ANAERQBIC TREATMENT OF CANE SUGAR EFFLUENT FROM MUHORONI SUGAR FACTORY

USING BATCH REACTORS

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OF
CANE SUGAR EFFLUENT
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DECLARATION

This research thesis is my own original work and has not been presented for a degree in any other institution.

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Date: 30/10/97

This thesis has been submitted for examination with my approval as the university supervisor.

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Finally, I am grateful to my family for their encouragement.

DEDICATION

To my family,

especially my mother, Mama Elizabeth,

and

my late brothers, Wasonga and Oduor.

ABSTRACT

Cane sugar mill effluent is characterized by high COD, BOD and Suspended solids (SS) contents and its treatment by aerobic biological methods is usually difficult. Due to the high content of lignin-cellulose in the SS of the wastewater, its pH falls rapidly during treatment to low levels which is adverse to micro-organisms. This study, whose aim was to determine the anaerobic biodegradability of sugar mill effluent, presents a batch reactor experiment for anaerobic treatment of the waste. Three kinds of reactor were set out:- Case I with both pH correction and seeding; Case II with seeding and no pH correction; and Case III without both pH correction and seeding.

After 30-days retention period the COD, BOD, and SS percentage reductions for the three cases were as follows: for Case I 81.5%, 14%, and 63% respectively; Case II 78%, 39%, and 67% respectively; and Case III 3%, 26%, and 37% respectively. Retention periods less than 10 days resulted in very little improvement in effluent quality. Biodegradability, as measured by the BOD/COD ratio, rose steadily during the reactor operation for cases I and II but remained relatively constant for case III. The findings of the study compared well with previous achievements by Hartman et al. (1984), Wheatley et al. (1984) and Rusten et al. (1990).

It was therefore concluded that anaerobic treatment, particularly with pH control and seeding, shows potential in first stage management of sugar mill wastewater.

Key Words: wastewater treatment, anaerobic treatment, cane-sugar effluent, retention time, seeding, pH control, start-up process, batch reactor.

TABLE OF CONTENTS

DECLARATION....i

ACKNOWLEDGEMENT....ii

DEDICATION....iii

ABSTRACT....iv

LIST OF FIGURES....viii

LIST OF TABLES....ix

ABBREVIATIONS....xi

CHAPTER 1: INTRODUCTION....*1*

1.1 SUGAR PRODUCTION....*1*

1.2 OBJECTIVES OF THE STUDY....*8*

CHAPTER 2: ANAEROBIC TREATMENT PROCESS....*9*

2.1 ANAEROBIC PROCESS....*9*

2.2 PROCESS DESCRIPTION....*11*

2.3 PROCESS MICROBIOLOGY....*12*

2.4 PROCESS ENVIRONMENTAL REQUIREMENTS....*15*

2.4.1 Substrates....15

2.4.2 Nutrients....16

2.4.3 Inhibitors....16

2.4.4 Temperature....17

2.4.5 pH....18

2.4.6 Solids Retention Time (SRT)....19

2.4.7 Summary of Environmental Conditions....19

2.5 TYPES OF ANAEROBIC PROCESSES....*20*

2.6 ADVANTAGES AND DISADVANTAGES OF ANAEROBIC TREATMENT PROCESS....*23*

2.7 DESIGN PROCEDURES FOR ANAEROBIC REACTORS....*24*

2.8 PAST APPLICATION OF ANAEROBIC LAGOONS FOR TREATMENT OF AGRO-INDUSTRIAL WASTEWATER....*25*

CHAPTER 3: CANE-SUGAR MILLING: THE PROCESS AND EFFLUENT TREATMENT 29

3.1 RAW MATERIALS IN SUGAR PROCESSING 29

3.2 CANE MANUFACTURING PROCESS 30

3.3 SOURCES AND QUANTITIES OF WASTE EFFLUENT 34

3.4 PREVIOUS STUDIES ON TREATMENT OF SUGAR MILL EFFLUENT 39

3.4.1 General 39

3.4.2 Anaerobic Treatment of Sugar Effluent 44

CHAPTER 4: EXPERIMENTATION AND RESULTS 48

4.1 BACKGROUND 48

4.2 REACTOR SELECTION 48

4.3 REACTOR DESIGN 50

4.4 WASTEWATER SAMPLING 53

4.5 REACTOR OPERATION STAGE 53

4.5.1 Start-Up Process 54

4.5.2 Operation of Reactors 55

4.6 RESULTS AND OBSERVATIONS 56

4.6.1 Stream Sampling Results 57

4.6.2 Start-Up Process 59

4.6.3 Reactor Operation Stage 63

4.7 ANALYSIS AND DISCUSSION OF RESULTS 70

4.7.1 pH Results 71

4.7.2 COD Variations 72

4.7.3 BOD5 Variations 75

4.7.4 Total and Suspended Solids Variation 78

4.7.5 Summary 79

4.8 DISCUSSION OF EXPERIMENTAL ERRORS 78

CHAPTER 5: CONCLUSIONS 82

5.1 SUMMARY 82

5.2 POTENTIAL OF ANAEROBIC TREATMENT 82

5.3 RETENTION TIME 83

5.4 REACTOR SEEDING 83

5.5 pH CORRECTION 84

CHAPTER 6: RECOMMENDATIONS **87**

6.1 TEMPERATURE 87

6.2 CONTINUOUS FLOW REACTORS 88

6.3 ON-SITE PILOT PLANT 89

REFERENCES

LIST OF FIGURES

FIGURE NO. & TITLE

2.1........Anaerobic Process Microbiology.

2.2........Types of Anaerobic Processes.

3.1........Cane-sugar Manufacturing Process.

4.1........Experiment Batch Reactor.

4.2........Muhoroni Sugar Manufacturing process.

4.3........pH Variation During Start-of Process.

4.4........pH Variation During Reactor Operation.

4.5........COD Variation During Reactor Operation.

4.6........BOD5 Variation During Reactor Operation.

4.7........SS Variation During Reactor Operation.

4.8........TS Variation During Reactor Operation.

4.9........BOD5/COD Ratios Variation During Reactor Operation.

LIST OF TABLES

TABLE NO. & TITLE

1.1........Muhoroni Sugar Factory Wastewater Characteristics.

1.2........Discharge Standards for Effluent Disposal into Kenyan Water Courses.

2.1........Temperature Ranges for Bacterial Action.

2.2........Summary of Anaerobic Pond Design Guidelines.

2.3........Results of Anaerobic Treatment of Tapioca Starch Factory Effluent

2.4........Results of Anaerobic Treatment of Palm Oil Mill Effluent.

2.5........Results of Anaerobic Treatment of Rubber Processing Effluent.

3.1........Quantities of Wastes in Cane Sugar Industry.

3.2........Quantities and Strength of Wastes from Raw Sugar Factory.

3.3........Cooling of Condenser Water Characteristics.

3.4........Characteristics of Cane-sugar Effluent.

3.5........Performance of the RT Lefrancois System on Sugar Effluent Treatment.

3.6........Results of Batch Surface Aerator Reactor Treatment of Cane-sugar Effluent.

3.7........Results of Anaerobic Treatment of Cane Sugar Effluent on a Pilot Scale.

3.8........Operating Data & Results for Anaerobic Reactors Treating Sugar Effluent.

3.9........Sugar Mill Wastewater Characteristic Before and After UASB, AFB and EAFB Treatment.

4.1........Characteristics of Different Waste Streams in Muhoroni Sugar Factory.

4.2........pH Daily Variation for Start-up Process.

4.3........pH Variation During Reactor Operation.

4.4........COD Variation During Reactor Operation.

4.5........BOD5 20oC Variation During Reactor Operation.

4.6........SS Variation During Reactor Operation.

4.7........TS Variation During Reactor Operation.

4.8........Percentage COD Removal Rate Variations

4.9........BOD5/COD Ratio Variations.

4.10......Percentage TS Removal Variations.

4.11......Percentage SS Removal Variations.

4.12......Preservation of Wastewater Samples.

5.1........Removal Rates at Day 30 With/Without Seeding.

5.2........Percentage Loading Removal Rates with/without pH correction.

5.3........BOD5/COD Variations for Certain Days.

ABBREVIATIONS

AFB	Anaerobic Fluidised Bed
BOD	Biochemical Oxygen Demand
BOD_5	5-day BOD Value
COD	Chemical Oxygen Demand
d	Day
EAFB	Entrapped Aerobic Fixed Bed
EEC	European Economic Community
FB	Fluidised Bed
GOK	Government of Kenya
H	Hydrogen
ICDICA	Cuban Institute for Research
IEF	Electrical Research Institute
N	Nitrogen
O	Oxygen
P	Phosphorous
SRT	Solids Retention Time
SS	Suspended Solids
TS	Total Solids
TSS	Total Suspended Solids
C	Carbon
UASB	Up-Flow Anaerobic Sludge Blanket
UN	United Nations
UNEP	United Nations Environmental Programme
UON	University of Nairobi
WHO	World Health Organization

CHAPTER 1 INTRODUCTION

1.1 SUGAR PRODUCTION

Sugar production on a commercial basis in Kenya was started in 1922 with the establishment of Miwani Sugar Mills in Western Kenya. Presently there are six operational mills in Kenya - Miwani, Muhoroni, Chemelil, Mumias, Nzoia and South Nyanza Mills - all in Western Kenya. In the **Economic Survey (1990)** sugar cane production for Kenya was reported to be 4.2 million tonnes with a corresponding sugar production of 0.434 million tonnes for the year 1990. The corresponding values for Muhoroni Sugar Factory were 516,408 tonnes of cane crushed in 253 days yielding 46,505 tonnes of sugar.

Sugar crystals are usually produced from two alternative raw materials. In temperate countries the basic raw material is sugar beet while in tropical countries sugar cane is used. Kenya processes all her sugar from sugar cane. The crystals are used for direct domestic consumption in beverages or as a secondary industrial raw material, for example in confectionery or soft drink industry.

The production of cane sugar results in several by- products. **Silvalingham et al (1978)** listed these by-products as molasses, bagasse, filter mud, furnace ash, and cane tops and leaves. Molasses may be used directly as fertilizer and animal feed or fermented to produce power alcohol or yeast and citric acids. Bagasse is frequently utilized as fuel to power boilers or as a new material for production of fibrous products such as paper or cardboard. Another by-product used as fertilizer and animal feed is filter mud.

Also generated in the sugar production process is liquid waste effluent that has to be disposed off. The production of sugar results in large quantities of wastewater.

This is mainly due to the following reasons. First, a high standard of housekeeping is necessary during the production process which necessitates frequent cleaning of the factory premises. Secondly, as **Bevan (1971)** noted, sugar cane contains 17% sugar, 13% fibrous material of cellulose and lignin and 70% water. During the refining of sugar the water has to be driven off which invariably leads to wastewater generation. Finally, most mills use steam generated from boilers to heat the sugar syrup at various production stages. The spent steam constitutes a substantial amount of liquid effluent from the factory.

Cane sugar is comprised of the carbohydrate sucrose which has the general formula $C_{12}H_{22}O_{11}$. As this formula indicates, the wastewater from the cane industry invariably has a high organic content as measured by the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values.

Silvalingham et al. (1978) reported that Brazilian cane sugar and alcohol industries released effluent with BOD and COD values in the ranges 13000 to 26000 mg/l and 15000 to 27000 mg/l respectively. **Chang et al.** (1990) listed the BOD and COD values of composite wastewater from the Hawaii sugar-cane industry as 2800 and 7000 mg/l, respectively. The BOD value reported **by Chang et al. (1990)** compare favourably with those observed in Kenya. **Thitai (1979)** found that the BOD values of the effluent from the Muhoroni and Chemelil sugar mills was 2000 and 4500 mg/l, respectively.

Sugar cane is a fibrous plant. During crushing, these fibres are broken into small pieces which find their way into the wastewater as suspended solids. In some factories, a lot of soil in form of sediments is brought into the factory because of the harvesting method employed. This is particularly so where the harvesting is mechanized. Cane sugar wastewater is therefore characterized by a high total and suspended solids content. **Chang et al. (1990)** observed that effluent from Hawaii sugar mills had suspended solids content as high as 11,700 mg/l. **Thitai (1979)** reported suspended solids concentration of 600 mg/l and 1700 mg/l for Muhoroni and Chemelil sugar factories, respectively. The lower values reported for Kenyan factories may be attributed to the non-mechanised harvesting practiced locally.

As noted earlier, cane sugar syrup has a high water content and the basic aim of sugar refineries is to reduce this water content to a level that can allow crystallization. This is usually achieved by heating the syrup using steam from the boilers. The condensate from the spent steam, if not recycled, but is discharged in to the waste streams while still at high temperature. Therefore, sugar cane effluents tend to have high temperatures. For example, the temperature ranges of wastewater from a sugar industry in Hawaii and Muhoroni were 32-40^{0}C **(Chang et al., (1990)** and 28-42^{0}C **(Abura, (1992))**, respectively. The characteristics of wastewater from Muhoroni Sugar Factory as determined in a previous study by **Abura (1992)** are shown in Table 1.1.

The composite wastewater from a sugar mill comprises of various streams. These streams have different characteristics. For instance, **Silvalingham et al. (1978)** found that continuous blow-off from the boiler had pH of 10.8 while neutralized effluent from the vacuum pans had a pH of 1.8. Despite this, the composite effluent pH is usually within the neutral range. **Chang et al. (1990)** observed that composite wastewater had a pH in the range 6.5-7.6.

Table 1.1: Muhoroni Sugar Factory Wastewater Characteristics

Parameter	Units	Mean Value	Range
Temperature	^{o}C	32.17	28-42
pH (before liming)	-	5.06	3.84-6.13
pH (after liming)	-	9.36	6.5-11.60
Electrical Conductivity	µS/cm	1085.05	813.5-1859.5
Total Solids	mg/l	5329	3250-7700
Total Dissolved Solids	mg/l	2882	1850-3800
Total Suspended Solids	mg/l	2610.5	1000-4950
DO	mg/l	7.12	6.45-7.50
BOD_5	mg/l	507.2	312-860
COD	mg/l	5527.94	3597.6-12530
Sulphates	mg/l	N.D	-
Potassium	mg/l	7.06	3.38-9.18
Total Phosphorus	mg/l	9.29	3.25-20.50
Total Nitrogen	mg/l	105.66	80-310
Total Carbon (organic)	mg/l	5414	420-6090
C/N Ratio (Estimated)	-	51.23:1	-
COD/BOD_5 Ratio	-	10.89:1	-

Notes: ND- Not detected.
Source: Abura (1992).

It may be noted that wastewater characteristics such as COD, BOD, alkalinity and suspended solids fluctuate due to soil type, water quality, and harvesting method. The wastewater from sugar mills contain high organic matter (COD, BOD) and high solids content. Nutrients such as nitrogen, phosphorous, potassium and sulphate are invariably low due to the chemical composition of the sugar cane.

From the general characteristics of sugar mill effluent it can be deduced that they do not satisfy the Water Pollution and Control Department standards of effluent discharge into water courses in Kenya (Table 1.2). Thus, treatment of the wastewater before discharge into watercourses is a prerequisite if the standards are to be achieved. All sugar industries are located in rural areas where there are no municipal wastewater treatment plants. The factories must therefore, have complete on-site treatment works for the management of their effluents.

Table 1.2: Discharge Standards for Effluent Disposal into Kenyan Water Courses.

Parameter	Allowable Range
BOD_5 at 20^oC	Less than 20mg/l
COD	Less than 50mg/l
Suspended Solids	Less than 30mg/l
pH	6 - 9

Source: Ministry of Water Development (1971).

Basically, there are two options of biological treatment processes to achieve these standards, aerobic and anaerobic processes. Aerobic processes are usually limited by the waste strength they can treat with respect to the maximum oxygen exchange rate from the gas phase to the liquid phase. **Stuckey (1981)** observed that due to this limitation the maximum BOD strength that can be economically treated through aerobic processes is about 2000 mg/l.

Stuckey (1981) also found that compared to aerobic treatment of wastewater, the anaerobic treatment process yields considerably less energy. This has two distinct advantages. First, due to their low energy yield, the excess biomass is smaller in quantity and this biomass is more stabilized. Hence the problem of excess sludge disposal is substantially reduced. Secondly, because of lower sludge generation the requirements for nutrients are considerably lower than in aerobic processes. Since many industrial wastes, cane sugar waste included, are often nutrient deficient, this is an important advantage anaerobic treatment has over aerobic.

Among the aerobic processes that have been employed to treat sugar wastewater are oxidation ponds, Pasveer ditches, activated sludge processes and on much rare occasions biological filters. A World Health Organisation (WHO) Sectorial Report (1973) noted that oxidation lagoons employed in Muhoroni Sugar Factory only managed to reduce the BOD from 4500 mg/l to 3400 mg/l. The corresponding values for Chemelil Factory were 2000 and 1200 mg/l respectively. These unsatisfactory results may have been due to the inability of the treatment methods employed to degrade wastewater with high lignin content. Currently, aerobic ponds are the most widely employed mode of treatment for cane sugar waste in Kenya being used in Mumias, Nzoia, Muhoroni, Chemelil and South Nyanza sugar factories despite their poor performance.

Activated sludge process in general is rarely used due to its high capital costs even though high efficiencies of the process have been reported. **Bevan (1971)** while conducting pilot tests on disposal of cane sugar mill waste in Australia using surface aerators achieved BOD removal efficiencies of up to 92 per cent.

Bevan (1971) noted that biological filters are not commonly used due to the following three reasons among others. First, filters require long induction periods, up to 2 months before optimum performance is achieved. This is a big handicap in an industry that is operated seasonally as is the case with sugar industry. Secondly, sugar mill effluent is produced in large volumes, a feature which requires many filters for efficient operation. Finally, biological filters can be temperamental and clog very easily. The last reason is especially pertinent for wastewater like cane sugar effluent which has high colloidal material content.

Activated sludge process and biological filters require skilled man-power for efficient operation and are based on a reliable power supply for smooth running. These are not easily available in an industry, especially in developing countries, whose priority is usually not wastewater disposal.

Thus, there is need for a treatment process that is simple enough yet effective. It was for this reason that in this study the possibility of employing anaerobic treatment for sugar mill wastewater was explored. Anaerobic processes are disadvantaged by their slow first start-up process, adverse effect of several compounds on anaerobic bacteria, and it's requirement of subsequent aerobic of its effluent so as to meet discharge standards. However, in comparison to aerobic treatment, anaerobic treatment has several advantages. Anaerobic treatment has low nutrient requirement, no limitations of oxygen exchange from gas to liquid phases and can therefore treat stronger organic effluent than aerobic process.

As **Stuckey (1981)** reported, anaerobic bacteria can survive unfed for long periods and overcome frequent high organic and hydraulic waste loads. The process leads to lower production of excess sludge which is usually more stabilized than in the aerobic case.

Since cane sugar mill effluent is characterized by high organic waste load, large volume and high suspended solid content, the anaerobic process was considered a possible treatment procedure. The purpose of this study was, therefore, to investigate the performance of anaerobic treatment on cane sugar wastewater.

1.2 OBJECTIVES OF THE STUDY

The aim of the study was to investigate the performance of anaerobic process when used as a first stage treatment process of sugar mill effluent. To achieve this a laboratory scale anaerobic batch reactor was set up and the characteristics of sugar mill effluent contained therein determined periodically.

The objectives of the study can thus be enumerated as:-

1. To determine the efficiency of the laboratory scale anaerobic batch reactor in reducing the organic load on sugar mill effluent as characterized by the BOD, COD and suspended solids content values. This was done so as to evaluate the appropriateness of anaerobic process for treatment of cane sugar mill wastewater.

2. To determine and compare the BOD, COD and SS removal rates of the anaerobic batch reactor after operating at different retention periods. The purpose of this was to determine the optimum retention period for operating such an anaerobic reactor.

3. To compare the performance of the anaerobic batch reactors when operated with and without pH correction and sludge seeding. This was done so as to determine the necessity of pH correction and sludge seeding while operating an anaerobic reactor.

CHAPTER 2 ANAEROBIC TREATMENT PROCESS

2.1 ANAEROBIC PROCESS

A very old process, anaerobic digestion has been practiced for years in the Asian Continent, especially China and India, for digestion of animal excreta. Conventionally the process has been used mainly for sludge treatment in sewage treatment plants. However, it also occurs in natural environments such as rivers, lakes and ocean sediments, swamps, soils, and the gastrointestinal tract of animals.

