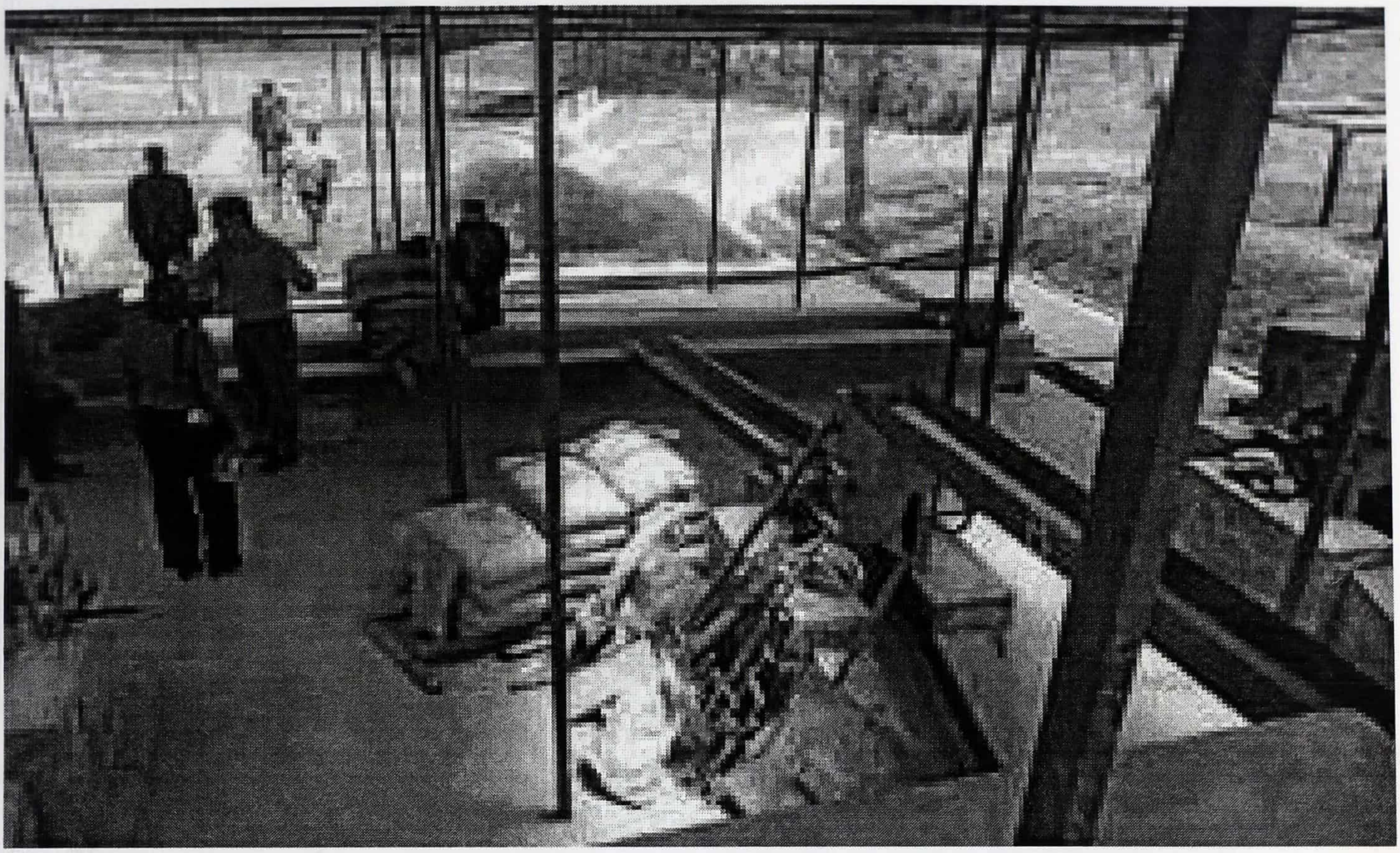
# INVESTIGATION OF AN APPROPRIATE TREATMENT SYSTEM FOR A WET COFFEE PROCESSING IN THE MARABA DISTRICT OF RWANDA




**BY**

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**MSc. THESIS**

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***Sanitation.***

**By**

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**JULY 2003**

# CERTIFICATION

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# DEDICATION.

***This report is dedicated to my Parents and Dr. Emile Rwamasirabo***



*Turyahumura Abel* *2003*

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I wish to thank all my course mates and friends particularly Miss Ruth Otoo who gave me support and encouragement throughout the course.

# ABSTRACT

Coffee processing plants have been a major source of environmental pollution.

This study focuses on the treatment of the coffee wastewater from wet coffee processing in order to avoid coffee wastewater from polluting the environment.

From the characterisation of the coffee wastewater, Biological Oxygen Demand ($BOD_5$), Chemical Oxygen Demand, (COD), Suspended Solids (SS), Phosphates ($PO_4^{3-}$), and Nitrates ($NO_3^{2-}$) had values of 2000 mg/l, 4700 mg/l, 256 mg/l, 25.2 mg/l, 4.0 mg/l respectively. These values were far above the GH-EPA (Environmental Protection Agency) acceptable limit for wastewater disposal into the environment.

Based on these findings, two treatment options were investigated and these were yeast and Ordinary Portland cement.

Ordinary Portland cement (2.5g/l) as a flocculent was chosen to be the best option for the primary treatment of coffee wastewater. This option gave a remarkable reduction in $BOD_5$, COD, $PO_4^{3-}$, SS, and $NO_3^{2-}$ with 69%, 79%, 98%, 98%, and 35% respectively. However the values of $BOD_5$, COD and Nitrates were still high above the acceptable level of GH-EPA standards for wastewater disposal into the environment. To further augment reduction in $BOD_5$, COD and Nitrates, secondary treatment system comprising of Anaerobic and Aerobic units was designed. The final quality effluent from the treatment plant had a percentage reduction of BOD, COD, $PO_4^{3-}$ ,$NO_3^{2-}$ , SS, by 98%, 96%, 98%, 97%, 98% respectively and pH of 8.25 which met the acceptable level of GH-EPA standards for wastewater disposal into the environment.

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# ACRONYMS AND ABBREVIATIONS

CWS: Coffee-Washing Station.

CRF: Coffee Resources Foundation

NRI: Natural Resources Institute.

MCPE : Management of Coffee Processing Effluent.

SS: Suspended Solids

TDS: Total dissolved solids

Sa: Sludge accumulation

Vst : Volume of the sludge tank

Alter: Alternative

GH-EPA: Environmental Protection Agency Ghana.

APHA: American Public Health Association

BOD: Biological Oxygen Demand

COD: Chemical Oxygen Demand

AN: Anaerobic Pond



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# 1.0 INTRODUCTION:

## 1.1 Background.

The Maraba coffee washing station started as a pilot plant to improve on the quality of coffee production by using wet coffee processing method.

The station at District Maraba was constructed under the Partnership for Enhancing Agriculture in Rwanda (PEAR) through linkages with organisations such as; USAID, UNR, ACDI /AVOCA and ABAHUZAMIGAMBI which is the coffee association of District Maraba in Rwanda. Prior to this project, coffee processing was done on household basis and there was the danger of both ground water and surface water pollution due to the extensive use of water. After the construction of the coffee washing station, the coffee that is produced at the station has emerged as the second in quality on the world market.

As the coffee washing station at District Maraba gained popularity it also created large volumes of wastewater. Thus the need to manage the coffee wastewater from polluting the environment.

## 1.2 Problem Statement

In general the environmental problems associated with washed coffee processing are related in particular to the following.

- Intensive use of water in the coffee processing This results in the high mucilage loading on the water streams therefore it has to be catered for.
- Extensive contamination of the receiving water bodies
- Accumulation of coffee pulp at the station.



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The coffee washing station of Maraba District in Rwanda discharges 50-190$m^3$/day of wastewater into a small stream (Kigogo) without being treated. As a result there is fast depletion of dissolved oxygen from the stream as the microorganisms break down the organic matter from the coffee effluent.

This causes environmental pollution of the stream, which can pose health risk to the people and livestock especially cattle in the downstream. Due to the high organic loading there is incomplete break down of the organic matter, which causes unpleasant odour of the stream and unable for it to sustain aquatic life.

## 1.3 Objectives:

- To characterise the wastewater from a wet coffee processing plant
- To determine an appropriate treatment technology for the coffee wastewater generated and optimises water use during wet coffee processing.
- To design coffee wastewater treatment plant

## 1.4 Scope of work:

To study the scheme of coffee processing at Maraba District.

Analysis and treatment of effluent from wet coffee processing at coffee washing station of Maraba District in Rwanda.

Design of the treatment plant.

# 2.0 LITERATURE REVIEW.

## 2.1 Methods of coffee processing

There are two main methods of coffee processing and these include;

- Dry method
- Wet method this includes both semi-wet and fully washed coffee

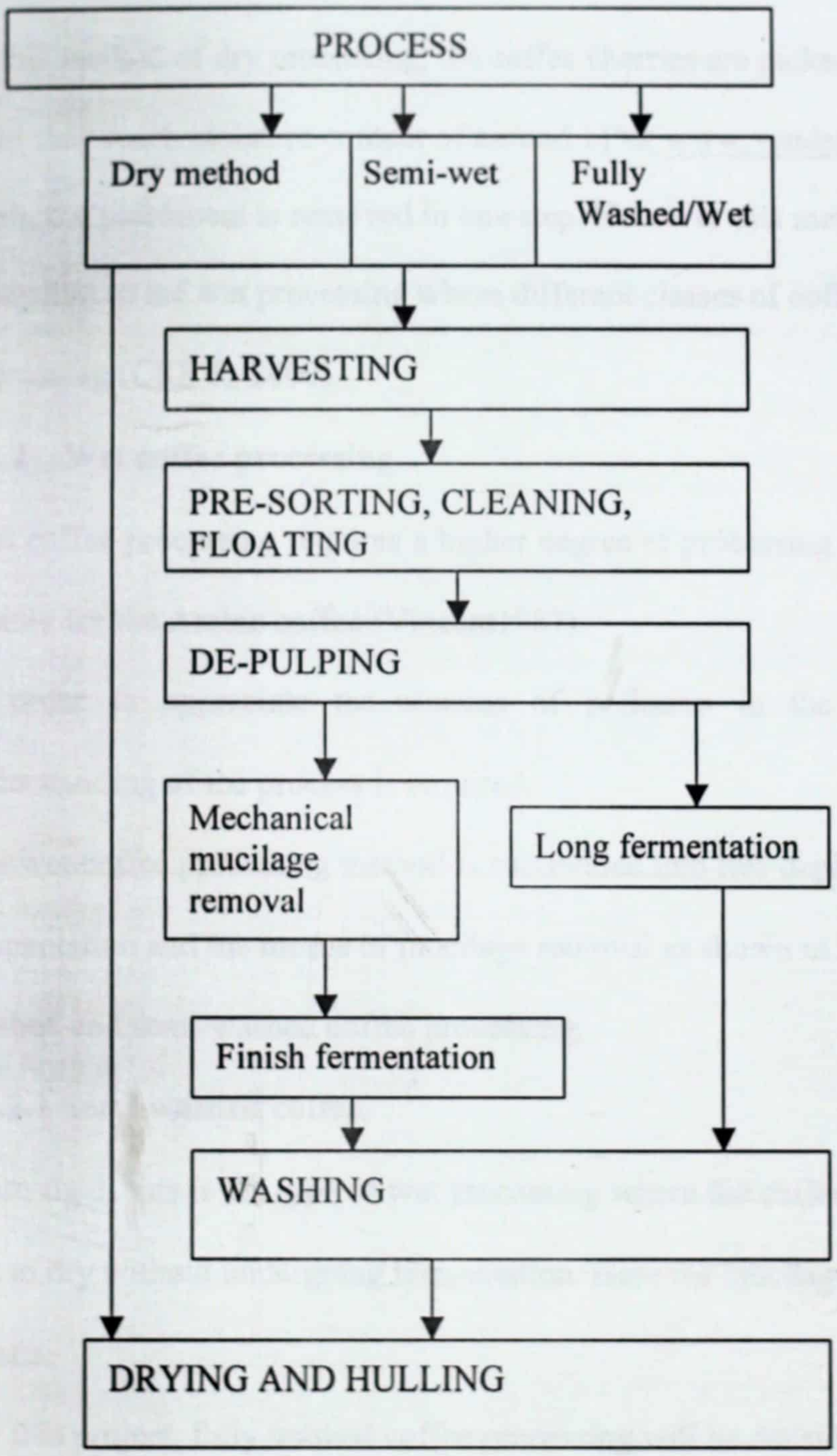



**Figure 1 General steps of coffee processing**



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### 2.1.1 Dry method of coffee processing

The most simple and least polluting way of processing coffee is the dry method as shown in fig.1, which is mostly applied for the robust coffee but also for larger amounts of Arabic coffee in Brazil and Uganda (GTZ PPP, 2002, Adams et la 1987).

In this method of dry processing, the coffee cherries are picked and left in the sun to dry until they reach moisture content of around 11%( www.venden.de). After drying the flesh, the parchment is removed in one step. However this method gives a low quality compared to the wet processing where different classes of coffee can be obtained during processing (CRF R, 2000).

### 2.1.2 Wet coffee processing.

Wet coffee processing requires a higher degree of processing know how and it is applied mainly for the Arabic coffee (Vincent1987).

In order to appreciate the sources of pollution in the wet processing, a basic understanding of the process is required.

The wet coffee processing method is subdivided into two depending on the time of fermentation and the means of mucilage removal as shown in Fig.1 This includes fully washed and semi-washed coffee processing.

#### 2.1.2.1 Semi-washed coffee.

From fig 1, this is the type of wet processing where the coffee that has been de-pulped is left to dry without undergoing fermentation. Here the mucilage is removed by mechanical means.

For this project, fully washed coffee processing will be considered.

### 2.1.2.2 Fully washed coffee.

Fully washed coffee refers to a good quality Arabic coffee obtained from wet processing where by coffee undergoes fermentation steps including a thorough cleaning after the long fermentation periods shown in fig1. (GTZ - PPP -2002).

After harvesting of coffee cherries, the fruit has to undergo several processes in order to remove the outer parts of the fruit i.e. skin, pulp, the mucilage layer and the endocarp parchment. (Ruthfos, 1979) www.venden.de. (March 2003)

During the processing, exocarp and coffee pulp are mechanically removed before the gelatinous hygroscopic mucilage layer, of which coating parchment is also removed. The mucilage removal is done during an approximate fermentation time of 36hrs depending on natural conditions like latitude and temperature (Ruthfos, 1979).

After the mucilage has been hydrolysed, all residues are washed off and the cleaned parchment is ready for further processing i.e. drying and hulling (Vincent 1987).

## 2.2 Wet coffee processing at Maraba District in Rwanda.

The wet processing done at District Maraba is similar to the traditional type of processing only that it has been upgraded.

COFFEE PROCESSING AT DISTRICT MARABA IN RWANDA

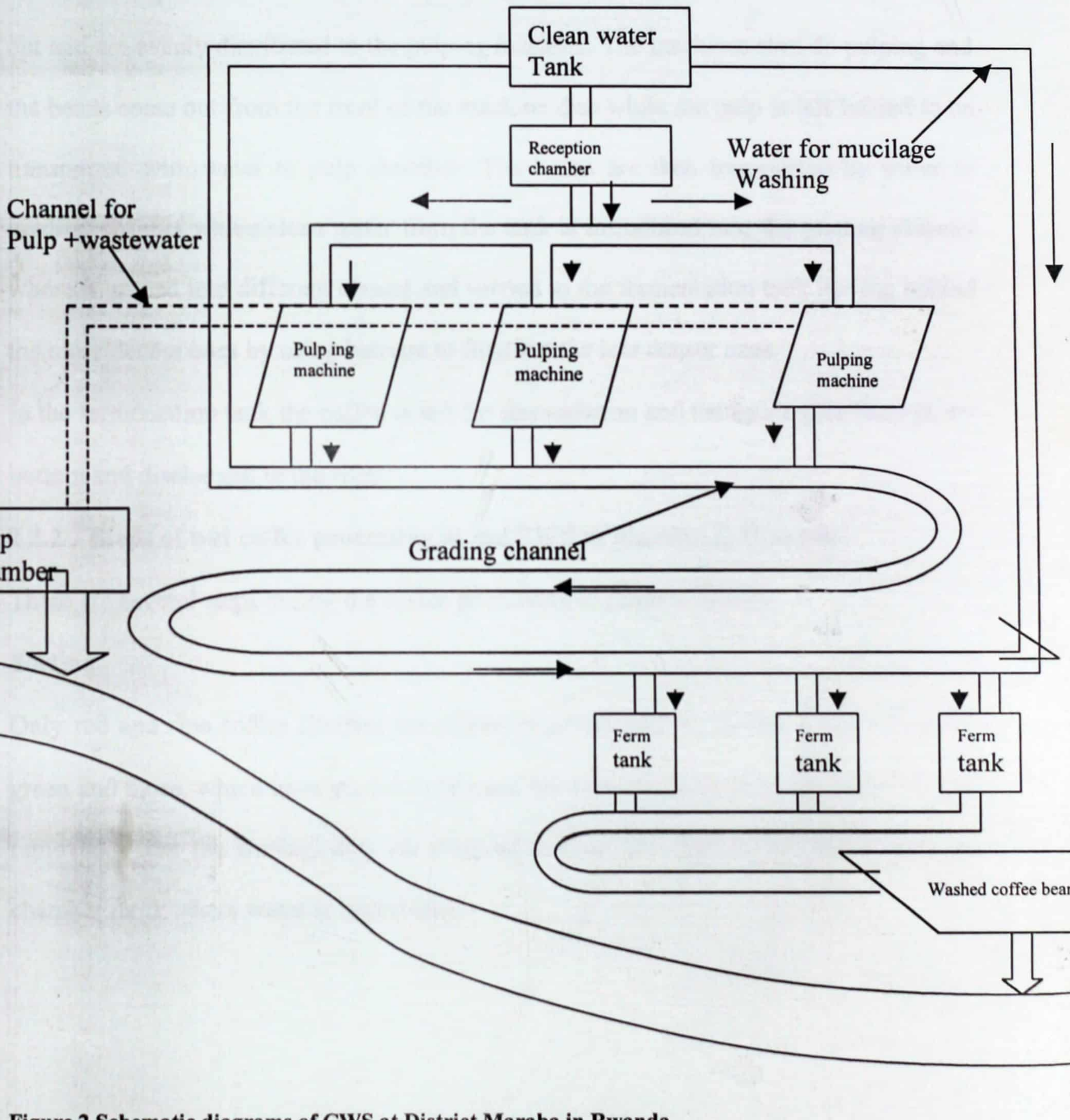



**Figure 2 Schematic diagrams of CWS at District Maraba in Rwanda**

### 2.2.1 Operation of the station

During the processing, clean water is supplied from the water storage tank as shown in fig .2, which also receives its water by the springs from the hills.

Well-sorted and good coffee is fed into the receiving coffee tank with water, and then a gate valve is opened at the bottom of the tank to let the coffee cherries with water flow out and are evenly distributed to the pulping machine. The machines start de-pulping and the beans come out from the front of the machine disc while the pulp is left behind to be transported with water to pulp chamber. The beans are then transported by water to grading channel where clean water from the tank is introduced into the grading channel where it graded into different classes and carried to the fermentation tank leaving behind the more denser ones by using barriers to float out the less denser ones.

In the fermentation tank the coffee is left for fermentation and the water goes through the bottom and discharged to the river.

### 2.2.2 Steps of wet coffee processing at the CWS of Maraba in Rwanda.

There are several steps during the coffee processing at District Maraba

**Sorting.**

Only red and ripe coffee cherries are picked or considered as shown in Fig.3 The dry, green and those, which have started to ferment are avoided, the stones and sticks are also removed. After the sorting, they are weighed and put into the coffee cherry reception chamber /tank where water is introduced.



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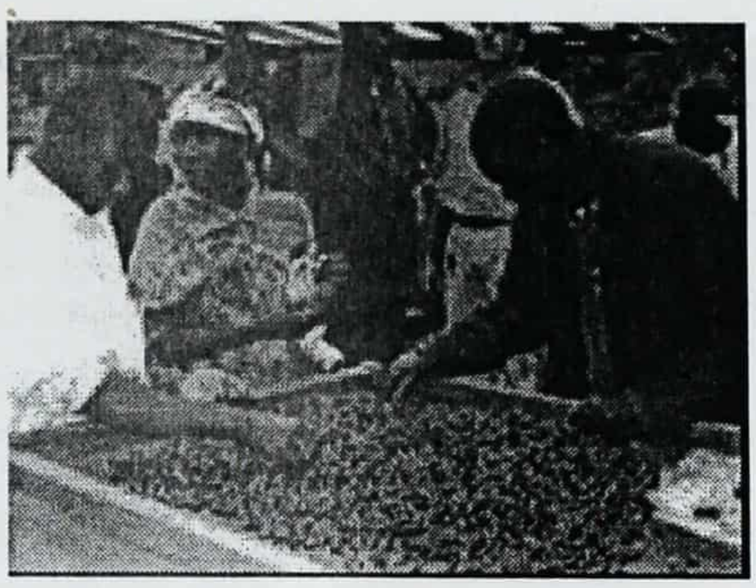


**Figure 3 Sorting of cherries at the reception of District Maraba CWS in Rwanda.**

**Pre-cleaning and float.**

This is done in the reception chamber where there is water to remove some dirt, settle any stone and then after led to the pulping machines by distributing channels.

**De-pulping.**

Manually operated de-pulping machines as shown in Fig.4 and a disc run by a 3hp diesel engine are employed to remove the coffee pulp. The beans are pushed forward to the grading channel and the pulp backwards of the machine and transported by water to the pulp chamber where they are trapped and the water moves through to join the stream.

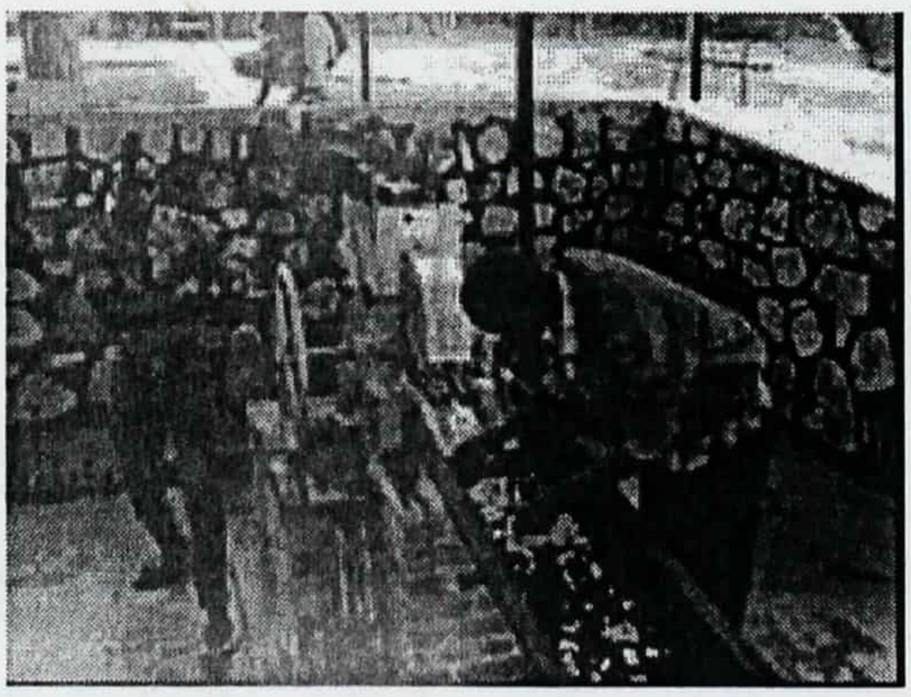


**Figure 4 De-pulping of the coffee at District Maraba CWS in Rwanda**

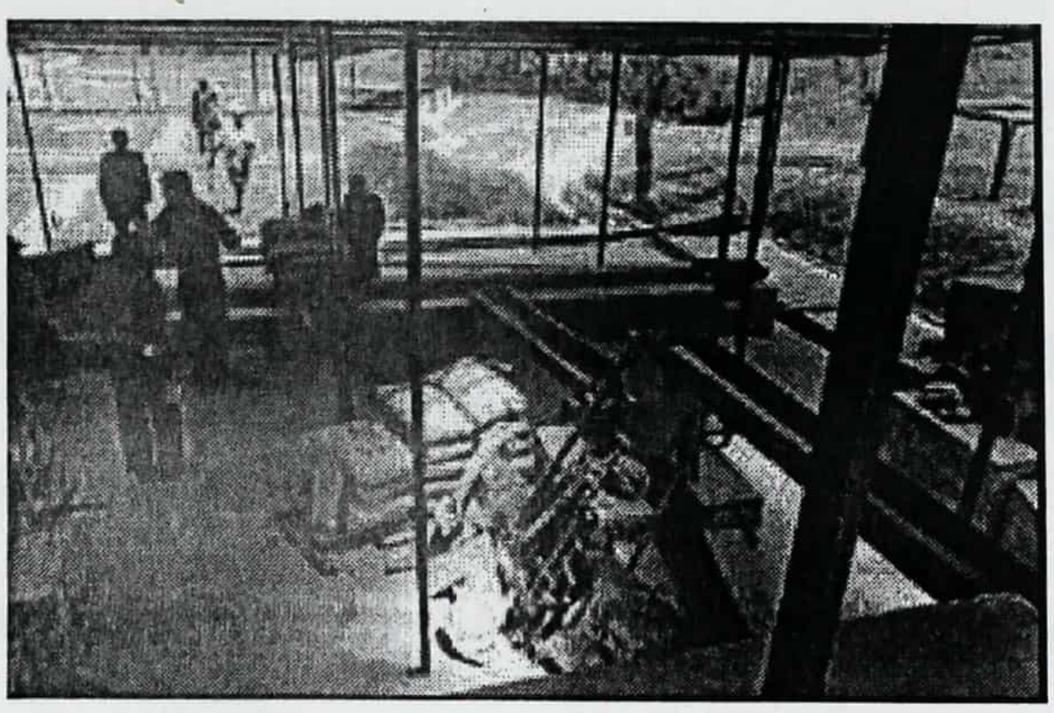


**Figure 5 Coffee washing stations at District Maraba in Rwanda**

**Grading/Washing.**

Fig.5 shows the step that uses the largest volume of water. Clean water is introduced into the grading channel to help in the grading using densification/floatation method. The good quality coffee beans are dense and sink in flowing water while low quality beans, less dense float and separated from good quality beans in the water streams by the help of the barriers at different levels in the channel during the grading processes. The water in the grading channel is relatively clean.

