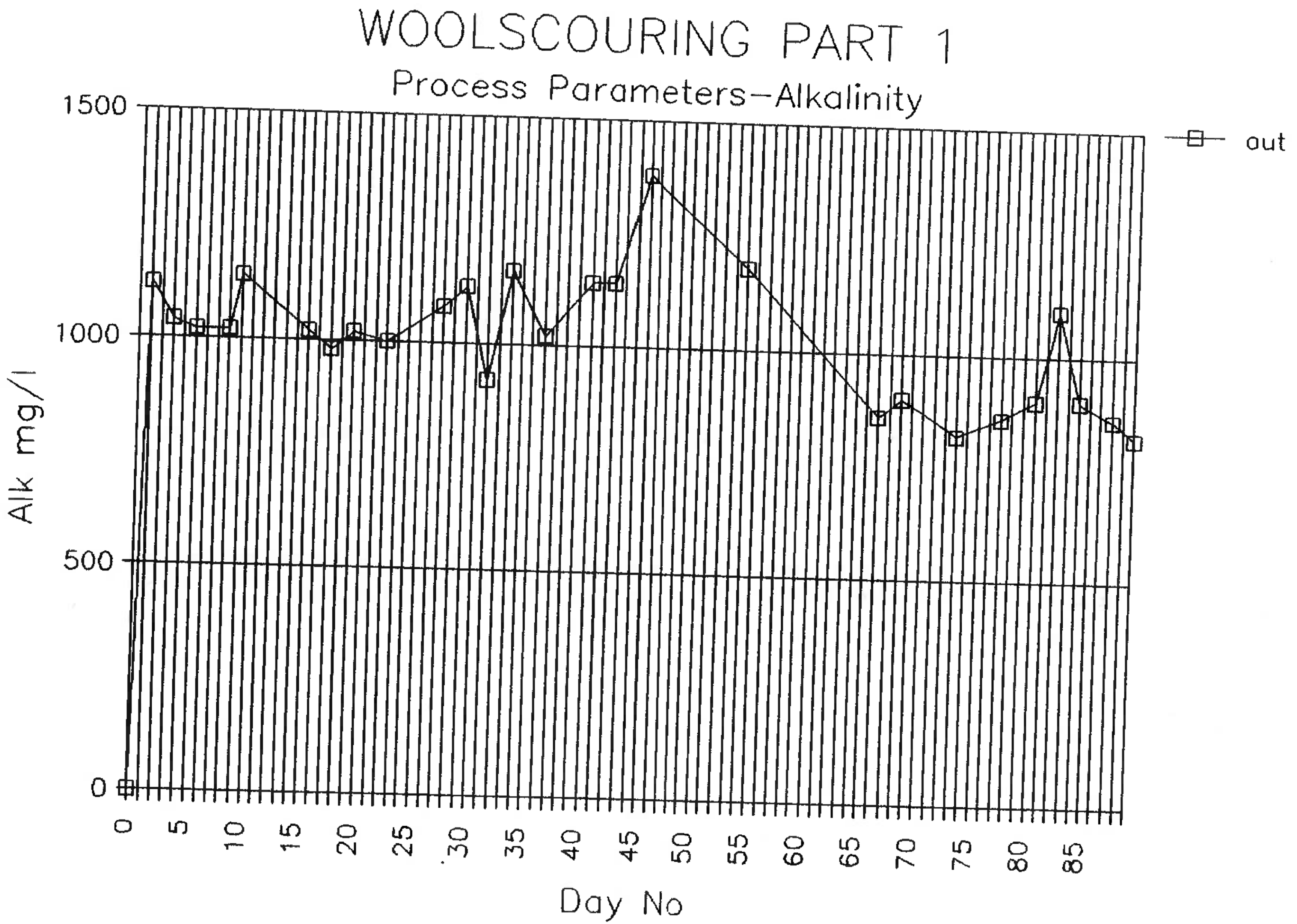
WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Process Parameters