Kiestra and Eggers (1986) noted that after the World War II, low energy prices and better aerobic process efficiency drew attention away from the anaerobic process and even anaerobic treatment of sludge became less attractive. **Stuckey (1981)** also observed that in the treatment of industrial wastes, anaerobic processes have tended to be regarded as poor second options to their competitors namely the aerobic and physical-chemical processes. He advanced the following reasons to explain this state of affairs:

1. Historically there was lack of understanding of the basic microbiology and biochemistry of the anaerobic process. This curtailed research which would have enabled the process to achieve its full potential.

2. The process was generally viewed to be unstable giving erratic performances. Though true to some extent, it should be noted that most anaerobic units were sewage sludge digesters which tended to receive the most refractory and often toxic organics. Further, due to limited knowledge, such digesters were rarely operated efficiently.

As from the late 1960's, interest in the application of the anaerobic process has been rekindled. **Stuckey (1981)** attributes the following reasons for this turn of events.

1. Since 1965 advances have been made in the understanding of the basic anaerobic microbiology and biochemistry. This has led to innovative engineering designs which have increased the competiveness of anaerobic treatment especially at high BOD loading rates.

2. The oil crisis of 1973 led to higher fuel cost and increased pressures on resources. This made anaerobic process attractive since it is, through its by-products, a net yielder of energy. This is especially so when compared to aerobic processes such as the activated sludge and the trickling filter which require external sources of energy.

3. Sewage authorities are becoming more reluctant to accept high strength industrial wastes into their sewers. These wastes often cause problems in sewage treatment plants due to organic overloading or toxicity. Indeed in some countries, industries are charged for treatment of their wastewater according to the strength of waste. Such occurrence of charges have been reported by **Hanisch (1980)** and **Wheatley et al. (1984)** among others. Secondly, increased environmental awareness has made indiscriminate dumping of industrial effluent into natural water bodies more unacceptable. These reasons have forced industries to look closely at viable pretreatment schemes. Since anaerobic processes are independent of oxygen transfer requirements and limitations, they are capable of higher organic loadings and hence could prove to be cheaper than aerobic treatment.

This renewed interest can be confirmed by the many kinds of anaerobic processes that have emerged since 1970. Before then, the types of anaerobic units in use were the cesspit, septic tank, Imhoff tank and the anaerobic pond. **Pol & Lettinga (1986)** reported that since 1970, the following anaerobic units have been commissioned; Upflow and downflow anaerobic filters, fluidised bed anaerobic reactors, anaerobic expanded bed reactors, upflow anaerobic sludge blanket, anaerobic baffled reactor, anaerobic gas lift reactors among others.

Unfortunately, the application of these modern anaerobic units is mainly concentrated in Europe and South America where research in the anaerobic process has been most intensive.

2.2 PROCESS DESCRIPTION

Gray (1989), Metcalf & Eddy (1979) and **Novaes (1986)** have described the anaerobic treatment as the biological process in which the organic fraction of a wastewater, namely proteins, carbohydrates and lipids, are degraded in the absence of oxygen to generate methane and carbon dioxide by a variety of microorganisms, principally the bacteria. The process takes place in the complete absence of free dissolved oxygen and the organisms utilize oxygen bound in other compounds such as nitrates or sulphates.

Metcalf & Eddy (1979) describe the main kinds of anaerobic processes as organic carbon removal, denitrification and sulphate reduction. Organic carbon removal is the conversion of organic carbon compounds to carbon dioxide and methane while denitrification is the conversion of the nitrate in the waste into gaseous nitrogen. Sulphate reduction leads to the production of hydrogen sulphide and acetate from sulphate compounds in the effluent.

2.3 PROCESS MICROBIOLOGY

Since 1970, several techniques and methods have been developed and adapted by researchers to allow for isolation and studies of anaerobic bacteria. **Novaes (1986)** noted that such studies have led to the conclusion that the anaerobic ecosystem is the result of complex interactions among microorganisms of several different species which are responsible for different steps in the anaerobic process.

The different steps involved in these microbial interactions have been described by **Novaes (1986)** and **Marty (1986)** as: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The relationship between the four steps is illustrated in Figure 2.1.

1. Hydrolysis: Through enzymes produced by fermentative bacteria, complex organic compounds are hydrolysed into simple compounds. Thus carbohydrates, proteins and lipids are converted into simple sugars, peptides and amino acids. Marty (1986) noted that cellulose is slowly attacked by hydrolytic enzymes and its biodegradability depends on its physical and chemical state.

2. Acidogenesis: Also due to the activities of fermentative bacteria on the simple organic compounds, this phase leads to the formation of hydrogen, carbon dioxide, acetate and other higher organic acids such as propionates and butyrates.

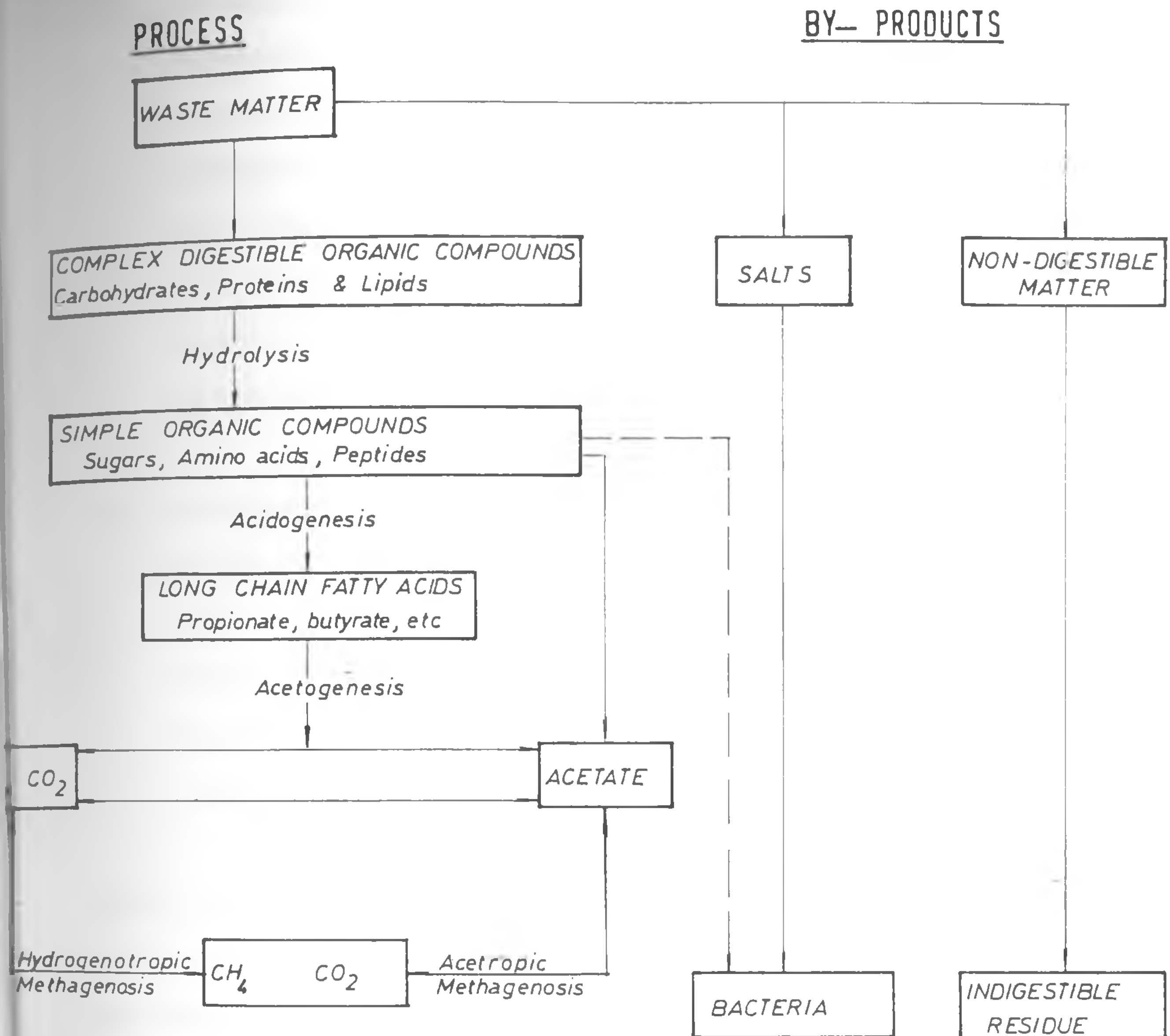


FIGURE 2.1 : SCHEMATIC DIAGRAM OF ANAEROBIC DIGESTION
[Sources: Novaes (1986), Marty (1986)]

3. Acetogenesis: During this stage, the organic acids produced in the acidogenesis are converted into hydrogen and acetate by the acetogenic bacteria. There are two kinds of acetogenic bacteria: hydrogen producing acetogenic bacteria catabolize organic acids larger than acetates, alcohols and certain aromatic compounds such as benzoate into acetate, carbon-dioxide and hydrogen; hydrogen consuming acetogenic bacteria, also known as homoacetogenic bacteria, are responsible for the conversion of hydrogen and carbon-dioxide into acetate.

4. Methanogenesis: The last stage of anaerobic reduction - methanogenesis - involves the reduction of carbon-dioxide and decarboxylation of acetate to form methane. Marty (1986) and Novaes (1986) observed that Methanogenic bacteria are extra sensitive to oxygen presence and temperature or pH variations. These bacteria are of two major kinds namely acetotrophic methanogens and hydrogenotrophic methanogens.

Marty (1986) observed that hydrolysis and acidogenesis lead to the formation of intermediary metabolites (propionates, butyrates etc), some end products (acetate), substrates that can be utilized by sulphate reducing bacteria and denitrifying bacteria, hydrogen and carbon-dioxide.

Bacteria are not the only organisms that play a role in the initial fermentative stages of hydrolysis and acidogenesis. **Marty (1986)** and **Novaes (1986)** noted that flagellate protozoa and fungi are both capable of producing enzymes necessary for hydrolysis of lignin into cellulose. Other anaerobic microorganisms include protozoa and yeast.

It will be noted that non-methanogenic bacterial action; hydrolysis, acidogenesis and acetogenesis, leads to production of acid and thus pH drop. During methanogenesis, this acid is converted into methane and carbon-dioxide. To avoid fluctuations of pH, the non- methanogenic and methanogenic bacteria must be in a state of dynamic equilibrium which can be achieved only at favourable environmental conditions.

2.4 PROCESS ENVIRONMENTAL REQUIREMENTS

Marty (1986) noted that methanogenic bacteria show great sensitivity to oxygen which curtails their activity. The presence of oxygen causes incomplete digestion since most methanogens are strict anaerobes whose activities lead to the release of obnoxious gases and system failure due to adverse pH among other factors.

The performance of an anaerobic reactor is also affected by factors such as substrates and nutrients, presence of inhibitors, method of addition of the waste into the reactor, internal mixing and circulation, temperature in the reactor, pH of reactor contents and solids retention time.

2.4.1 Substrates

Substrates are organics whose stabilization and subsequent utilization comprises the digestion process. These organics are carbohydrates, proteins and lipids. McCarty (1971) found that the biological growth resulting from the anaerobic digestion of different types of substrate varies considerably and that growth cannot be predicted from a knowledge of waste strength alone, but the components of the waste need also be considered. Long chain fatty acids produce the lowest growth, carbohydrate the highest with proteins in between.

2.4.2 Nutrients

Apart from substrates, anaerobic microorganism require growth factors, trace elements and nutrients for successful development. Nitrogen (N) and phosphorous (P) are two nutrients that are vital for bacterial growth. **Huss (1977)** found the optimum BOD:N:P ratio for successful anaerobic ecosystem is 100:0.5:0.1. **Henze & Harremoes (1983)** described the corresponding COD:N:P ratio to range between 100:1.7:0.2 and 100:0.5:0.1.

Kiestra & Eggers (1986) compared the nutrient requirements of aerobic and anaerobic processes and obtained the following carbon to nitrogen to phosphorous ratios; for aerobic process 100:5:1, and for anaerobic process 100:1.5:0.3.

Anaerobic organisms, therefore, have lower nutrient requirements than aerobes. This may be attributed to the slow cellular growth of anaerobes and is an advantage when dealing with wastewaters with relatively inadequate nutrients.

2.4.3 Inhibitors

Inhibitors are substances that adversely affect the rate of microbial activities when present above certain concentrations. All inhibitory substances affect the methanogenesis phase due to the following reasons:-

1. Methanogenic bacterial group is made up of only a few sensitive species, unlike the diverse hydrolytic and acidogenic bacteria.

2. Hydrolytic and acidogenic bacteria are present in raw waste usually and are therefore constantly replenished. Methanogenic bacterial population, however, is self-sustaining and once the population is depleted, it takes a long time for it to recover; it may even need re-seeding.

Gray (1989) noted that ammonia and sulphates are among the most common inhibitors. Ammonia and ammonium ion, though essential nitrogen sources for anaerobic digestion, are inhibitory at concentrations greater than 150 mg/l and 3000 mg/l Nitrogen respectively. Sulphate concentration greater than 500 mg/l can reduce methane production and lead to excessive sulphide production.

2.4.4 Temperature

Gray (1989) observed that anaerobic digestion can occur over a wide range of temperature which may be subdivided into three separate ranges as indicated in Table 2.1.

Table 2.1: Temperature Ranges for Bacterial Action

Type	Range (^0C)	Optimum Range (^0C)
Psycrophillic	-2 – 30	12 – 18
Mesophilic	20 – 45	25 – 40
Thermophilic	45 – 75	55 – 65

Source: Gray (1989)

Septic tanks and lagoons usually operate in the psycrophillic range and in some cases mesophillic depending on the climatic conditions of the area of operation. **Souza (1978)** observed that as temperature increases above 15°C, the rate of anaerobic digestion also rises, but remarked that sharp temperature variations should be avoided because of the adverse effect on bacteria.

As in the case of inhibitors, the effect of temperature is not as great on hydrolytic and acidogenic stages as on acetogenic and methanogenic phases. This is basically due to the many different species being involved in the first two stages as compared to the latter two. **Gray (1989)** noted that acetogenic and methanogenic bacteria are extremely sensitive to temperature variation with even a drop of 2 - 3^{0}C affecting the performance of mesophillic reactors.

2.4.5 pH

As discussed earlier, the activities of acidogenic bacteria tend to lower the pH of the reactor contents due to acid production. On the contrary, acetogenic and methanogenic bacteria raise the pH by their consumption of the generated acid during methane formation. Due to different growth rates of the various bacteria responsible for the different stages, anaerobic systems may have problems with pH control.

Unsuitably low pH may result when methanogenic bacterial action is inhibited or not yet established. **Gray (1989)** also noted that system overload may result in accumulation of volatile fatty acid. He observed that anaerobic digesters may operate at the satisfactory pH range of 6.2 - 8.0 while the optimum range is 6.8 - 7.2. Growth of methanogens is inhibited below pH 6.2 although fermentative bacteria will continue to function even when pH has dropped to 4.5 - 5.0. It should be noted that it is mainly the undissociated fraction of volatile fatty acids and the pH that is detrimental to the methanogens.

The pH is an important indicator of the efficient operation of an anaerobic reactor and a continuous drop in the pH is a sign that all is not right. During the start-up stage, especially, it is important to monitor the pH since its trend may indicate whether the process is successful or not. Before a stable population of each of the various bacterial groups has been established in an anaerobic digester, external pH control by chemicals such as lime and bicarbonates or carbonates of either sodium or potassium may be used.

2.4.6 Solids Retention Time (SRT)

McCarty (1971) observed that the proportional quantity of waste converted into biological suspended solids decreases with increase in solids retention time (SRT). When cells are maintained for long periods of time, they decay resulting in lower net growths. Thus, greater waste stabilization and lower biological cell production are obtained at longer SRT.

The minimum SRT is a function of organic waste converted to biological cells, the maximum rate of waste utilization and the raw waste concentration as is indicated in Monod's Model.

The value of the fraction of waste converted to biological cells is much lower in anaerobic treatment than in aerobic case. This is one of the reasons why the minimum SRT for anaerobic treatment is much longer than for aerobic treatment. The rate of waste utilization is dependent on temperatures. Thus, solids retention times are lower at higher temperatures.

2.4.7 Summary of Environmental Conditions

It may then be summarized that for successful growth of anaerobic microorganisms, the following process environmental requirements must be fulfilled:

1. Anaerobic conditions

2. Constant temperatures with an optimum temperature of 35°C for mesophilic bacteria.

3. A pH in the range 6.4 - 8.0 with an optimum mean of 7.0.

4. Absence of materials above toxic concentrations, in particular salts of sodium, potassium, ammonia, calcium, magnesium and heavy metal ions.

5. Presence of all nutrients in sufficient quantity in particular nitrogen, phosphorous, together with traces of sodium, potassium, calcium, magnesium, cobalt and iron.

There are several unit processes that satisfy the above conditions and thus qualify as anaerobic unit processes. Some of these unit processes are subsequently described.

2.5 TYPES OF ANAEROBIC PROCESSES

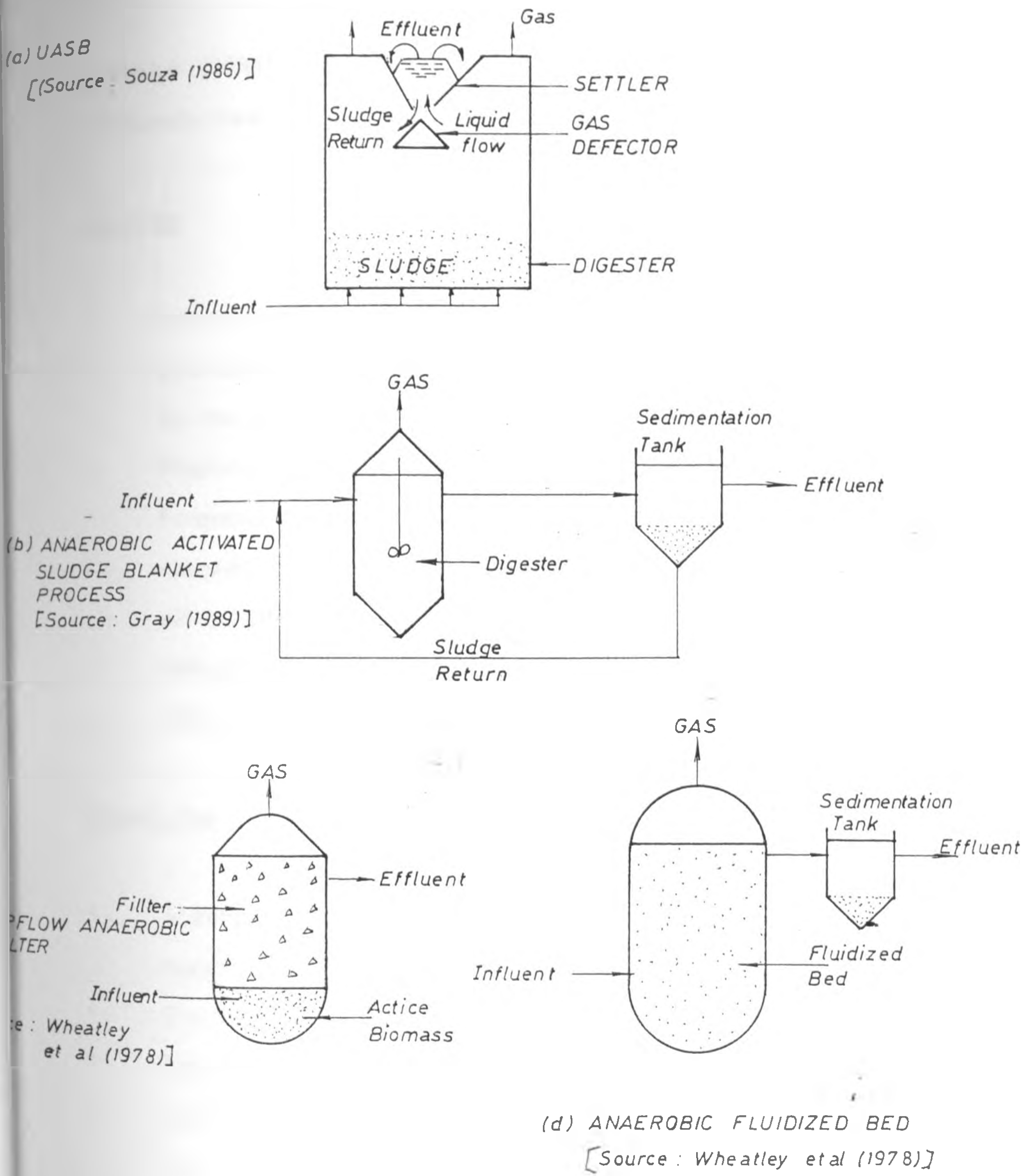
Present day anaerobic technology can be divided into two broad categories: Flow-through systems and contact systems. In Flow-through systems the solids retention time is equal to the hydraulic retention time whereas in the latter, the solids retention time is far greater than the hydraulic retention time. Examples of Flow-through systems are cess-pools, septic tanks, Imhoff tanks and anaerobic lagoons.