**Fermentation.**

The fermentation stage is designed to remove the layer of mucilage from the beans. The stage is comprised of two different parts.

i) Fermentation of the beans for 24 hrs.

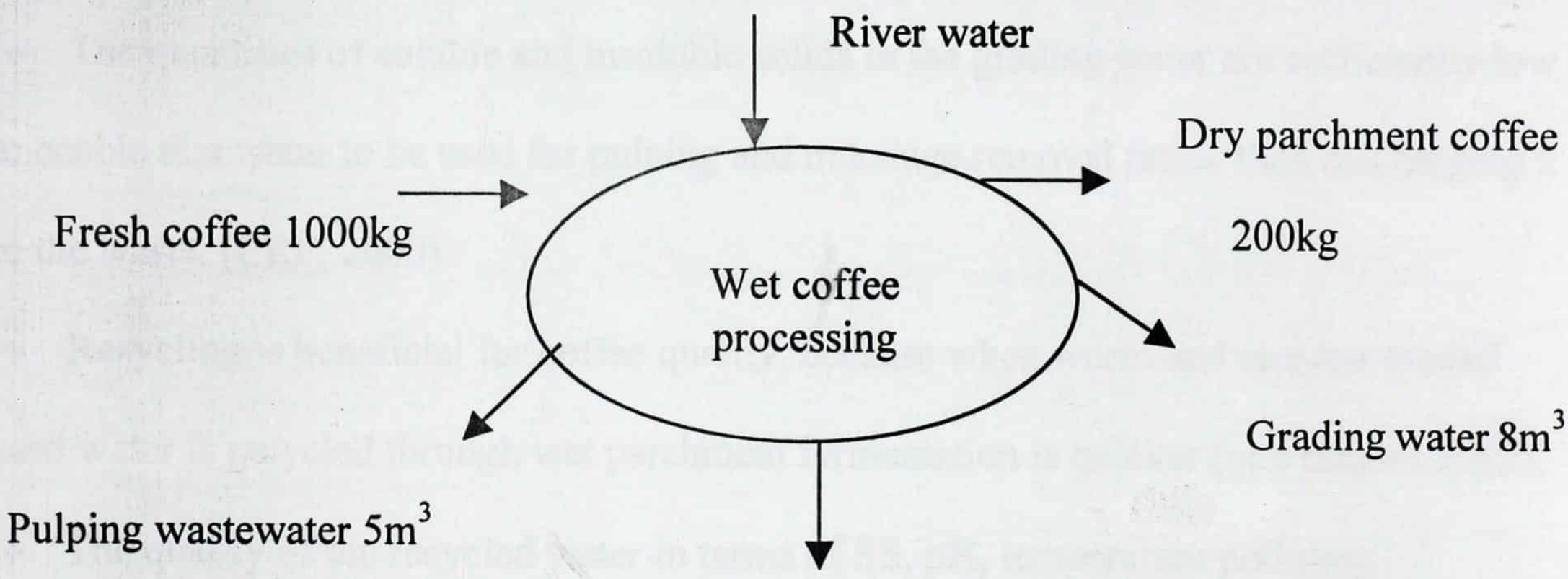
ii) Fermentation of the coffee beans for forty-eight (48) hrs.

After twenty-four hour fermentation, the beans are washed to remove fermented mucilage and are again left to ferment for 48hrs after which the mucilage is washed off again The washed water from the fermentation tank is discharged directly into the river.

## 2.3 Water quantities used in wet coffee processing.

Depending on the type of technology applied, quantities of coffee wastewater may vary as shown in Fig.6. Modern mechanical mucilage removal machines producing semi-washed coffee use only $1m^3$ per tone of fresh cherry (without finish fermentation and washing) where as the traditional fully washed coffee technique without recycling uses up to $20.0m^3$ per tonne cherry (Mburu et al, 1994) in order to treat the coffee wastewater properly and of reasonable costs, the amount of waste water must be minimised (GTZ PPP, 2002).

### 2.3.1 General mass balance for wet coffee processing.




*Source from (CRF Ruiru June 2000)*

**Figure 6 Mass balance of wet coffee processing**

### 2.3.2 water reduction for the wet coffee processing

The use of water during the processing must be minimised and should always fall with in the limit of water regulatory board of the country this can be achieved through re-circulation process. . (CRF, 2000).

#### 2.3.2.1 Key principals for re-circulation flow.

- Clean water is not essential for pulping or mucilage removal though it should not be water containing decomposing coffee solids, soluble or insoluble
- The volume of water used for mucilage removal can be reduced by washing the fermented beans through a pump rather than by foot treading or raking.
- The quantities of soluble and insoluble solids in the grading water are sufficiently low to enable this water to be used for pulping and mucilage removal rather than discharging it to the waste. (CRF, 2000).
- Recycling is beneficial for coffee quality, because when worm and enzyme loaded used water is recycled through wet parchment fermentation is quicker (ppp project 2002).
- The quality of the recycled water in terms of SS, pH, temperature polluting parameters such as BOD COD need to be monitored and kept at optimum levels (PPP project, 2002).

## 2.4 Coffee wastewater characteristics:

The environmental impact of wet processing and semi-wet processing is considerable.

Problems occur through large amounts of effluent disposal that are heavily loaded with organic matter into the water courses (Adams et al 1987). As a result the self-purification of the watercourses is exceeded, the microbial degradation reduces the level of oxygen to anaerobic conditions under which no longer aquatic life is possible.

### 2.4.1 Potential pollutants from coffee wastewater.

The soluble solids (sugars, caffeine, organic acids and phenols) are naturally present in the maturing of the coffee cherry, or can be generated through skin/pulp decomposition during fermentation. (CRF, 2000).

Most of the insoluble substances in the pulp and the skin are comprised of cellulose and pectin, though their degradation products can be acids or sugars.

During fermentation, natural enzymes present in the coffee tissue, together with those released by organisms naturally present in the coffee cherry partially break down the pectin polymers in the mucilage layer enabling them to be removed from the beans by mechanical agitation or washing. (CRF, 2000).

Two main pollution streams are identified, depending on the processing technology applied.

- Effluent from the pulpers that are highly loaded with quick fermenting sugars from the break down of the pulp and parts of the mucilage.
- Effluent from the fermentation tanks or mechanical mucilage removers, contain Hydrolysed sugars and high concentrations of thick pectin.



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### 2.4.2 Pulping wastewater.

Pulping water consists of quickly fermenting sugars from both the pulp and the mucilage components. These sugars and pectin can ferment to produce alcohol and eventually acid thereby making the effluent acidic (pH between 3 and 4) www.vended.de (march 2003) The pulp is rich in nutrients and can often be used for fertilizer. The nutrients in the pulp include. Nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, copper iron manganese, molybdenum and zinc.

The pulping water usually has a deep-red colour and consists of the suspended solids from the breakdown of the pulp during the de-pulping processes.

#### 2.4.2.1 Characteristics of the wastewater from the pulp.

| | |
|---|---|
| COD | 3000-28000 |
| DO | 0.00- 0.12 |
| pH | 6.17- 5.03 |
| SS | 2130-8794 |

*Source from (CRF Ruiru June 2000)*

### 2.4.2.2 Composition of the coffee pulp.

**Table 1 Composition of the coffee pulp**

| | |
|---|---|
| Ether extract | 0.48% |
| Crude fibre | 21.4% |
| Crude protein | 10.1% |
| Ash | 1.5% |
| Nitrogen free extract | 31.3% |
| Tannin | 7.8% |
| Pectin substances | 6.5% |
| Non reducing | 2.0% |
| Reducing sugars | 12.4% |
| Chlorogenic acid | 2.6% |
| Caffeine | 2.3% |
| Total caffeic acid | 1.6% |

(Gathuo et al, 1999), (GTZ- PPP 2002).

### 2.4.3 Wastewater from fermentation.

Fermentation is a natural biological process where nutrients are broken down through microbial activities or enzymes. This helps to remove the slimy, hygroscopic mucilage layer from the parchment in order to prepare it for later drying.

During fermentation, long chain pectin is split by enzymes (pectinase, pectase) into short chains of pectin oligosacharides. Oligosacharides are soluble in the alkaline and neutral solution but in acidic conditions they are thrown out of the solution as pectic acids. In the

presence of calcium or other multivalent ions, the pectic acid fragments are cross-linked into a non-soluble gel of calcium pectate. (Treagust, 1994), www.venden.de, March 2003

The wastewater from the mucilage after mechanical removal contains certain amount of sugars (disaccharides, carbohydrates). In order to biodegrade the undigested mucilage and pectic substances, the solid material have to be fermented, acidified and hydrolysed by natural fermentation. (GTZ-PPP, 2002)

During the fermentation and acidification of sugars in the wastewater, pectin, oligosacharides form a superficial layer and float on top of the wastewater. The remaining highly resistant materials left in the effluent are acids and flavanoids colour components of the coffee cherries. However the flavanoid do not cause any harmful defects to the environment nor add significantly to the BOD or COD (www.venden.de, (GTZ-PPP, 2002).

The resistant organic materials, which can only be broken down by chemical means indicated by COD, make up around 80% of the pollution load. (Treagust, 1994)

The materials making up the high COD precipitate out of the wastewater as mucilage solids.

### 2.4.4 Acidity.

During the fermentation stage, the effluents from the pulping process, fermentation tanks and the mucilage removal contain sugars which are degraded and converted to alcohol and $CO_2$ in the presence of natural yeast from the coffee Cherrie. However, in this reaction, the alcohol is quickly converted to vinegar or acetic acid in the fermented pulping water. (Treagust, 1994) The simplified equation of the biological fermentation of

6 carbon sugars by yeast to ethanol is typified by conversion of fructose to ethanol reaction

$C_6H_{12}O_6 \longrightarrow 2CH_3\,CH_2OH + 2CO_2$

Sugar 2-ethanol 2 carbon dioxide

Ethanol is quickly acted upon by bacteria and converted into acetic acids. This enzymatic reaction can be simplified as.

$2CH_3CH_2OH + O_2 \longrightarrow 2CH_3COOH$

2ethanol oxygen 2 acetic acid

(GTZ -PPP, 2002) www.venden.de March 2003

The acidification of the sugars causes a drop in the pH to around 4 and the digested mucilage will precipitate out of the solution and will build a thick crust on the surface of the wastewater, black on top and slimy orange/brownish colour underneath. If not separated from the water, this crust will quickly clog up the waterways and further contribute to anaerobic conditions in the waterways. (GTZ –PPP, 2002) www.venden.de

## 2.5 Mucilage.

Mucilage is the protective coating around the coffee bean. It is loosened by the action of natural coffee enzymes and by microorganisms, which naturally grow on the coffee. Mucilage is slimy in texture, hygroscopic when dry and does not easily settle out of the suspension, but when it does, it can block the bottom of the pit or pores in the soil when discharged preventing the percolation of water through the soil. (CRF, 1997).

### 2.5.1 Composition of the mucilage

**Table 2 composition of the mucilage**

| | |
|---|---|
| Water | 84.2% |
| Protein | 8.9% |
| Glucose reducing | 2.5% |
| Sucrose non reducing | 1.6% |
| Pectin | 1.0% |
| Ash | 0.7% |

Clifford and Wilson 1985

### 2.5.2 Removing of the mucilage from the beans.

There are two main methods of removing the mucilage from the washed beans.

i) Mechanical means.

ii) Natural fermentation.

#### 2.5.2.1 Mechanical means.

Studies have concentrated on the determination of simple mechanical means of mucilage removal and subsequent separation of suspended mucilage from the wastewater.

(CRF, 2000).

The beans are passed through a sustainable centrifugal pump. The pressure and the movement of the beans against one another is sufficient to remove the mucilage.

This step has to be followed by another step that includes removal of the mucilage from suspension. (GTZ- PPP, 2002).



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### 2.5.2.2 Natural fermentation

Natural fermentation is the biological way to remove the mucilage from the parchment coffee in order to prepare it for drying.

After fermentation has taken place, the parchment coffee fills rough and grips, and then the coffee is washed to discharge the liquefied mucilage. This can be done traditionally by treading the fermented beans followed by washing and raking the beans in streams of water. Again this step has to be followed by another one to remove the mucilage from suspension to avoid clogging of the waterways when discharged in waterways.

(MCPE, 2000).

### 2.5.3 Removal of the suspended mucilage from the effluent.

It is desirable to remove the suspended mucilaginous pectin from wastewater before it reaches the effluent discharge pit. This is because once it is discharged; it increases the clogging of the pit or waterways.

Mucilaginous pectins are relatively slow to break down even after they have been left to stand for several days. They are also difficult to filter out because of their texture. So other mechanism of removal were employed. (CRF, MCPE, 2000)

### 2.5.4 Action of chemical flocculants.

Laboratory trials that were carried out at CRF Ruiru Kenya have shown that pure lime produced a partial flocculation and slow sedimentation of the suspended mucilage solids. The rate of sedimentation was improved when natural magnesium silicate clay was used (sepiolite) as flocculent but neither was suitable in terms of rate of sedimentation. (CRF, MCPE, 2000).

### 2.5.4.1 Lime.

The laboratory trials on the efficiency of lime to remove suspended mucilage have been carried out but had a small positive effect on the settling of the mucilage from the wastewater streams. Even after 18days of standing the degree of settling was insufficient to make a great impact on the separation of the mucilaginous insoluble solids from water. (CRF, 2000).

### 2.5.4.2 Silicaceous clay.

Trials have been conducted using finely ground silicaceous clay with high water adsorption capacity added to the mucilage effluent. The compound added was sepeolite, low-density magnesium silicate mineral clay. $Mg_4(Si_2O_5)_3(OH)_26H_2O$.

When this compound was added to the wastewater a floc formed which settled out to give a precipitate volume of about 40% in one hour.

This marked an improvement over the application of lime. However the use of lime for the formation of calcium pectate was very important because of the neutralisation effect.

### 2.5.4.3 Lime + Silicaceous clay

The blending of lime and silicaceous clay was possible, but this is in the form of Portland cement.

Cement is a mixture of calcium carbonate and aluminium silicates heated over $1700^0C$ and blended with calcium sulphate. During the heating, the calcium carbonate is converted to calcium oxide (lime).

So the most successful flocculent was found to be a combination of lime and silicaceous clay and this existed in the form of Portland cement. (CRF, 2000)

The precipitated mucilage of lime and silicaceous clay can be easily filtered out and when dry formed a friable sand textured solid since the mucilage no longer has a gelatinous texture, any associated water can quickly separate and drain into the soil. .

### 2.5.5 The chemistry of pectin reacting with calcium.

The chemical reaction of the pectin from coffee mucilage with lime is not fully understood but it is probably similar to the general reactions of the pectins with calcium. Pectic substances are complex polysaccharides based on the galactoronic acid. Pectin is characterised by the presence of methyl ester groups that can be attacked by pectin esterase enzymes from within the plant tissue this reaction results in the releases of a methyl group, as methanol the other by-product is pectic acid. (CRF, 2000)

### 2.5.1 Calcium bind of low pectins.

The reaction of calcium with pectin can simulate the function of rigid gel of calcium pectate. The optimum actively of pectin esterase, which catalyse the removal of the methyl groups from the pectin molecule, occur at pH 7.5 (GTZ- PPP, 2002)

Calcium cooperative binding is negligible when more than 40% of the carboxyl groups are randomly esterified, but a gel forming ability increases with decreasing degree of methylation.

## 2.6 Wastewater treatment (General).

Generally wastewater discharged from the domestic, commercial and industries area must be treated because it contains waste that pollutes the environment. This treatment has two main objectives.

i) To remove the pollutants such as organic matter, in the form of BOD, COD SS, phosphates, nitrates which cause the pollution to the environment.

ii) To remove pathogens (disease causing organisms) which cause sereous health risks? (World Bank, 1986)

The degree of treatment of wastewater depends on the following:

i) The degree of pollutant that can be realised.

ii) The cost that the community can afford.

iii) The characteristics of the receiving water body into which the waste is discharged.

### 2.6.1 wastewater treatment technologies.

The wastewater treatment processes are classified according to the degree of treatment. There are three major treatment processes and these include. Primary, secondary and tertiary.

**Table 3 Wastewater treatment technologies**

| PRIMARY | SECONDARY | TERTIARY |
|---|---|---|
| Minimum quality | Good quality | High quality |
| Screening<br>Grit removal<br>Sedimentation<br>Floatation | Trickling filters<br>Aerated lagoons<br>Extended aeration<br>Stabilization ponds | Filtration<br>Chemical precipitation<br>Ion exchange<br>Nutrient removal<br>Disinfections |

**Source veenstral et al 1995**



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### 2.6.2 Treatment options for coffee wastewater treatment.

Viable approaches for environmentally friendly coffee processing encompass the following aspects.

- Reduction of wastewater generation and water consumption through water recycling of use water (EDE, 1999). This will help to keep the treatment costs low
- Reduction of the pollution load that is discharged into water bodies through treatment of the wastewater before discharge.

### 2.6.3 Available technology for coffee wastewater treatment.

Wide range of technology is available that could be used to treat coffee wastewater and generate an effluent which will have a negligible adverse impact on a receiving water bodies. Many of these technologies are capital intensive, require sophisticated operating and monitoring regimes and necessitate a high level of infrastructure support. (CRF, 2002).

There are four main options for coffee wastewater treatment, which have been investigated in Kenya. These include;

- Improved seepage pits.
- Seepage trench.
- Anaerobic stabilisation ponds.
- UASB Up flow Anaerobic Sludge Blanket.

An advantage of all the above options is that each can be used to give a limited degree of effluent treatment independently or in combination to generate a much-improved effluent quality with varying cost implications.

### 2.6.3.1 Improved seepage pits.

The design criteria for seepage pits and their efficiencies are based on established formulae and the site conditions (CRF, 2000) summarised below.

The area of seepage pit required for infiltration is,

$A = Q/I$ ..... 2.0

Where

A= Pit infiltration area ($m^2$)

Q= Daily flow ($m^3$/day)

I= Infiltration rate of the soil ($m^3/m^2$ day)

Thus based on maximum daily flow rate of the coffee wastewater and the infiltration rate measured, the area required can be determined.

It is also recommended that the base of the pit should not be considered as an infiltration surface because of its tendency to clog CRF 2000).

Ideally two pits should be provided so that essential maintenance can be undertaken on one pit without interrupting the other.

The efficiency of BOD removal is very low and requires a frequent cleaning.

### 2.6.3.2 "Leeds" seepage Trench.

The seepage trench was developed to eliminate most of the problems associated with traditional seepage pits such as clogging of the pit base leading to pit overflow, and the need for two pits to facilitate maintenance of empty trench.

The seepage trench provides a large surface area for percolation of the feed, but unlike the seepage pit most of the surface area comprises of the pit sides and not the pit base. Thus making the solids settle to the base of the trench as normal, this does not result in

clogging as it would with the seepage pit. Because the majority of the fluid percolates through the sides of the pit, which is kept solid, free (CRF, 2000).

The main features of the seepage trench systems are a trench of 1m deep, 05m wide.

The required length of the trench is given by the equation below.

$L = Q/2DI$ .....2.1

Where

L= Length off the trench (m).

D= trench depth (m).

Q= Daily flow ($m^3$/day).

I= Infiltration rate ($m^3/m^2$day).

Thus with a daily flow of Q ($m^3$/day), and infiltration rate of the soil I ($m^3/m^2$day), and then the length of the trench can be determined. (CRF, 2000).

A gap between the trenches should be at least three times the width of the trench to minimise the dangers of collapsing.

The operation and maintenance costs associated with a trench system are also very low and are quite similar to that of seepage pit system. There is no requirement for chemical dosage of any form and there is no electricity requirement.

**2.6.3.3 Anaerobic pond system.**

Anaerobic pond is commonly designed based on organic surface loading rate (Kg BOD /m3 day). However research undertaken at CRF suggested that a simplified design based on Hydraulic retention time is acceptable.

(CRF, 2000). Designs basing on organic surface loading always require surface area, which are so big and not easily available.

Unlike both pits and trenches, pond system should be impermeable and this is achieved by lining them.

Pond systems give consistently better and more reliable performance than pit and trench systems.

Pond operation and maintenance is considerably more involving in capital than seepage pit and seepage trench. Sound operation with minimisation of odours requires chemical addition of lime.

Pond systems give consistent better and more reliable performance than pit and trench systems.

**2.6.3.4 UASB (Upward Flow Anaerobic Sludge Blanket).**

The design of UASB can be based on either hydraulic retention time or the organic loading rate.

UASB has significantly smaller land requirement as compared to pits, trenches and ponds thus it is possible to site it closer to the main centre of coffee processing operations.

## 2.7 Anaerobic ponds.

Anaerobic ponds are used to remove BOD by sedimentation of settleable solids and breakdown of organic matter through anaerobic digestion (World Bank 5.4, 1997). There are two main processes that take place in anaerobic ponds.

Solids in the incoming wastewater settle at the bottom of the pond and form a layer of sludge.

Anaerobic bacteria break down the organic matter in the sludge to produce gas (which is lost to the atmosphere) and some soluble products, which pass into other ponds. This process causes very slow build up of sludge in the anaerobic pond. (World Bank, 1999).

During anaerobic reaction, the particulate organic matter is converted into dissolved compounds of a lower molecular weight. Proteins are degraded to amino acids, carbohydrates are transformed into soluble sugars (mono- and disaccharides) and lipids are converted into long chain fatty acids and glycerine.

Exo-enzymes, excreted by fermentative bacteria, are required for this process

The two main reactions in the anaerobic process are acid genesis and methanogenesis. The anaerobic acid genesis, methanogenesis, and those in anaerobic ponds are equally sensitive to the same toxicants one of which is pH. (www.venden.de).

(Van Handel and Lettiga, 1994).

**Acidogenesis.**

Once the particulate organic materials have been converted into soluble compounds as a result of the hydrolysis, the fermentative bacteria takes up the dissolved compounds in this acid forming phase, various short chain acids are formed together with alcohols and mineral compounds such as carbon dioxide, hydrogen, ammonia and hydrogen sulphide gas. This phase is carried out by a diverse group of bacteria, most of which are obligate anaerobes. However, some facultative group of bacteria is involved and metabolises organic matter via the oxidative pathway. (Mudrack et al, 1986). In this way, the little dissolved oxygen that otherwise become toxic to the obligate anaerobic organism is used.