Day No	pH in	pH out	Alk mg/l out	TVA mg/l
0			0	0
	8	8.5	1120	120
	8	8.5		
	8.3	8.5	1040	120
	8.3	8.5		
5	8.2	8.3	1020	108
	8.2	8.3		
	8.2	8.3		
	8	7.8	1020	108
	8.4	8.3	1140	132
10	8.4	8.3		
	8.4	8.3		
	8.2	8.5		
	8.2	8.5		
	8.2	8.5		
15	7.9	8.4	1020	96
	7.9	8.4		
	8.2	8.3	980	156
	8.2	8.3		
	7.5	8	1020	300
20	7.5	8		
	7.5	8		
	8.5	8.5	1000	156
	8.5	8.5		
	8.4	8.3		120
25	8.4	8.3		
	8.4	8.3		
	8.4	8.4	1080	156
	8.4	8.4		
	8.4	8.4	1125	135
30	8.4	8.4		
	8.2	8.3	920	120
	8.2	8.3		
	7.7	8.5	1162	140
	7.7	8.5		
35	7.7	8.5		
	7.8	8	1020	144
	7.8	8		
	7.8	8		
	7.8	8		
40	8.3	8.5	1140	144
	8.3	8.5		
	8.3	8.5	1140	144
	8.3	8.5		
	8.3	8.5		


WOOLSCOURING PART 1
Process Parameters—Alkalinity
out
Alk mg/l
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Day No

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Process Parameters cont.

Day No	pH in	pH out	Alk mg/l out	TVA mg/l
45	8.4	8.4	1380	192
	8.2	8.4		
	8.1	8.7		144
	8.1	8.7		
	8.1	8.7		
50	8.1	8.7		
	8.1	8.7		
	8.1	8.7		
	8.1	8.7		
	8.1	7.9	1180	204
55	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
60	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
	8.1	7.9		
65	8.1	7.9		
	8.4	8.4	860	180
	8.4	8.4		
	8.5	8.4	900	180
	8.5	8.4		
70	8.3	8.3		
	8.3	8.3		
	8.3	8.3		
	8	8.4	820	156
	8	8.4		
75	8	8.4		
	8	8.4		
	8.3	8.2	860	180
	8.3	8.2		
	8.3	8.2		
80	8.5	8.4	900	156
	8.5	8.4		
	8.1	8.3	1100	180
	8.1	8.3		
	8.2	8.2	900	144
85	8.2	8.2		
	8.2	8.2		
	8.2	7.9	860	180
	8.2	7.9		
	8.1	8.3	820	156
90	8.1	8.3		