Anaerobic lagoons are waste stabilization ponds designed to be predominantly anaerobic, that is, operate in the absence of free oxygen. **Gray, (1989)**, noted that oxygen transfer through the air-water interface is not desirable, hence deep ponds, up to 4.5 m deep are usually employed. This also reduces the surface area to volume ratio thus minimizing re-aeration and heat loss.

Pescod & Thanh (1977) noted that anaerobic ponds are generally the simplest and cheapest forms of anaerobic treatment. However, they will not usually achieve an effluent quality suitable for discharge and a final aerobic stage of treatment is usually necessary.

Degradation of particulate organic matter is a slow process and anaerobic bacteria, particularly methanogens, grow very slowly. Therefore, flow through systems have to be designed with long hydraulic retention times, which leads to large expensive units.

Contact anaerobic systems are specially designed so as to retain the biomass and have a hydraulic retention time less than the solids retention period. This leads to reduced unit sizes and cheaper construction costs. **Gray (1989)** listed the four major contact systems in common use as the up-flow anaerobic sludge blanket (UASB), the anaerobic activated sludge process, the static media filter process and anaerobic fluidized bed reactor (Fig 2.2).



IRE 2.2 : SCHEMATIC DIAGRAM OF CONTACT ANAEROBIC SYSTEM

2.6 ADVANTAGES AND DISADVANTAGES OF ANAEROBIC TREATMENT PROCESS

Lettinga (1984) listed the following benefits and limitations of anaerobic wastewater treatment over the conventional aerobic methods.

Benefits

* Low production of stabilized excess sludge.
* Low nutrient requirements.
* No energy requirements for aeration.
* Production of methane gas.
* Frequent high organic and hydraulic shock loads can be applied.
* Adapted anaerobic sludge can survive long periods of no influent addition without dramatic deteriorations.
* Valuable compounds, such as ammonia, are conserved which in specific cases such as post-treatment irrigation may be beneficial.

Drawbacks

* Anaerobic bacteria, particularly methanogens, are susceptible to a large number of compounds.
* The first start-up of the anaerobic process is slow.
* Anaerobically treated effluent generally requires aerobic polishing.
* There exists little practical experience with most high rate anaerobic treatment systems.

The main advantages and disadvantages of the anaerobic degradation of organic wastes, as compared to aerobic treatment, stem directly from the slow growth rate of the methanogenic bacteria. **Metcalf & Eddy (1979)** noted that the low growth yield of anaerobic bacteria signified that only a small portion of the degradable organic waste is being synthesized into new cells. The rest are converted into mostly methane and carbon-dioxide gases.

Because of the low cellular growth rate and the conversion of the organic matter to methane gas, the resulting solid matter is reasonably well stabilized and small in quantity. Secondly, the inorganic nutrient requirement is reduced.

In summary, anaerobic digestion is ideal for waste treatment, having several significant advantages over other available methods. The advantages become more pronounced when dealing with strong industrial wastes which are nutrient deficient.

2.7 DESIGN PROCEDURES FOR ANAEROBIC REACTORS

The current design practice of anaerobic reactors, particularly lagoons, is basically empirical due to lack of predictability of the removal process. It is based on loading rates, retention time and depth.

Several authors have given guidelines for design of anaerobic lagoons which are given in Table 2.2.

Table 2.2: **Summary of Anaerobic Pond Design Guidelines**

Source	PARAMETER			
	Lagoon Depth (m)	Retention Time (days)	Loading Rates	
			(kg BOD/mg^3/d)	(kg COD/m^3/d)
Gloyna (1971)	–	–	0.125	–
Mara (1976)	2.0 – 4.0	Less than 5	0.10 – 0.4	–
White (1980)	–	–	0.19 – 0.24	–
Stuckey (1981)	2.8 – 6.0	7.0 – 80	–	0.16 – 0.32
Ellis (1981)	3.0 – 6.0	–	0.10 – 0.15	–

Sources: (Gloyna 1971; Mara 1976; White 1980; Stuckey 1981; Ellis 1981)

It may be noted that the ranges prescribed vary considerably. This is basically due to design of ponds being based on empirical methods and the different climatic conditions where such formulae were developed. Since the authors do not indicate the expected efficiency of the system it is important to monitor the ponds after commissioning to see if the desired goals are being achieved.

2.8 PAST APPLICATION OF ANAEROBIC LAGOONS FOR TREATMENT OF AGRO-INDUSTRIAL WASTEWATER

As stated earlier, anaerobic ponds are the simplest and cheapest kind of anaerobic unit processes. Despite a major disadvantage in having big areal requirement, these ponds have been extensively used for treatment of both domestic and industrial effluent. It is however necessary to review the performance of anaerobic ponds in the treatment of agro-based industrial liquid wastes.

Uddin (1970) found that maintaining high BOD loading rates on anaerobic ponds resulted in better BOD removals. He used a 90 cm deep experimental anaerobic pond to degrade effluent from Tapioca starch (cassava) factory with average influent BOD of 3000 mg/l and loading rates of 1347 kg BOD/ha/d and 7439 kg BOD/ha/d. After a retention period of 5 days, the BOD removal was 36.4% and 57.8% respectively.

Yothin (1975) conducted experiments at pilot scale on treatment of Tapioca starch factory effluent with anaerobic ponds. Despite the low initial pH of 3.0, loading rate of 1320 kg BOD/ha/d and retention period of 17 days, the COD, BOD, and suspended solids (SS) concentration reductions were as shown in Table 2.3.

Table 2.3: Results of Anaerobic Treatment of Tapioca Starch Factory Effluent

Parameter	Initial Value (mg/l)	Final Value (mg/l)
COD	8816	816.0
BOD	5200	448.5
SS	1299	182.5

Source:Yothin (1975)

Studies on anaerobic treatment of palm oil mill effluent were conducted by **Sinnappa (1978)** who operated anaerobic digesters of different retention times and volumes at ambient temperatures. The influent characteristics were pH - 3.7; BOD_5- 2500 mg/l, COD- 45000 mg/l, total Nitrogen 610 mg/l, suspended solids 25000 mg/l, and temperatures 37^0C. The findings were that for digesters with retention times less than 20 days the reactor failed and that it was not economical to extend the retention time beyond 40 days. Table 2.4 contains some of the results obtained by **Sinnappa (1978)**.

Table 2.4: Results of Anaerobic Treatment of Palm Oil Mill Effluent

	pH	BOD mg/l	COD mg/l	SS mg/l
Influent Characteristics	3.7	2500	45000	25000
Effluent Characteristics				
1. 20 days Retention	7.5	800	4500	2000
2. 30 days Retention	7.8	650	3500	100
3. 120 days Retention	7.8	600	3500	75

Source: Sinappa (1978)

It may be observed that despite the low initial pH, the BOD removal rate was high, 74% for retention period of 30 days. These results were particularly impressive considering the low nitrogen content; the BOD_5 to Nitrogen ratio for the wastewater was 100 : 2.4.

Pineapple canning wastes in Thailand are characterized by high BOD content (3000-8000 mg/l), high suspended solids content and low pH values. In a study conducted by **Frankel et al. (1978)**, wastewater treatment through anaerobic process, after pH correction, reduced the BOD to an average of 1500 mg/l. Subsequent aerobic treatment reduced the BOD_5 to 60 mg/l.

Chin et al. (1978) conducted a pilot study of anaerobic treatment of rubber processing factory effluent using a 75m x 35m x 1.86m deep pond. The retention period was 18 days. Table 2.5 shows a summary of the results of this study.

Table 2.5: Results of Pilot Study of Anaerobic Treatment of Rubber Processing Effluent

Parameter	Influent	Effluent	% Removal
pH	5.7	6.7	–
Total Solids (mg/l)	1915	895	53.3
COD (mg/l)	2740	518	81.1
BOD_3 at 30°C (mg/l)	174	241	86.2
Total Nitrogen (mg/l)	147	73	50.3
E.Coli x 103 (/100ml)	18000	2645	85.3

Source: Chin *et al.* (1978)

The results obtained by **Chin et al. (1978)** highlighted the ability of anaerobic pond to reduce pathogenic organisms as indicated by the *E. Coli* removal efficiency of 85.3%.

Holder et al. (1978) has also reported an anaerobic-aerobic treatment of dairy whey. The anaerobic pond reduced the BOD of the effluent by 98% when the influent BOD was 50,000 mg/l.

The deductions that can be made from these studies is that anaerobic ponds are effective in BOD removal. The removal efficiency is better with wastes of high BOD than those with comparatively lower BOD. All the studies mentioned are agro-industrial based, and such a deductions gives impetus to the present study which intends to investigate the application of anaerobic treatment to sugar cane mill wastewater.

CHAPTER 3: CANE-SUGAR MILLING: THE PROCESS AND EFFLUENT TREATMENT

3.1 RAW MATERIALS IN SUGAR INDUSTRY

Sugar crystals are produced from two different kinds of raw materials namely beet and cane. Beet is a root crop and grows in the temperate climates. Cane is a tropical plant mainly cultivated in Africa, Caribbean Countries, Malaysia and Australia. **Imrie (1975)** observed that about 58% of world's sugar production is derived from sugar cane.

In Kenya, all the sugar is manufactured from cane. The Kenyan Sugar Belt of the Lake Victoria Basin comprises of mainly Kisumu, Migori, Bungoma and Busia Districts and to a lesser extent Siaya, Homa Bay, Kericho and Kakamega.

Due to the similarity in the manufacturing processes in beet and cane sugar industry, the waste products of the two processes are remarkably the same. **Chang et al. (1990)** noted that the characteristics of cane wastewaters are similar to beet waste effluent.

Differences have recently arisen due to introduction of mechanized harvesting in the beet-sugar industry. Also causing dissimilarities is the introduction of water transport system in the beet factories as compared to the conveyor belt system used in most cane mills. This has led to higher volumes of water being used in the beet industry as compared to the cane industry. **Imrie (1975)** noted that though the actual quantities of water used in cane processing vary widely, published results range from 5-20 gallons (19-76 litres) of water per fonne of sugar processed.

Typical water requirement per tonne of beet crushed is 3500 gallons (13,250 litres) of water.

This study concentrates on cane-sugar processing, but due to similarity of waste from the two manufacturing processes, experience gained from beet-sugar will be occasionally referred to.

3.2 CANE MANUFACTURING PROCESS

Thitai (1979) listed the basic steps in sugar production from sugar cane as follows:-

* Cane weighing
* Juice Extraction (milling)
* Juice Clarification
* Evaporation of Juice
* Curing and Centrifugation
* Drying and Bagging

The sequence of the above steps are diagrammatically presented in Figure 3.1.

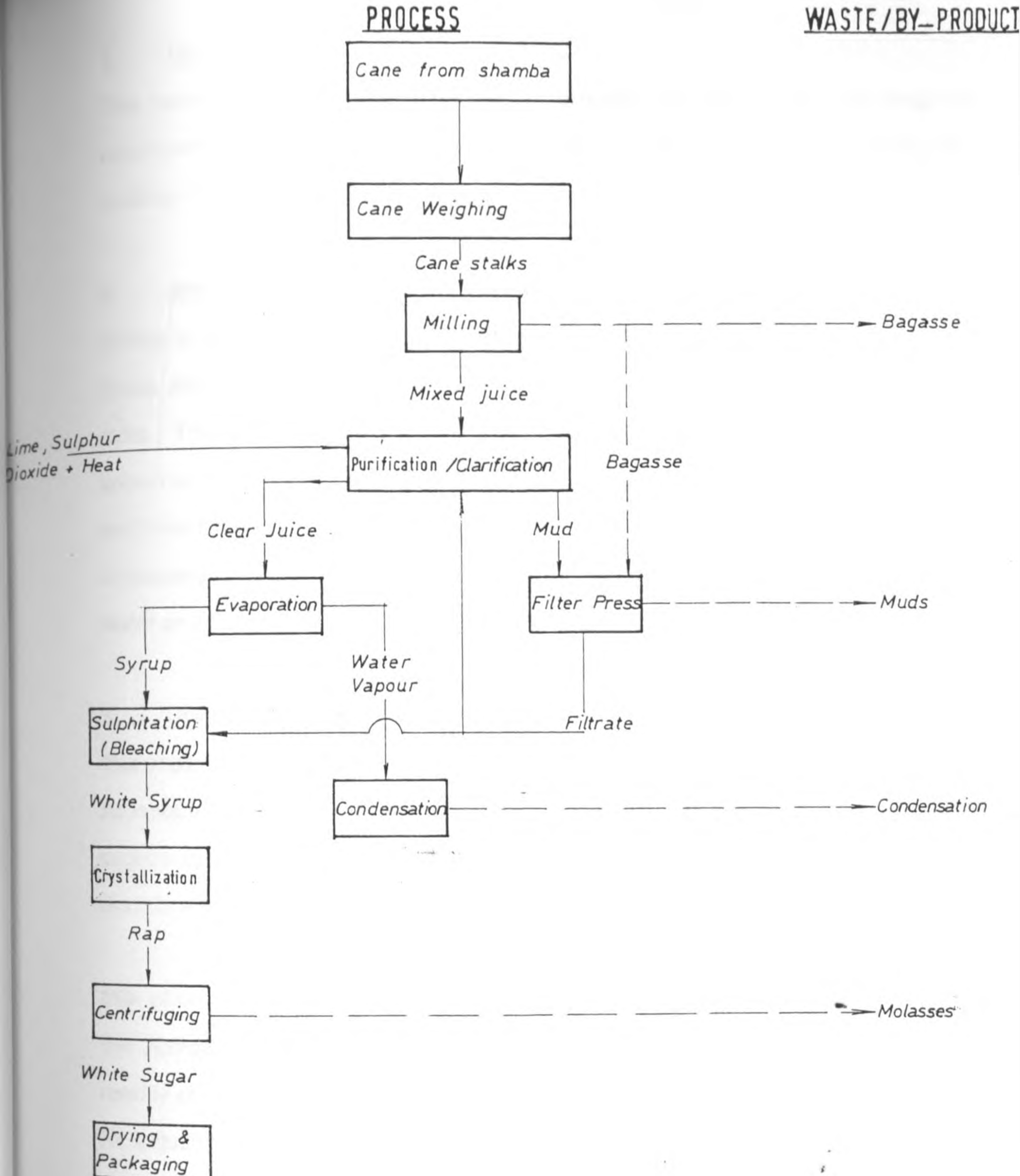


FIGURE 3.1 : CANE-SUGAR MANUFACTURING PROCESS

1. Cane Weighing

The cane that is harvested manually, is brought into the factory and weighed, usually on weigh bridges. The section of the factory where weighing, unloading and holding of cane is done before milling is called the "cane yard".

2. Milling

Milling is the extraction of juice from the cane. On delivery from the yard, the cane stalks are conveyed to revolving knives, crushers and a set of three to five rolling mills. The juices from the first and second mills are mixed resulting in what is known as "mixed juice". As the crushed cane (bagasse) emerges from the second and third mills, water is sprayed on it. At the last mill, a thin juice is extracted and it is pumped back to the bagasse which leaves the first mill. The process of returning water and thin juice to the bagasse from the earlier mills is called maceration.

3. Juice Purification and Clarification

The mixed juice contains non-sugars whose presence may adversely affect the subsequent separation of sucrose crystals from the mother liquor. These non-sugars are therefore precipitated out through addition of milk of lime, sulphur dioxide and heating of the juice.

Milk of lime neutralizes any acidity in the juice thereby preventing the inversion of the sucrose to glucose and fructose. Further, due to precipitation of its salts, it readily coagulates impurities. Sulphur dioxide is added as a bleaching agent and for adjustment of pH to about 7.0, hence facilitating lime coagulation. The juice is heated to boiling point so as to coagulate the albumin, fats, waxes and gums. The resultant precipitates entrap both suspended solids and fine particles as they settle out.

Finally the clear juice is separated from the coagulated sludge, also known as mud, through clarification. The settled mud is taken to the filter press where it is mixed with bagasse. This provides a porous material through which juice can be filtered easily. The filtrate is pumped back to the sulphitation tank where it is mixed with juice yet to be purified. The retained filter cake may be used as soil conditioner in the cultivation fields.

4. Evaporation

The clarified juice contains about 85% water. The aim of the evaporation process is to reduce the amount of water to suitable levels where crystallization can occur. Reduction of moisture content also facilitates smaller subsequent manufacturing units.

The thick syrup obtained from the concentration of the juice in the evaporators is sulphated one more time to allow bleaching of the crystals. This syrup still contains about 35-40% water. The water content is further reduced by boiling under vacuum in the boiling pans until crystals begin to form.

5. Crystallization

The thick syrup from the boiling pans, also called rap, is directed to crystallizers fitted with stirrers. Here it is cooled by air and stirred gently for durations as long as 2 days while crystals form. The remaining liquid is called molasses and the thick mixture of crystals in molasses is known as massecuite or magma.

6. Centrifugation

The massecuite is drawn into centrifugal machines which comprise of cylindrical perforated metal baskets lined with wire cloth. When these are rotated at high speeds the crystals are retained in the lining while the mother liquor (molasses) passes through due to the resultant centrifugal force.

The molasses is returned back to the vacuum pan for reboiling with a portion of massecuite yet to be heated in the pans. The reboiling and subsequent centrifugation is done three to four times until it is uneconomical to recycle the molasses. It is then removed from the production line as a by-product. The resultant crystals are taken for drying and bagging.

7. Drying and Bagging

The crystals from the centrifuges are wet and have to be dried before bagging. This is usually done by rotating the wet crystals in a drum in contact with warm air after which the crystals are fed into a conveyor belt connected to a bagging machine.

3.3 SOURCES AND QUANTITIES OF WASTE EFFLUENT

Biaggi (1968) listed the four main categories of wastes as bagasse, filter cake from the vacuum filter, cooling and condenser water, and concentrated wastes from spillage, scum leaks, washings, cleanings, boiler blow down, grease and oil from factory machines.

In Table 3.1 the quantities of the various wastes generated per tonne of sugar produced as reported by **Biaggi (1968)** are indicated.

Imrie (1975) also estimated the quantities and strength of effluent from a cane-sugar factory. However, he cautioned that the practice in the mill greatly influences the quantities of wastewater generated.

Table 3.1: Quanitities of Waste in the Cane Sugar Industry

Waste	Production (kg/tonne of cane)	m^3/tonne of sugar produced
Bagasse Fibre	109	–
Filter Cake	27.2	–
Cooling and Condenser Water	–	113.6

Source: Biaggi (1968)

For instance, when cane-washing is practiced in a factory, it results in a big wastewater problem in terms of volume and strength. The characteristics of the various waste streams as determined by **Imrie (1975)** are outlined in Table 3.2.

Table 3.2: Quantities and Strength of Waste from Raw Sugar Factories

Waste Stream	Waste Production/Tonne of Cane Crushed		
	Average Flow Rate (l/min)	Average BOD5 (mg/l)	Total BOD Load (kg/d)
Cane Washwater	1.58	680	3703
Floor Washing & Boiler Blowdown	0.16	378	205.7
Excess Condensate	0.08	10	2.7
Reuse Condenser Water	7.89	69	1878.7

Source: Imrie (1975)

Bagasse and Filter cake are usually produced in the solid form and should be treated as a solid waste problem rather than wastewater. The common disposal method for bagasse is through use as boiler fuel and a soil conditioner while filter cake may be used as manure in the cultivation fields.

The wastewater streams from the factory that pose an effluent treatment problem are therefore:-

1. cooling and condenser water
2. Concentrated wastes
3. Molasses Spills

Cooling and Condenser Water

These are discharged after use at temperatures ranging from 36^0C to 51^0C and therefore have low dissolved oxygen content. **Biaggi (1968)** listed the average characteristic values of these wastes for Puerto Rican factories and a summary of his findings as shown in Table 3.3.

Table 3.3: Cooling and Condenser Water Characteristics

Parameter	Value
1. Average Discharge (l/m)	9.7
2. Total Solids (mg/l)	42.1
3. Suspended Solids (mg/l)	56
4. Dissolved Solids (mg/l)	365
5. BOD_5 at 20°C (mg/l)	97
6. BOD Load (kg/tonne of cane)	1.35

Source: Biaggi (1968).

Recirculation of the cooling and condenser water was a potential means proposed by **Biaggi (1968)** of reducing volumetric waste load from the industry.