**Acetogenisis.**

Among the products formed in the acidogenesis stage, only acetic acid (acetate), hydrogen and carbon dioxide can be converted by the methane bacteria directly into methane; hence the other products of acetogenesis are transformed into acetate, hydrogen

and carbon dioxide. Therefore approximately 70% of the original COD is converted into methane via acetate rout. (Van Handel and Lettiga, 1994).

**Methanogenesis.**

This is the final stage of reaction in the anaerobic pond. In methanogenesis stage, methane is produced from acetate or from reduction of carbon dioxide using acetophilic and hydrogenotrophlic bacteria respectively.

ACETROPHIC METHANOGENESIS.

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

HYDROGENOTROPHIC METHANOGENESIS

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_20$$

Methanogenesis being the final stage of the anaerobic digestion it must be taken as the most important process. (Henze and Harremoes, 1983) The optimum pH for methanogenesis ranges between 6.8 – 7.8 and a pH of 6.0 probably constitutes the lower limit for anaerobic tropical ponds. (McGarry and Pescod, 1970).

### 2.7.1 Anaerobic pond design principles.

There four major factors that affect the size and lay out of the pond system.

- The volume of the wastewater to be treated (Q)
- The strength of the sewage to be treated (Li)
- The desired quality of the final influent from the pond system.
- Climate.

### 2.7.1.1 Volume of the sewage to be treated.

The volume of the wastewater to be treated is the total amount of wastewater that is discharged by the community or an industry that is being considered.

### 2.7.1.2 Strength of the wastewater

The strength of the wastewater depends on its content of organic material, and is measured by its Biochemical Oxygen Demand (BOD). This is the amount of oxygen that would be needed for degradation of the organic matter in the wastewater and is usually measured in mg/l (World bank, 1991).

### 2.7.1.3 The desired quality of the final effluent.

The desired quality of final effluent will depend on the use to which the effluent will be put or how it is going to be disposed off and also the quality of the receiving water body.

### 2.7.1.4 Climate.

The climate affects the performance of the anaerobic pond. This also leads to how much space can be used in comparison to hot climate and cold climates. Anaerobic ponds perform better at temperature above 20°C (Cairn cross Feachem May 1999).

### 2.7.2 Anaerobic pond design

Anaerobic ponds are designed to receive BOD loadings of between 100-400 $g/m^3/d$. The actual loading will depend on the climate, with higher loadings possible at higher temperature. The retention time is usually in the range 1-4 days and a rate of BOD removal up to 80% (but normally about 60%) is possible under tropical conditions.

The depth of 2-4 m is preferred and the dislodging of 2-5 years (World bank, 1991, cairn cross Feachem, 1999).



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The depth of anaerobic pond is between 2-4 meters, a depth that ensures anaerobic conditions and provides space for the storage of sludge.

## 2.8 Conclusion of literature review.

From the above literature review, the efficiency of the combination of silicaseous clay and lime which is in the form of Portland cement as mucilage treatment has to be investigated

Other treatment processes such as yeast treatment have to be investigated.

The optimum cement dosage for the mucilage settlement has also to be determined dosage.

The efficiency of Anaerobic and aerobic treatment processes have to be investigated.

The design procedure for anaerobic ponds is based an the volumetric BOD loading

($\lambda_v$, $g/m^3d$. which is given by.

$\lambda_v = LiQ/V_a$ ..... 2.2

Where;

$\lambda_v$ = Volumetric loading $g/m^3d$.

Li = influent $BOD_5$ concentration in $g/m^3$.

Q = influent flow rate $m^3/d$ that comes to the pond.

$V_a$ = anaerobic pond volume $m^3$.

The permissible design value of $\lambda_v$ increases with temperature and ranges between

100-400$g/m^3d$. (Mara and Pearson 1986, World bank, 1986, Mara et al, 1998).

The recommended design values are given in the table below.

**Design values of permissible volumetric BOD loadings and percentage BOD removal in anaerobic ponds at various temperatures.**

**Table 4 Design Values of permissible BOD loading**

| Temperature $^0C$ | Volumetric loading | BOD %removal |
|---|---|---|
| <10 | 100 | 40 |
| 10-20 | 20T -100 | 20T+20 |
| 20-25 | 20T +100 | 20T+20 |
| >25 | 350 | 70 |

T = Temperature $^0C$

*Source: Mara and Pearson 1986 and Mara et al 1997.*

Once the value of $\lambda_v$ has been selected, the anaerobic pond value is then calculated from equation (2.2).

The mean hydraulic retention time in the pond is determine from

$V_a /Q = t.$

# 3.0 METHODOLOGY

## 3.1 Analysis of the wastewater from wet coffee processing:

For this project, fully washed coffee method with long fermentation period for the removal of mucilage was considered.

### 3.1.1 Source of the coffee

The coffee samples processed were obtained from Ghana Cocoa Research Foundation at Bonsu in the Eastern Region, Ghana.

### 3.1.2 Appearance and the nature of coffee processed.

The coffee that was processed was Arabic coffee.

It was not fresh directly from the field and stayed over night before it was processed.

The coffee cherries were mixed up, the ripe ones, green ones, dry ones and others were too ripe. Fermentation of the some of cherries was already taking place even before processing.

## 3.2 Experimental set up during the processing of the coffee.

The experimental set up consisted of the piston, sieve, bucket and water to enhance the de-pulping and grading.

The processing stages included;

### 3.2.1 Sorting:

The coffee beans were sorted out manually to remove those which were unripe /green, dry, infected and the over ripe.

### 3.2.2 De-pulping.

The coffee beans were squeezed out from the pulp with the help of water to separate the pulp from the beans, this was done manually using a mortal to squeeze the cherries in the sieves where the beans passed through the sieves, and the pulp was retained on the sieves.

### 3.2.3 Grading.

Fresh water was introduced to grade the beans. The heavy beans settled at the bottom and the lighter ones floated. The good quality beans settle at the bottom and are termed as the first class. The second class floated on top. During the grading stage some little mucilage was observed to have come out of the beans, which shows that the coffee was not very fresh at the time de-pulping.

### 3.2.4 Fermentation.

There were two deferent periods of fermentation; a 24hr period and a 48hr period.

After grading, the coffee beans were fermented for twenty-four hours in the absence of water. And then the beans were washed to remove the mucilage that had been formed during the 24 hr fermentation period. Fermentation was then allowed to go on for another 24hrs as a polishing stage to remove any further mucilage from the beans that may not have been removed during the 24hr fermentation period. After the beans were washed to remove mucilage.

## 3.3 Quantity of coffee processed.

Amount of coffee that was processed was 2.7kg.

### 3.3.1 Quantity of water that was used during processing

Amount of water used for de-pulping = 15 litres.

Amount of water used for grading = 21 litres.

Amount of water used for mucilage washing = 7 litres.

Total amount of water used = 46 litres.

### 3.3.2 Samples from different stages of processing.

SS1: Wastewater from de-pulping that goes with the pulp.

SS2: Wastewater from the grading of coffee beans.

SS3: Wastewater from a 24hr fermentation period.

SS4 Wastewater from a 48hr fermentation period.

SS5 Wastewater for the composite of SS1+SS2+SS3+SS4.

## 3.4 Coffee processing at the washing station of Maraba District in Rwanda.

There are three manually operated machines that are used for de-pulping and one electrically operated disc being driven by a diesel engine which has just been introduced recently.

### 3.4.1 Quantity of coffee processed at the station.

The manually operated machines have been de-pulping 6 tonnes of cherries which eventually yields 1 tone of the dried beans per day. The quantity of water used for processing 6 tones of cherries is $80m^3$.While the diesel-engine operated disc de-pulp 1000kg/hour of cherries

### 3.4.2 Quantity of wastewater discharged.

The quantity of wastewater-discharged from the coffee washing station into the stream is $50\text{-}190m^3$/day.

## 3.5 Analytical procedures.

The methods used in the laboratory analyses of BOD and COD according to APHA/AWWA standard methods1995. In situ measurements of temperature, pH,

conductivity, TDS and salinity were made using portable electronic probe meters available in the Environmental Quality Engineering Laboratory of the Civil Engineering Department of KNUST. A summary of various analytical procedures is shown in table 5 and their relevant sources. The details of the method are given in appendix L

**Table 5 summary of the analytical methods**

| **Parameter** | **Analytical method.** |
|---|---|
| pH/ temperature | Microprocessor pocket-pH/mV meter pH 323/set WTW |
| Conductivity /TDS/Salinity. | Microprocessor conductivity meter/WTW. |
| Suspended solids. | Photometric method DR/2010 HACH spectrophotometer. |
| BOD | Incubation at 20 $^{0}$C for five days. |
| COD | Closed reflux followed by titration with ferrous ammonium sulphate titration (ApH/AWWA Standard methods, 1995). |
| Total phosphate/phosphorus | PhosVer 3(ascorbic acid) method using powder pillows by DR/2010 spectrophotometer |
| Nitrates | Cadmium reduction method (using powder pillows nitraVer 5) DR/2010 spectrophotometer<br>DR/2001HACH spectrophotometer. |
| Turbidity | Attenuation Radiation method by using DR/2010 spectrophotometer. FAU<br>1FAU=1NTU |



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## 3.6 Flocculation test for Mucilage settlement (primary treatment).

Different concentrations of ordinary Portland cement were dosed in the wastewater and settlement was monitored for each of the concentrations to determine the optimum dosage for the effective settlement of the mucilage.

The settlement of mucilage was done by dosing 2.5g/l of ordinary Portland cement to the wastewater, stirred using bilbird pedal stirrer at 200 rpm for 5 minutes, and then allowed to settle in Inhomfs cones.

Settlement was monitored every after 5 minutes and a settlement of 80 percent was reached with in one hour. It was then left to stand up to 16 hrs at this point there was no further settlement.

## 3.7 Anaerobic and Aerobic processes (Secondary treatment).

**Anaerobic process**

This was carried out on a composite sample for 8 days.

500ml of the coffee wastewater was pored into a plastic bottle and sealed then a tube was fixed into the bottle and connected to the water. This was to remove the gases produced from the wastewater during fermentation and also fixed into the water to stop air (oxygen) from entering into the sample to create anaerobic conditions.

Samples were drown out from the bottle using a syringe every day for eight days and analysed.

**Aerobic process.**

The wastewater was subjected to aeration for 10 hrs suing an aeration pump of 24cm Hg. Analysis of different parameters was then carried out after every two hours during the aeration process.

## 3.8 Yeast treatment.

1. The freeze-dried (saccharmyces) yeast was streaked on prepared nutrient agar plates and incubated for 24hrs.
2. A loop full of the 24hr culture was then transferred into 40ml malt extracts broth (in 5 separate conical flasks) and incubated for 48hrs.
3. 5ml of the broth was then transferred as innoculum into 200ml of the samples namely. SS1 (wastewater from the pulp), SS2 (grading water), SS3 (wastewater from a 24hr fermentation), SS4 (wastewater from a 48hr fermentation), SS5 (a composite of all the samples)
4. Triplicates of these samples were made and analysis performed on them.
5. The conical flasks containing the samples were then placed on a shaker at a temperature of 20 $^{o}$C and 120 rpm.
6. Samples were monitored for 2 days and analysis was carried out.

# 4.0 RESULTS AND DISCUSSIONS

The results for wastewater from the wet coffee processing are presented, analysed and discussed.

The stages that were passed through during the processing yielded different samples with different characteristics at different stages of processing. The stages that were considered during the processing were:

- De-pulping stage.
- Grading stage.
- Fermentation after 24 hrs.
- Fermentation after 48 hrs.

In order to come out with a uniform sample, the samples from all the stages were mixed and made into a composite sample whose characteristics could represent the wastewater from wet coffee processing. The individual samples were also characterised.

The wastewater from each stage had different levels of pollutants and these were all high when compared to GH-EPA standards for discharge into the environment.

The results in table 6 imply that the coffee wastewater has to be treated before discharge into environment.

## 4.1 Results of the raw samples.

The raw samples from different stages of processing consisted of wastewater from Pulp, Grading, 24hr Fermentation, 48hr Fermentation and the Composite from all the stages. This wastewater was characterised and the results are shown in table 6

**Table 6 Laboratory results of the raw sample obtained from wet coffee processing**

| mple | pH | TDS | SS | Turbidity | Colour | Cond. | Sal. | Temp | BOD | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nits | | mg// | mg// | FAU | Pt cobalt | µs/cm | | °C | mg// | mg// | mg// | mg// |
| SS1 | 5.47 | 1091 | 790 | 462 | 3610 | 1093 | 0.3 | 23.4 | 1900 | 9467 | 43.25 | 9.8 |
| SS2 | 6.48 | 327 | 139 | 116 | 348 | 324 | 0 | 24.8 | 1700 | 7605 | 7.6 | 1.4 |
| SS3 | 5.13 | 666 | 1160 | 2024 | 491 | 665 | 0.1 | 27.130.9 | 2300 | 6130 | 3.3 | 1.8 |
| SS4 | 6.79 | 243 | 103 | 151 | 329 | 243 | 0 | 27.9 | 400 | 1862 | 17.5 | 1.8 |
| SS5 | 5.28 | 532 | 256 | 324 | 945 | 533 | 0 | | 2000 | 4734 | 25.2 | 4 |

**SS1: WATER FROM THE PULP**
**SS2: GRADING WATER**
**SS3: WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48 hr FERMENTATION**
**SS5: COMPOSITE SAMPLE OF SS1 + SS2 + SS3 +SS4 + SS5**

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| SS3 | 5.13 | 666 | 1160 | 2024 | 491 | 665 | 0.1 | 27.130.9 | 2300 | 6130 | 3.3 | 1.8 |
| SS4 | 6.79 | 243 | 103 | 151 | 329 | 243 | 0 | 27.9 | 400 | 1862 | 17.5 | 1.8 |
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**SS1: WATER FROM THE PULP**
**SS2: GRADING WATER**
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**SS5: COMPOSITE SAMPLE OF SS1 + SS2 + SS3 +SS4 + SS5**

### 4.1.1 The pH of the raw samples

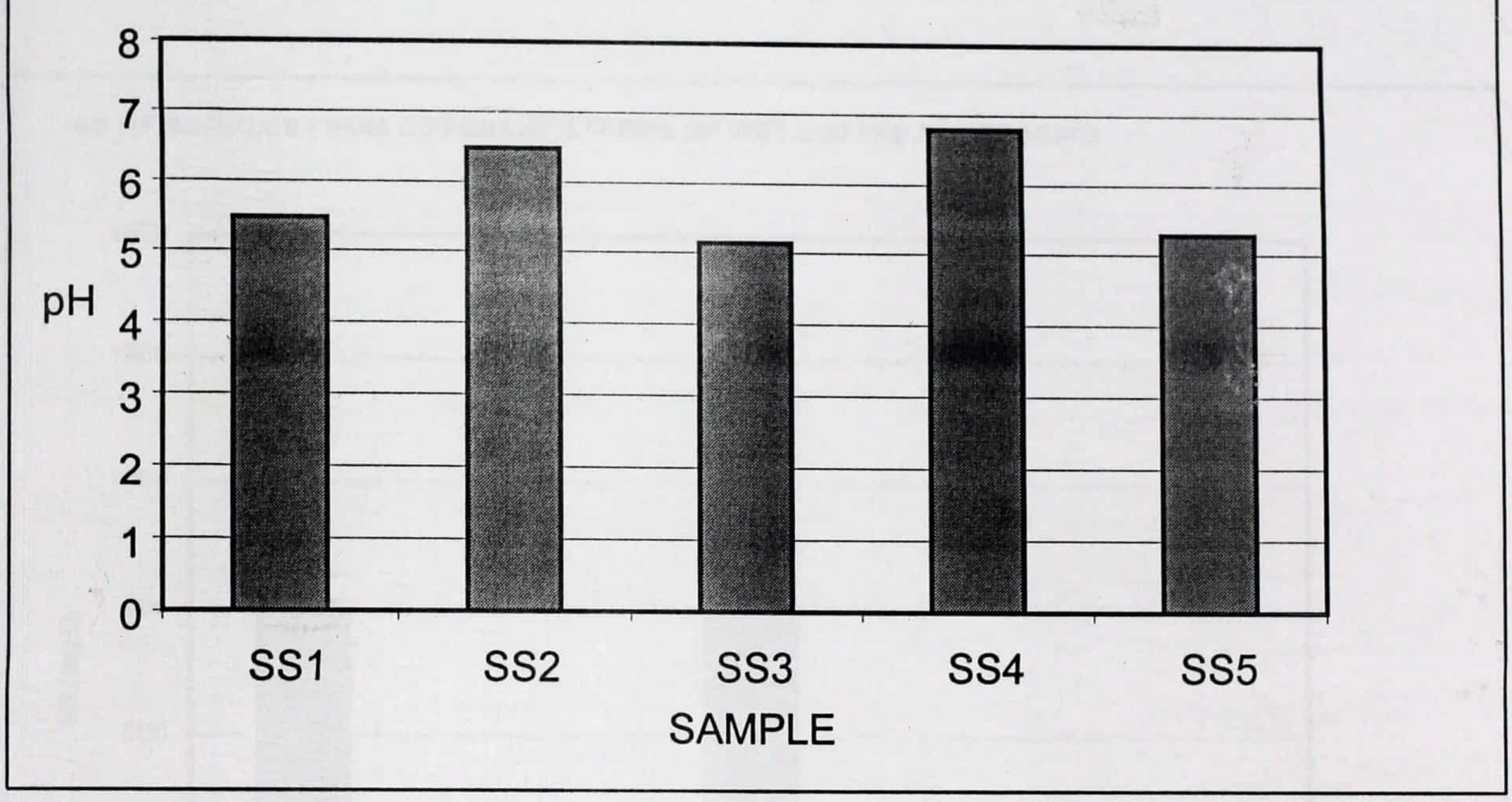



**Figure 7 pH of the raw samples**

*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

The pH of samples obtained from different stages of processing as shown in Fig.7

The pH of the SS1, which is the water from the pulp, is lower than the one for SS2 (the grading water) this is simply because the pulp is acidic and the grading water is more clean since it is the fresh water that is introduced to the beans after de-pulping. The pH of SS3, which is the wastewater after 24hr fermentation, is lower than the rest. This is because during fermentation there is production of carbon dioxide from the sugars and production of organic acids lowers the pH.

The pH of SS4 is higher than the rest (6.79). This is because most of the mucilage has been washed out after the 24hr fermentation period, and the fermentation that leads to production of $CO_2$ is almost complete.

The pH of SS5 is the composite sample of all the samples and expected to strike a balance at an average of all the pH's of the different samples in the stages of processing.

### 4.1.2 Suspended solids of the raw samples

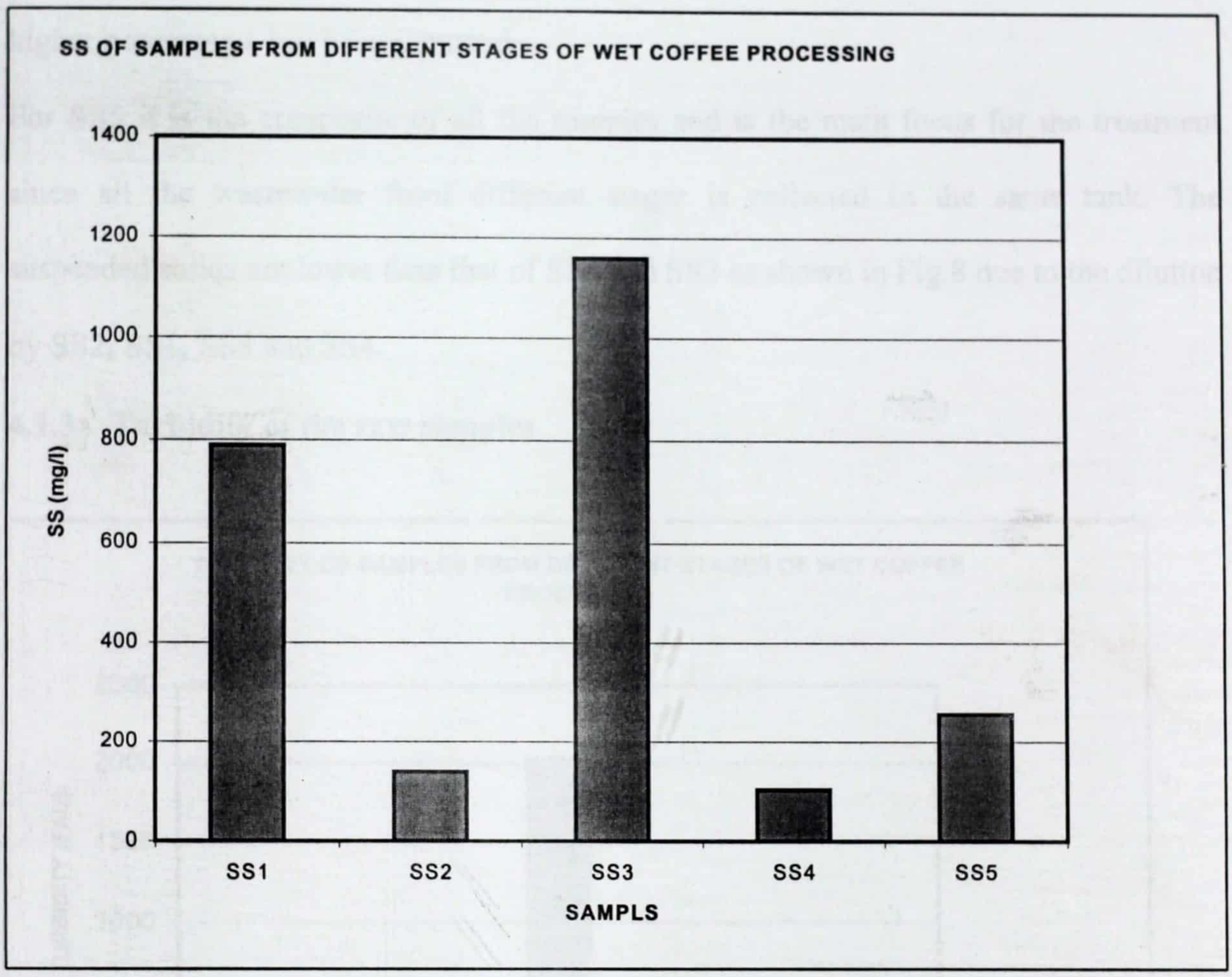



**Figure 8 Suspended solids of raw samples from different stages of coffee processing**

*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

The suspended solids for SS1are mainly from the pulp, which are accumulated during the de-pulping stage. Those of SS2 are from the mesocarp of the beans and they are not much since the water introduced for grading is clean.



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The suspended solids from SS3, which is the fermentation water after 24hrs are mainly due to the mucilage decomposition, which occurs during the fermentation and appear as suspended solids after washing.

For the SS4, the suspended solids are low because the mucilage, which contributes to a higher percentage, has been removed.

For SS5 it is the composite of all the samples and is the main focus for the treatment since all the wastewater from different stages is collected in the same tank. The suspended solids are lower than that of SS3 and SS2 as shown in Fig.8 due to the dilution by SS2, SS1, SS3 and SS4.