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

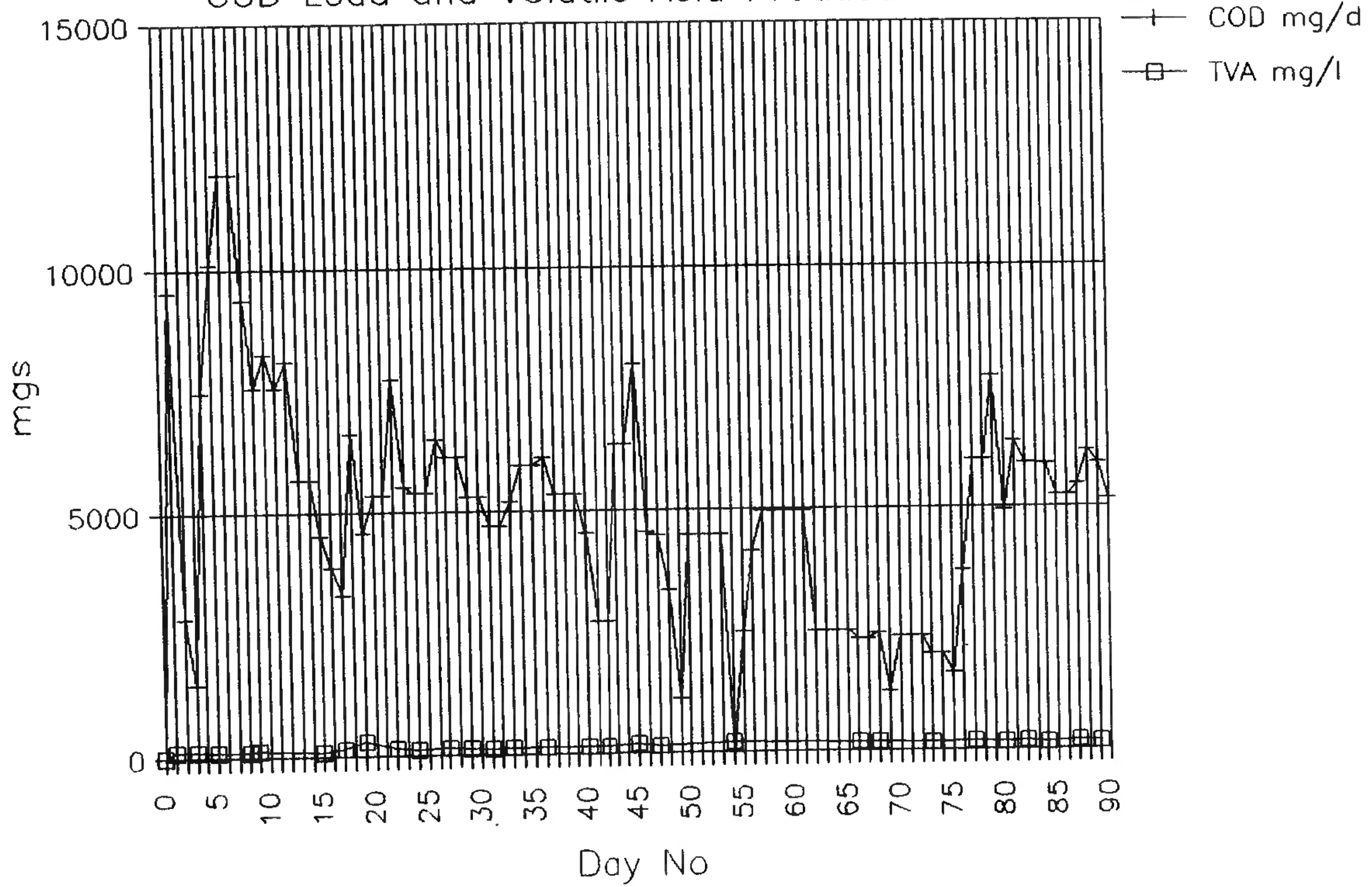
Single Stage Anaerobic Digester

Lindane Removal [ppb]

Day No	Lindane in tot	Lindane out tot	Lindane snat in	Lindane snat out
0	0	0	0	0
5				
10				
15				
20	34	14	22	1.1
25				
30				
35				
				2.1
40				

WOOLSCOURING PART 1

COD Load and Volatile Acid Production–Raw Data



APPENDIX II

COD REMOVAL EFFICIENCY

(Graphs and Tabulations)