Concentrated Wastes

These are the wastes from plant clean-up water, cleanings of the juice heaters and evaporator tubes, washings of the weighing and molasses tanks and spills of molasses and sugar. Such wastes may be acidic or alkaline, depending on the method of production practiced. The spent water from the washings have a high carbohydrate concentration which leads to an acidic environment during biological decomposition.

Among the chemicals used for cleaning is caustic soda which is used to clean the juice heater tubes. Though recycled several times, the spent caustic soda solution is finally discharged into the waste streams and hence contribute to the waste effluent problem.

Hot water is used to clean the mills and, as had been noted previously the wastewater is usually of temperature ranging from 36^{0} - 51^{0}C.

Molasses

Molasses is a by-product of the sugar milling process and may be used as animal feed, or fertilizer. It is also used as a raw-material in the distilling industry. It is therefore, in the strict sense, not a wastewater stream.

However, occasional disposal of this material into streams has been responsible for pollution of such water courses to the detriment of aquatic life. **Thitai (1979)** reported that disposal of effluent, mainly molasses, from the Chemelil Sugar Factory in 1970 into River Mbogo, a tributary of River Nyando, resulted in both fish kills and obnoxious odour of the putrefying organic matter.

Molasses poses the most serious water polluting material associated with sugar refining. **Biaggi (1968)** observed that the BOD_5 of raw molasses can be as high as 436,000 mg/l, possibly the highest BOD figures ever reported for a particular liquid waste.

Composite Waste Stream

As may therefore be concluded, sugar factory effluent is comprised of two components. These are:-

a) cooling and condenser waters

b) concentrated wastes from spillage, leaks washings

Chang et al. (1990) analyzed samples of wastewater from a cane-sugar factory in Hawaii. The results are indicated in Table 3.4.

Table 3.4: Characteristics of Cane-Sugar Effluent

Characteristic	Waste Producing Source		
	Cane Washing	Filter-Cake Washing	Composite
Alkalinity (mg/l)	1,600	4,500	1,100
BOD_5 (mg/l)	300	30,000	2,800
COD (mg/l)	7,400	43,000	7,000
SS (mg/l)	19,000	24,000	11,700
Nitrogen (mg/l)	3	17	4
Phosphorus (mg/l)	0.17	66.6	1.78
Potassium (mg/l)	21.8	40.6	18.6
Sulphate (mg/l)	39.8	19.5	28.6
pH	6.0-7.6	7.4-8.1	6.5-7.6
Temperature (^{o}C)	31-38	35-50	32-40

Source: Chang *et al.* (1990).

From the data contained in Table 3.4 the following deduction can be made. The waste is characterized by high BOD and COD values and low nutrient content.

The COD : N : P ratio for the composite stream is 100:0.14:0.06. This compares unfavourably to the nutrient requirement for effective aerobic and anaerobic degradation which are given by **Kiestra and Eggers (1986)** as 100:5:1 and 100:1.5:0.3 respectively.

It is therefore concluded that sugar-cane waste is characteristically nutrient deficient. Another characteristic of the waste as found by **Chang et al. (1990)** is the high content of suspended solids attributed to the fibrous nature of bagasse waste.

The pH of the composite waste falls within the neutral range but due to the high organic content it usually drops during treatment into the acidic range thereby stopping further biological action. The waste is further characterized by high temperatures; however, the temperature can be used as an advantage when modelling high-rate anaerobic reactors for the management of cane-sugar effluent.

It may be concluded that cane-sugar effluent must be treated to reduce organic strength, suspended solids and temperature before it is discharged safely into the environment. Such treatment methods must take into consideration the waste characteristics and seasonal nature of the cane industry.

3.4 PREVIOUS STUDIES ON TREATMENT OF SUGAR MILL EFFLUENT

3.4.1 General

For all industries, several methods exist for reduction of pollution loads of effluent to acceptable levels. The actual method chosen depends on a multitude of factors including cost, legislation, composition and amount of wastewater, land availability, level of technology available and the kind of industry among others. **Imrie (1975)** noted that the best method of effluent management in the sugar industry is to practice water economy.

Measures of water economy include minimization or elimination of cane-washing, and re-utilization of condensate and cooling waters. Correct factory practice, good house-keeping and proper engineering maintenance can often reduce the magnitude of effluent management problem considerably.

Imrie (1975) documented several methods of management of sugar factory wastewater. These are; removal of solids, irrigation, and biological purification.

a) <u>Removal of Solids</u>

Cane washwater is amenable to treatment by settlement after which the water may be reused. The waste from this stream is directed to a sand trap where the coarse solids settle out of the solution. The partially clarified water is used to pre-wash the cane in the first section of the cane carrier after which it is now taken to a settling basin from where it overflows to a retention basin pending further treatment.

Coarse filters may also be used to segregate solids such as stones, leaves, weeds and trash while addition of flocculants such as lime may accelerate the settlement of solids from the effluent. The advantage of treatment through removal of solids is that it involves simple technology. However it can not provide a complete treatment, subsequent additional treatment is essential to ensure that the discharge standards are achieved.

b) <u>Irrigation</u>

Hernandez (1980) noted that organic wastewater such as those from sugar mills are suitable for use in irrigation. He listed the advantages of irrigation as a means of waste treatment as being low energy costs, potential increase in crop yields, low initial capital investment, and less skill requirement among others. However, it has the disadvantage of possible accumulation of hazardous materials and nutrients in soils or surface and groundwater. Other disadvantages include odour problem and inability to accept wastewater for crop irrigation during periods of heavy rain.

Wastewater discharge for irrigation undergoes biological, physical and chemica treatment in the fields as it percolates into the soil. Both aerobic and anaerobic digestion take place through action of bacteria, fungi, plants and othe microorganisms. Sedimentation and soil filtration remove particulate matter fron the wastewaters while many diverse chemical interactions take place in the top so thereby treating the effluent.

Irrigation is a potential means of cane waste-water management if proper design i conducted. This is especially so due to the proximity of cane-fields to sugar mill: **Imrie (1975)** reported that settled factory effluent has been used for irrigation (cane-fields in South Africa without any noticeable detrimental effect.

c) <u>Biological Purification</u>

The biological purification processes employed for treatment of sugar effluent a lagooning, biological filters and the activated sludge process. **Imrie (197** observed that lagooning is the most widely used of all methods for sugar efflue treatment. However, he did not give any figures on the process efficiency.

In the same study, it was reported that biological filters are not commonly used treatment of cane effluent since they have a long induction period (upto t months) before maximum efficiency is obtained. **Bhaskaran and Chakraba (1966)** reported that cane-sugar waste is deficient in nitrogen, and this fact appe to be mainly responsible for its failure to respond well to treatment by trickling filters.

Several past studies on biological treatment of cane-sugar effluent are documented. **Taygun et al. (1980)** described the purification of sugar factory wastewater in the RT-Lefrancois system developed in Belgium in 1975.

The system is an activated sludge process with nutrients addition. In the fermentor the activated sludge concentration was controlled at 12 to 15 g/l, temperature maintained at 20^0C and the hydraulic retention time of 2 to 3 hours. It was found that the system had lower nutrient requirement than that of a conventional aerobic process. The RT-Lefrancois system nutrients requirement measured by the Carbon: Nitrogen: Phosphorus (C:N:P) ratio was 100.3:0.5 as compared to 100:5:1 in the conventional aerobic system.

The performance data of the system is summarised in Table 3.5.

Table 3E: Performance of the RT-Lefrancois System on Sugar Effluent Treament

Parameter	**Loading Rate**	Removal Rate	
		Centrifugal Effluent	Clarified Effluent
COD	9000 - 11000 kg COD/d	91%	80%
BOD	7000-9000kg BOD/d	96%	90%

Source: Taygun *et al.* (1980).

The wastewater treated in the system had initially been pre-treated by sedimentation in settling ponds. **Taygun et al. (1980)** observed that the aerobic treatment of the wastewater must be preceded by anaerobic treatment for effectiveness. This allows the decomposition of sugars into organic acids.

Bevan (1969) also described an activated sludge process for treatment of cane-sugar effluent. In a continuous treatment system the influent BOD_5 of 1015 mg/l was reduced by 68% to 320 mg/l. The waste was fed at the rate of 0.55 m^3/hr and the sludge recyle rate was 100 l/s.

Bevan (1969) also operated a batch surface aerator reactor for treatment of the sugar effluent. The findings of his study are summarized in Table 3.6. An interesting feature of the results is the relatively high removal rates in all cases including the instances when no nutrient is added nor pH adjusted. In all cases the effluent BOD was still too high for discharge into water courses and subsequent treatment was necessary.

Table 3.6: Results of Batch Surface Aerator Reactor Treatment of Cane-Sugar Effluent

Experimental Conditions	BOD		Removal Rate (%)	Initial pH Range
	Influent (mg/l)	Effluent (mg/l)		
No nutrient additon No pH adjustment	2475	930	62.4	4.8-5.6
Nutrient addition No pH adjustment	2690	725	73	4.8-5.6
No nutrient addition pH adjusted	2115	240	88.6	7.0-7.4
Nutrient addition pH adjusted	2880	305	89.4	7.0-7.4

Source: Bevan (1969).

Bhaskaran and Chakrabarty (1966) conducted experiments on a pilot plant for treatment of cane-sugar waste in India. The pilot plant comprised a bar screen, grease trap, two-stage digestion ponds having a total effective volume of 30 cubic metres and an oxidation pond having a surface area of 100 square metres and an average depth of 1.2 m.

With a retention period of 15 days in the anaerobic pond, the results in Table 3.7 were obtained.

Table 3.7: Results of Anaerobic Treatment of Cane Sugar Effluent on a Pilot Plant Scale

Parameter	Anaerobic Pond Influent	Anaerobic Pond Effluent
pH	4-5	6-8
TS (mg/l)	5093	1634
SS (mg/l)	526	42
BOD_5 (mg/l)	1600	550

Source: Bhaskaran & Chakrabarty (1968).

Subsequent oxidation pond treatment with retention periodic of 7 and 13 days reduced the BOD_5 from an average of 272 and 307 mg/l respectively to 88 and 87 mg/l respectively. In both cases, the BOD_5 removal efficiency in the oxidation ponds was about 70%. The results of the experiment shows that the wastes are amenable to treatment by anaerobic digestion followed by stabilization in an aerobic pond, with overall efficiency of 90% in terms of BOD removal.

3.4.2 <u>Anaerobic Treatment of Sugar Effluent</u>

Taygun et al. (1980) observed that direct aerobic treatment of sugar factory wastewater is not possible since the wastewater contains a great amount of sucrose (sugar). Hence, they concluded that before, the aerobic treatment of the wastewater, an anaerobic treatment process must take place for the decomposition of the sugar into the organic acids. An European Economic Community (EEC) Report (1979) noted that the required treatment for these effluent consist of an initial anaerobic process to eliminate sugars, followed by digestion of the sludge and aeration of the water.

From the these references, it is evident that anaerobic treatment of sugar mill effluent is an important first step in handling the wastewater. Various applications of anaerobic treatment, ranging from ponds to upflow anaerobic sludge blanket reactors have been reported. **Mudrack and Kunst (1986)** listed down the performances of stirred tank anaerobic reactor, upflow anaerobic reactor and fluidised bed reactors on the treatment of sugar effluent. (Table 3.8).

Table 3.8: Operating Data & Results for Anaerobic Reactors Treating Sugar Effluent

Type of Reactor	Country of Operation	Volume (m^3)	Retention Time	Input COD (mg/l)	COD loading g(COD)/d	COD Removal (%)
1. Stirred Tank Anaerobic	- USA	16,000 25,000	8d 1d	6,000 1,200	- 1.2	77 -
2. Upflow Anaerobic	Holland Holland	800 800	4d 5.7d	1,850 4,000	12 16.5	70 78
3. Anaerobic Fluidilised-bed Reactor	-	0.040	5hr	5,000	12	86
4. Same as above but treating molasses	-	0.040	72hr	9,300	2.8	88

Source: Mudrack and Kunst (1986).

More descriptive studies have been conducted by **Iza et al. (1990) and Chang et al. (1990). Iza et al. (1990)** conducted a study to compare the performances of upflow Anaerobic Sludge Blanket (UASB) and Fluidized Bed (FB) reactors in treating beet-sugar wastewater. The wastewater was first retained in lagoons for solids settlement before anaerobic treatment. Lime was added for control of pH to a typical value of 7.0. The design parameters for the UASB were:- load - 12t(COD)/d; Flow - 95m^3/d; Hydraulic retention time - 12hours; and temperature 35^{0}C. They concluded that both UASB and FB reactor were able to treat sugar beet wastewater with removal rates greater than 90% in both cases.

Chang et al. (1990) described results of preliminary laboratory treatment of sugar-cane wastewater. The system incorporated sedimentation, anaerobic pretreatment (UASB), and aerobic polishing (Aerobic Fixed Bed (AFB) or Entrapped Aerobic Fixed Bed (EAFB)). The sugar mill wastewater quality before and after anaerobic and aerobic treatment are shown in Table 3.9.

Table 3.9: Sugar Wastewater Characteristics Before and After UASB, AFB and EAFB Treatment

Parameter	Initial	After UASB	After Settling & AFB	After Settling & EAFB
Soluble COD (mg/l)	1,500	225	45	45
BOD (mg/l)	1,200	113	12.5	12.6
BOD_5/COD	0.8	0.5	0.28	0.28
TSS	650	250	195	50
pH	7.8	8.5	9	9

Source: Chang *et al.* (1990).

It was observed that effluent quality from anaerobic treatment corresponded to that of domestic sewage. The overall organic removal was greater than 99% though the EAFB had better solids removal efficiency than 80%.

Monteverde and Olguin (1984) reported that the Cuban Institute for Research (ICIDCA) on sugar cane by-products undertook a research project on anaerobic digestion of stillage by means of UASB. At a loading rate of 25 kg COD/m^3/d and retention period of 2 days, the COD removal rate was 70% with methane yield of 0.33 m^3/kg COD removed. In the same study, it was reported that the Mexican Electric Research Institute (IEF) conducted a batch experiment on anaerobic treatment of sugar cane effluent. With addition of 40% cow manure (diluted with 50% water), a stable system was maintained, and the initial BOD of 1580 mg/l was reduced to 680 mg/l after a retention time of 60 days. This represents a BOD reduction of 57%.

It may therefore be concluded that sugar wastes have characteristics that indicate the suitability of anaerobic treatment. These characteristics are high BOD and COD values, high suspended solids content and high sugar content.
Krieston et al. (1986) pointed out that industrial wastewater treatment is a non-productive activity to the establishment and hence the management tends to invest as little as possible in treatment facilities. In Kenya, as is the case in most developing countries, the treatment method should be simple to operate and maintain and must have low capital and operation costs. It is for this reason that anaerobic process was considered to be a viable solution to the wastewater treatment problems in the sugar industry.

CHAPTER 4 EXPERIMENTATION AND RESULTS

4.1 BACKGROUND

The basic objective of this study was to investigate the potential of anaerobic biodegradation of cane-sugar mill waste effluent. **Bhaskaran and Chakrabarty (1966)** observed that cane-sugar wastewater is deficient in nitrogen nutrients and that this fact appears to be mainly responsible for its failure to respond well to aerobic treatment. Instances of failure of aerobic ponds have been documented as outlined in a report by **Thitai (1979)** and discussed in previous chapters.

Anaerobic treatment offers an alternative method of waste management for waste which are deficient in nutrients. **Lettinga (1984)** noted that one of the advantages of anaerobic treatment is that its nutrient requirement is lower than that of aerobic treatment.

To achieve the objectives of this study, laboratory anaerobic reactors were modelled to treat wastewater obtained from a sugar mill.

4.2 REACTOR SELECTION

Metcalf & Eddy (1979) describe two basic kinds of reactors, namely batch reactors and continuous flow reactors. A batch reactor is one in which the fluid is neither entering nor leaving the reactor on a continuous basis, but is contained in the vessel. The liquid contents of such vessels are usually completely mixed. A continuous flow reactor is one where the fluid passes through the tank and is discharged continuously from the reactor. This may involve varying degrees of mixing.

The controlling factor of this study was the source of cane- sugar effluent. All the operating factories are located in Western Kenya and involves at least eight-hours journey from Nairobi. For a continuous flow reactor, it would have been necessary to have regular supply of wastewater to sustain the inflow into the reactor. This was not possible since the collection of wastewater could not be done on a daily basis. An alternative would be to sample enough volume to last a longer duration, say a week. This, however, would be limited by possible partial changes in wastewater characteristics before treatment in the reactor due to long period of storage and was therefore not practical.

The option of installing a continuous flow reactor at the sugar factory was considered. However the analytical laboratory apparatus within the factory was either not adequate or broken-down.

The third option was to conduct a batch reactor experiment at the University of Nairobi laboratory. **Metcalf & Eddy (1979)** recommended that a batch reactor is the best alternative as first-stage reactor in determining the biodegradability of any wastewater. The concept of conducting batch reactor experiments before adoption of continuous flow experiments is also recommended by **Besselievre & Schwartz (1976). Sinnappa (1978)** conducted batch reactor experiments on anaerobic treatment of Palm Oil waste effluent, on the basis of whose results he later conducted a successful continuous flow experiment.

The option of conducting batch reactor experiments on the wastewater was therefore adopted. The main handicap of this option was the preservation of the wastewater from the time of collection to the time of introduction into the reactor. **Metcalf & Eddy (1979)** reported that there is no perfect universal treatment to the problem of sample preservation.

However, it is known that most degradation and hence sample deterioration is due to micro-organisms present in the sample. The activity of these organisms are minimal at low temperatures and hence refrigeration minimizes sample deterioration.

In this Study, the wastewater was preserved in a refrigerator immediately after sampling and transported in an ice-box to Nairobi.

4.3 REACTOR DESIGN

The fabricated reactor for this experiment had to fulfill the following criteria:-

1. The reactor had to be anaerobic
2. There had to be provisions for escape of any generated gas.
3. There had to be provisions for mixing the liquid contents of the reactor.
4. The volume of the reactor had to be of adequate capacity to sustain sampling over the whole period of the experiment.

To achieve the condition of anaerobicity, the reactors were designed as enclosed jars but with perforated covers to allow for the escape of gaseous products of decomposition. The analysis of the composition and the nature of the generated gases were not among the objectives of this study. The gas was therefore left to escape into the atmosphere.

The volume of the reactor was determined by the number of characteristic determination tests necessary and the volume of samples required for each test. **Besselievre & Schwartz (1976)** recommended the following analytical tests for wastewater streams:- Biochemical Oxygen Demand (BOD), Chemical Oxygen

Demand (COD), suspended solids (SS), pH and temperature. For a batch reactor, the determination of temperature has no value since the contents are held for long durations without replacement. The parameters that were determined in this experiment were BOD, COD, total solids, SS and pH.

Estimating that each test would require 50 ml of sample and that sampling would be done three (3) times a week for four weeks, the minimum reactor volume was computed as follows:

Total No. of tests per Reactor	=	5No.
Estimated Volume required per test	=	50ml.
Estimated Volume per set of tests	=	(5x50)ml.
	=	250ml
Total No. of tests to be conducted	=	3 times x 4 weeks
	=	12No.
Total minimum volume of sample required	=	(250x12)ml
	=	3 litres

To allow for non-disturbance of the scum and sludge layers that are characteristic of anaerobic reactors, it was decided to have a volume large enough and reactors of adequate height to allow for stratification of the different layers. A volume of 10 litres and height of 40 cm were selected. For ease of stirring to achieve mixing, a cylindrical reactor with a diameter of 18 centimetres was adopted.

To facilitate mixing and sampling of the reactors content a paddle and siphoning device were fitted respectively as indicated in Figure 4.1. The reactor was constructed out of perspex glass to allow for visual inspection of the various layers.