### 4.1.3 Turbidity of the raw samples

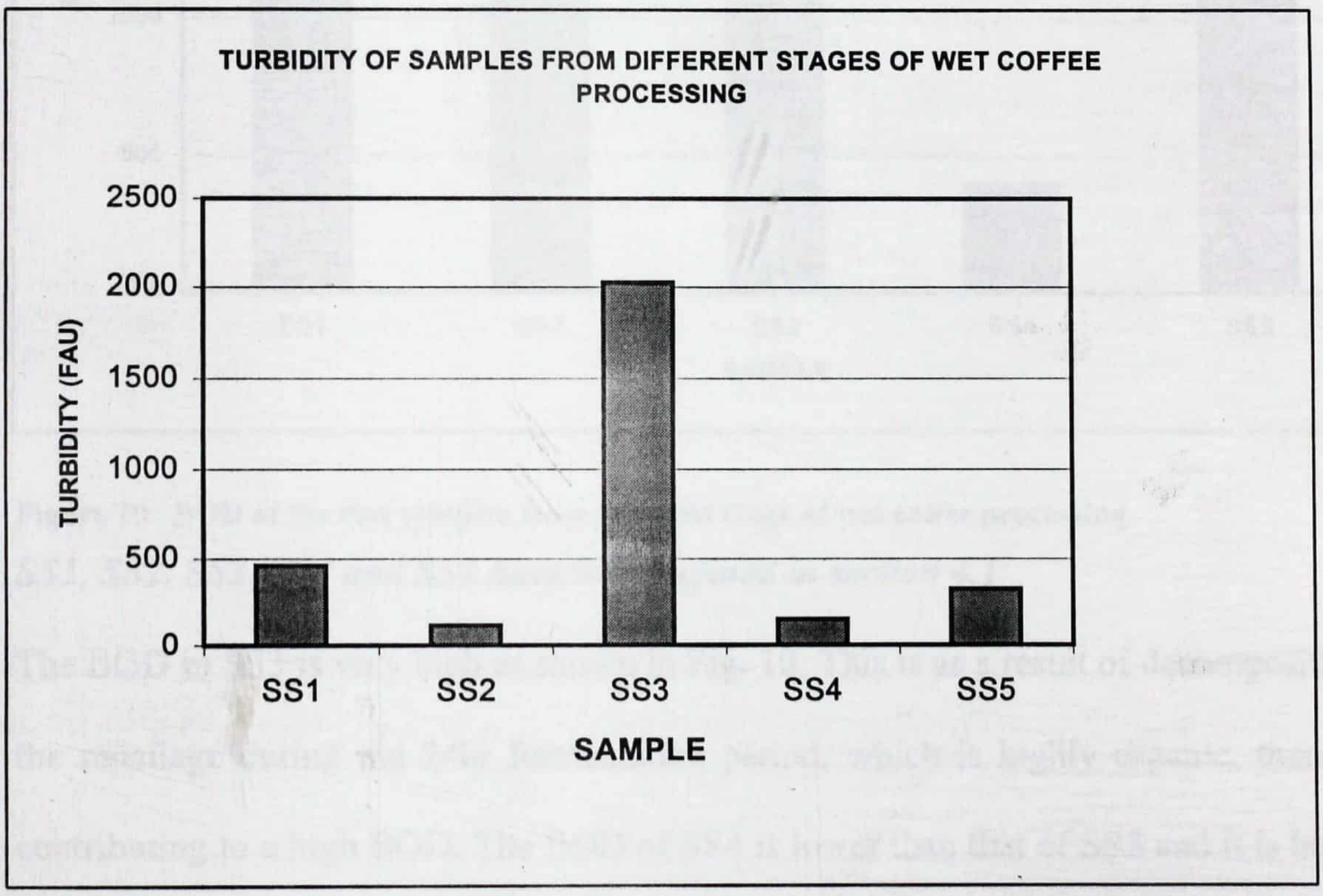



**Figure 9 Turbidity of the raw samples from different stages of coffee processing.**

*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

The turbidity of samples obtained from the pulp during different stages of processing follows the same trend as the suspended solids since turbidity is due to the presence of suspended solids.

### 4.1.4 BOD of the raw samples

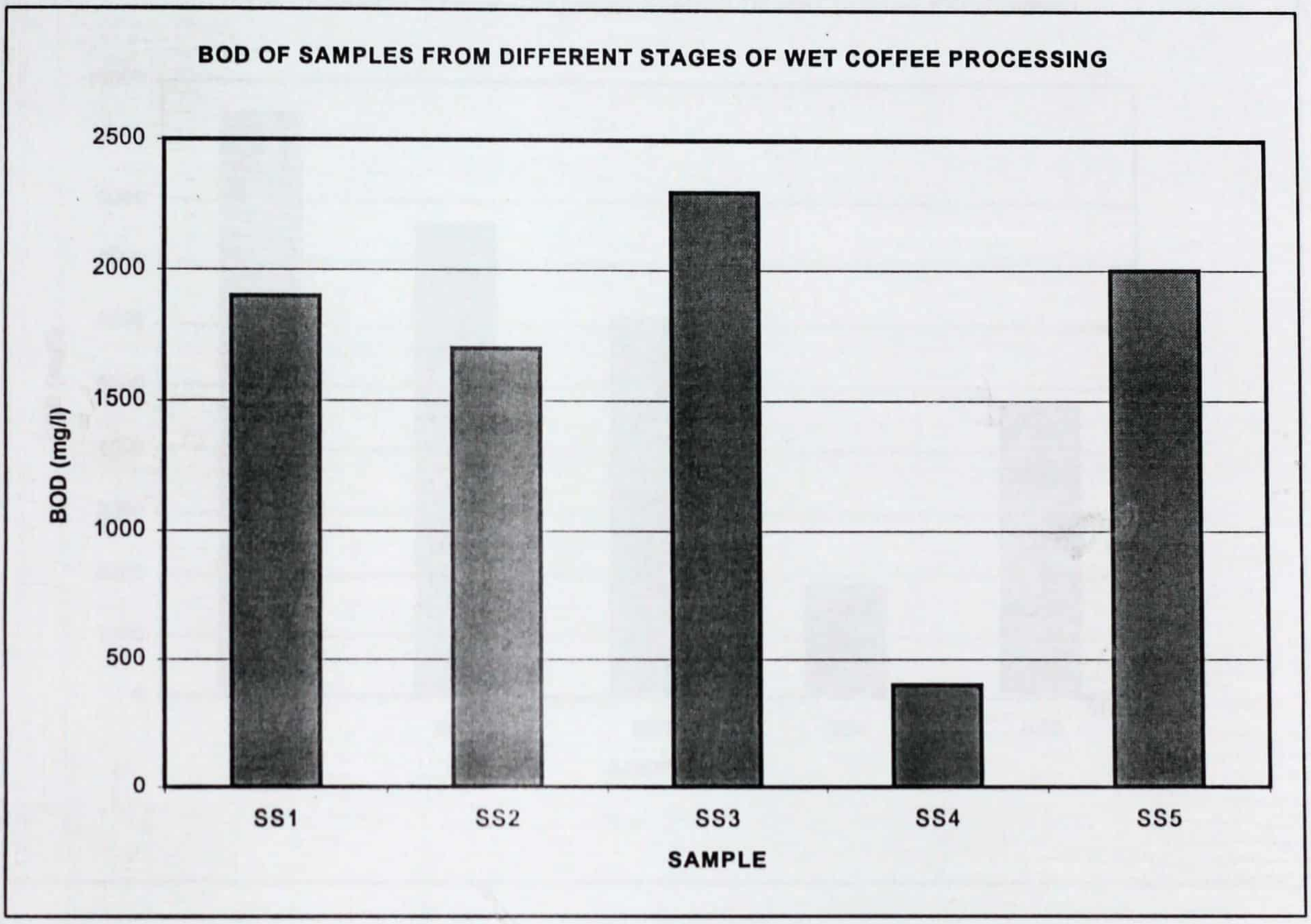



**Figure 10 BOD of the raw samples from different stage of wet coffee processing**

***SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1***

The BOD in SS3 is very high as shown in Fig. 10. This is as a result of decomposition of the mucilage during the 24hr fermentation period, which is highly organic, there fore contributing to a high BOD. The BOD of SS4 is lower than that of SS3 and it is because much of the mucilage that contributes to a high BOD was removed and washed away during the first washing of twenty-four fermentation processes. The BOD of SS5 is due

to the mixture of all the four samples obtained from the four stages of processing and it is lower than that of SS3 because of the dilution from different samples.

### 4.1.5 COD of the raw samples.

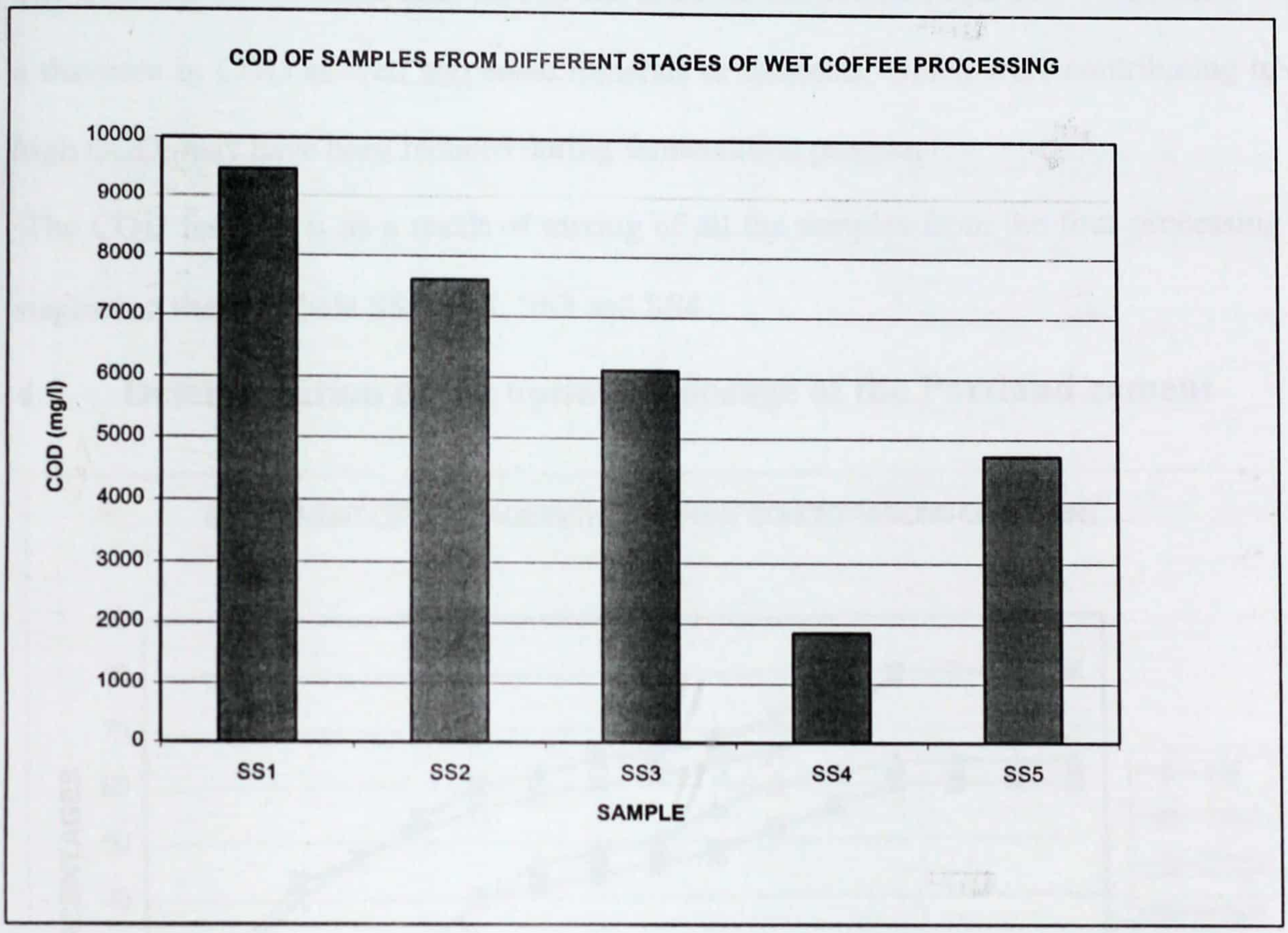



**Figure 11 COD of the raw samples from different stages of wet coffee processing**

*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

The COD of SS1 is very high as shown in Fig. 11. This is because the SS1 is the water from the pulp. The pulp and the hull are very rich in nutrients and minerals such as iron, manganese, phosphorus calcium and magnesium as reported in the literature review. These exert a high COD and require oxygen to be oxidised. (www.coffeeresearch.org , March 2003).

For the SS3 the COD is lower than that of SS1and SS2 because much of the oxygen consumed is utilised in decomposing the organic components of the mucilage. Mucilage degradation is the major activity in SS3.

The COD for SS4 is lower than the rest this is due to the decrease in BOD, which leads to a decrease in COD as well and some minerals or nutrients, which were contributing to high COD, may have been reduced during fermentation process.

The COD for SS5 is as a result of mixing of all the samples from the four processing stages and these include SS1, SS2, SS3 and SS4.

## 4.2 Determination of the optimum dosage of the Portland cement

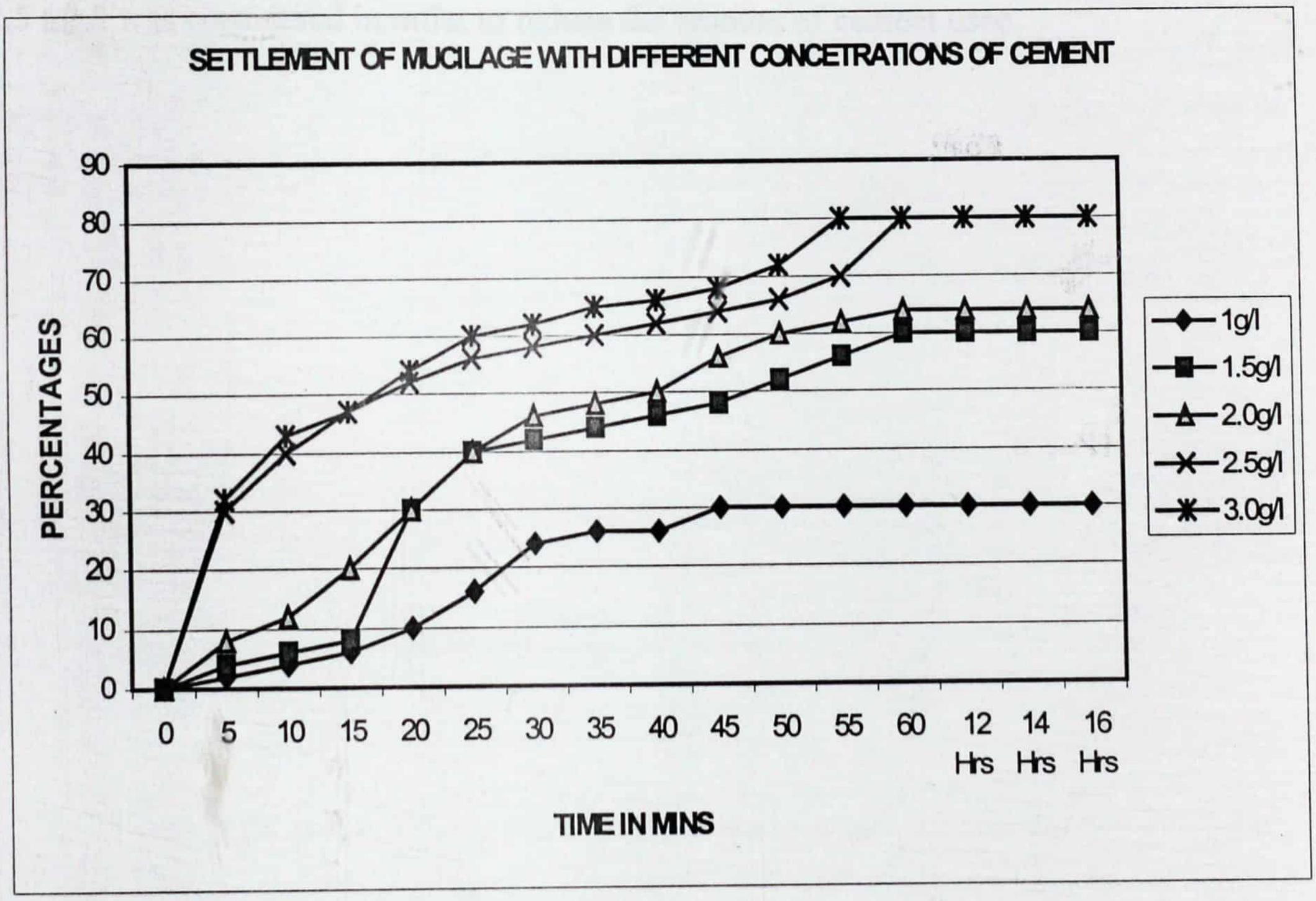



**Figure 12 Settlement of mucilage with different concentrations of cement**

Different concentration of 1, 1.5, 2, 2.5 and 3mg/l were used to determine the optimum dose of cement to sufficiently settle down the mucilage as shown in Fig12. Different concentrations were prepared in the range of 1, 1.5, 2, 2.5 and 3 mg/l these were then dosed in 1 L of the coffee wastewater in five different beakers each containing. The mixture was stirred vigorously and then left to stand. The settlement was then recorded against time and a graph of different concentration plotted against percentage settlement. In Fig, 13, the concentrations of 2.5 and 3mg/l showed a high percentage of mucilage settlement. The 3mg/l reached the maximum of 80% faster than that of 2.5mg/l but however they all attained the same maximum settlement within one hour. An optimum of 2.5 mg/l was considered in order to reduce the amount of cement used.

## 4.3 Variation of pH with different concentrations of cement

**Table 7 variation of pH with different concentration of cement**

| Concentration mg/l | pH |
|---|---|
| 0 | 5.28 |
| 1 | 10.9 |
| 1.5 | 10.98 |
| 2 | 11.03 |
| 2.5 | 11.03 |
| 3 | 11.03 |

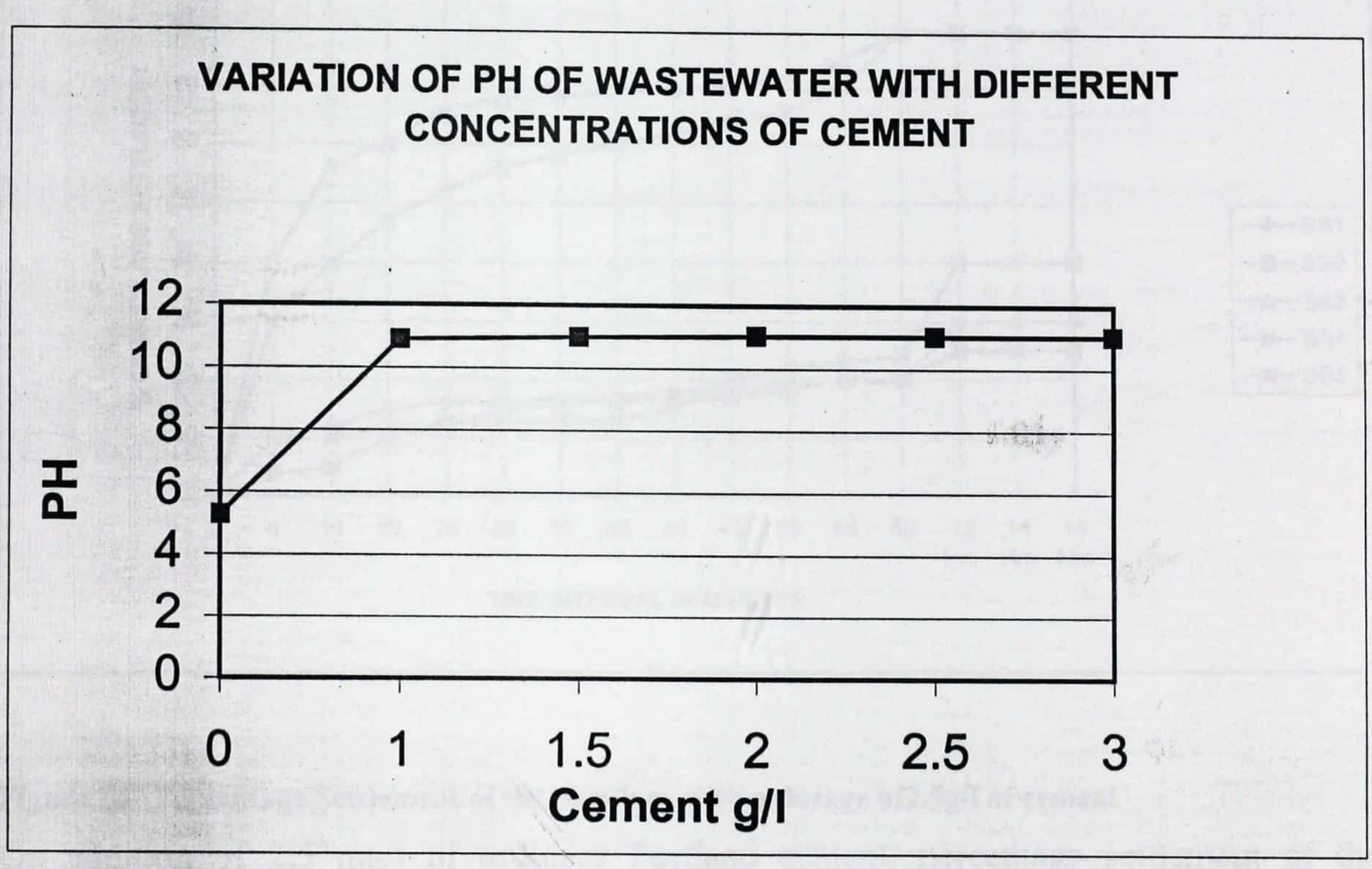



**Figure 13 Variation of pH with different concentration of cement**

The addition of cement had an effect of neutralising the coffee wastewater. On addition of 1g/l of cement there was no mucilage settlement and the pH rose from 5.28 to 10.9, this is because the cement contains lime, which is a basic media. On addition of 2 to 3 g/l of cement the pH remained constant. The efficient settlement of the mucilage was attained at 2.5g/l at a pH of 11.03. However on addition 3g/l of cement the pH remained

the same and at 1.5 to 2g/l the pH is the same so this shows that the settlement of the mucilage does not depend on pH. It instead depends on the concentration of the cement.

## 4.4 Effect of cement on mucilage settlement.

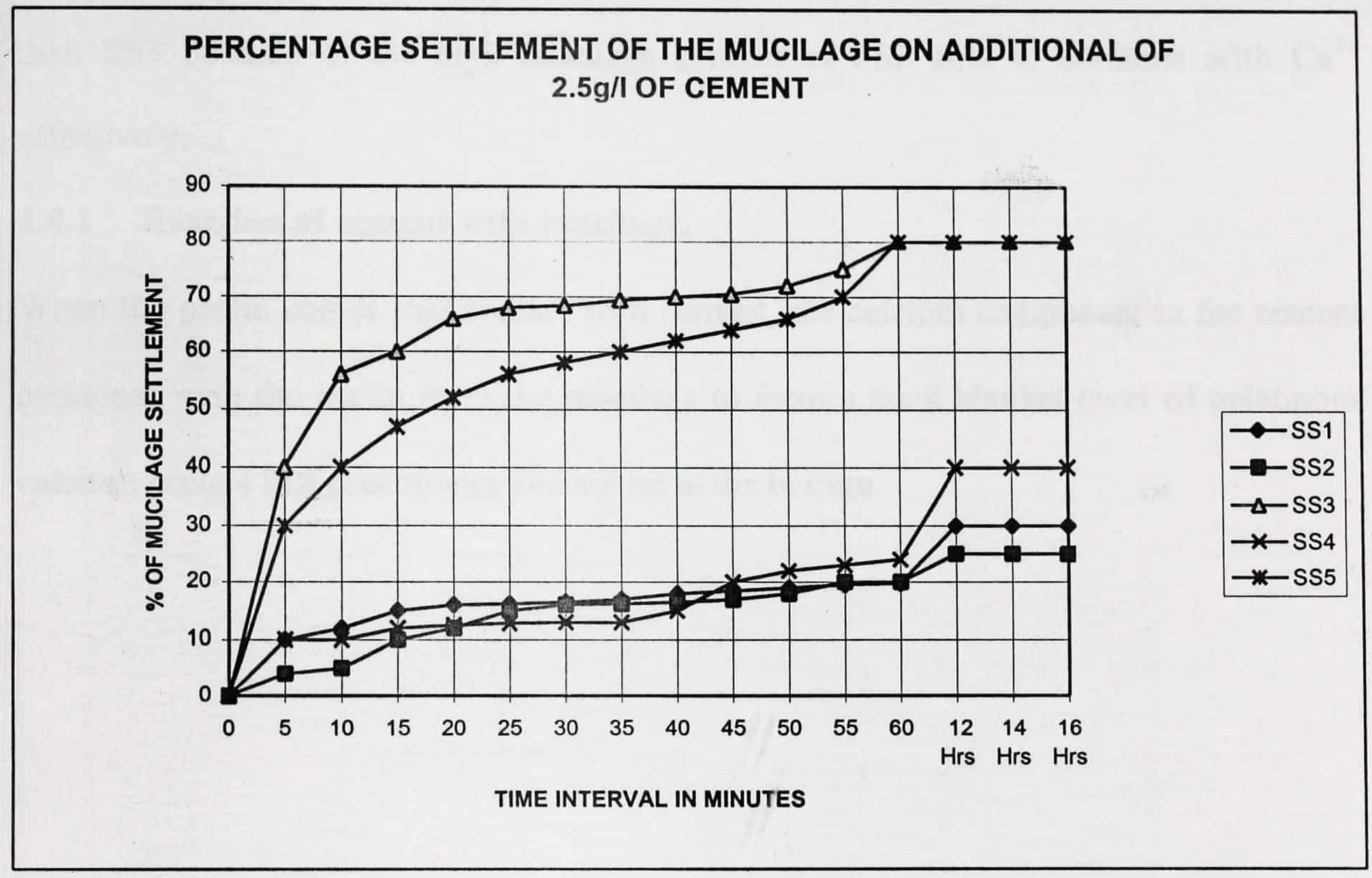



**Figure 14 Percentage Settlement of the mucilage with a dosage of2.5g/l of cement**

On addition of 2.5 mg/l of ordinary Portland cement, percentage settlement of the mucilage against time was determined and a graph plotted as shown in Fig 14.