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

Process Efficiency-COD

Day No	Vol.l/d	MLSS mg/l	COD g/d in	COD g/d out	COD g/d rem
0	0	13200	0	0	0
	1	13200	9.53	.868	8.662
	.3	13200	2.859	.2604	2.5986
	.2	15850	1.496	.1888	1.3072
	1	15850	7.48	.944	6.536
5	1.1	15850	10.109	.9284	9.1806
	1.3	15850	11.947	1.0972	10.8498
	1.3	15850	11.947	1.0972	10.8498
	1.3	15850	9.373	1.17	8.203
	1.1	13750	7.568	.99	6.578
10	1.2	13750	8.256	1.08	7.176
	1.1	13750	7.568	.99	6.578
	1	13750	8.11	1.01	7.1
	.7	13750	5.677	.707	4.97
	.7	13750	5.677	.707	4.97
15	.7	13750	4.529	.5208	4.0082
	.6	13750	3.882	.4464	3.4356
	.5	15750	3.305	.4015	2.9035
	1	15750	6.61	.803	5.807
	.6	15750	4.584	.4044	4.1796
20	.7	15750	5.348	.4718	4.8762
	.7	15750	5.348	.4718	4.8762
	.7	15750	7.728	.4396	7.2884
	.5	15750	5.524	.314	5.21
	.5	13650	5.405	.507	4.898
25	.5	13650	5.405	.507	4.898
	.6	13650	6.486	.6084	5.8776
	.7	13650	6.132	.5908	5.5412
	.7	13650	6.132	.5908	5.5412
	.7	13650	5.313	.6132	4.6998
30	.7	13650	5.313	.6132	4.6998
	.7	13250	4.697	.5768	4.1202
	.7	13250	4.697	.5768	4.1202
	.7	13250	5.201	.5908	4.6102
	.8	13250	5.944	.6752	5.2688
35	.8	13250	5.944	.6752	5.2688
	.8	9800	6.112	.672	5.44
	.7	9800	5.348	.588	4.76
	.7	9800	5.348	.588	4.76
	.7	9800	5.348	.588	4.76
40	.5	9800	4.54	.638	3.902
	.3	9800	2.724	.3828	2.3412
	.3	9800	2.724	.3828	2.3412
	.7	9800	6.356	.8932	5.4628
	.7	9800	6.356	.8932	5.4628