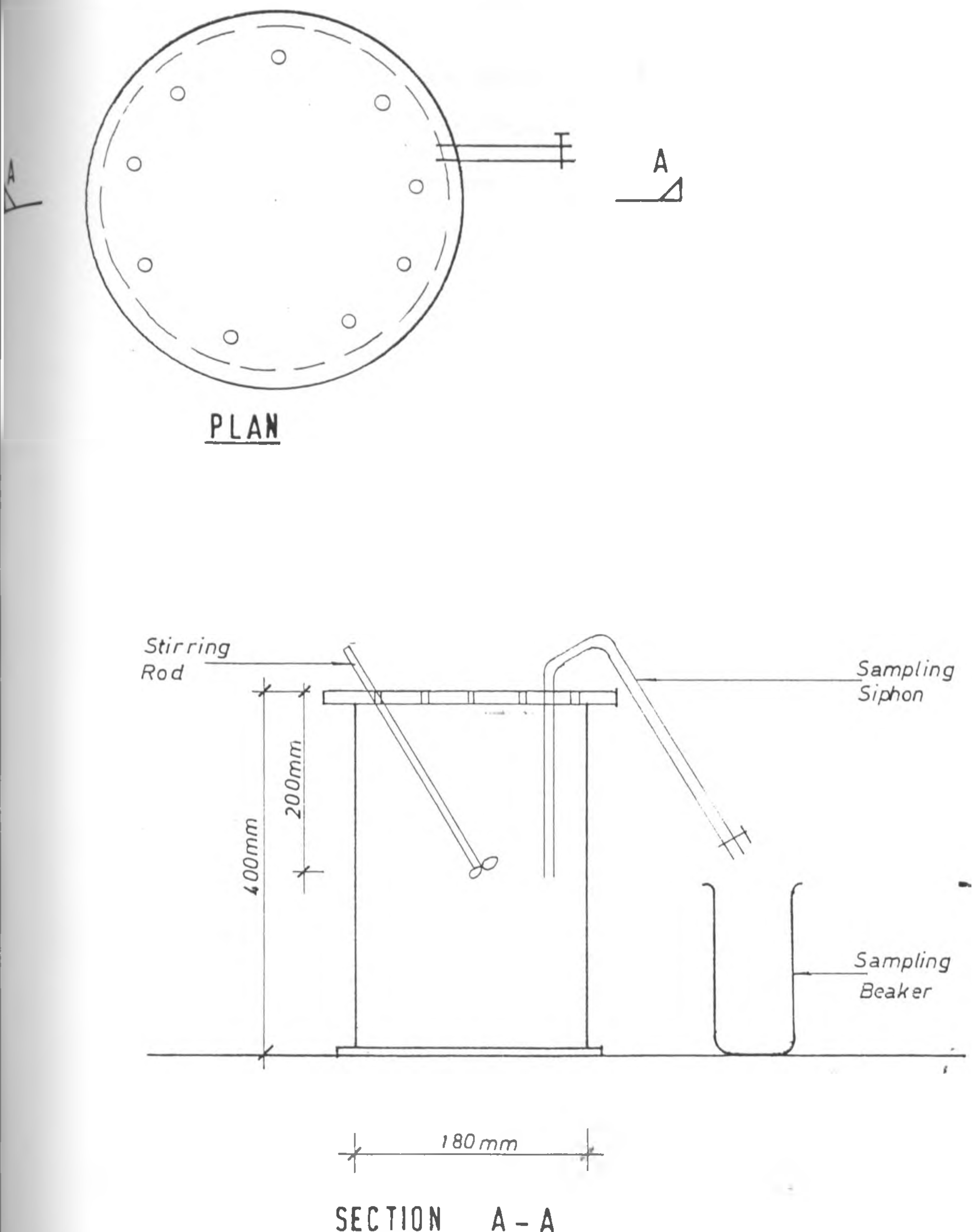


FIGURE 4.1 SKETCH OF EXPERIMENTAL BATCH REACTOR

4.4 WASTEWATER SAMPLING

The wastewater was obtained from the Muhoroni Sugar Factory. The factory was selected because of its location and ease of access to public transportation. Secondly, its production schedule fitted with the time programme for this study.

A pre-sampling visit to the factory was made during which the various waste streams were identified. Apart from visual observations, discussions were held with operation and maintenance personnel of the factory. From these discussions, the cane-sugar production process and subsequent wastewater generation streams were outlined. The average rate of waste stream flows was also obtained from records kept in the department.

Following the identification of the various streams, arrangements were made to collect representative samples from these streams. For each stream, 10 equi-volume samples were extracted at hourly intervals from 8.00 a.m. - 5.00 p.m.

The waste samples were collected on days that the factory was crushing normally. On instances when the production process was interrupted, the collected sample was discarded and the sampling process restarted the following day. To prevent premature degradation wastewater samples collected were placed in a refrigerator within the factory laboratory during the period of collection. At the end of the day, the samples were placed in an ice-pack box and transported to Nairobi for analysis and experimentation.

4.5 REACTOR OPERATION STAGE

The samples from the different waste streams obtained from the factory were analyzed for physical and chemical characteristics. On subsequent days, only samples from the mixed stream were collected for experiments in Nairobi. The study comprised of two distinct phases. The first phase involved the start-up process while the latter phase represented the actual running of the experimental reactors with data being collected.

4.5.1 Start-Up Process

Wheatley et al. (1984) in their study of anaerobic treatment of olive processing wastes reported that slow acclimatization of organisms with small increases in load is essential for successful reactor operation and that start-up is even more important for wastes that are nutrient deficient. **Sinnappa et al. (1978)** successfully initiated the process of anaerobic degradation of palm oil wastewater using a mixture of actively digesting sludge and the wastewater.

The same procedure was adopted for this study. Presently, wastewater from the Muhoroni Sugar Factory is treated through a series of nine oxidation ponds. The first three ponds are heavily silted. The sludge accumulation has led to anaerobicity within the ponds as indicated by continuous gas bubble stream observed on the pond surface. The surface is practically completely covered with black scum.

The start-up process was carried out as follows. In one of the fabricated reactors, sludge obtained from the first oxidation pond was poured to about one-fifth (1/5) of the total volume. This represented 2000 ml of sludge. The pH of wastewater collected from the factory was corrected to about pH 7.0 ± 0.5 using lime. Using the pH-corrected wastewater, the reactor was topped to three-tenths of the total volume. This mixture, representing two parts sludge for one part wastewater was thus maintained undisturbed for a period of one week.

At the expiry of one week, the reactor was filled gradually over a period of two days with seven equal aliquots of wastewater. Each aliquot, representing one-tenth of the reactor volume, was administered after every two hours. This was done to allow acclimatization through small increases in load to the biomass.

The reactor was thereafter monitored through pH determination. After two weeks the pH had stabilized within the neutral range, a scum layer had developed and bubbles of gas were observed on the water-surface in the reactor.

4.5.2 Operation of Reactors

Three different cases of experimental set-up were conducted to simulate different environmental conditions of anaerobic degradation. These are:-

CASE I Seeding the contents of the reactor were seeded with start-up sludge and pH correction of the wastewater.

CASE II The contents of the reactor were seeded with start-up sludge but no pH correction of the wastewater.

CASE III No seeding of the contents of the reactor nor pH correction of the wastewater.

The experiments for all the three cases were carried out simultaneously. For Case I, after the start-up process the liquid portion of the reactor was decanted leaving only 2000 ml of sludge-wastewater mixture. Thereafter pH adjusted wastewater was introduced in 8 aliquots of 1000 ml each over a period of one day.

For Case II, after start-up and decanting as in Case II, the wastewater was introduced, without pH correction, in 8 aliquots of 1000 ml each over a period of one day. In Case III the reactor was simply filled with wastewater with no pH correction nor seeding being done.

For each case of treatment, two sets of reactors were installed. This was done to confirm the reproducibility of results obtained in each case. To encourage mixing of the reactor contents, the liquid portions were stirred periodically and at least 4 times a week.

Day 0 (zero) was taken as the time the wastewater was brought into the laboratory and analysis done without any treatment, seeding or pH correction. Thereafter the reactor contents were sampled at certain days through the siphon mechanism and taken for analysis. Before any sample was taken, the siphon was left to run momentarily to let out the liquid trapped within the siphon tube.

The wastewater characteristics determined were BOD, COD, total and suspended solids and pH. All analyses were done in accordance with **Standard Methods for the Examination of Water and Wastewater (APHA, (1985)).** The experiment was discontinued after the fourth week when it was observed that no appreciable changes occurred in the characteristics of the contents of the reactors.

4.6 RESULTS AND OBSERVATIONS

The results of this experiment may be categorized into three groups. These are stream sampling results, the start-up process and the reactor operation stage. The first two stages were done to form guidelines for the last stage.

4.6.1 Stream Sampling (Results)

The sugar milling process in Muhoroni is shown diagrammatically in Figure 4.2. The process generally conforms to the case already described in Section 3.2.

The main waste streams were identified as:-

1. **BOILER AND MILLS WASTE WATER**

   Comprised of run-off from caneyard, condensate from boilers, spills and leaks from the mills, factory wash water and particles of bagasse.

2. **BOILING HOUSE WASTEWATER**

   The boiling house is made upof the clarifier, evaporators, boiling pans, centrifugals and the Power House where electricity is generated using steam. The wastes are from spills, leaks and wash water. Occasionally spent steam is discharged into the effluent channels.

3. **SPRAY POND WATER**

   Designed to cool wastewater from the Boilers and Power House, for possible reuse, the spray pond contributes wastewater through occasional discharge into waste streams.

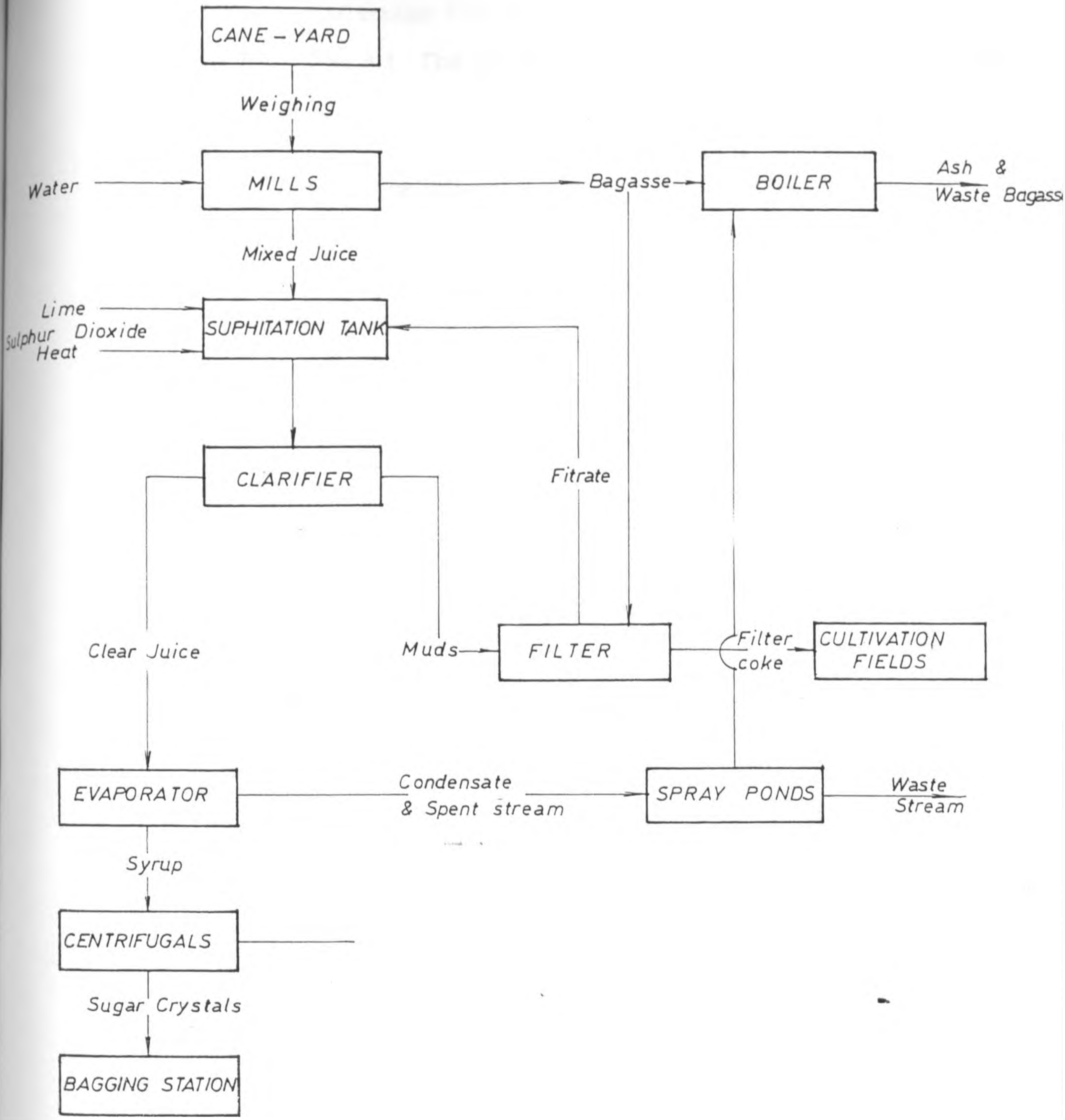


FIGURE 4.2 : <u>SUGAR MANUFACTURING PROCESS IN MUHORONI SUGAR FACTORY</u>

The characteristics of wastes from the three streams as determined in this study are tabulated in Table 4.1. The quantity of wastewater were derived from records kept in the factory.

Table 4.1: Characteristics of Different Waste Streams in Muhoroni Sugar Factory

Characteristics	SAMPLE STREAM			
	Boiler Mills	Boiler House	Spray Pond	Combined Stream
Estimated Flow (m3/d)	220-320	330-390	-	650-820
BOD_5 (mg/l)	450.6	5955	540	445.6
COD (mg/l)	14880	7360	1440	16000
pH	4.3	4.2	7.2	4.5
Suspended Solids (mg/l)	840	440	240	950
Total Solids (mg/l)	9200	6660	1440	5250

4.6.2 Start-Up Process

The performance of the start-up process was monitored through pH determination. The results of this monitoring exercise are indicated in Table 4.2 and illustrated in Figure 4.2.

Table 4.2: Daily pH Variation for the Start-up Process

DAY	10	11	13	15	17	19	22	24	26	29	30
pH	4.5	4.4	4.5	4.7	5.5	6.0	6.6	6.8	6.7	6.8	6.8

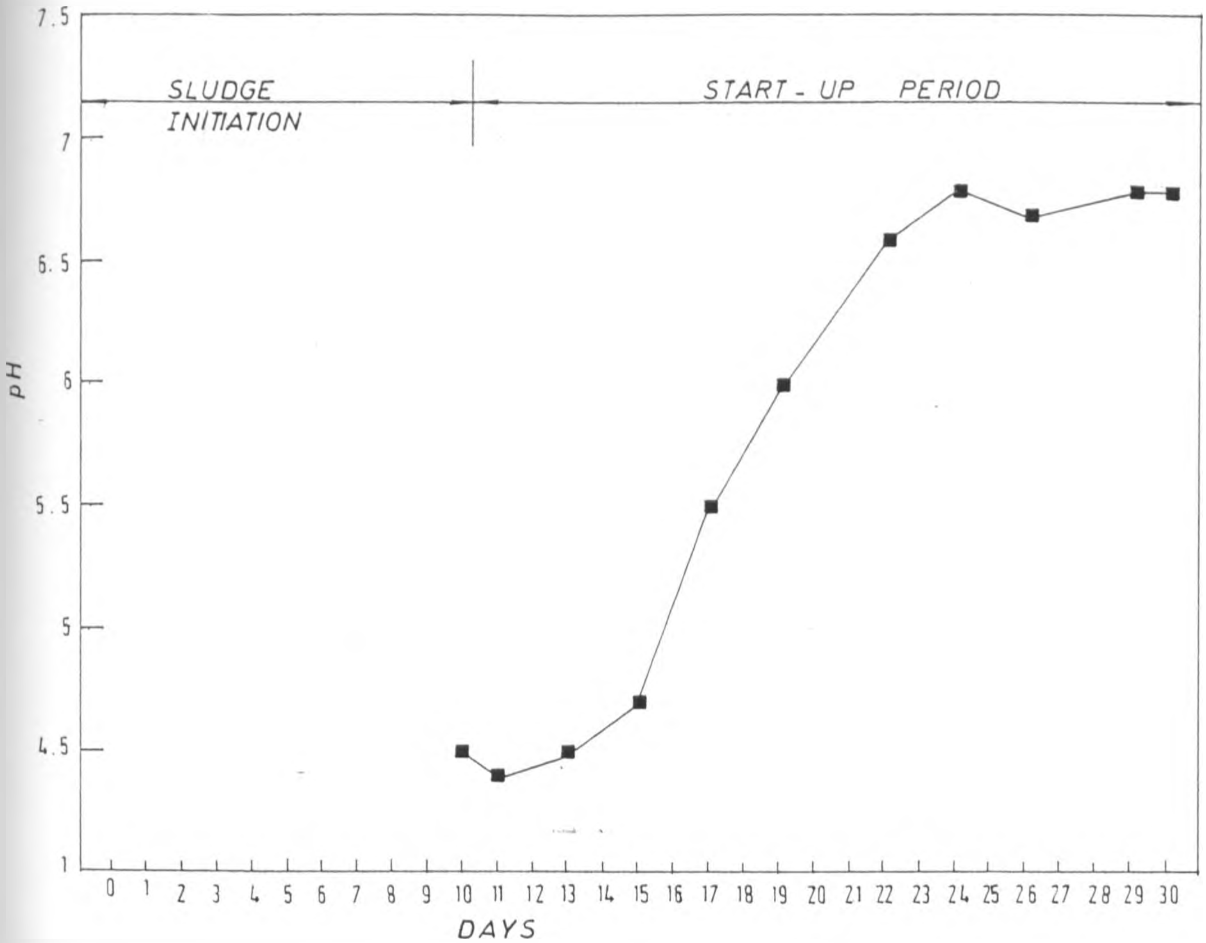


FIGURE 4.3: pH VARIATIONS DURING START - UP PROCESS

4.6.3 The Reactor Operation Stage

During the reactor operation stage, three distinct changes were observed to occur in cases I and II reactors.

CHANGE 1. Change of colour from light brown to black accompanied by formation of small black flocs within the liquid component of the reactor. The latter occurred 10-14 days after the start of operation.

CHANGE 2. Gradual formation of a black scum layer on day 20-24 after start of operation.

CHANGE 3. Appearance of bubbles of gas on the scum layer. This occurred on day 24 onwards from the inception of operation.

The results of sample analysis are indicated in Tables 4.3 - 4.7 and illustrated in Figures 4.4 to 4.8.