The characteristics of the curve of SS5 sample shows that the mucilage settlement increases with time and reaches 80 percent within 1 hour. Beyond this point, there was no any more settlement of mucilage. This shows that the cement can remove or settle 80% of mucilage with in a period of one hour. For the curve of SS2, the settlement is slow, this is because the sample of SS2 is grading water which is relatively clean free from mucilage (pectin) which would combine with the $Ca^{2+}$ component in the cement so once the

cement is added, it remains in the suspension since there is no pectin to react with and also other suspended particles remain in solution since there is no calcium pectate formed to settle them out.

For the characteristic curve of SS3, the settlement of the mucilage reaches 70% faster than SS5 because of the high mucilage content of SS3 able to combine with $Ca^{2+}$ effectively.

### 4.4.1 Reaction of cement with mucilage.

When the pectin comes into contact with cement, the calcium component in the cement combines with the pectin from the mucilage to form a thick blanket layer of gelatinous calcium pectate that precipitates and settles at the bottom.

## 4.5 Effect on pH of the supernatant after addition of cement.

**Table 8 Variation of pH after addition of cement.**

| Sample | A | B | C | D | E |
|---|---|---|---|---|---|
| SS1 | 5.47 | 1015 | 9.78 | 8.45 | 6.91 |
| SS2 | 6.68 | 11.23 | 10.52 | 10.22 | 8.27 |
| SS3 | 5.13 | 10.12 | 9.8 | 9.58 | 7.41 |
| SS4 | 6.79 | 11.3 | 10.8 | 10.3 | 7.89 |
| SS5 | 5.28 | 11.03 | 10 | 9.44 | 7 |

**A: Initial pH of the wastewater after processing**
**B: pH after addition of cement**
**C: pH of the supernatant**
**D: pH of the supernatant after standing for 1 day**
**E: pH of the supernatant after standing for three days**

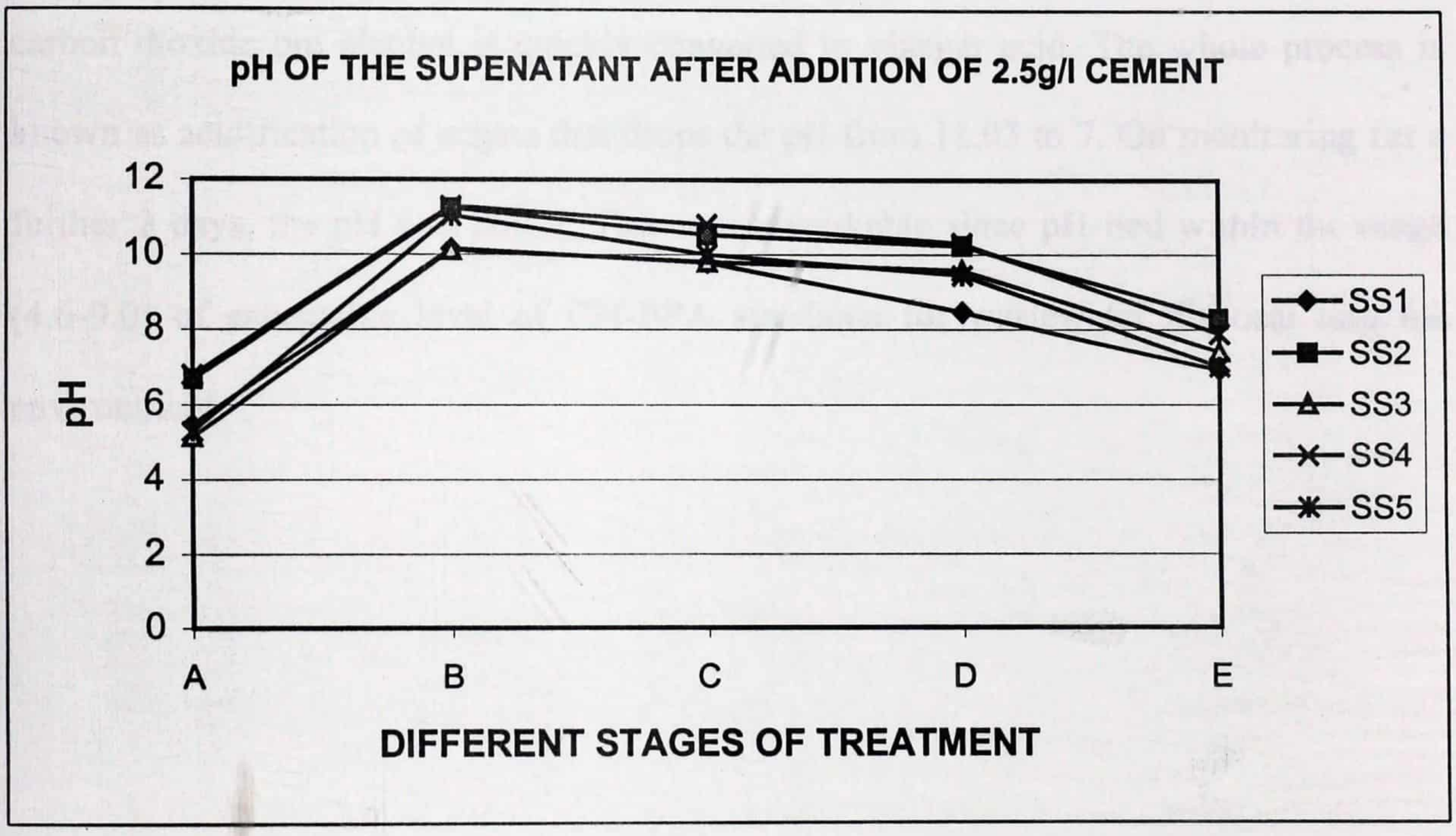



**Figure 15 Effect on pH of the supernatant after addition of 2.5g/l of cement**

### 4.5.1 Variation of pH of SS5 after addition of cement.

The pH of the raw samples of SS5 before addition of cement was 5.25 as shown in Fig 15 and table 8. On dosing with cement, the pH increased to 11 because cement contains lime and makes the media alkaline. After the mucilage has settled, the pH of the supernatant was 10. This pH continued to drop up to a pH of 7 in three days. The pH dropped because coffee wastewater contains pectin and readily fermenting sugars. The sugars undergo acidification process to bring down the pH from 10 to 7. As the calcium from the cement combines with the pectin; a settleable precipitate of calcium pectate is formed. The sugars remain in the supernatant and fermentation continues to take place in the presence of natural yeast present in the coffee cherries. The sugars are fermented to alcohol and carbon dioxide but alcohol is quickly converted to vinegar acid. The whole process is known as acidification of sugars that drops the pH from 11.03 to 7. On monitoring for a further 2 days, the pH was still 7. This was remarkable since pH lied within the range (4.6-9.0) of acceptable level of GH-EPA standards for wastewater disposal into the environment

## 4.6 Characteristics of the effluent after dosing with 2.5g/l of cement

**Table 9 Average results of the effluent after cement treatment**

| Sample | pH | TDS | SS | Turb. | Colour | Cond. | Sal. | Temp. | BOD | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | Pt cobalt | µs/cm | | $^oC$ | mg/l | mg/l | mg/l | mg/l |
| SS1 | 6.95 | 2100 | 71 | 115 | 732 | 2100 | 0.9 | 22 | 912 | 2560 | 0.61 | 7 |
| SS2 | 8.25 | 620 | 0 | 6 | 3 | 620 | 0 | 23 | 300 | 1000 | 0.6 | 2.2 |
| SS3 | 7.41 | 1244 | 80 | 95 | 392 | 1245 | 0.4 | 23.4 | 520 | 700 | 0.69 | 6 |
| SS4 | 7.89 | 662 | 15 | 30 | 16 | 662 | 0.1 | 21.7 | 300 | 968 | 0.73 | 1.7 |
| SS5 | 7 | 964 | 5 | 9 | 97 | 964 | 0.2 | 22 | 620 | 988 | 0.42 | 2.6 |

Cond. = Conductivity
Temp. = Temperature
Sal. = Salinity
*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

### 4.6.1 Effect on BOD after the addition of cement.

After addition of cement there was a remarkable percentage reduction of the BOD

compared to the raw samples

**Table 10 Percentage removal of BOD on addition of cement**

| Sample | BOD mg/l of Raw sample | BOD mg/l after addition of cement | Percentage Removal of BOD |
|---|---|---|---|
| SS1 | 1900 | 912 | 52 |
| SS2 | 1700* | 300 | 82 |
| SS3 | 2300 | 520 | 77 |
| SS4 | 400 | 300 | 25 |
| SS5 | 2000 | 620 | 69 |

* This value seems to be excessively high due to the condition of the initial coffee cherries, which were not fresh.

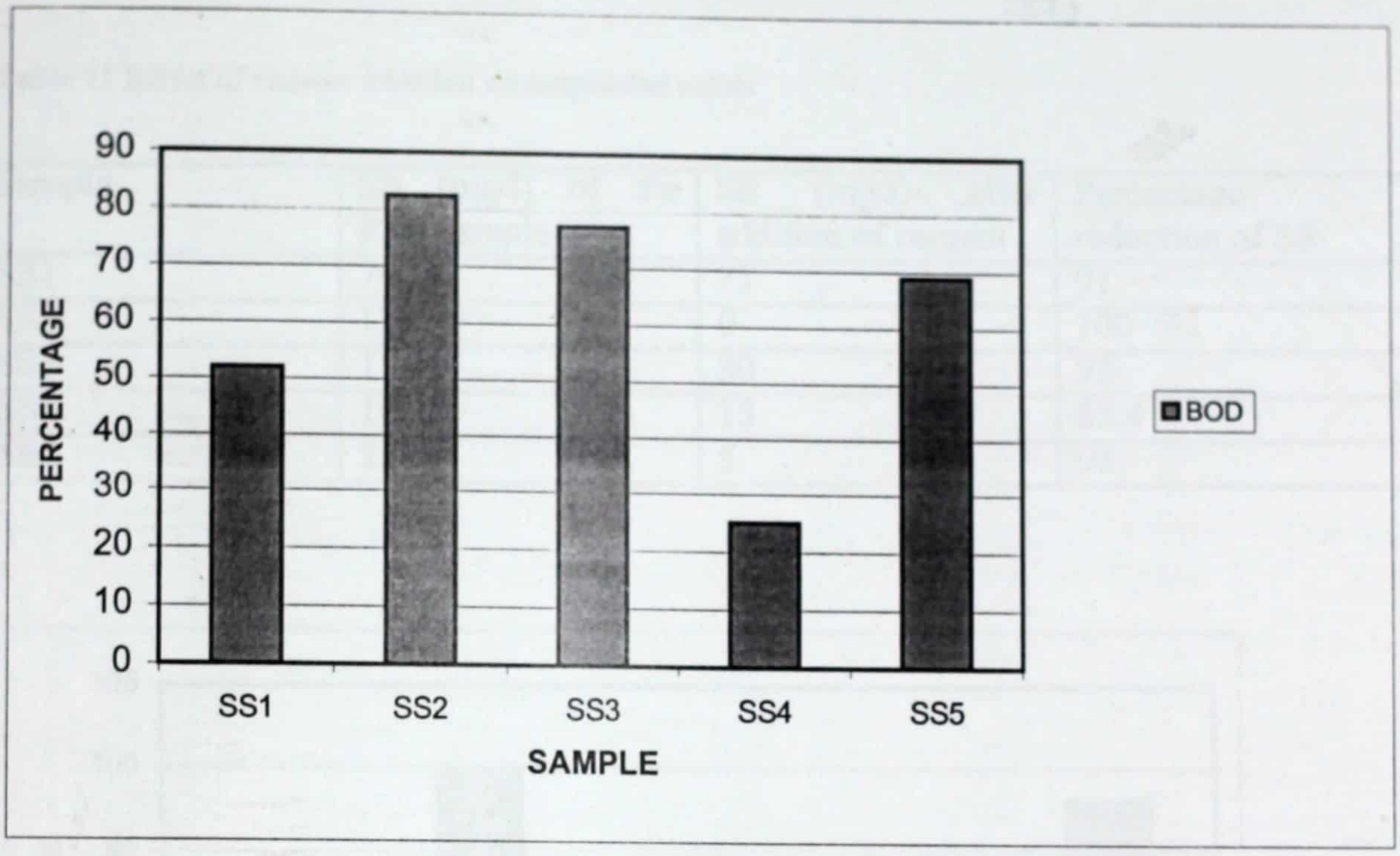



**Figure 16 percentage removal of BOD after addition of cement**

*SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1*

From table 10, the BOD of the raw samples was very high above the required standard, which should be <200mg/l for low strength of coffee wastewater. The BOD range of the raw samples was 400-2300. The BOD of SS5 decreased from 2000 to 620mg/l, which showed a remarkable reduction by attaining a percentage removal of 69% as shown in Figure 16. The reduction of BOD on addition of cement is due to chemical precipitation whereby much of the mucilage (pectin) that contributes to the high BOD reacts with lime (from cement) to form a settleable solid of calcium pectate. According to Metcalf and Eddy (1995) it is possible to remove (50-80) % BOD by chemical precipitation. For this particular sample, 69% BOD removal has been attained by precipitation with cement.

### 4.6.3 Effect on suspended solids after addition of cement.

**Table 11 Effect of cement addition on suspended solids**

| Sample | SS (mg/l) of the Raw sample | SS (mg/l) after addition of cement | Percentage reduction of SS |
|---|---|---|---|
| SS1 | 790 | 71 | 91 |
| SS2 | 139 | 0 | 100 |
| SS3 | 1160 | 80 | 93 |
| SS4 | 103 | 15 | 85.4 |
| SS5 | 256 | 5 | 98 |

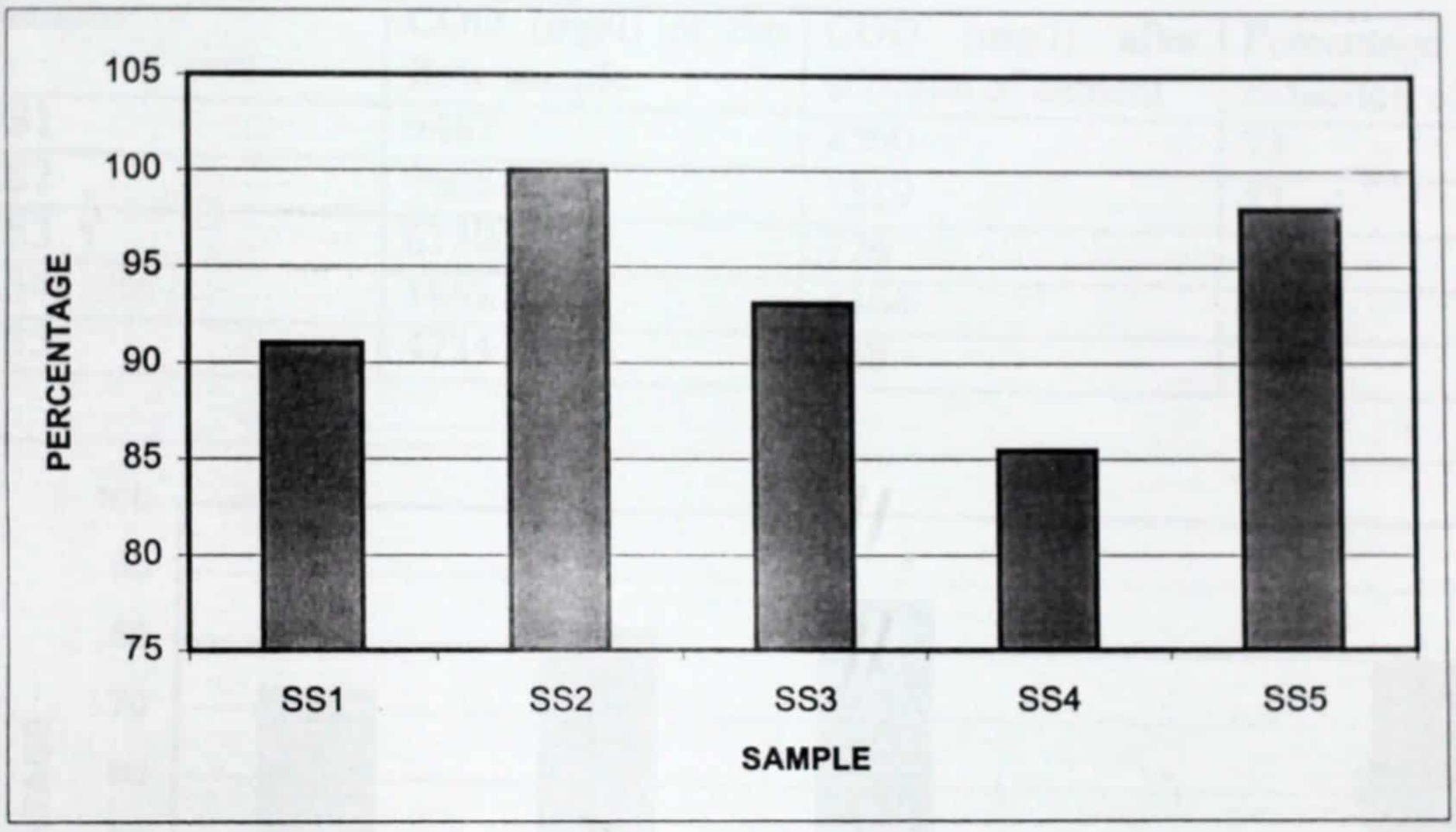



**Figure 17 Percentage removal of Suspended solids**

The suspended solids in the samples obtained from different stages during processing were very high above the GH-EPA standards for wastewater disposal to the environment. The SS3 of the raw sample showed a high value of Suspended solids due to high mucilage concentration in the suspension. On addition of cement, the suspended solids were reduced from 1160 to 80 mg/l attaining a percentage reduction of 93% as shown in table 11 and Fig 17. This was achieved through chemical precipitation process by lime

from the cement. In figure17, 98% for SS5 and 100% for SS2 were achieved. The Suspended solids for SS5 reduced from 250 to 5mg/l, for the SS2, 100% reduction was achieved. These results confirm to the report by Metcalf and Eddy (1995) that 80-90% of suspended solids can be removed by chemical precipitation. The drop in SS is reflected in the results obtained for turbidity monitoring as shown in table 11.

### 4.6.4 Effect on COD after addition of cement.

**Table 12 Effect of cement on COD**

| Sample | COD (mg/l) of the Raw sample | COD (mg/l) after addition of cement | Percentage reduction of COD |
|---|---|---|---|
| SS1 | 9467 | 2560 | 73 |
| SS2 | 7605 | 1319 | 82 |
| SS3 | 6130 | 776 | 87 |
| SS4 | 1862 | 1164 | 38 |
| SS5 | 4734 | 988 | 79 |

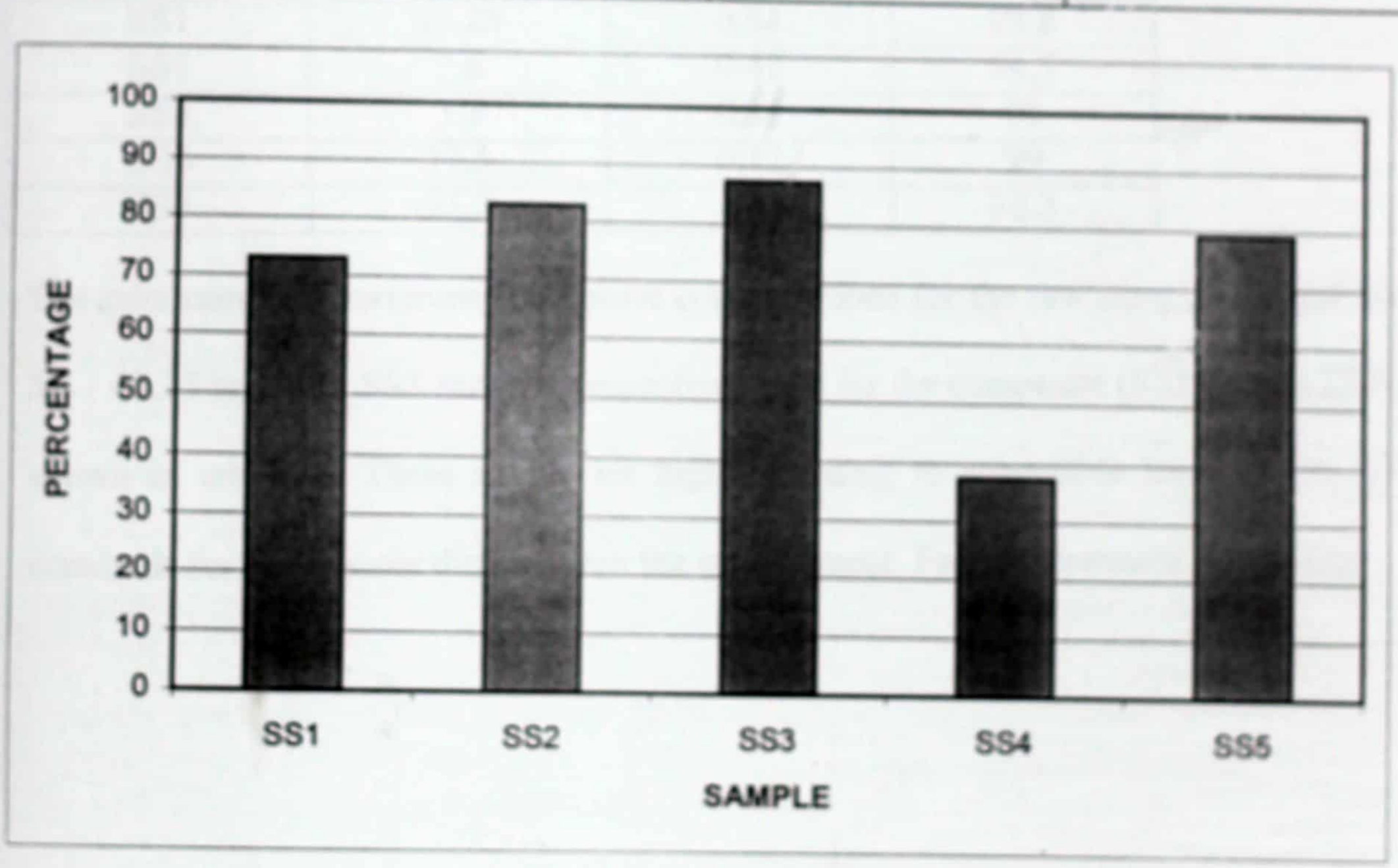



**Figure 18 Percentage removal of COD**

SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1

SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1

The COD range of the samples that were obtained at different stages of processing was from 1862-9467 mg/l as shown in table 12. These were above GH-EPA acceptable level for wastewater disposal. On addition of cement the COD reduced considerably by 79% as shown in Fig 19 i.e. from 4734 to 988 in table 12. However it is still above the maximum acceptable limit for wastewater disposal into the environment so other steps have to be applied to polish the effluent to the required standards of 250mg/l.

### 4.6.5 Effect of cement addition on phosphates

**Table 13 Effect of Cement on Phosphates**

| Sample | $PO_4^{3-}$ (mg/l) of the Raw sample | $PO_4^{3-}$ after addition of cement | Percentage Removal $PO_4^{3-}$ |
|---|---|---|---|
| SS1 | 43.25 | 0.54 | 98.8 |
| SS2 | 7.6 | 0.42 | 94.5 |
| SS3 | 3.3 | 0.33 | 90 |
| SS4 | 17.5 | 0.12 | 99 |
| SS5 | 25.2 | 0.42 | 98.3 |

The minimum and maximum phosphate concentrations for the raw samples ranged from 3.3 - 43.25 mg/l, for SS3 and SS1 respectively and for the composite (SS5) it was 25.2 as shown in table 13. These values are high according to acceptable level of GH-EPA standards for wastewater disposal into the environment. Further treatment is required.