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

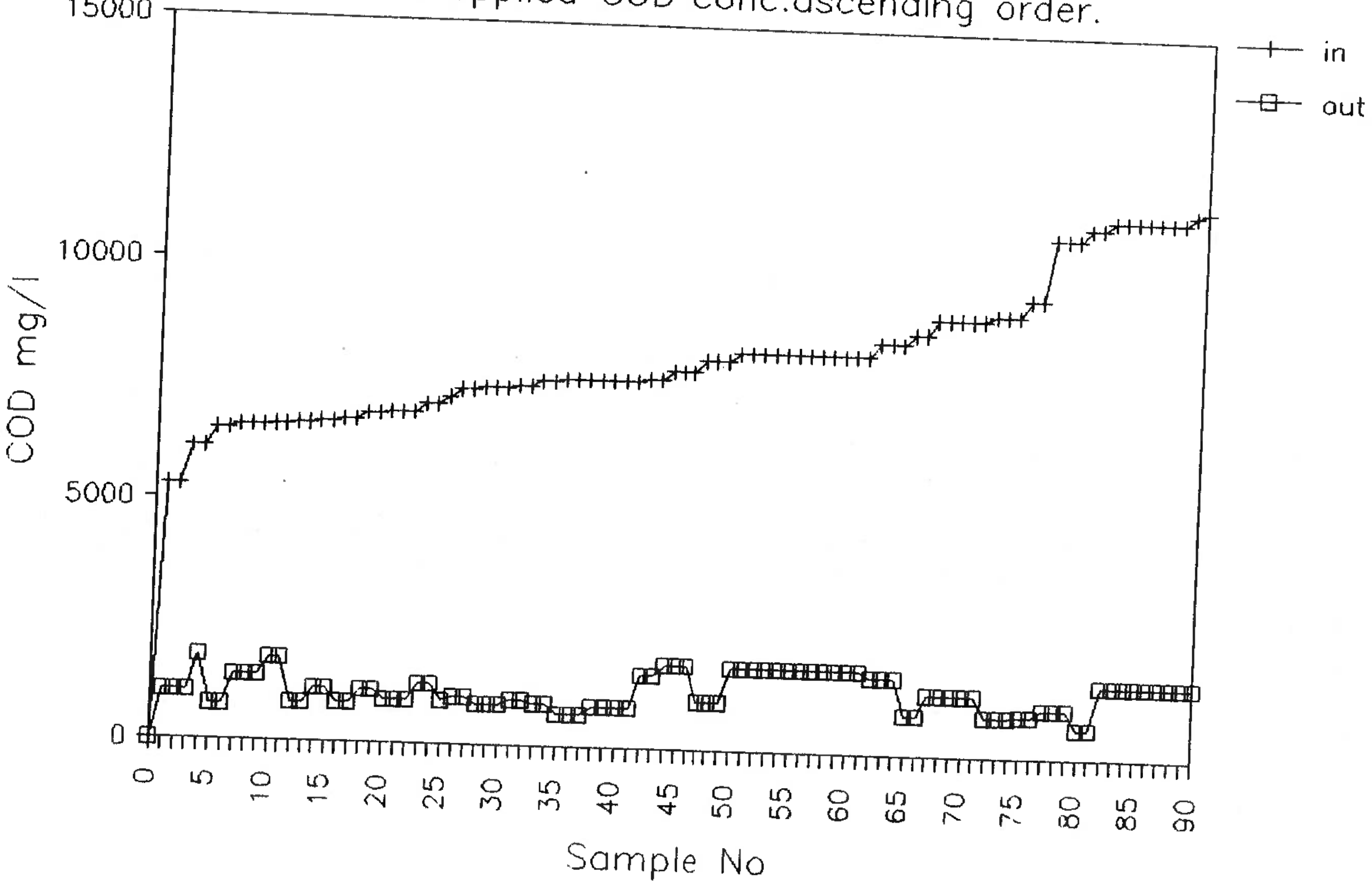
Single Stage Anaerobic Digester

Process Efficiency-COD cont.

Day No	Vol.l/d	MLSS mg/l	COD g/d in	COD g/d out	COD g/d rem
45	.7	9800	8.008	1.064	6.944
	.4	9800	4.548	.608	3.94
	.4	9800	4.484	.608	3.876
	.3	9800	3.363	.456	2.907
	.1	9800	1.121	.152	.969
50	.4	9800	4.484	.608	3.876
	.4	9800	4.484	.608	3.876
	.4	9800	4.484	.608	3.876
	.4	9800	4.484	.608	3.876
	0	9800	0	0	0
55	.3	9800	2.484	.5208	1.9632
	.5	9800	4.14	.868	3.272
	.6	9800	4.968	1.0416	3.9264
	.6	9800	4.968	1.0416	3.9264
	.6	9800	4.968	1.0416	3.9264
60	.6	9800	4.968	1.0416	3.9264
	.6	9800	4.968	1.0416	3.9264
	.3	9800	2.484	.5208	1.9632
	.3	9800	2.484	.5208	1.9632
	.3	9800	2.484	.5208	1.9632
65	.3	9800	2.484	.5208	1.9632
	.3	9800	2.307	.4608	1.8462
	.3	9800	2.307	.4608	1.8462
	.4	14700	2.436	.4064	2.0296
	.2	14700	1.218	.3512	.8668
70	.3	14700	2.361	.5268	1.8342
	.3	14700	2.361	.5268	1.8342
	.3	14700	2.361	.5268	1.8342
	.3	14700	1.995	.3336	1.6614
	.3	14700	1.995	.3336	1.6614
75	.3	13500	1.59	.306	1.284
	.7	13500	3.71	.714	2.996
	.7	13500	5.992	1.1256	4.8664
	.7	13500	5.992	1.1256	4.8664
	.9	13500	7.704	1.4472	6.2568
80	.7	13500	4.942	.8722	4.0698
	.9	13500	6.354	1.1214	5.2326
	.9	15500	5.913	1.5588	4.3542
	.9	15500	5.913	1.5588	4.3542
	.9	15500	5.895	1.2276	4.6674
85	.8	15500	5.24	1.0912	4.1488
	.8	15500	5.24	1.0912	4.1488
	.8	15500	5.472	.88	4.592
	.9	15500	6.156	.99	5.166
	.8	18900	5.904	.7872	5.1168
90	.7	18900	5.166	.6888	4.4772

WOOLSCOURING PART 1

Data in applied COD conc.ascending order.



WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

Single Stage Anaerobic Digester

COD removal analysis

[a]=CODmg/l applied
[v]=CODg rem/g app/day

[a]	[v]	[a/v]/100
0	0	0
5300	.8075472	65.63084
5300	.8075472	65.63084
6090	.8331691	73.09440
6090	.7116585	85.57476
6470	.8850077	73.10671
6470	.8850077	73.10671
6550	.7917557	82.72754
6550	.7917557	82.72754
6550	.7917557	82.72754
6570	.7363775	89.22055
6570	.7363775	89.22055
6610	.8785174	75.24040
6610	.8785174	75.24040
6650	.8327820	79.85283
6650	.8327820	79.85283
6710	.8771982	76.49354
6710	.8771982	76.49354
6840	.8391813	81.50801
6840	.8391813	81.50801
6880	.8691860	79.15452
6880	.8691860	79.15452
6880	.8691860	79.15452
7060	.8235127	85.73031
7060	.8235127	85.73031
7210	.8751734	82.38368
7380	.8666667	85.15385
7380	.8666667	85.15385
7430	.8864065	83.82159
7430	.8864065	83.82159
7430	.8864065	83.82159
7480	.8737968	85.60343
7480	.8737968	85.60343
7590	.8845850	85.80295
7590	.8845850	85.80295
7640	.9117801	83.79213
7640	.9117801	83.79213
7640	.9117801	83.79213
7640	.8900524	85.83765
7640	.8900524	85.83765
7640	.8900524	85.83765
7640	.8900524	85.83765
7690	.8002601	96.09376
7690	.8002601	96.09376