Table 4.3: pH Variations during Reactor Operation

DAY	pH RUN 1			pH RUN 2		
	CASE			CASE		
	I	II	III	I	II	III
0	5.8	5.8	4.9	5.5	5.5	4.5
1	6.8	5.7	4.8	7.2	5.5	4.6
2	6.3	5.7	4.8	6.5	5.4	4.4
3	6.0	5.8	4.7	6.2	5.5	4.5
4	5.7	5.8	4.7	6.4	5.6	4.5
5	5.8	5.9	4.6	6.5	5.6	4.5
8	6.0	5.9	4.6	6.5	5.6	4.6
9	6.0	6.0	4.7	6.6	5.8	4.5
10	6.1	6.2	4.7	6.7	5.9	4.4
11	6.1	6.3	4.6	6.6	6.2	4.5
12	6.2	6.5	4.7	6.6	6.4	4.6
15	6.6	6.5	4.8	6.8	6.6	4.6
16	6.7	6.7	4.6	6.8	6.6	4.6
17	6.9	6.8	4.6	6.9	6.6	4.5
18	7.0	6.9	4.7	7.0	6.8	4.4
19	6.9	7.1	4.7	6.9	6.7	4.5
22	7.1	7.3	4.5	7.0	6.6	4.4
23	7.1	7.2	4.7	7.1	6.8	4.5
24	7.0	7.2	4.7	7.1	6.9	4.6
25	7.1	7.3	4.8	7.2	6.8	4.6
26	7.2	7.3	4.8	7.0	6.9	4.5
29	7.1	7.2	4.7	7.1	6.9	4.5
30	7.1	7.2	4.8	7.1	6.8	4.4

Table 4.4: COD Variations during Reactor Operation

DAY	COD (mg/l) RUN 1			COD (mg/l) RUN 2		
	CASE			CASE		
	I	II	III	I	II	III
0	15120	15160	16000	12020	12100	14800
1	9020	11980	14400	7120	8640	12200
2	8840	11900	14320	6880	8500	12060
3	8740	11880	13700	6800	8380	12100
4	8720	11740	13880	6660	8260	11980
5	8280	11500	13720	6380	8040	11920
8	7980	11380	13600	5820	7740	11780
10	7520	11320	13660	4580	7000	11840
15	4280	9340	13640	3820	6580	11820
19	3720	6200	13580	2820	4200	11840
25	2740	4020	13580	1460	2120	11800
30	2240	3000	13620	980	1640	11780

Table 4.5: BOD_5 20°C Variations during Reactor Operation

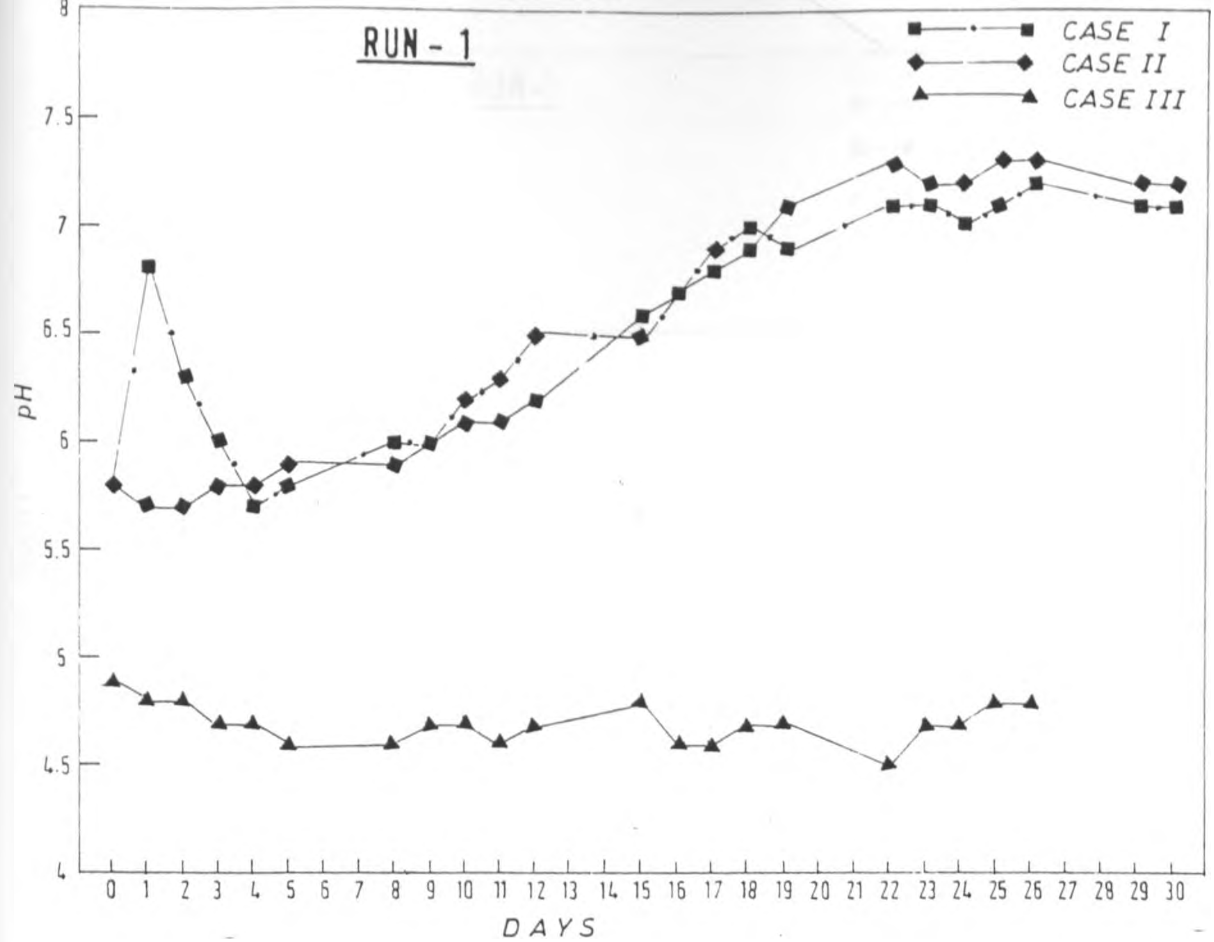
DAY	BOD_5 (mg/l) RUN 1			BOD_5 (mg/l) RUN 2		
	CASE			CASE		
	I	II	III	I	II	III
0	525	530	528	396	404	444
1	324	432	476	248	292	415
2	352	464	490	262	306	420
3	426	536	548	326	370	472
4	522	635	570	406	454	476
5	615	782	575	474	560	512
8	720	956	544	505	666	507
10	825	1186	532	501	770	498
15	495	1051	567	440	656	504
19	444	738	598	339	496	520
25	338	492	570	181	260	531
30	279	378	596	120	216	519

Table 4.6: Suspended Solids (SS) Variations during Reactor Operation

DAY	RUN 1			RUN 2		
	CASE			CASE		
	I	II	III	I	II	III
0	2320	2390	2640	2640	2624	2800
1	475	591	794	561	684	819
2	451	563	753	539	587	792
3	439	561	711	531	549	757
4	432	542	708	535	540	741
5	406	529	693	506	532	696
8	368	526	681	458	514	678
10	319	518	619	397	485	655
15	243	459	572	341	419	597
19	223	361	526	263	343	571
25	211	255	508	183	211	543
30	205	223	502	175	198	524

Table 4.7: Total Solids (TS) Variations during Reactor Operation

DAY	TS (mg/l) RUN 1			TS (mg/l) RUN 2		
	CASE			CASE		
	I	II	III	I	II	III
0	5140	5100	5500	5480	5520	6390
1	3020	3540	4650	3400	4210	5650
2	2850	3360	4600	3190	3920	5530
3	2800	3380	4510	3160	3860	5480
4	2680	3350	4390	3250	3720	5350
5	2700	3300	4300	3260	3760	5300
8	2780	3350	4350	3190	3800	5230
10	2790	3410	4210	3100	3850	5150
15	2410	3240	4250	2350	2930	4810
19	1980	2370	4100	1720	2280	4650
25	930	1290	4030	1130	1390	4520
30	950	1140	4050	1100	1320	4490



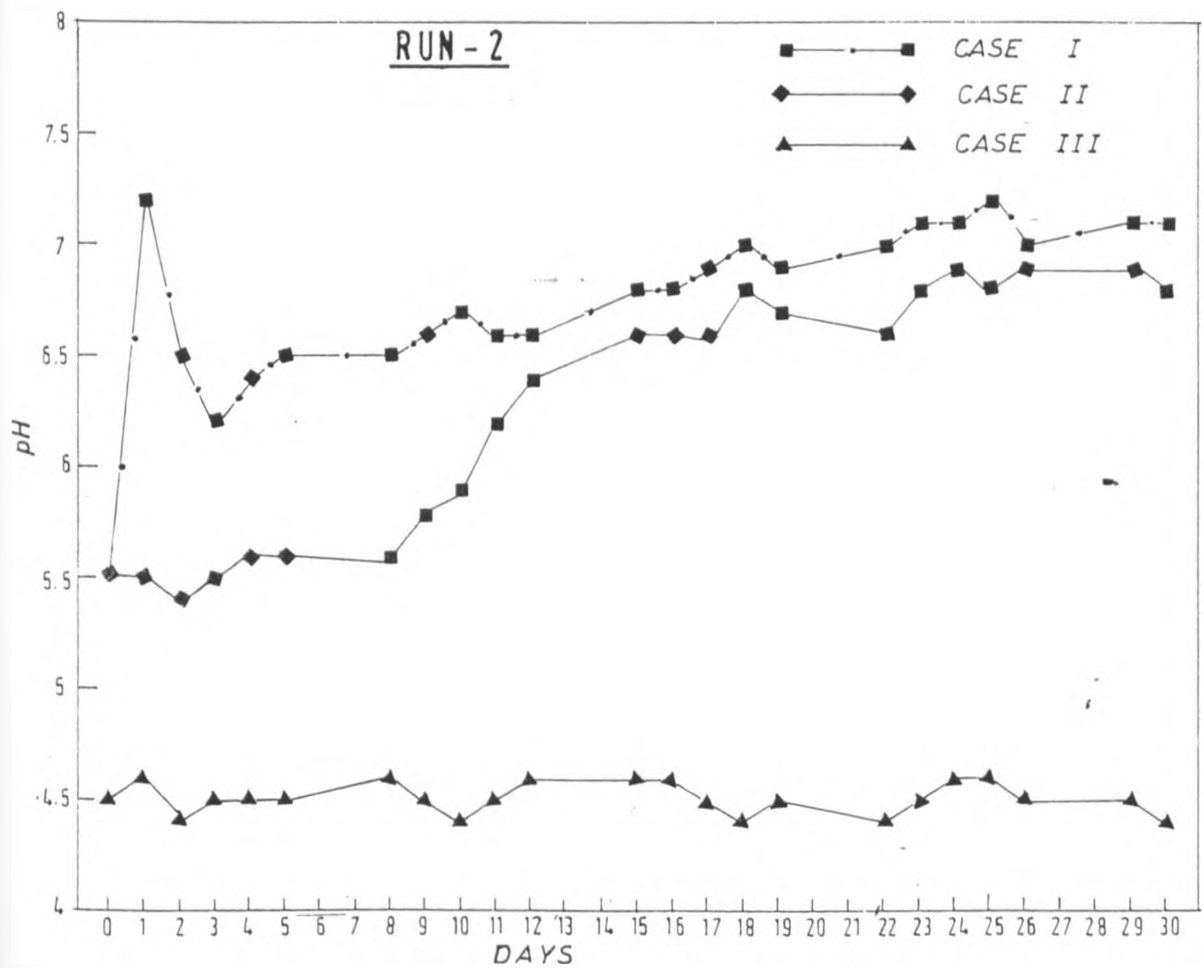


FIGURE 4.4 : pH VARIATIONS

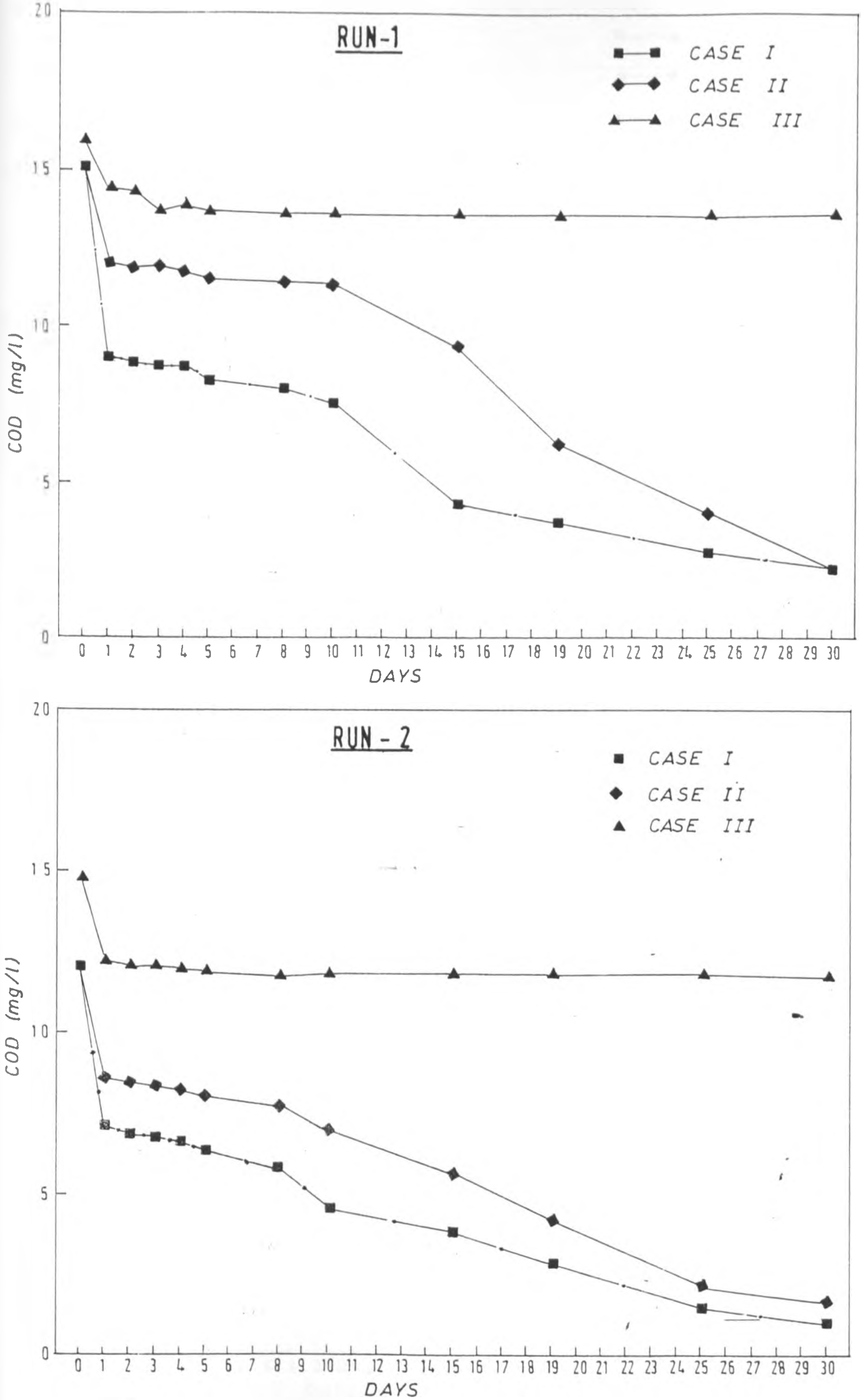
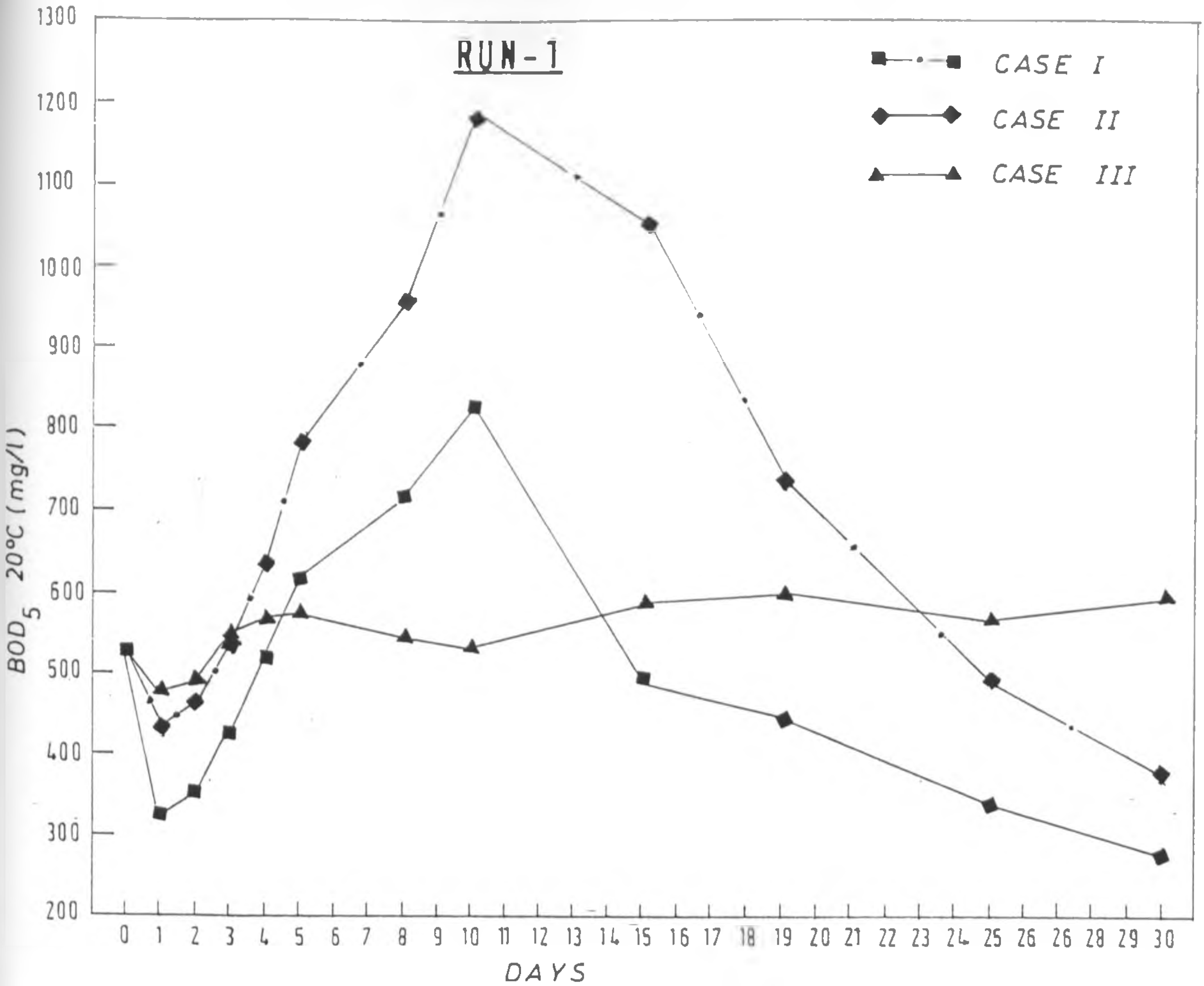


FIGURE 4.5 : COD VARIATIONS



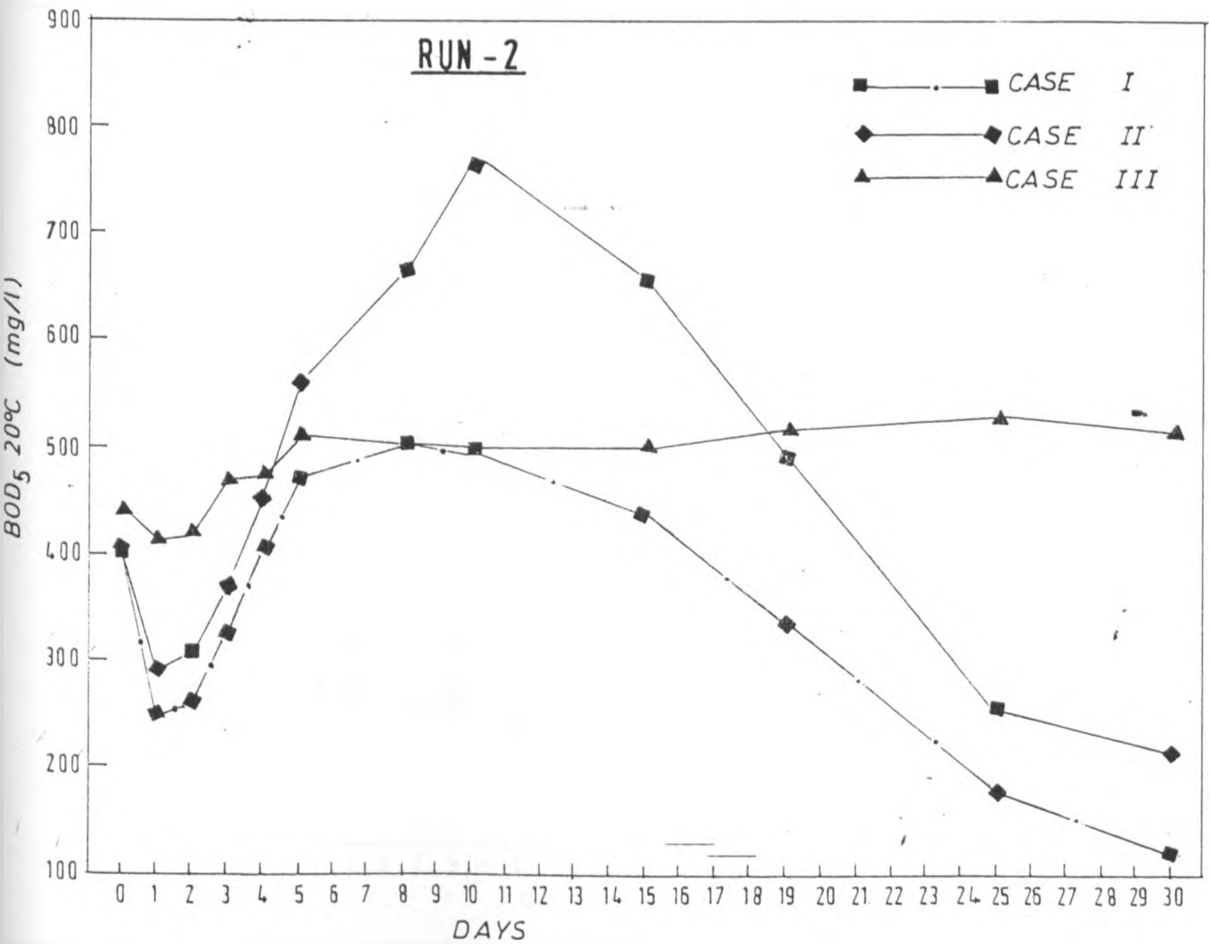
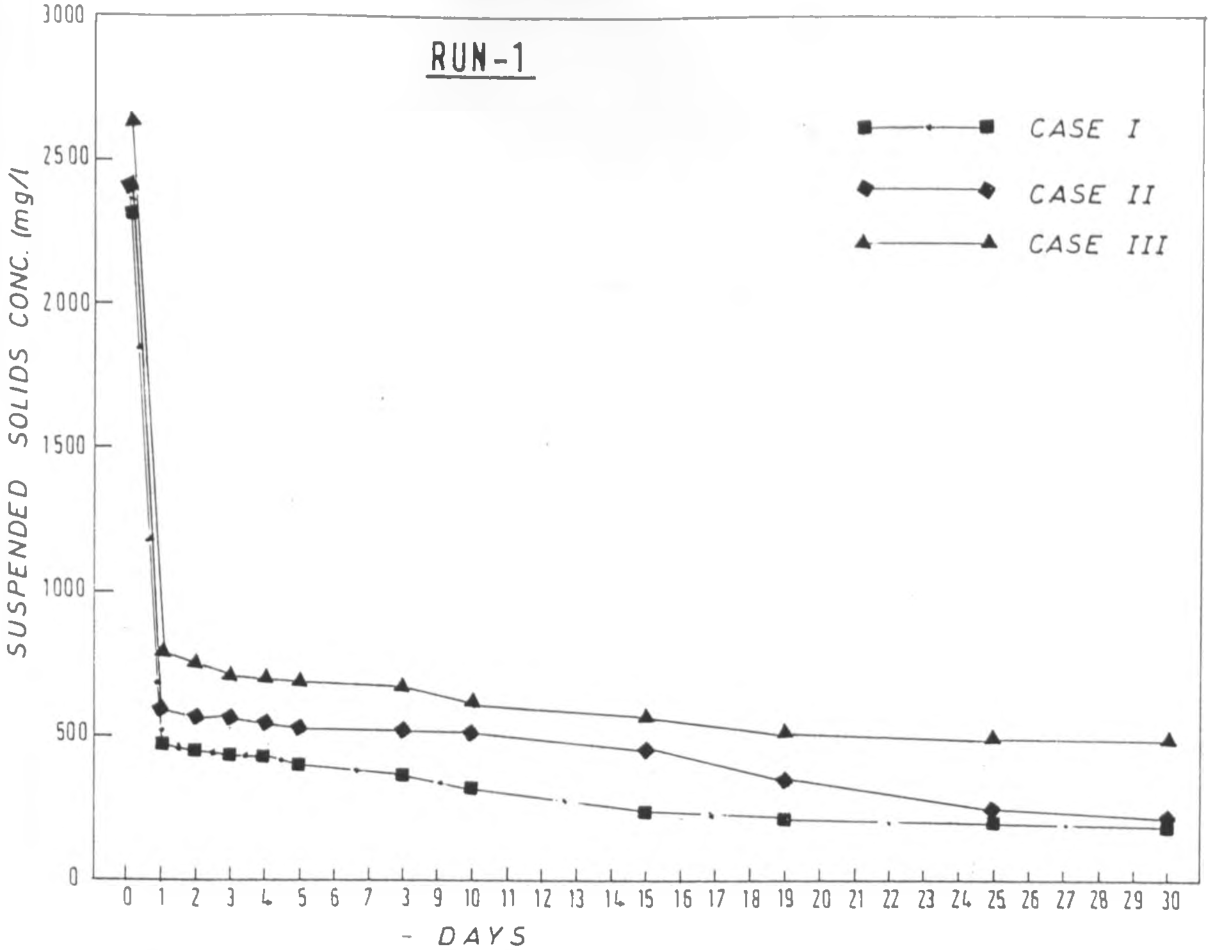