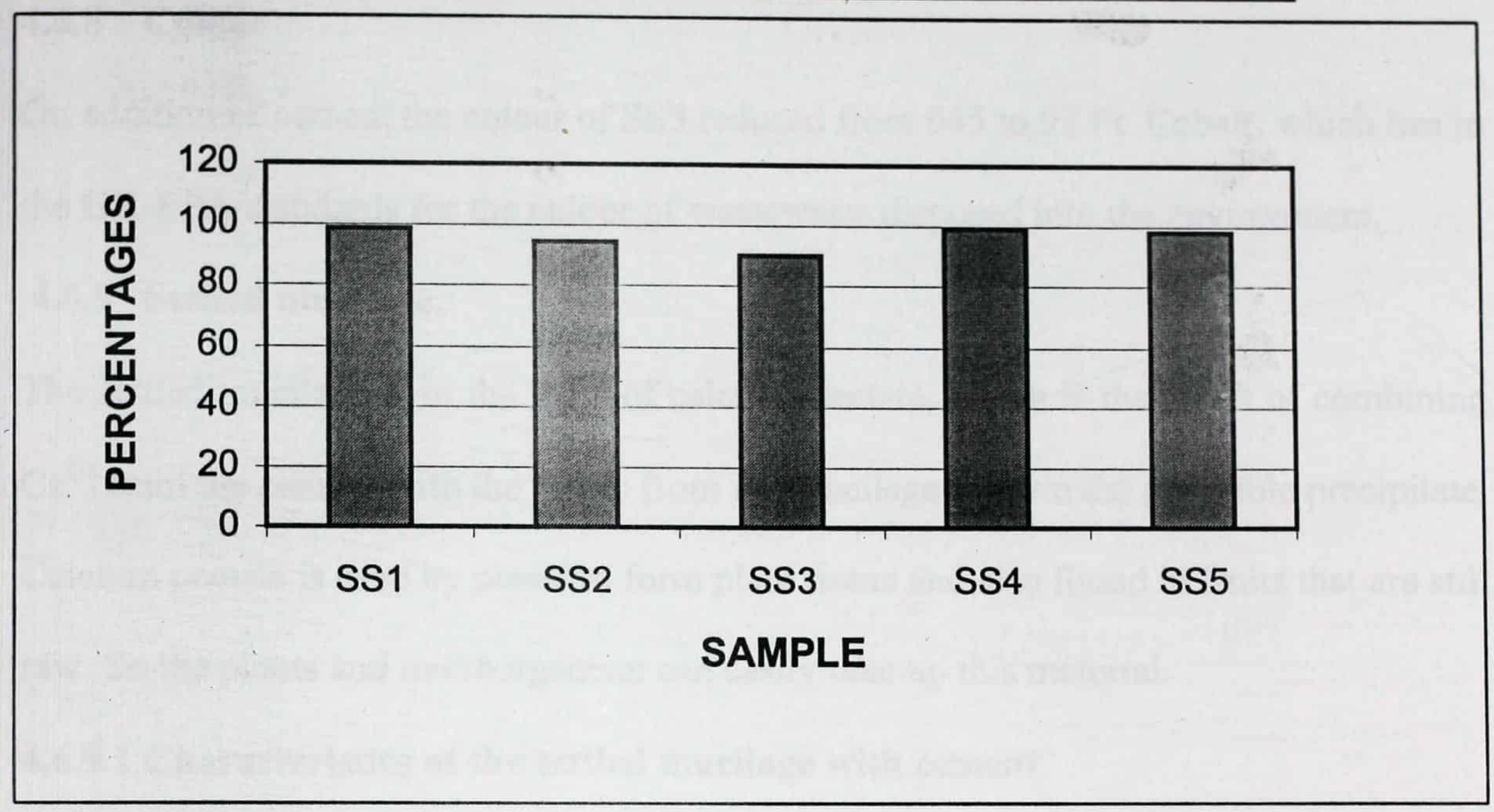



**Figure 19 Percentage removal of phosphates**

SS1, SS2, SS3, SS4 and SS5 have been defined in section 4.1

From Fig 19, there was a remarkable reduction of the phosphates (98.3%) i.e. from 25.2 to 0.42 mg/l. as shown in table 13.

The reduction of phosphate was by chemical precipitation for which according to (Metcalf &Eddy, 1995), is between 70-90 % as reported in the literature review.

When calcium component in the cement combine with phosphate at high pH, a complex precipitate is formed which precipitates out phosphates from the solution. The high pH of about 9 favoured the formation of the insoluble precipitate.

### 4.6.7 Odour

The odour normally associated with fermentation process was reduced appreciably. As the pH of the wastewater became high after dosing with cement, it favoured the removal of soluble ammonia.

### 4.6.8 Colour

On addition of cement the colour of SS5 reduced from 945 to 97 Pt. Cobalt, which lies in the GH-EPA standards for the colour of wastewater disposed into the environment.

### 4.6.9 Settled mucilage.

The settled mucilage is in the form of calcium pectate, which is the result of combining $Ca^{2+}$ from the cement with the pectin from the mucilage to form the settleable precipitate. Calcium pectate is used by plants to form plant tissue and also found in fruits that are still raw. So the plants and microorganism can easily take up this material.

#### 4.6.9.1 Characteristics of the settled mucilage with cement

**Table 14 Characteristics of the Settled Mucilage**

| | |
|---|---|
| Organic Carbon | 10.05 % |
| Organic matter | 17.32 % |
| Total nitrogen | 0.923 % |
| Crude protein | 5.77 % |
| Potassium | 0.148 % |
| (Na) Sodium | 0.170 % |
| Calcium | 25.28 % |
| Magnesium | 38.88 % |
| pH | 8 |

** *These results were obtained from soil science department in the faculty of Agriculture after analysing the settled mucilage.*

From the above results, the settled mucilage had a high content of calcium and magnesium but the essential elements Na and K (potassium) required for the formulation of good fertilizer are relatively in low quantities. With a high organic carbon, organic matter and pH the mucilage could be good soil conditioner for acidic soils. The presence of ions like Ca, Mg, Na, and K would boost the conditioning potential of the mucilage.



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## 4.7 Treatment of the wastewater with yeast

**Table 15 Average results from yeast treatment after two days incubation**

| Sample | pH | TDS | SS | Turb. | Colour | Cond. | Salinity | Temp. | BOD | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | Pt. cobalt | µs/cm | mg/l | $^oC$ | mg/l | mg/l | mg/l | mg/l |
| SS2 | 5.7 | 480 | 31 | 75 | 108 | 482 | 0 | 20 | 800 | 1086 | 1.03 | 4.25 |
| SS3 | 4.4 | 542 | 153 | 186 | 1250 | 542 | 0 | 33 | 1300 | 2086 | 097 | 5.3 |
| SS5 | 4.1 | 538 | 135 | 176 | 1365 | 538 | 0 | 19.6 | 1200 | 4650 | 097 | 10.2 |

***200ml of the sample were seeded with 5ml of the yeast and incubated for 2 days***

**Table 16 Average results from yeast treatment after incubation for 5 days**

| Sample | pH | TDS | SS | Turb. | Colour | Cond. | Salinity | Temp. | BOD | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | Pt. cobalt | µs/cm | mg/l | $^oC$ | mg/l | mg/l | mg/l | mg/l |
| SS2 | 5 | 364 | 199 | 290 | 3130 | 364 | 0 | 20.5 | 200 | 776 | 0.68 | 3.6 |
| SS3 | 4.2 | 542 | 507 | 692 | 1874 | 542 | 0 | 23.2 | 250 | 965 | 0.76 | 5.5 |
| SS5 | 4 | 542 | 454 | 707 | 2900 | 542 | 0 | 20.6 | 400 | 1086 | 0.69 | 11.5 |

***200ml of the sample were seeded with 5ml of the yeast and incubated for 5 days***

Turb. = Turbidity

Cond. = Conductivity

Temp. = Temperature

*SS2, SS3 and SS5 have been defined in section 4.1*

**Table 17 Effect of Yeast on suspended Solids**

**Comparison of suspended solids after seeding with yeast**

| SS | SS | SS | SS |
|---|---|---|---|
| SAMPLE | Raw sample | 2 days | 5 days |
| SS2 | 139 | 31 | 199 |
| SS3 | 1160 | 153 | 507 |
| SS5 | 256 | 135 | 454 |

## 4.7.1 Removal of suspended solid by yeast

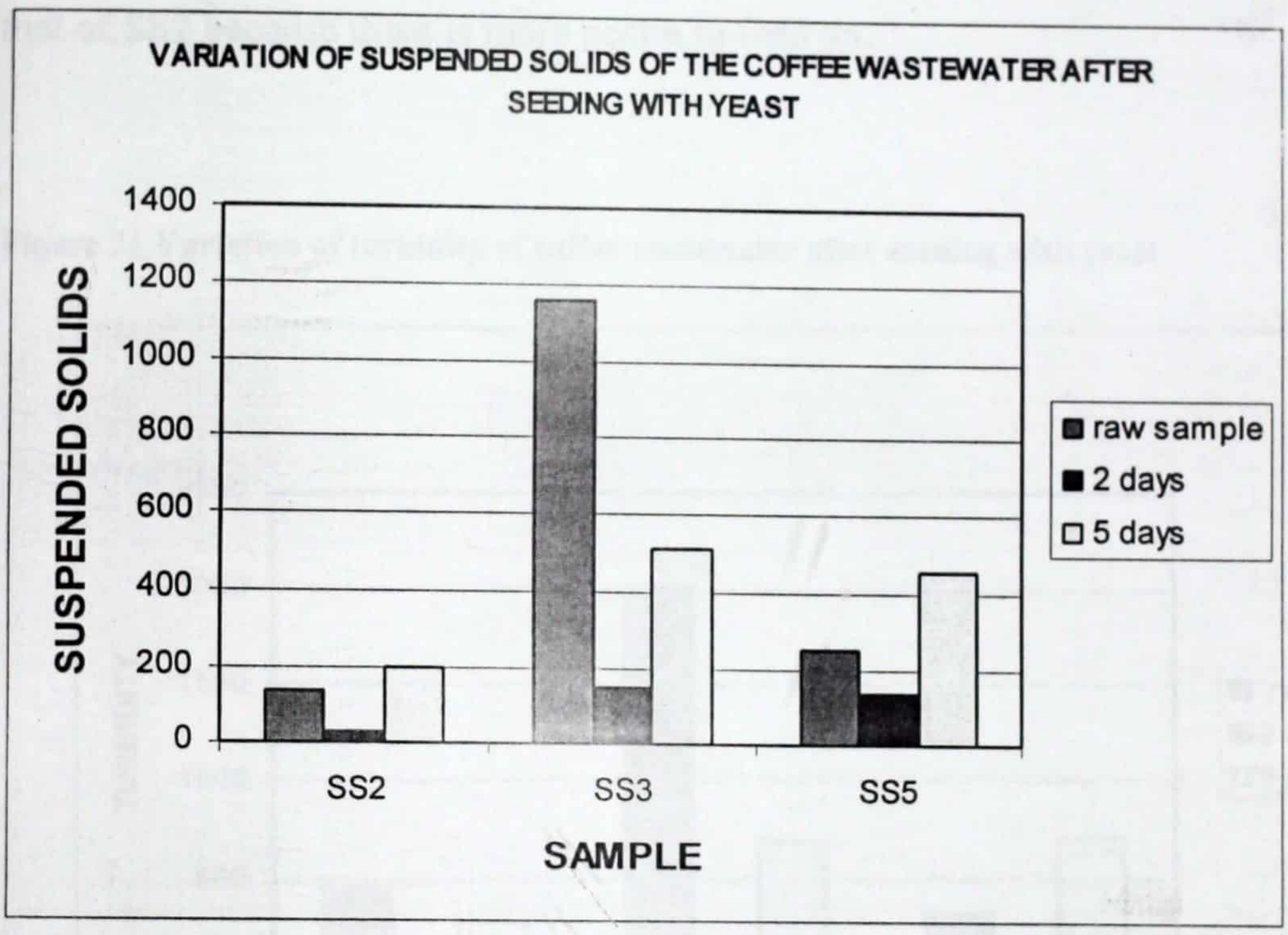


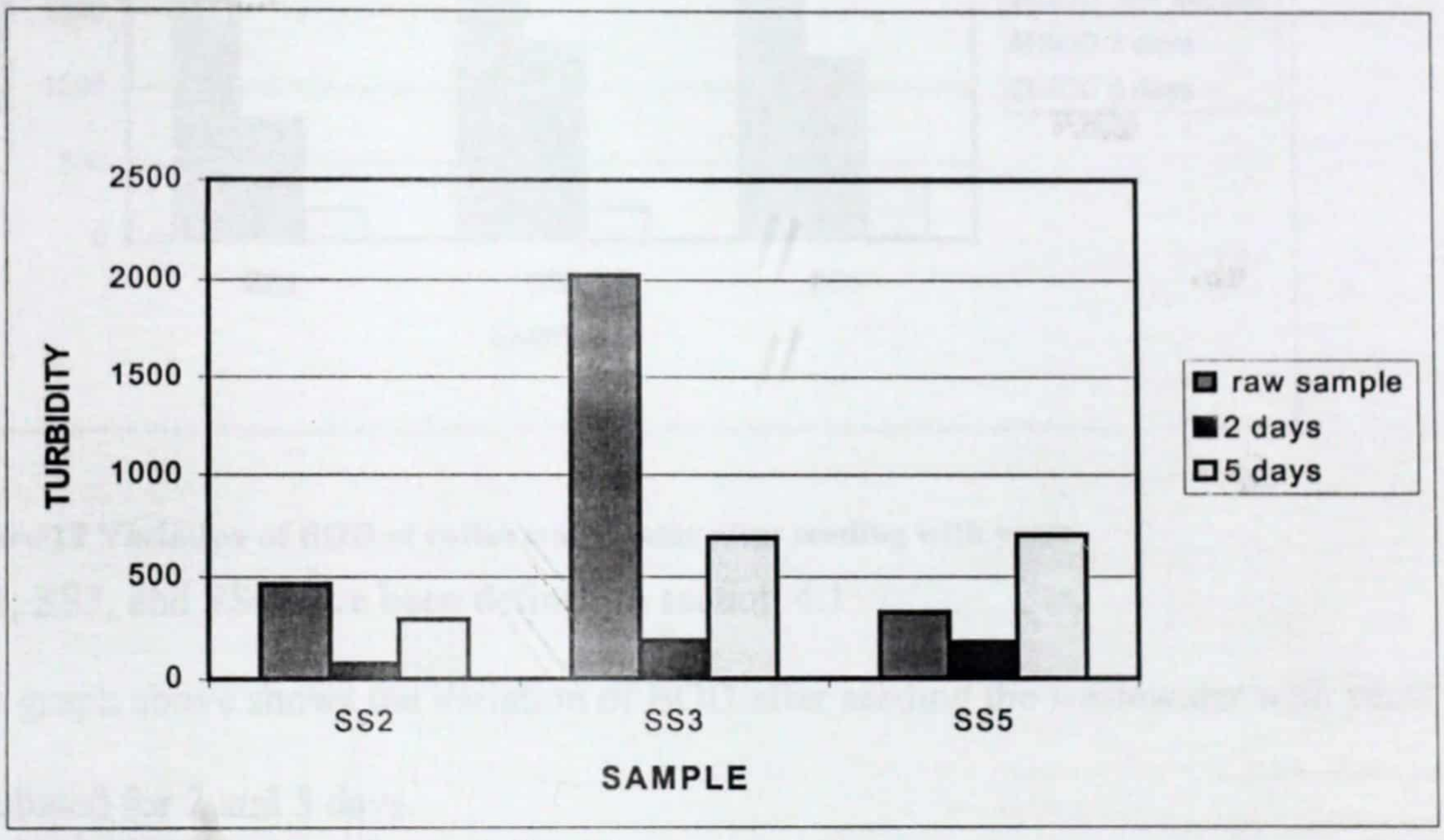

**Figure 20 Variation of suspended solids of coffee wastewater after seeding with yeast**

SS2, SS3, and SS5 have been defined in section 4.7

The graph above shows the variation of suspended solids after seeding the wastewater with yeast and incubated for 2 and five days. The suspended solid in the coffee wastewater are merely made of pectin on which the yeast cells feed. As the yeast cells are introduced in the samples, they are able to break down and feed on the pectin, which is part of the mucilage. From SS2, there are very few suspended solids which have been

reduced after two days but within five days, the suspended solids increases this is also reflected on turbidity as shown in table 16 and 17. This increase is due to the in yeast biomass resulting from the utilisation of the dissolved nutrients for survival and reproduction. For SS3, the mucilage is more compared to the rest and the suspended solids after 5 days are more than the rest because there is more mucilage or pectin on which yeast cells could feed and grow more in numbers. This is also reflected on turbidity as shown in Fig.21, For SS5 it follows the same reasoning and it is higher than that of SS2 because there is more pectin to feed on.

**Figure 21 Variation of turbidity of coffee wastewater after seeding with yeast**




SS2, SS3, and SS5 have been defined in section 4.7

### 4.7.2 Removal of BOD by treating the wastewater with yeast

**Table 18 Effect of Yeast on BOD**

**Comparison of BOD solids after seeding with yeast**

| BOD (mg/l) | BOD (mg/l) | BOD (mg/l) | BOD (mg/l) |
|---|---|---|---|
| Sample | Raw sample | 2 days | 5 days |
| SS2 | 1900 | 800 | 200 |
| SS3 | 2300 | 1300 | 200 |
| SS5 | 2000 | 1200 | 400 |

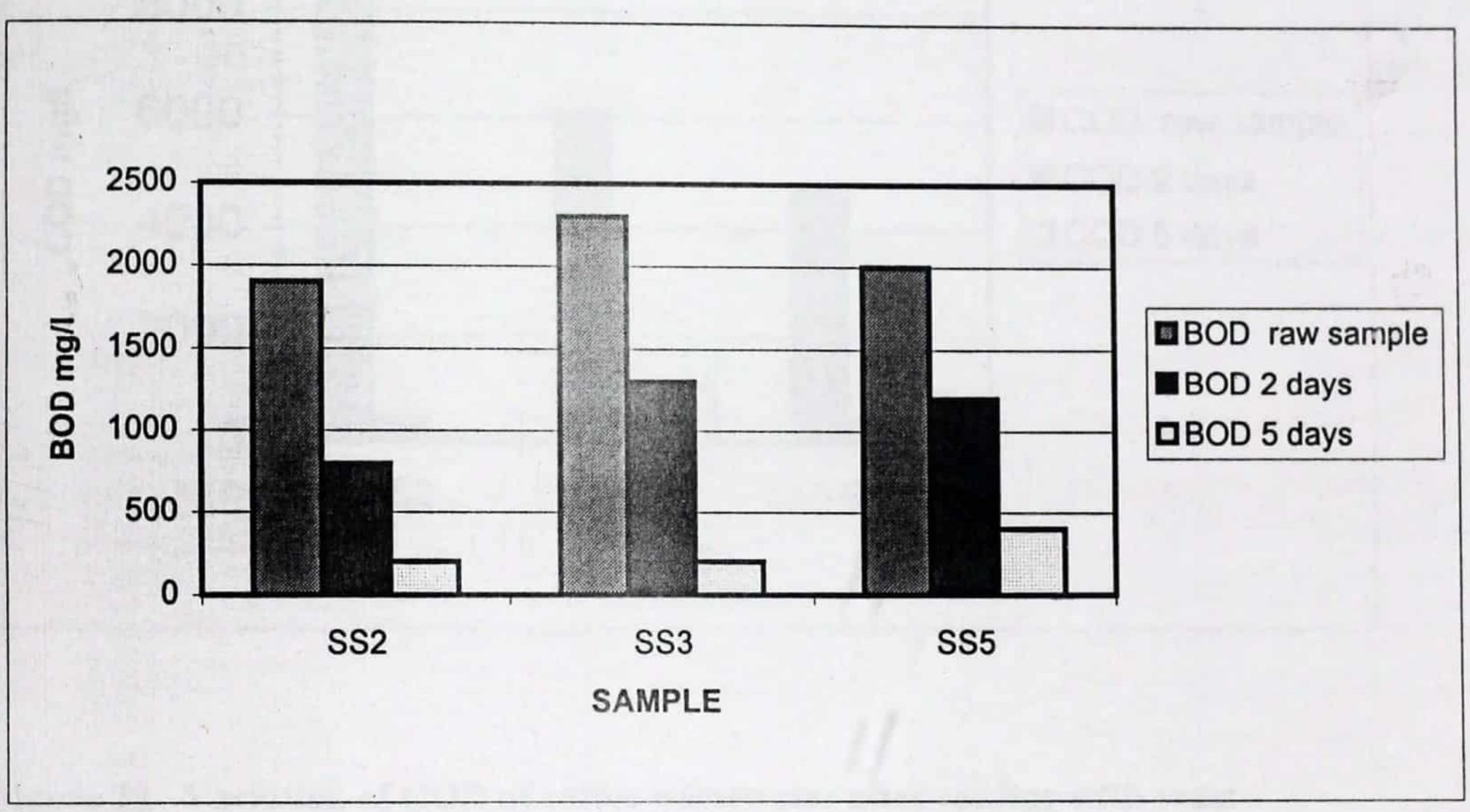



**Figure 22 Variation of BOD of coffee wastewater after seeding with yeast**

SS1, SS3, and SS5 have been defined in section 4.1

The graph above shows the variation of BOD after seeding the wastewater with yeast and incubated for 2 and 5 days.

The BOD of SS5 reduced significantly because the yeast cells have degraded the mucilage, which significantly contributes to the high BOD.

### 4.7.3 Removal of COD by treating the wastewater with yeast

**Table 19 Effect of yeast on COD**

**Comparison of COD solids after seeding with yeast**

| COD (mg/l) | COD (mg/l) | COD (mg/l) | COD (mg/l) |
|---|---|---|---|
| Sample | Raw sample | 2 days | 5 days |
| SS2 | 9467 | 465 | 77.6 |
| SS3 | 6130 | 1086 | 1086.4 |
| SS5 | 4734 | 465 | 965.6 |

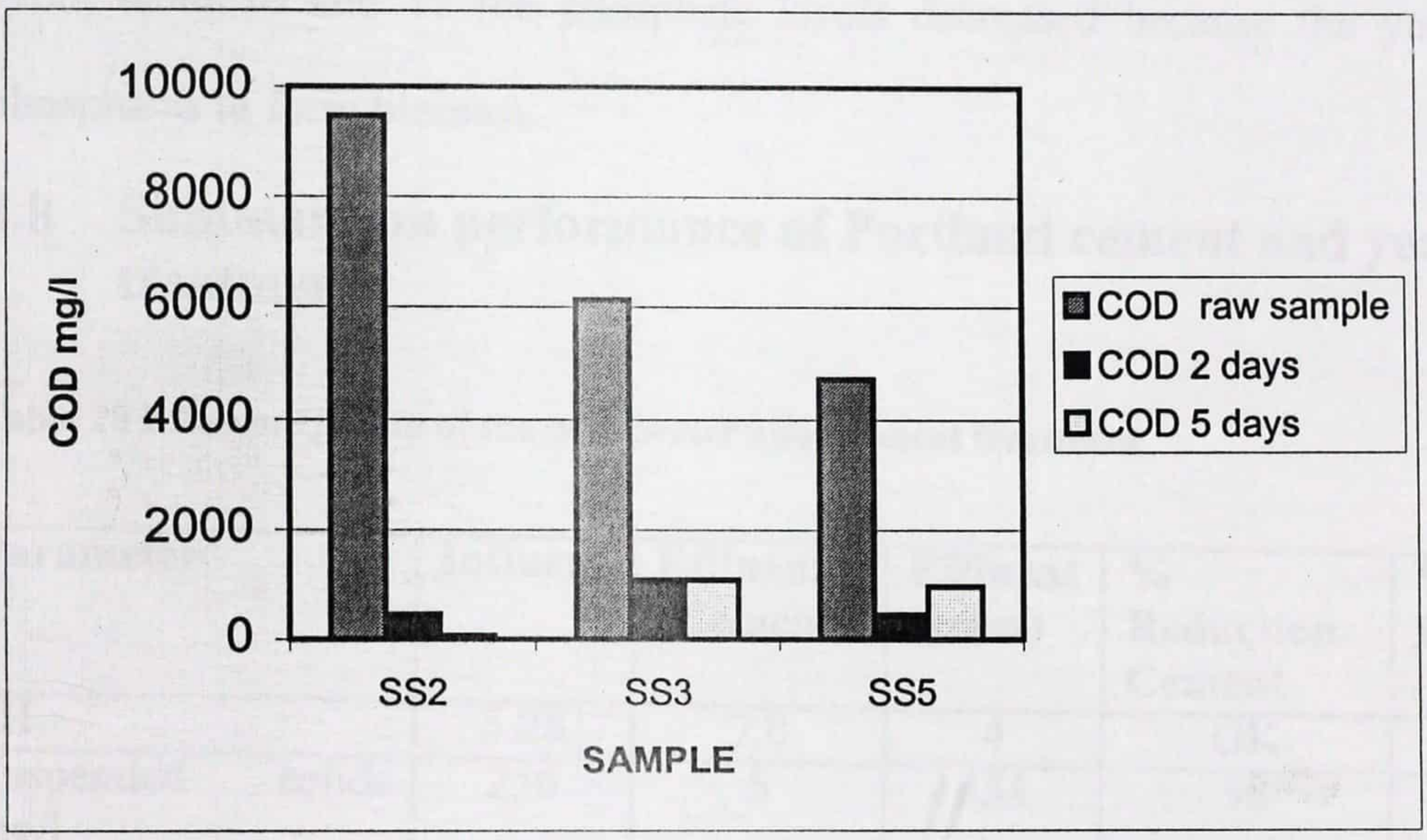



**Figure 23 Variation of COD of coffee wastewater after seeding with yeast**

SS1, SS3, and SS5 have been defined in section 4.7

The COD of the samples as shown in Fig. 23, reduced after seeding the wastewater with yeast and incubated for 2 and 5 days. This is because much of the high COD contributions, which can be broken down by chemical means, are from the resistant organic materials in the wastewater, such as acids. When the yeast is introduced, it feeds on sugars and mucilage that contributes to the high COD.