WOOLSCOURING PART 1

Effluent source:Hawarth Scouring

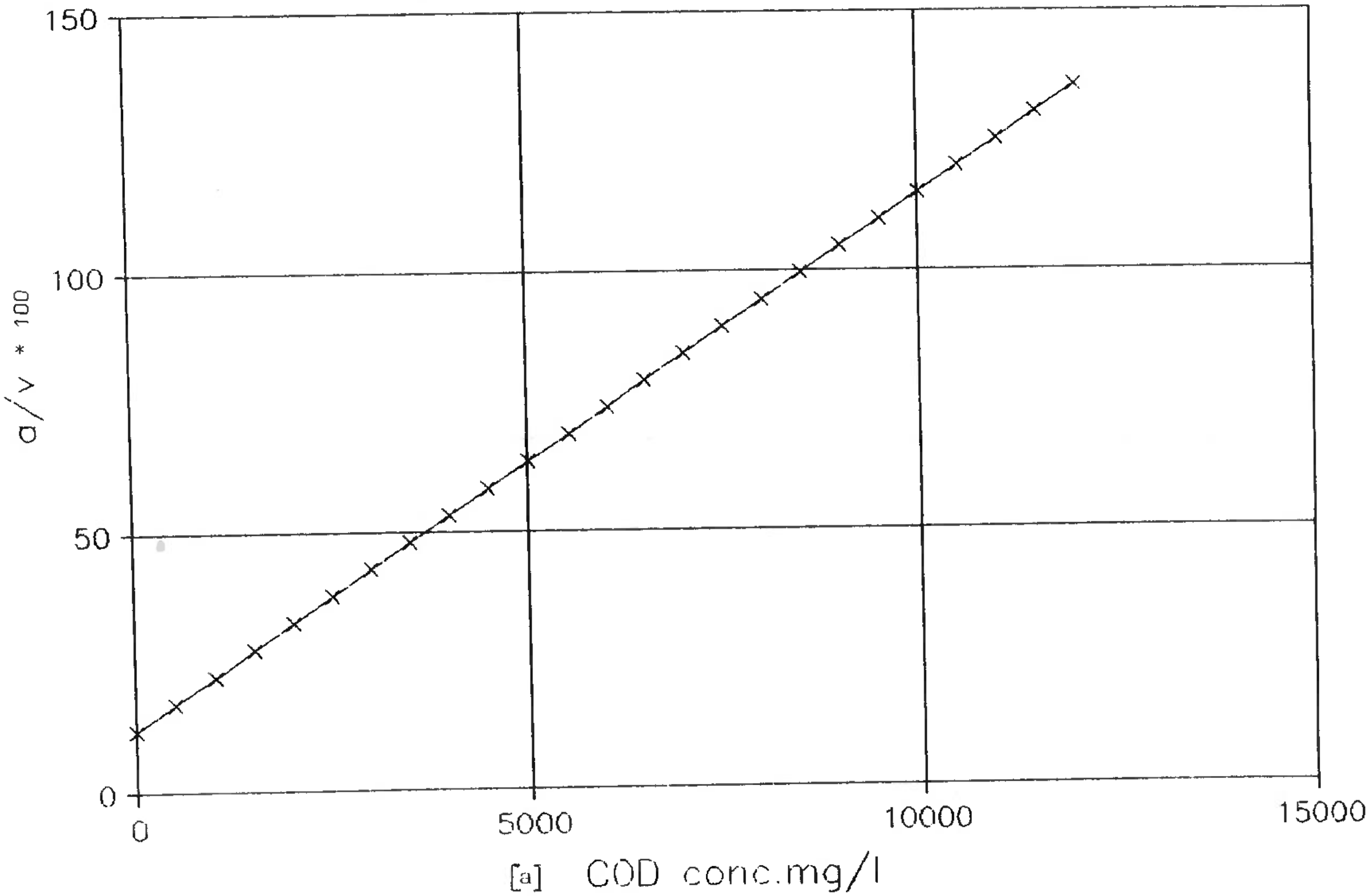
Single Stage Anaerobic Digester

COD removal analysis cont.

[a]	[v]	[a/v]/100
7870	.7768742	101.3034
7870	.7768742	101.3034
7870	.7768742	101.3034
8110	.8754624	92.63676
8110	.8754624	92.63676
8110	.8754624	92.63676
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8280	.7903382	104.7653
8560	.8121495	105.3993
8560	.8121495	105.3993
8560	.8121495	105.3993
8760	.9036530	96.93987
8760	.9036530	96.93987
9080	.8594714	105.6463
9080	.8594714	105.6463
9080	.8594714	105.6463
9080	.8594714	105.6463
9080	.8594714	105.6463
9190	.9081610	101.1935
9190	.9081610	101.1935
9190	.9081610	101.1935
9530	.9089192	104.8498
9530	.9089192	104.8498
10810	.9061980	119.2896
10810	.9061980	119.2896
10810	.9061980	119.2896
11040	.9431159	117.0588
11048	.9431571	117.1385
11210	.8644068	129.6843
11210	.8644068	129.6843
11210	.8644068	129.6843
11210	.8644068	129.6843
11210	.8644068	129.6843
11210	.8644068	129.6843
11210	.8644068	129.6843
11370	.8663149	131.2456
11440	.8671329	131.9290

WOOLSCOURING PART 1

COD Removal Process Efficiency



WOOLSCOURING PART 1

Modelled Process

COD Removal

		COD conc.mg/l	[a]
		% removal	[v]*100

[a]	[a/v]/100	[v]*100
0	11.97461	0
500	17.12552	29.19619
1000	22.27644	44.89048
1500	27.42735	54.68994
2000	32.57826	61.39063
2500	37.72918	66.26171
3000	42.88009	69.96254
3500	48.03101	72.86959
4000	53.18192	75.21353
4500	58.33283	77.14352
5000	63.48375	78.76031
5500	68.63466	80.13444
6000	73.78558	81.31670
6500	78.93649	82.34468
7000	84.0874	83.24672
7500	89.23831	84.04462
8000	94.38923	84.75543
8500	99.54014	85.39269
9000	104.6911	85.96719
9500	109.842	86.48786
10000	114.9929	86.96189
10500	120.1438	87.39527
11000	125.2947	87.79302
11500	130.4456	88.15936
12000	135.5965	88.49786

Linear correlation of [a] against [v]*100 gave :-

A = 11.97461
B = 1.030183E-02
r = 0.9504787

When [v]*100 = B[a] + A

WOOLSCOURING PART 1

COD Removal Process Efficiency