FIGURE 4.6 : BOD_5 20°C VARIATIONS



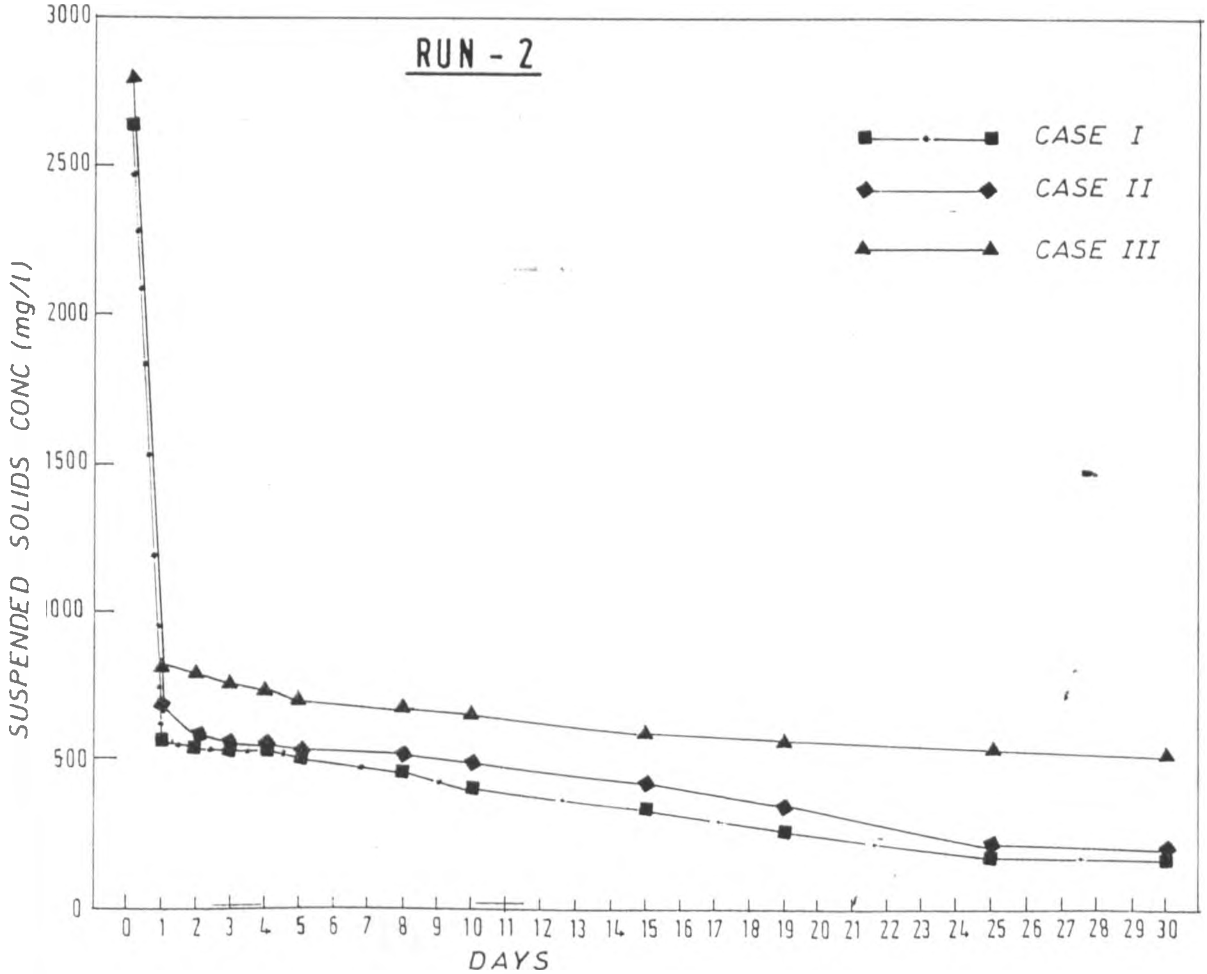


FIGURE 4.7: SUSPENDED SOLIDS VARIATIONS

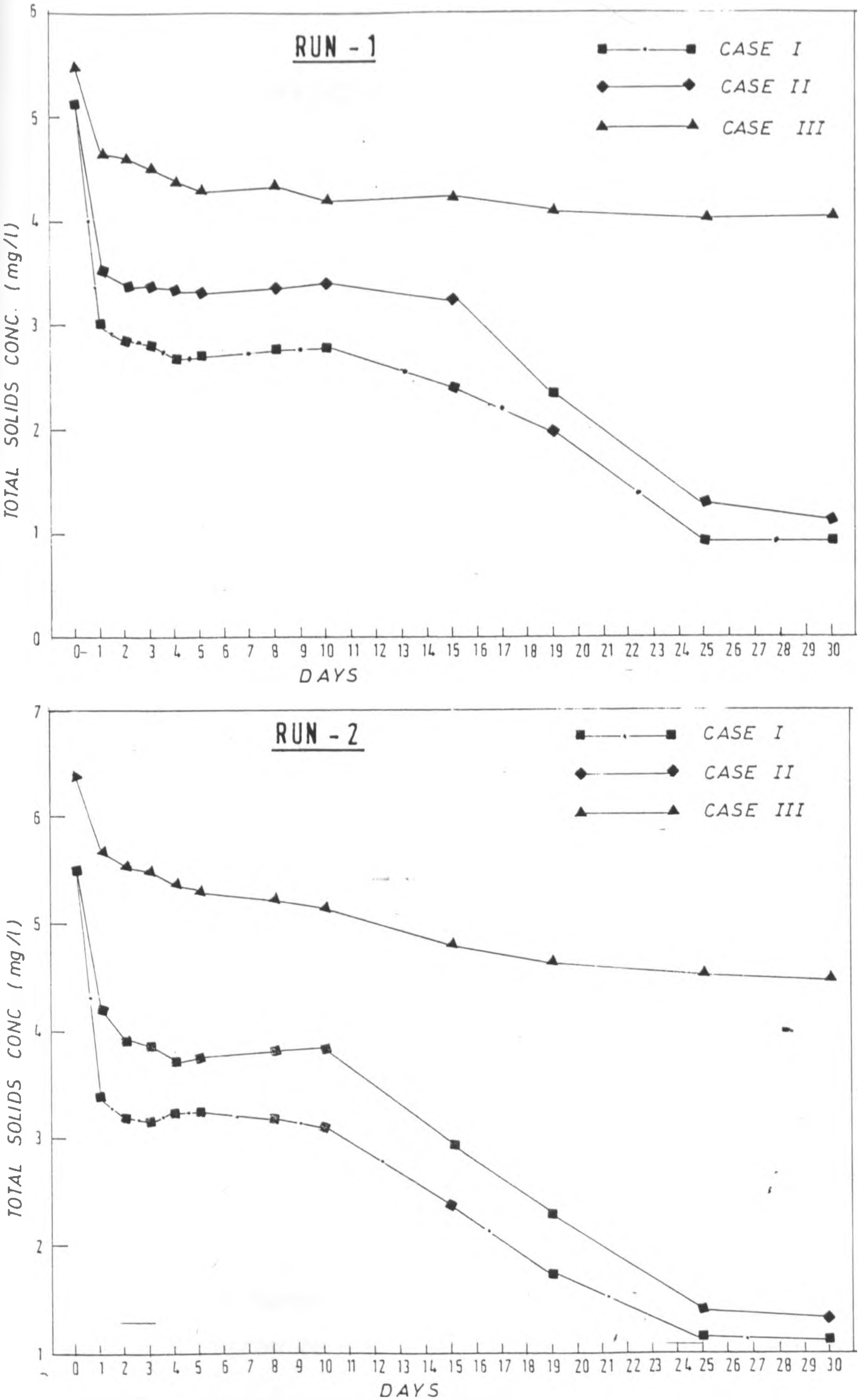


FIGURE 4.8 : TOTAL SOLIDS VARIATIONS

4.7 ANALYSIS AND DISCUSSION OF RESULTS

In this Section the results obtained during the experimental running stage and all the observations made are analyzed and discussed. The following is an itemization of the highlights of the observation of the results obtained during the reactor operation stage:-

1. Initially, there was a drop in all the parameters measured; COD, BOD_5, SS, TS and pH.
2. The initial drops were highest in Case I (with both pH correction and seeding) followed by Case II (with only seeding) and least in Case III (no pH correction nor seeding).
3. In all cases the BOD_5, after the initial fall, rose to a maximum value, but began to fall after about 10 days of reactor operation.
4. The characteristics of samples from case III, the control experiment, remained relatively constant after the initial fall without any appreciable change.
5. Three distinct stages in development were observed during the reactor operation with respect to appearance. Stage I was the change of colouration of the reactor contents from the characteristic brown to black with appearance of particulate flocs; stage 2 saw the beginning of formation of a scum layer; and the last stage was the formation of gas bubbles on the scum layer.
6. None of the above changes were observed in Case III. Their occurrence was noticed earlier in Case I than in Case II.

As mentioned in Section 2.4.5, pH is an important indicator of the successful operation of an anaerobic reactor. The start-up process was, therefore, monitored through pH determination. The pH of Muhoroni sugar mill wastewater was within the neutral range (6.5-7.0), however by the time the start-up process commenced, it had fallen to 4.5 despite pH correction. During the process it started rising at day 5 and by the end of two weeks it stabilized around pH 6.8.

The initial drop in pH is attributed to the degradation of cellulose and other higher compounds within the effluent. Anaerobic hydrolysis of cellulose leads to formation of acids and thus pH drop. The gradual rise and eventual stabilization in pH were due to development of anaerobic methanogenic bacteria; **Wheatley et al. (1984)** observed similar pH variations in their experiment of anaerobic degradation of carbohydrate waste. They observed that under stable operating condition, which develop later, a balance is established between methanogenic and acidogenic bacteria, and the combined population are able to operate without external pH control.

The results of the wastewater characteristics of the various streams (Table 4.1) compared well with the findings of **Abura (1992)** who conducted a study on management of Muhoroni Sugar Factory effluent. Her results are shown in Table 1.1.

4.7.1 pH Results

The pH variations in Cases I and II fitted within the same pattern as for the start-up process. For Case I, the pH was adjusted, through addition of lime, to be within the range 6.8-7.2 described by **Gray (1989)** as the optimum pH range for anaerobic bacteria. Thereafter the reactor content were also seeded with sludge from the start-up process. However, after only 4 days the pH fell to about 6.0 (5.7 for Run 1 and 6.2 for Run 2) before beginning to rise.

The fall in pH was due to the fact that by this time, methanogenic bacteria were probably not fully established and acid formation exceeded acetate consumption by methanogens. It was noted that despite correction, the pH eventually fell to values which compared with those of Case II. Thereafter the pH values of both cases rose gradually and stabilized in the neutral range (6.8-7.2).

Therefore it may be deduced that the initial pH correction did not offer significant advantages over non-pH correction in cases where seeding was done. This agrees with the findings of **Wheatley et al. (1984)** who found that under stable operating conditions in anaerobic reactors, the bacterial population are able to operate without external pH control.

In case III where no seeding nor pH correction was done, the pH remained relatively constant, though with cyclic small rises and falls. This variation in pH could be explained as follows. The pH fall was attributed to acid formation activities of acidogenetic and acetogenetic bacteria. However, subsequent fall in pH led to unsuitable environmental conditions even for these acid formers and their activity was curtailed. Due to settlement of the acid portion in the liquid section of the reactor, the pH rose and bacterial action was revived. This led to a further drop in pH and hence a cyclic change in pH for Case III. It may also be deduced that methanogenic bacteria did not develop in this case since no pH balance was observed and the physical characteristics of the reactor contents remained constant.

4.7.2 COD Variations

As outlined in the earlier sections of this chapter, all the measured parameters, COD included, reduced sharply initially. This initial reduction in COD was attributed to settlement of the solid components of the wastewater. For Run No. 1 the falls were 40%, 20% and 12.5% for Cases I, II and III respectively. In Run No. 2 the corresponding initial falls were 41%, 34% and 17.6% respectively.

It may be noted that the fall was greatest in Case I, followed by Case II and least in Case III. This may be explained as follows: The coagulation action due to the addition of lime added for pH correction in Case I led to increased settlements of solids. Secondly the sludge used for seeding assisted, through entrapment, in reduction of solids concentration in the liquid phase of the reactors. In case III since neither pH correction nor seeding was done, solids settlement was least.

Similar results were obtained by **Rusten et al. (1990)** who conducted studies on viability of coagulation as a pretreatment method on dairy and slaughter-house wastewater. A pilot plant was modelled to treat slaughter-house wastewater. Using a combination of ferric chloride and lime as coagulant with doses of 70 g/m^3 and 150 g/m^3 respectively the COD and SS removal rates were 82% and 81% respectively.

Since this initial COD was attributed to settlement of solids and not anaerobic action, the initial COD was taken as the COD at Day 1 and the percentage COD removal computed. The removal rates subsequently calculated on this basis are indicated in Table 4.8.

The COD removal rates for Case I and II compared favourably in both runs but the actual COD was lower in Case I than in Case II. It may therefore be deduced that when seeding has been done, pH correction may not have pronounced advantages over non-correction of pH with respect to COD removal rates.

Table 4.8: Percentage COD Removal Rate Variations

DAY	CASE I			CASE II			CASE III		
	1A	1B	Av.	2A	2B	Av.	3A	3B	Av.
1	0	0	0	0	0	0	0	0	0
2	2	3	2.5	1	1	1	-	-	-
3	3	4	3.5	1	2	1.5	-	-	-
4	3	6	4.5	2	4	6	-	-	-
5	9	10	9.5	4	7	5.5	-	-	-
8	11	18	14.5	5	10	7.5	-	-	-
10	17	35	26	6	19	12.5	-	-	-
15	52	46	49	23	34	28.5	-	-	-
19	59	60	59.5	48	51	49.5	-	-	-
25	70	80	75	67	77	72	-	-	-
30	76	87	81.5	75	81	78	3	3	3

A significant feature of the results is that appreciable reduction in COD occurred only after day 10. This corresponded to the stage when the pH steadily rose and thereafter stabilized. As suggested earlier, this represented the period when the various microbial organisms had established and effective anaerobic degradation started taking place. A retention time of less than 10 days may, therefore, not results in significant COD removal for anaerobic reactors.

For Case III, the COD reduction was negligible and the observed fall in this parameter could be attributed to settlement of solids from the liquid phase. At the end of 30 days of Run 1 the percentage removal was only 3% as compared with 76% and 87% for Cases I and II respectively. The corresponding values for Run 2 were 3%, 75% and 81% respectively. The non-performance of Case III could have resulted from the adverse pH values which could not allow microorganisms to grow.

The COD removal rates achieved in the present study compared favourably with those by **Abura (1992)** who obtained a 83% removal rate after a retention period of 5 days.

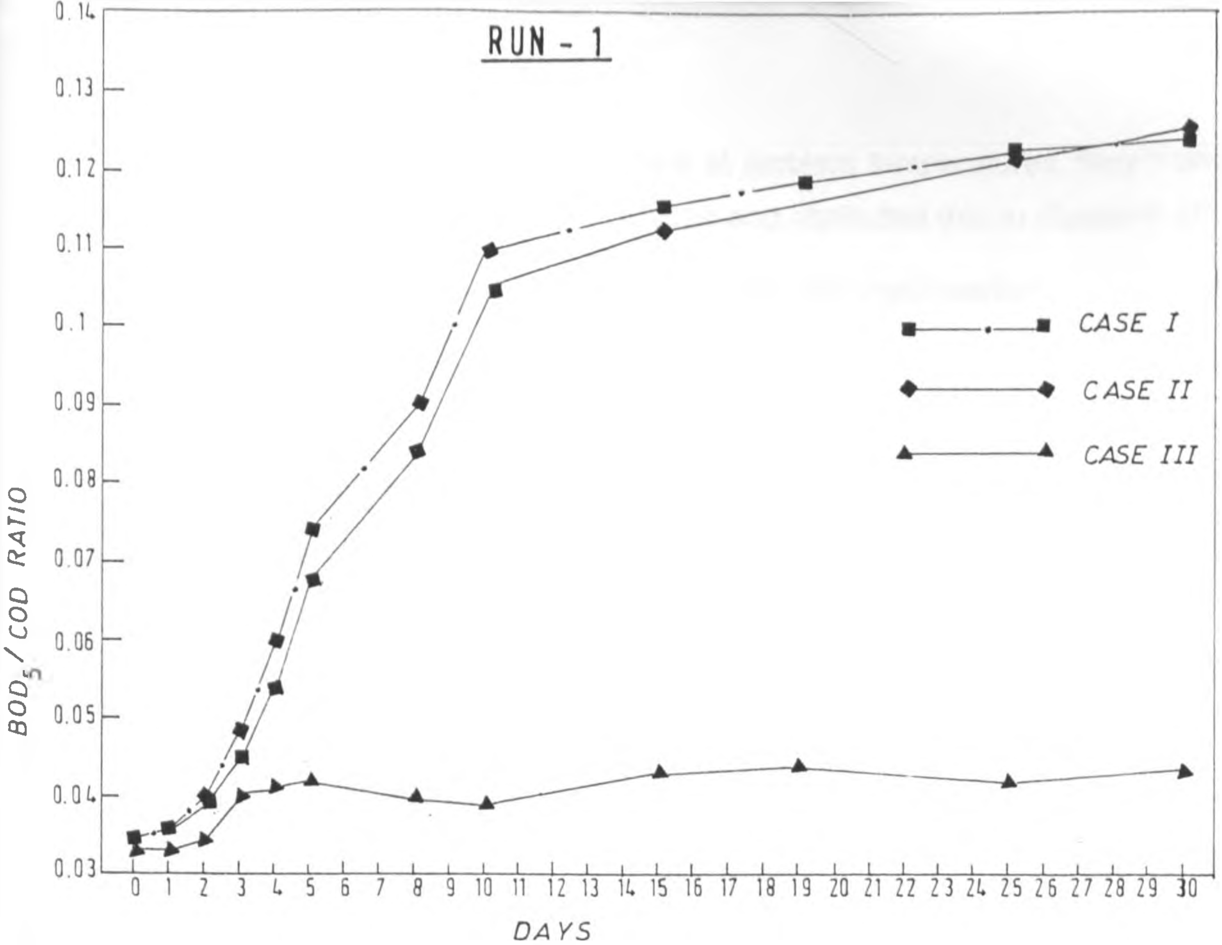
4.7.3 BOD$_5$ Variations

As indicated in Figure 4.6, the BOD$_5$ fell initially for all cases. Thereafter, for days 1-10 the BOD$_5$ value rose significantly for case I and II and to a lesser extent for Case III. In the first two cases the BOD$_5$ started falling after day 10 whereas for Case III, the BOD remained relatively constant.