### 4.7.4 Effect of yeast on pH, phosphates and nitrates

After seeding the wastewater with yeast and incubated for 2 and 5 days, the pH of the samples decreased because the sugars in the wastewater ferment to alcohol in the presence of yeast. However, the alcohol is quickly converted to acetic acid. This contributes to the lowering of pH as shown in table 16 and 17.

From table 16 and 17 the phosphate levels decreased because the yeast utilises the phosphates to form biomass.

## 4.8 Summary on performance of Portland cement and yeast treatment.

**Table 20 Effluent Quality of the wastewater after cement treatment**

| Parameter | Influent | Effluent (Cement) | Effluent (yeast) | % Reduction Cement | % Reduction (Yeast) | GH-EPA guidelines |
|---|---|---|---|---|---|---|
| pH | 5.28 | 7.0 | 4 | OK | | 4.5-9 |
| Suspended solids mg/l | 256 | 5 | 454 | 98 | -77 | 50 |
| Turbidity FAU | 324 | 9 | 707 | 97 | -118 | 75 |
| Colour (pt. Cobalt) | 845 | 97 | 120 | 89.7 | 86 | 200 |
| BOD mg/l | 2000 | 620 | 400 | 69 | 80 | 50 |
| COD mg/l | 4734 | 988 | 465 | 79 | 90 | 250 |
| $PO_4^{3-}$ mg/l | 25.2 | 0.42 | 3 | 98 | 88 | 1 |
| $NO_3^{2-}$ mg/l | 4 | 2.6 | 7 | 35 | -75 | 0.1 |
| Salinity | 0 | 0.2 | 0.1 | - | - | - |
| TDS mg/l | 532 | 964 | 575 | -81 | 29.32 | 50 |
| Conductivity (s/cm) | 533 | 964 | 575 | -81 | 29.46 | 750 |

### 4.8.1 Raw samples

The characteristics of the wastewater from the raw samples apart from pH were high and exceeded the acceptable level of EPA standards for the wastewater disposal into the environment.

### 4.8.2 Mucilage removal.

For the effective removal of the mucilage to be faster, the composite effluent must be thoroughly mixed after cement dosing to enhance the reaction between the $Ca^{2+}$ component in the cement and the pectin in the mucilage to be able to form a settleable precipitate (calcium pectate). This will also help to reduce the size of the sedimentation tank.

### 4.8.3 pH.

The pH of the effluent after dosing with cement and left to settle meets the required standards of GH-EPA for wastewater disposal.

### 4.8.4 Suspended solids.

The dosing of the wastewater with cement removed 98% of the suspended solids by means of chemical precipitation. The suspended solids of SS2 (grading water) are low this is because the grading water is relatively clean and can be re-circulated back to the de-pulping process in order to reduce the quantity of the wastewater generated hence reducing the cost of treatment.

### 4.8.5 Turbidity.

The addition of the cement to the wastewater reduced the turbidity by 97% there by conforming to acceptable level of GH-EPA standards for wastewater disposal.

### 4.8.6 BOD.

By dosing with cement, BOD removal of 69 percent was achieved. A BOD of 50-80% can be achieved. This shows a positive progress in the BOD reduction. However, further treatment is required to attain the acceptable level of GH-EPA standards for wastewater disposal into the environment.



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### 4.8.7 COD

The 79% COD removal attained after the dosing is remarkable. But the value is still above the of GH-EPA standards for wastewater disposal. So further treatment has to be considered to bring down the value to the required GH-EPA standard.

### 4.8.8 Phosphates.

The addition of cement reduced the phosphates by 98% (from 25.2 to 0.42 mg/l) through chemical precipitation to the acceptable level of GH-EPA standards for wastewater disposal.

## 4.9 Conclusions and recommendations on Performance of yeast and Portland cement

- The yeast treatment performed well in reducing BOD and COD. However it increased Suspended Solid and turbidity.
- Yeast has to be removed from the treated effluent before it is discharged into the environment and this is very expensive since it requires in- activation by autoclaving.
- The effluent quality after dosing with cement is good considering the pH, SS, Turbidity, colour, Phosphates, and odour all conformed to the required standards of GH-EPA for wastewater discharge into the environment. However, there is a need for subsequent treatment to reduce high BOD, COD, TDS and conductivity.
- The settled mucilage can be applied to acidic soils to increase their pH since the mucilage has a high pH. However, the application of the mucilage as a soil conditioner and fertilizer has to be further investigated by Agronomist.

A cheap and simple means of disposal of yeast has to be investigated further before it can be used as a treatment method for coffee wastewater.

From the analysis carried out, dosing of wastewater with cement is the recommended treatment method and thus the treatment design that follows will be based on the cement dosing method.

Part of the grading water (30%) will be re-circulated back to the de-pulping machines for de-pulping and also to make the cement solution used for dosing. The 60% will be left to join the rest for the treatment and also to dilute the strength of wastewater from fermentation and de-pulping processes. There will be two pumps (one is on standby) for pumping the water from the re-circulation tank back to the pulping machines.

# 5.0 DESIGN OF THE TREATMENT PLANT.

In this chapter, a treatment plant is designed based on the effluent quality characteristics of the wastewater from the coffee processing plant.

The effluent from cement treatment showed that BOD, COD, TDS and DO were above the GH-EPA standards and needed further treatment.

Different alternatives for secondary treatment of the effluent after the cement treatment were investigated.

The alternatives that were investigated after cement treatment are;

- Aeration process
- Anaerobic process
- Anaerobic + Aeration

## 5.1 Secondary Treatment alternatives for the effluent from cement treatment.

### 5.1.1 Anaerobic treatment.

The effluent after cement treatment was subjected to anaerobic conditions and the results were obtained as shown in table 21 and 22

**Table 21 Results from Anaerobic process**

| Parameter | Raw sample | Effluent after cement treatment | 2days | 6days | 8 days |
|---|---|---|---|---|---|
| pH | 5.28 | 10.89 | 7.16 | 6.68 | 6.5 |
| Conductivity µs/cm | 533 | 964 | 900 | 904 | 941 |
| TDS (mg/l) | 533 | 964 | 900 | 904 | 941 |
| BOD (mg/l) | 2000 | 620 | 247 | 234 | 179 |
| COD (mg/l) | 4734 | 988 | 843 | 442 | 367 |
| Temp °C | 27.1 | 28.3 | 26.8 | 26.2 | 26.9 |
| DO (mg/l) | 0.07 | 1.51 | 0.14 | 0.11 | 0 |
| Salinity | 0 | 0.3 | 0.1 | 0.2 | 0.2 |

**Table 22 Variation of BOD and COD under anaerobic process**

| Time in days | DO mg/l | BOD mg/l | COD (mg/l) | % Red. BOD | % Red. COD |
|---|---|---|---|---|---|
| 0 | 1.51 | 620 | 988 | 0 | 0 |
| 2 | 0.14 | 247 | 843 | 60 | 15 |
| 6 | 0.11 | 234 | 442 | 62 | 55 |
| 8 | 0 | 179 | 367 | 71 | 63 |

Red. = Reduction

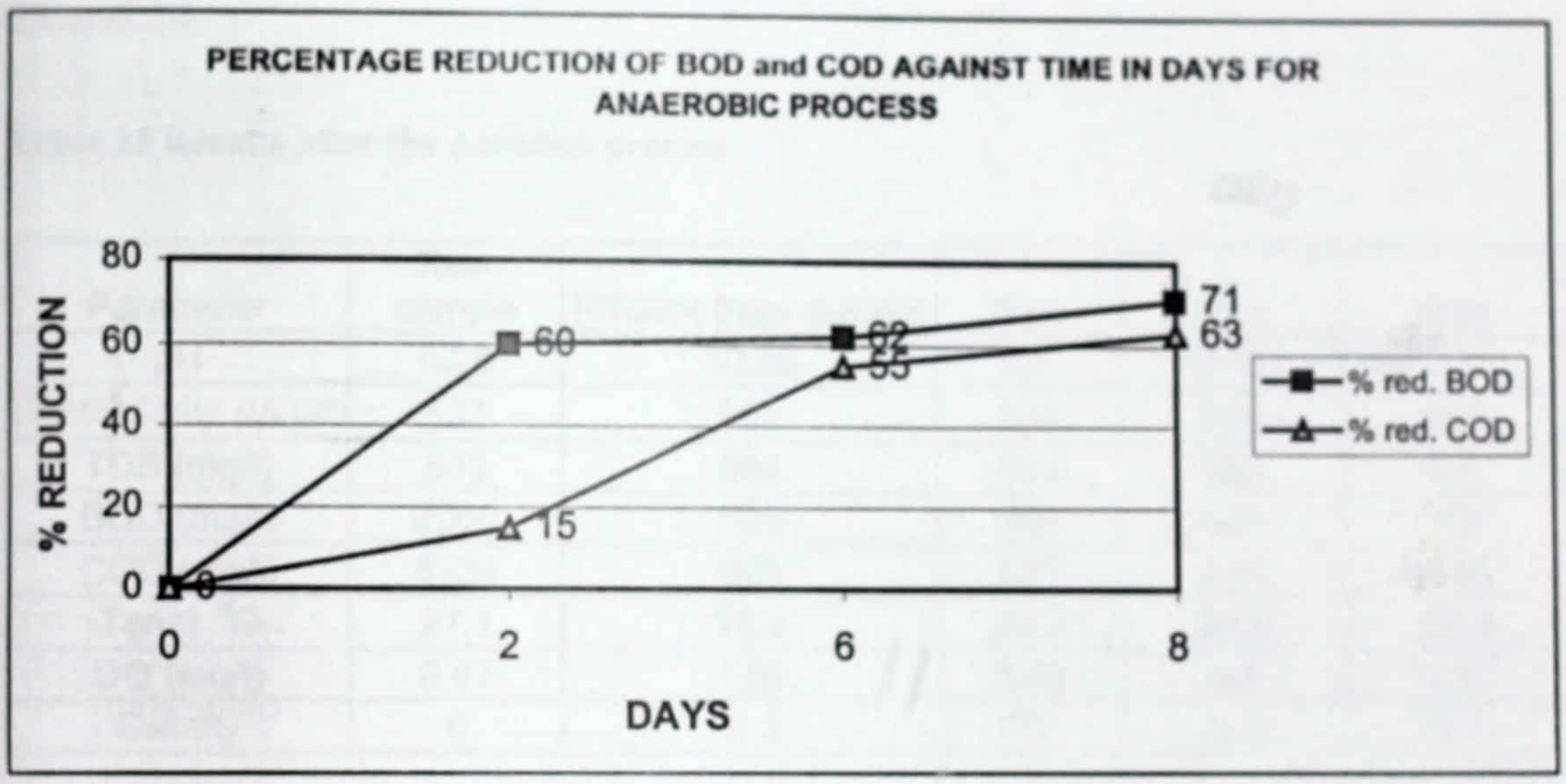



**Figure 24 Percentage Reduction of COD and BOD against time for alternative one**

From Fig.24, the BOD was reduced after 8 days, by 71%. The reduction within two days is intensive by 60 % and slows down gently after. This is because the organic matter is being digested by both anaerobes and aerobes. The aerobes use the little available oxygen of 1.15 mg/l after cement treatment. The two processes contributed to the faster rate of BOD reduction within two days. After two days, the oxygen is used up and the conditions turn to completely anaerobic digestion. This also applies to COD curve for the reduction of 63 %. Using anaerobic treatment option, the BOD and COD are still high and do not meet the acceptable level of GH-EPA standards.

From table 22, the dissolved oxygen was reduced to zero after 8 days because the microorganisms use up all the oxygen to break down the organic matter present in the wastewater.

### 5.1.2 Aeration treatment.

The effluent from cement treatment process was aerated for ten hours and DO, BOD, COD, pH TDS were taken at two-hour interval. The results obtained are shown in table 23 and 24.

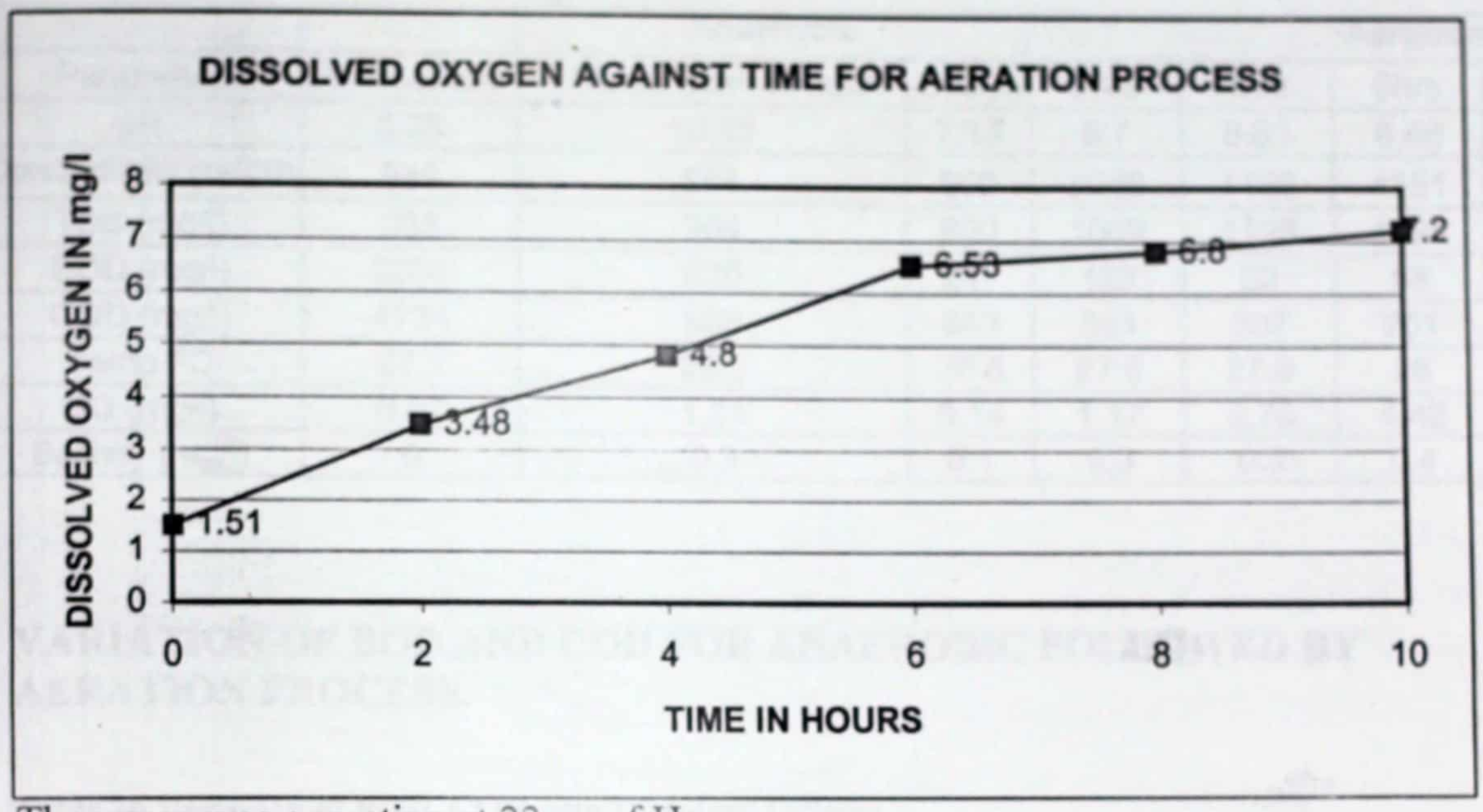
**Table 23 Results after the Aeration process**

| Parameter | Raw sample | Effluent from cement | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|---|
| pH | 5.28 | 10.89 | 9.7 | 8.62 | 7.2 | 7.3 | 7.1 |
| Conductivity µs/cm | 533 | 964 | 914 | 952 | 952 | 960 | 965 |
| TDS (mg/l) | 533 | 964 | 914 | 952 | 952 | 960 | 965 |
| BOD (mg/l) | 2000 | 620 | 400 | 386 | 289 | 250 | 200 |
| COD (mg/l) | 4734 | 988 | 653 | 614 | 345 | 300 | 260 |
| Temp °C | 27.1 | 28.3 | 26.3 | 26.8 | 27.4 | 28.4 | 28.6 |
| DO (mg/l) | 0.07 | 1.51 | 3.48 | 4.8 | 6.53 | 6.8 | 7.2 |
| Salinity | 0 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

**Table 24 Results for the Variation of BOD and COD for aeration process**

| Time in Hrs | DO mg/l | BOD mg/l | COD (mg/l) | % Red. BOD | % Red. COD |
|---|---|---|---|---|---|
| 0 | 1.51 | 620 | 988 | 0 | 0 |
| 2 | 3.48 | 400 | 653 | 35 | 34 |
| 4 | 4.8 | 386 | 614 | 38 | 38 |
| 6 | 6.53 | 289 | 345 | 53 | 65 |
| 8 | 6.8 | 250 | 300 | 60 | 70 |
| 10 | 7.2 | 200 | 260 | 68 | 73 |

Red. = Reduction




The pump was operating at 22cm of Hg

**Figure 25 Dissolve oxygen against time for alternative two**

From table24, BOD and COD were reduced by 68% and 74% respectively.

The BOD at dissolved oxygen of 7.2mg/l was 200mg/l, which was still high and needed more treatment to achieve a BOD of 50mg/l as GH-EPA guidelines.

In Fig. 25, the dissolved oxygen increased with time during aeration process. As the dissolved oxygen of the aerated effluent was approaching its saturation limit of 8.07 at temperature of 27°C, the BOD was observed to be still high far above the GH-EPA standards. Hence the aeration process alone will not be effective in the BOD removal however it is affective for COD reduction.

### 5.1.3 Anaerobic followed by Aeration.

After comparing anaerobic and aeration treatment an option, the anaerobic was found to work better and faster in BOD removal than COD while aeration worked better for COD removal so a combination of the two processes was investigated.



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**Table 25 Results for Anaerobic process followed by Aeration.**

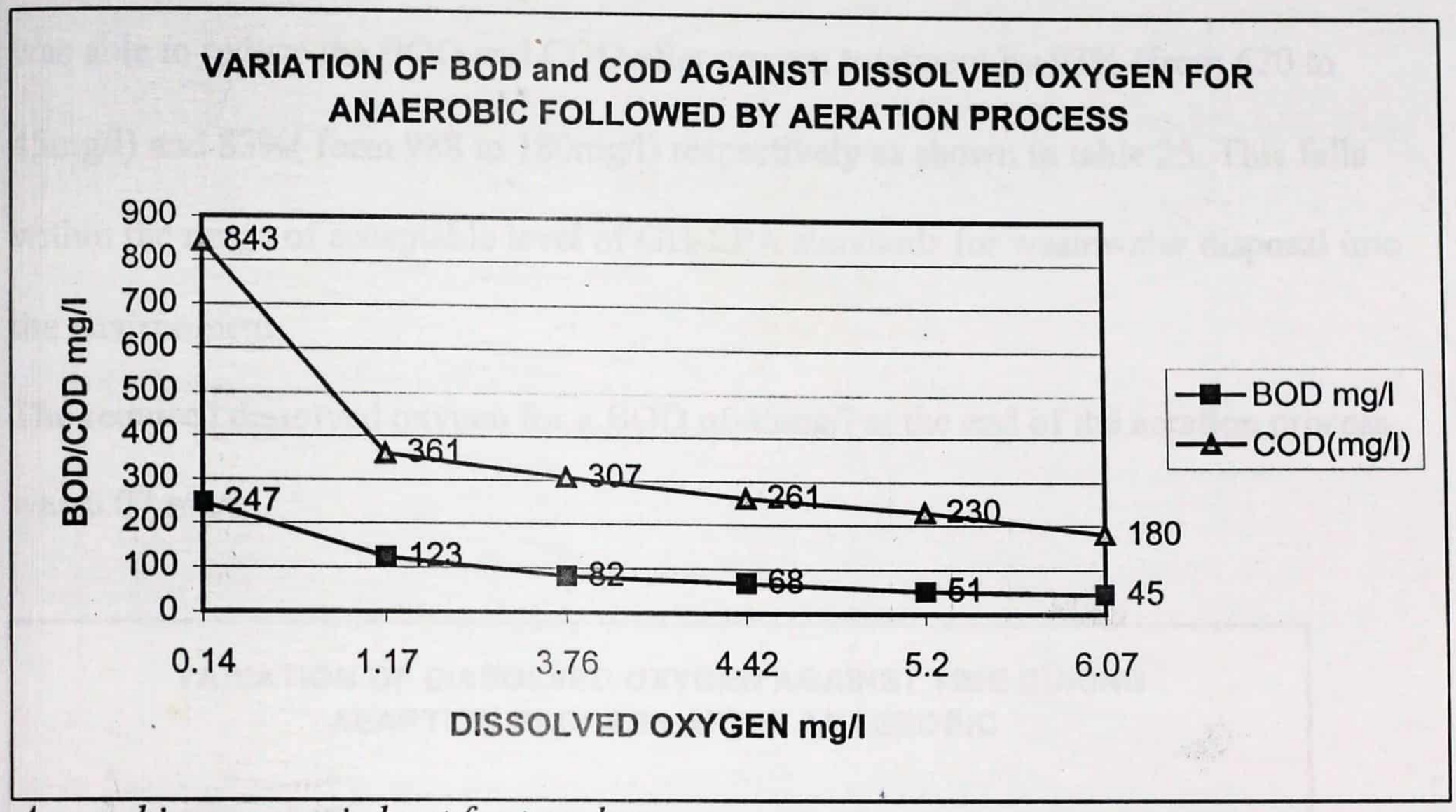
| | | Anaerobic | | Aeration | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Raw sample | Effluent from cement | 2 days | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
| pH | 5.28 | 10.89 | 7.16 | 8.7 | 8.83 | 8.66 | 8.5 | 8.25 |
| Conductivity µs/cm | 533 | 964 | 900 | 1059 | 1128 | 1191 | 1120 | 1089 |
| TDS (mg/l) | 533 | 964 | 900 | 1059 | 1128 | 1191 | 1120 | 1089 |
| BOD (mg/l) | 2000 | 620 | 247 | 123 | 82 | 68 | 51 | 45 |
| COD (mg/l) | 4734 | 988 | 843 | 361 | 307 | 261 | 230 | 180 |
| Temp °C | 27.1 | 28.3 | 26.8 | 27.6 | 27.9 | 28 | 28.1 | 28.6 |
| DO (mg/l) | 0.07 | 1.51 | 0.14 | 1.17 | 3.76 | 4.42 | 5.2 | 6.07 |
| Salinity (mg/l) | 0 | 0.3 | 0.1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 |

## VARIATION OF BOD AND COD FOR ANAEROBIC FOLLOWED BY AERATION PROCESS.

**Table 26 Variation of BOD, COD with Dissolved Oxygen**

| Time in Hrs | DO mg/l | BOD mg/l | COD (mg/l) | % Red. BOD | % Red. COD |
|---|---|---|---|---|---|
| 0 | 0.14 | 247 | 843 | 60 | 15 |
| 2 | 1.17 | 123 | 361 | 80 | 63 |
| 4 | 3.76 | 82 | 307 | 87 | 69 |
| 6 | 4.42 | 68 | 261 | 89 | 75 |
| 8 | 5.2 | 51 | 230 | 92 | 77 |
| 10 | 6.07 | 45 | 180 | 93 | 82 |