As was the case with COD, the initial drop in BOD$_5$ was attributed to settlement of solids, from the liquid fraction of the effluent. Thereafter hydrolysis of cellulose, which is not easily biodegradable, caused the rise in BOD$_5$ as time lapsed. Generally, the hydrolysis of cellulose leads to improved biodegradability of the effluent as measured by the BOD$_5$/COD ratio. For each day the BOD$_5$/COD ratio was computed and the results are shown in Table 4.9 and illustrated in Figure 4.9. As mentioned earlier, the BOD$_5$ of the wastewater increased with time from day 1-10. This phenomenon of rise in measured organic strength of an effluent during treatment is previously recorded by **Wheatley et al. (1984)** who carried out experiments on treatment of final effluent from 3 sewage works over a period of 3 months.

Table 4.9: BOD5/COD Ratio (per 1000) Variations

DAY	CASE I			CASE II			CASE III		
	1A	1B	Av.	2A	2B	Av.	3A	3B	Av.
1	36	35	35.5	36	34	35	33	34	33.5
2	40	38	39	39	36	37.5	34	35	34.5
3	49	54	51.5	45	44	44.5	40	39	39.5
4	60	61	60.5	54	55	54.5	41	40	40.5
5	74	74	74	68	70	69	42	43	42.5
8	90	87	88.5	84	86	85	40	43	41.5
10	110	110	110	105	110	1.8	39	42	40.5
15	116	115	116	113	115	114	43	43	43
19	119	120	120	119	118	119	44	44	44
25	123	125	124	122	123	123	42	45	43.5
30	125	129	127	126	131	129	44	44	44



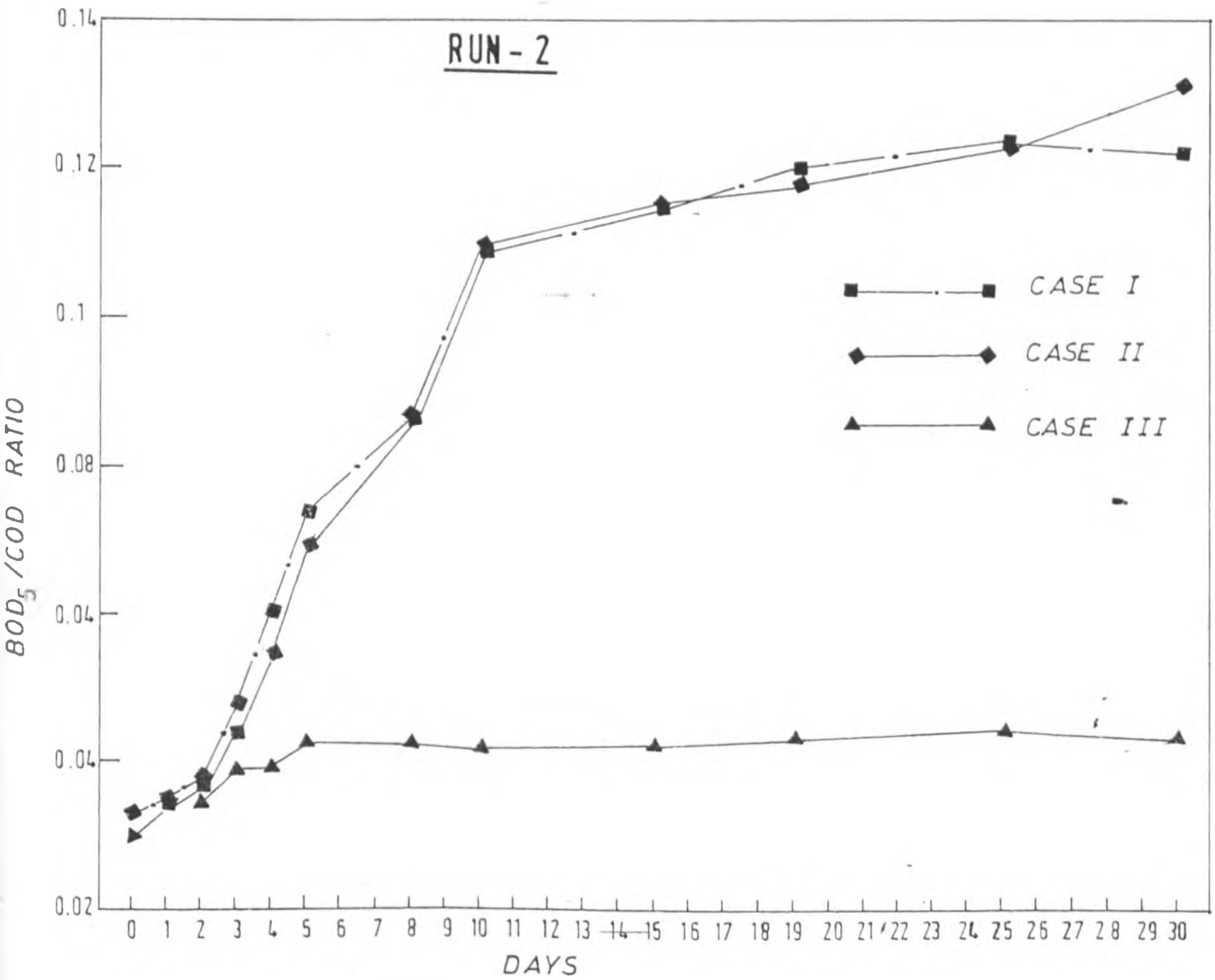


FIGURE 4.9 : BOD_5 / COD RATIO VARIATIONS

Treating this effluent by anaerobic filters at ambient temperatures, they found that both SS and COD reduced but BOD_5 rose and attributed this to digestion of solids in the waste leading to increased organic load in the liquid portion.

In the present study, the rate of increase of the BOD_5/COD ratio was not significantly different for Cases I and II. For Case I, on average, it rose from 0.034 on day 0 to 0.110 on day 10 and by day 30 it was 0.127. For Case III the ratio increased from 0.030 to approximately 0.043 where it stabilized after 5 days. This was attributed to suppression of biological action within the reactors, the initial rise being assigned to initial microbial action, and settlement of non-degradable cellulotic component of the wastewater.

Similar results have been obtained by **Hartman et al. (1984)**. In a study of anaerobic treatment of Olive processing wastes, **Hartman et al. (1984)** optimized the retention time to 12 days and found that the BOD/COD ratio rose from 1:4 to 1:2.8. Olive processing wastes are not dissimilar to sugar mill wastes being of low pH and high carbon content.

In the current study, it may be observed that the maximum BOD_5 occurred around day 10 after which it reduced. This marks the effective end of cellulotic degradation since further hydrolysis of the cellulose would lead to higher BOD_5 values. It may also mark the effective day of balance of actions of methanogenic and acidogenic bacteria. Therefore to enable total decomposition of the cellulose, the minimum retention period should be 10 days. This compares well with the 12-day retention period determined by **Hartman et al. (1984).**

4.7.4 Total and Suspended Solids Variation

As with COD and BOD_5, there was an initial marked fall in the Total Solids (TS) and suspended solids (SS) contents for all the three cases. This was attributed to settlement of solids in the reactors. However, the fall was highest in Case I, second highest in Case II and least in Case III.

This may be explained as follows. In Case I, the settlement action was assisted by two external forces. The lime added for pH correction acted as a coagulant while the solids in the seeding sludge assist in settlement through entanglement of settleable solids. In Case II the settlement was aided by the seeding sludge only while Case III there was no assistance at all. Since the initial drop in TS and SS concentrations was due to direct settlement and not anaerobic treatment, the solids concentration at day 1 were taken as the initial concentrations. With these initial values, the percentage solids reduction rates were computed and are indicated in Tables 4.10 and 4.11.

Table 4.10: Percentage Total Solids Removal Variation

DAY	CASE I			CASE II			CASE III		
	1A	1B	Av.	2A	2B	Av.	3A	3B	Av.
10	8	9	8.5	4	9	6.5	9	9	9
15	20	31	25.5	8	30	19	9	15	12
19	34	49	41.5	33	46	39.5	12	18	15
25	69	67	68	64	67	65.5	13	20	16.5
30	69	68	68.5	68	69	68.5	13	21	17

Table 4.11: Percentage Suspended Solids Removal Variation

DAY	CASE I			CASE II			CASE III		
	1A	1B	Av.	2A	2B	Av.	3A	3B	Av.
10	33	29	31	12	24	18	22	20	21
15	49	39	44	22	39	30.5	28	27	27.5
19	53	53	53	39	50	44.5	33	30	31.5
25	56	67	61.5	57	70	63.5	36	34	35
30	57	68	62.5	62	71	66.5	37	36	36.5

4.7.5 Summary

In summary, there was an initial fall in all the measured characteristics which was attributed to settling of solids from the liquid phase into the sludge layer. Marked reductions in COD, BOD and solids concentration occurred only after the environmental pH had stabilized and this began after day 10.

Case I, with both pH correction and seeding, had the highest removal rates. However after running for 20 days, the removal rates were similar for Cases I and II. Even the development of scum layer occurred first for Case I then for Case II but did not occur at all for Case III.

4.8 DISCUSSION OF EXPERIMENTAL ERRORS

In this study, several sources of errors were identified, the main one being partial decomposition of wastewater during transportation. Other sources of errors included:-

i) Sampling errors during collection of the wastewater in the factory.

ii) Human errors when conducting tests to determine the characteristics of the samples.

Partial Decomposition

Metcalf & Eddy (1979) observed that all wastewater tests and analysis should be conducted as soon as the sample is collected. Where this is not possible, the sample should be preserved using prescribed means but the total duration of this preservation time should not exceed the values indicated in Table 4.12. They also noted that there is no universal preservation treatment.

Table 4.12: Preservation of Wastewater Samples

Parameter	Preservative	Maximum
BOD	Refrigeration at 4°C	6h
COD	2 ml/L H_2SO_4	7d
pH	none available	-
Solids	none available	-

Source: Metcalf & Eddy (1979).

Due to the distance from the factory to the laboratory, the possibilities of sample deterioration were real in this study. The time taken to move the sample from the factory to the laboratory was about 15 hours (5.00pm - 8.00am).

However some remedial actions were improvised. Firstly, through storing the sample in a refrigerator within the factory during sampling stage and secondly, storing the sample in an ice-box during transportation.

Some degree of preservation is indicated by the fact that the values of waste characteristics determined in this study compare reasonably with those determined by the Muhoroni Sugar Factory within their laboratory.

Sampling Errors

Another source of errors could be that attributed to sampling. Generally, wastewater samples should be collected over a long period so as to get a representative sample. In this study the waste was sampled over a of normal operating day duration (8am-5pm). However the volumetric variation of waste discharge over the daily operations was not taken into consideration when determining the volume of wastewater to be collected at various times. Therefore in cases where, for instance, a particularly weak waste was discharged in large volumes at a certain time and later a strong waste discharged in small volumes, the effect of the strong waste would be amplified since the sample volume collected was not proportional to rate of flow. This may have led to unbalanced representation of the various streams in the collected waste.

Also related to the sampling error, is seasonal variation of waste characteristics. The experimentation was conducted over a period of 2 months (May - June 1992). **Biaggi (1968)** notes that effluent characteristics in the sugar industry vary with season, and method of production and level of mechanization among others. Therefore studies conducted over a longer period of time give more representative results than those conducted over shorter durations.

CHAPTER 5 CONCLUSIONS

5.1 SUMMARY

Some conclusions can be made based on the objective of the this study and the results obtained during the reactor operation stage. The highlights of these conclusions, which are further presented in subsequent sections of this chapter, are:

1. Anaerobic process indicated potential for first stage treatment of sugar mill wastewater.
2. Retention periods of less than 10 days may not be sufficient for effective anaerobic treatment of sugar mill wastewater.
3. Seeding of reactor contents with acclimatized sludge at the start of the reactor operation enhances the performance of the anaerobic batch reactors.
4. When seeding is done, pH correction offers no significant advantages to development of anaerobic conditions.

5.2 POTENTIAL OF ANAEROBIC TREATMENT

Analysis and discussion of the results obtained in this study was presented in Section 4.7. The average percentage COD removal rates for cases I and II was about 80% at the end of the 30 day reactor operation period. The corresponding values for Total solids and suspended solids removal were 68% and 64% respectively. Although the BOD_5 removal rate was low at 26% the biodegradability of the wastewater as measured by the BOD_5/COD ratio increased from an average 1:28.6 (35 per 1000) to 1:7.8 (128 per 1000). These removal rates are satisfactory when compared with results from similar studies.

It may, therefore, be concluded that the anaerobic treatment offers potential as a first stage treatment of sugar mill wastewater.

5.3 RETENTION TIME

As presented in section 4.7.3, it was observed that 10 days after the start of reactor operation, a maximum BOD_5 value was observed for cases I and II. It was further argued that this marks the effective end of cellulotic degradation or the point where the activities of acetogenic and methanogenic bacteria are balanced.

For comprehensive treatment of sugar mill wastewater, which characteristically has high solids content, the cellulotic fibres have to be degraded. During the reactor operations, upto Day 10 days, the BOD_5 was still rising and this was explained as being due to the cellulotic decomposition still proceeding.

It is therefore concluded that the minimum retention period for anaerobic treatment which can facilitate the appreciable degradation of the organic matter is approximately 10 days. This compares favourably with the 12 days retention period determined by **Hartman et al. (1984)** in a study of treatment of olive processing waste. Olive processing wastes are not dissimilar to sugar mill wastewater being of low pH and high carbon content.

5.4 REACTOR SEEDING

The percentage removal rates for the measured parameters, BOD, COD, TS and SS, were substantial in cases I and II where the reactor contents had been seeded with sludge previously acclimatized to sugar mill wastewater. In case III where this was not done such removal rate were minimal. These results are summarised in Table 5.1.

Table 5.1: Removal Rates (%) at Day-30 with and without Seeding

Parameter	Percentage Removal Rates	
	With Seeding	Without Seeding
BOD_5	26%	-
COD	80%	3%
TS	68%	17%
SS	64%	36%

Note: This computation of removal rates do not take into account reduction in parameter values attributed to settlement.

In all measured parameters, in instances where seeding was done, the removal rates are noticeably higher than the case where no seeding was done. This can be attributed to the non-adaptation of the micro-organisms to the environment created by the wastewater in the case of non-seeding.

In summary it is therefore concluded that, since seeding of the reactor contents resulted in markedly higher removal rates of measured parameters, it therefore must have enhanced the performance of the anaerobic reactors.

5.5 pH CORRECTION

Comparison of the results of cases I and II of the reactor running stage presents an opportunity to draw conclusions on the effect of pH correction on the performance of anaerobic batch reactors. A summary of these results is presented in Table 5.2.

Table 5.2: Average Percentage Removal Rates with & Without pH Correction

Parameter	Day	Average % Removal Rates	
		With pH Correction	Without pH Correction
COD	10 19 30	26.0 59.5 81.5	12.5 49.5 78.0
TS	10 19 30	8.5 41.5 68.5	6.5 39.5 68.5
SS	10 19 30	31.0 53.0 62.5	18.0 44.5 66.5

From Table 5.2 it can be noticed that, initially, the removal rates for COD, TS, and SS, were higher in case I (with pH Correction) than in case II (No pH correction), as indicated by the results at day 10. However by day 19, the removal rates for the two cases were comparable and by day 30 practically the same. The BOD_5/COD ratio was comparable in the two cases for all days indicating that neither of the two had an advantage over the other with respect to this parameter.

Table 5.3: BOD_5/COD Variations for Certain Days

CASE	BOD5/COD Ratio (per 1000) DAY			
	1	10	19	30
I	35.5	110	120	127
II	35.0	108	119	129

It is therefore concluded that, allowing for the initial days when the microbial balance is yet to be established, pH correction offers no appreciable advantage when seeding is done to the reactor contents. This can be explained as follows: Due to seeding of the reactors contents a stable operating condition for the anaerobic bacterial population is easily established. This enables the anaerobic processes, described earlier in Section 2.2, to take off immediately, and in the case where no pH correction was done, to regulate the pH by itself. This agrees with the findings by **Wheatly et al. (1984)** that under stable operating conditions, the bacterial population is able to operate without external pH control.

CHAPTER 6 RECOMMENDATIONS

The results of this study, though still at the stage of laboratory bench reactor phase, indicate that there is potential for first stage anaerobic treatment of sugar-mill wastewater. Such potential is indicated, firstly, by the appreciable waste load reduction rates and, secondly, by the increased bio-degradability of the wastewater as measured by the BOD_5/COD ratio which increased substantially during the reactor operation. The second reason would suggest that there be a better chance of successful further biological treatment than before if sugar mill wastewater is first treated anaerobically.

However, in recognition of the limiting conditions which prevailed during the reactor operations in this study, the following recommendations are made.

6.1 TEMPERATURE

The present study did not investigate the effect of temperature on the operation of the batch reactors. As mentioned in Section 2.4.4, temperature is one of the environmental conditions that affect the activities of various anaerobic bacterial populations and different bacterial species are functional at different temperature ranges. Subsequently it is expected that variation in temperature may affect the performance of anaerobic reactors.

It is therefore recommended that further studies be conducted to determine the impact of temperature on the performance of anaerobic reactors treating sugar mill wastewater. Such a study may provide information on whether the relatively high temperature of sugar mill effluent can be exploited in the treatment of the wastewater.

6.2 CONTINUOUS FLOW REACTORS

The present study was a laboratory batch reactor experimentation. In such a study it is not possible to analyse the effects of variation of influent wastewater characteristics on the anaerobic process and its efficiency. Therefore no conclusion can be made on how the anaerobic process can perform under shock loads.

Further experimentation of anaerobic treatment of sugar mill wastewater should be conducted with establishment of laboratory continuous flow reactors to investigate, among others, the effect of variation of influent characteristics. Particular attention should be placed on retention periods in the range of 8 - 25 days. The lower value of 8 days is selected since it was noticed that the BOD of the wastewater in the batch reactor started falling only after 10 days of the reactor operation. The upper limit is chosen since it was observed that most characteristics of the batch reactor contents did not reduce much 25 days after the start of reactor operation. This would signify that, allowing for experimental margins, the retention period 8 - 25 day provides the period when wastewater characteristics undergo change and should be investigated further.

Since anaerobic treatment may not provide adequate treatment for the effluent to meet the statutory discharge standards, it is recommended the continuous flow reactor be set up as a anaerobic-aerobic process. Such an arrangement will provide subsequent aerobic treatment of the effluent from the anaerobic reactor thereby ensuring better final effluent quality.

6.3 ON-SITE PILOT PLANT

Subsequent to the continuous flow reactors, it is recommended that an on-site pilot plant for complete anaerobic-aerobic system be studied. An in-situ arrangement usually allows for the study of the existing normal day operations and how these affect the wastewater treatment. Generally the findings of such a study provide a more accurate insight as to the practicability of the studied wastewater management process since the site conditions usually prevail.

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