Red. = Reduction




*Anaerobic was carried out for two days*

**Figure 26 Variation of BOD and COD Vs Dissolved oxygen for alternative three**

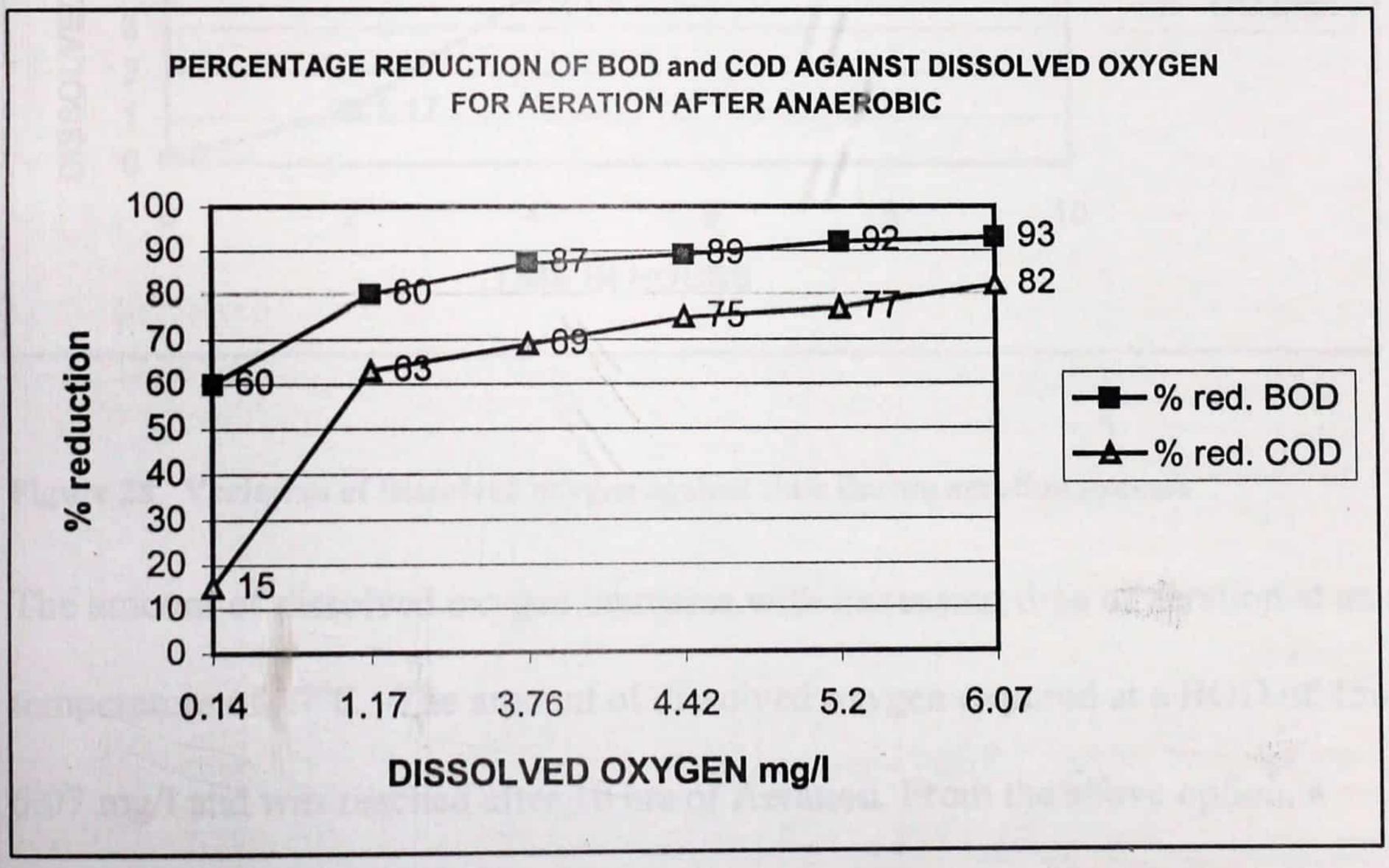



**Figure 27 Reduction (%) of BOD and COD Vs dissolved oxygen for alter. three**

From Fig 27, a combination of anaerobic and aeration process worked effectively and was able to reduce the BOD and COD after cement treatment by 93% (from 620 to 45mg/l) and 83%( form 988 to 180mg/l) respectively as shown in table 25. This falls within the range of acceptable level of GH-EPA standards for wastewater disposal into the environment.

The required dissolved oxygen for a BOD of 45mg/l at the end of the aeration process was 6.07 mg/l.

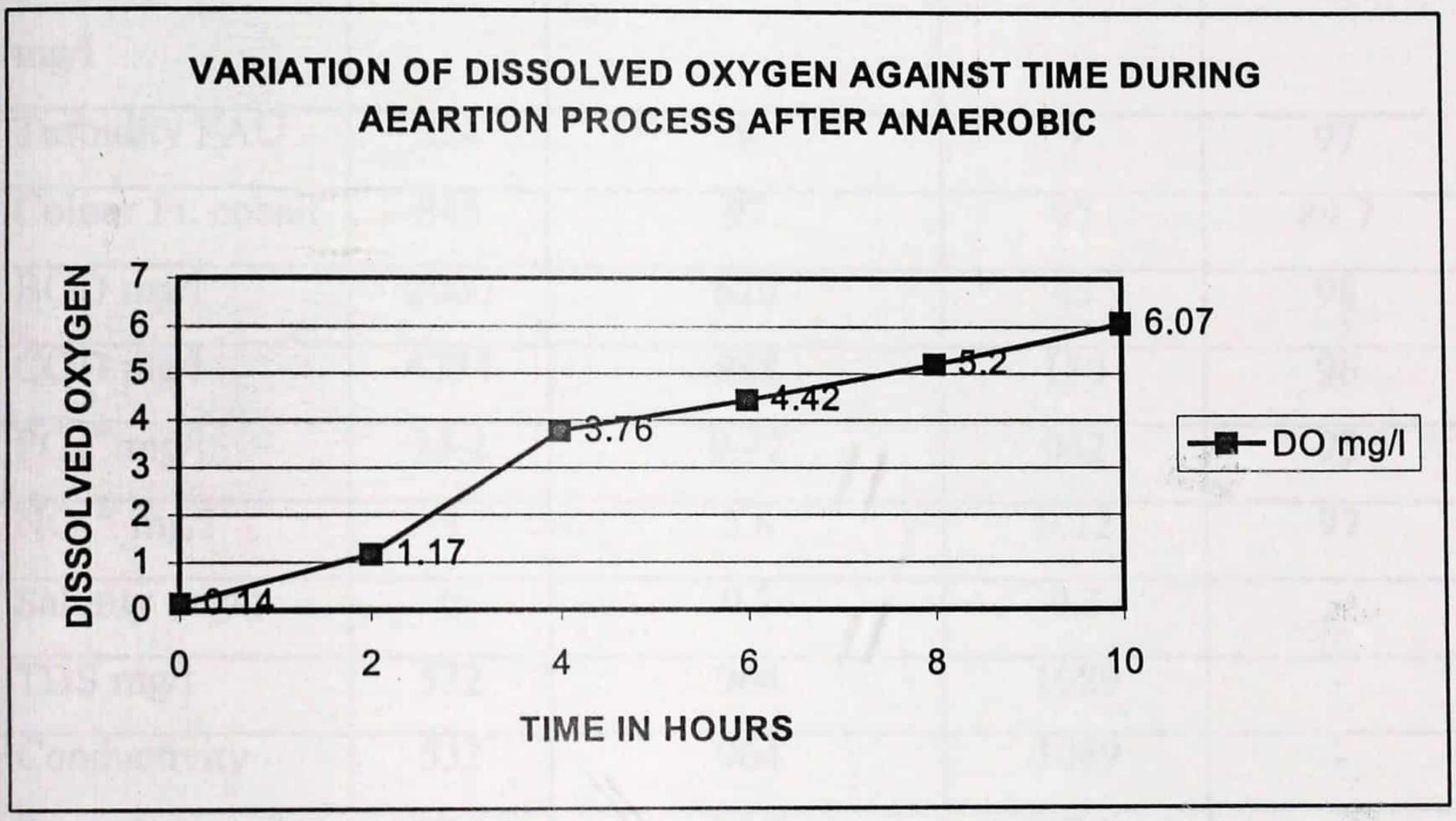



**Figure 28 Variation of Dissolved oxygen against time during aeration process**

The amount of dissolved oxygen increases with increasing time of aeration at an average temperature of 27°C. The amount of dissolved oxygen required at a BOD of 45mg/l was 6.07 mg/l and was reached after 10 hrs of Aeration. From the above option, a combination of anaerobic followed by aeration process was more successful compared to anaerobic and aeration.

Therefore the design of the treatment plant will be based on the anaerobic followed by aeration process, as it was the most successful one.

## 5.2 Summary of the effluent quality from the proposed treatment plant

**Table 27 summary of the effluent from the proposed treatment plant**

| Parameter | Influent | Effluent after Cement treatment (Primary) | Secondary treatment | % Reduction | GH-EPA guidelines |
|---|---|---|---|---|---|
| PH | 5.28 | 7.0 | 8.25 | - | 4.5-9 |
| Suspended solids mg/l | 256 | 5 | 5 | 98 | 50 |
| Turbidity FAU | 324 | 9 | 9 | 97 | 75 |
| Colour Pt. cobalt | 845 | 97 | 97 | 89.7 | 200 |
| BOD mg/l | 2000 | 620 | 45 | 98 | 50 |
| COD mg/l | 4734 | 988 | 180 | 96 | 250 |
| $PO_4^{3-}$ mg/l | 25.2 | 0.42 | 042 | 98 | 1 |
| $NO_3^{2-}$ mg/l | 4 | 2.6 | 0.12 | 97 | 0.1 |
| Salinity (mg/l) | 0 | 0.2 | 0.3 | - | - |
| TDS mg/l | 532 | 964 | 1089 | - | 50 |
| Conductivity | 533 | 964 | 1089 | - | 750 |
| Temperature °C | 27.1 | 28.3 | 27.6 | - | < 30 |

From the summary in table 27, it can be seen clearly, that the effluent quality from the combination of anaerobic and aeration treatment process meets the acceptable level of GH-EPA guidelines for wastewater disposal into the environment. However the high TDS are due to the formation of flavanoic acids, which may impose colour to the effluent but do not contribute to any BOD, COD increase and they have no harm on the environment.

## 5.3 Schematic diagram of the proposed treatment plant for Maraba District CWS.

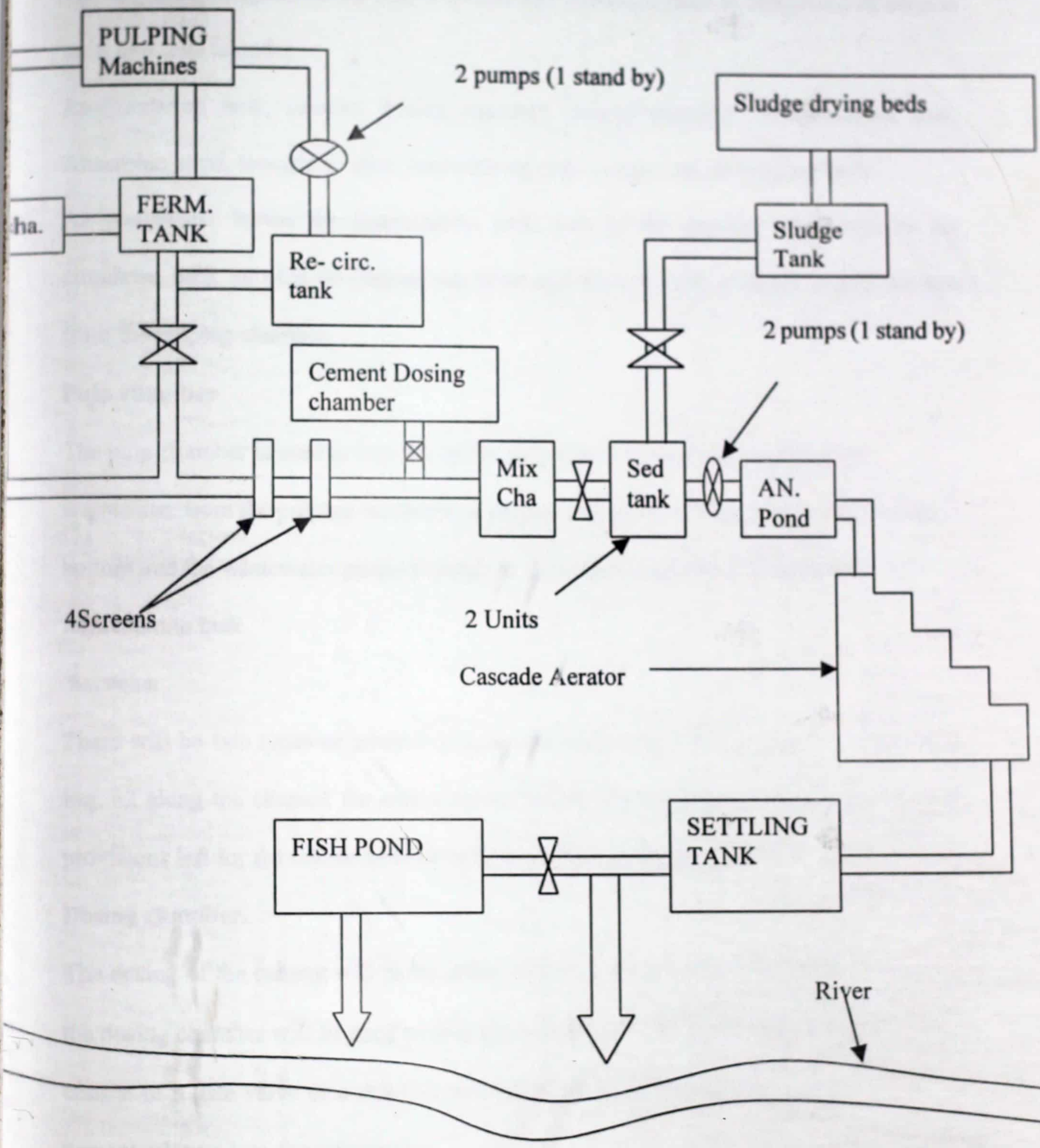



**Figure 29 Schematic diagram of the proposed treatment plant Maraba CWS**

### 5.3.1 Description of the proposed treatment plant.

The schematic diagram of the coffee wastewater treatment plant is comprised of several units and they include;

Re-circulation tank, screens, dosing chamber, mixing chamber, sedimentation tank, Anaerobic pond, cascade aerator, final settling tank, sludge tank and drying beds.

As wastewater leaves the fermentation tank, part of the grading water will be re-circulated back into the de-pulping machines and the rest will continue to join the one from the pulping chamber.

**Pulp chamber**

The pulp chamber is used to trap the coffee pulp that is being transported by the wastewater from the pulping machines as shown in Fig2. It is fitted with screens at the bottom and the wastewater passes through to the outlet to join the one from the fermentation tank.

**Screens.**

There will be two types of screens (coarse and fine), which will be placed as shown in Fig. 32 along the channel the coarse screen before the fine screen. There are two other provisions left for the course and fine screens as standby during maintenance.

**Dosing chamber.**

The dosing of the cement will be by inline dosing in an open channel. The channel from the dosing chamber will be used to dose the cement mixture to the wastewater and it will consist of a gate valve or a slot that will be used to control the dosage discharge of the cement mixture into the wastewater.

**Mixing chamber.**



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The wastewater that has been dosed with cement has to be vigorously mixed in the mixing chamber. There should be high turbulence in order to break down the mucilage to enhance effective mixing to form an insoluble precipitate that will settle down in the sedimentation tank. After the mixing chamber there will be a valve to regulate the flow that will be enter the sedimentation tank for settling out the mucilage and other settleable materials.

**Sedimentation tank.**

The sedimentation tank will be used for settling the precipitate formed between the mucilage and the cement and also other settleable particles.

The sedimentation tank will be rectangular. After the sedimentation tank, there will be a pump to pump the wastewater to the anaerobic pond at the top of the hill so that it can flow by gravity from the pond to the cascade aerator.

**Sludge tank.**

The sludge accumulation at the bottom of the sedimentation tank will be dislodged into the sludge tank every day and it will be retained for two days to further enhance anaerobic treatment. After two days, it will be discharged onto drying beds for drying.

**Sludge drying beds.**

These will consist of a layer of sand and gravel and the wastewater will infiltrate through to the cascade aerator for further treatment.

**Anaerobic pond.**

The anaerobic pond will be at a higher elevation than the cascade aerator so that the wastewater from it will flow by gravity to the cascade aerator.

**Cascade aerator.**

After the wastewater has spent two days in the anaerobic pond, it is aerated by using a cascade aerator where the water falls down the stairs of the aerator in a thin film to increase the concentration of dissolved oxygen.

**Final settling tank.**

The final settling tank will be used to settle some particles accumulated with in the wastewater during the aeration process before it is discharged into the river.

**Fishpond.**

There is a provision of a fishpond in case a need arises for raring fish.

## 5.4 Design of different treatment units.

Different treatment units that have been designed include;

Re-circulation tank, dosing chamber, mixing chamber, sedimentation tank, anaerobic pond, cascade aerator, final settling tank, Sludge tank, and sludge drying beds

**Design parameters for coffee wastewater treatment plant.**

**Table 28 Design parameters**

| **Parameter** | **Value** |
|---|---|
| Discharge Q $m^3$/day | 190 |
| BOD mg/l | 2000 mg/l |
| Temp $^o$ C | 27 |
| Cement dosage | 2.5g/l |
| **Quantity of water used at different stages of processing per Tone of cherries** | |
| De-pulping | 5 $m^3$ |
| Grading | 8 $m^3$ |
| Mucilage washing | 3 $m^3$ |
| Total quantity per tone (1000kg) | 16 $m^3$ |
| Maximum quantity of coffee de-pulped per day | 12 tones |
| Working hours /day | 10 hrs |
| Re-circulation | 30% |
| Wastewater water to be treated in m3/day | 130 |

### 5.4.1 Design of the Re-circulation tank.

Quantity of water to be re-circulated Qr = 30% of daily discharge = $0.3*190 \approx 60\ m^3$/day

Re-circulation time = 2 hours (in order to settle down some particles) and the pump will start pumping every after two hours when the circulation tank is full

Volume of water collected in two hours (q) = (Qr / working hours)* re-circulation time

= $(60/10)*2 = 12\ m^3$ where 10 is the working hours per day.

Tank capacity = $12\ m^3$

**Tank size**

Choosing a depth of 2 meter,

Length to width ratio (L: W) = 3:2

Area of the tank = Volume /depth = $12/2 = 6\ m^2$.

$L*W = 6\ m^2$.

Let w = width.

$3w*2w = 6m^2$

$6w^2 = 6m^2$

$w = \sqrt{(6/6)}$.

$w = 1$

Width (W) = $1*2 = 2.0$ m

Length (L) = $1*3 = 3.0$ m

Taking a free board of 0.5 m.

Volume of the tank = $2*3*2 = 12\ m^3$.

## Re-circulation tank dimensions.

**Table 29 Dimensions of Recycling Tank**

| Parameter | Dimension in meters |
|---|---|
| Length | 3 |
| Width | 2 |
| Depth | 2 |
| Free board | 0.5 |

### 5.4.2 Design of Dosing chamber.

**Quantity of cement required for dosing.**

Discharge Q = 130 $m^3$/d = 130000 l/d (after reducing 30% of 190 $m^3$/d through re-circulation).

Cement dosage/l = 2.5g/l (from table 28)

Dosage per day = 2.5*130000 = 325000 g = 325kg/d

No. of bags 325/50 = 6.5 bags/day ( 1 bag = 50kg)

The water used for mixing will be from the grading water.

From the laboratory experiment, 2.5 g of cement required 50ml for making the cement solution.

Amount of water required per gram of cement = 50/2.5 litres.

Total amount of water required for making the cement solution per day is.

(50/2.5) *325000g = 6500000ml /d

6500000/100000 = 6.5$m^3$/d

The mixing will be 5 times a day to avoid sating of the cement.

The tank volume = quantity of water required for mixing per day/ number of times of mixing per day $= 6.5/5 = 1.3m^3$

The cement required for a volume of $1.3m^3$ for each time of mixing $= 325/5$ kg

= 65kg equivalent to 1.3 bags.

**Tank size**

Choosing a depth of 1meter,

Length to width ratio (L: W) = 1.5:1 for easy mixing to maintain uniform concentration.

Area of the tank = $1.3m^2$

Let w = W

$w*w = 1.3m^2$

$w = \sqrt{1.3}$

$W = 1.14 \approx 1$ m

L = 1*1.5 = 1.5 m

Free board = 0.5m

**Dosing Tank dimensions.**

**Table 30 Dimensions of the dosing tank**

| Parameter | Dimension in meters |
|---|---|
| Length | 1.5 |
| Width | 1.0 |
| Depth | 1.0 |
| Free board | 0.5 |

### 5.4.3 Mixing chamber.

The mixing time will be 5 minutes.

Discharge per minute = (130/10)/60 = 0.22 $m^3$ /minute

Volume after 5 minutes = 0.22*5 = 1.1 $m^3$ ≈ 1 $m^3$

Taking a depth of 1m,

Area = 1 $m^2$

Length = 1m

Width = 1m

Depth = 1m

Tank volume 1*1*1 = 1$m^3$

An appropriate mixing device will be provided.

**Table 31 Dimensions of the mixing chamber.**

| Parameter | Dimension in meters |
|---|---|
| Length | 1 |
| Width | 1 |
| Depth | 1 |
| Free board | 0.3 |

### 5.4.4 Design of Rectangular horizontal Sedimentation Tank.

**Table 32 Design parameters for horizontal rectangular tank**

| Item | Range | Typical |
|---|---|---|
| Depth (meters) | 3-5 | 3.6 |
| Length (meters) | 19-90 | 25-40 |
| Width (meters) | 3-24 | 6-10 |
| Free board (meters) | 0.5-1 | 0.5 |
| Length: width ratio | 3:1,2:1 | 2:1 |
| Detention time | 1.5-2.5 | 2.0 |
| Surface loading rate $m^3m^2/d$ | 32-45 | - |

*Source Metcalf and Eddy 1991.*

**Influent design parameters for sedimentation tank**

$Q = 130\ m^3/d.$

Considering 10 hrs working day, $Q = 13\ m^3/hr.$

Sludge accumulation rate of 20% per hour from the Laboratory analysis.

Dislodging every day

Choosing a surface-loading rate (q) of $32\ m^3/m^2/d.$

The surface-loading rate for 10 hrs = $(32/24) * 10 = 13.33\ m^3/m^2/d$

Surface area = Q/ surface loading rate

$A = Q/q\ m^2$

$A = 130/13.33 \quad = 9.8\ m^2$

Using a ratio of L: W = 3: 1

$3W^2 = 9.8m^2$

$W = \sqrt{(9.8/3)}$

W = 1.8 m ≈ 2.0 m

L = 5.4 m ≈ 6.0 m

Tank area = 6*2 = 12 $m^2$

Depth = V/A

Choosing a retention time of 1.5 hrs.

Volume of the wastewater in the tank after 1.5 hrs = 1.5*13 = 19.5$m^3$

Sludge accumulation per day = 0.2*130 = 26$m^3$ (assuming a dislodging per day)

Total volume of the tank = 19.5 + 26 = 45.5 ≈ 46 $m^3$

Depth 46/12 = 3.8 m ≈ 4m

Tank volume = 2*6*4 = 48 $m^3$

**Sedimentation tank Dimensions**

**Table 33 dimensions of rectangular tank**

| Parameter | Dimension in meters |
|---|---|
| Length | 6 |
| Width | 2 |
| Depth | 4 |
| Free board | 0.3 |

### 5.4.5 Sludge Tank.

Taking the sludge accumulation rate to be 20% per hr, and dislodging every two days to the sludge drying beds.

The sludge volume Vs = Sa*Q

Where Sa is sludge accumulation rate

Q is wastewater discharge per day.

Q = 130 $m^3$/d

Sa = 20%

Vs = (Sa*Q) *dislodging rate.

Vs = 0.2*130 = 26*2 = 52 $m^3$

Taking Depth to be = 2.5 m.

Area = 52/2.5 =20.8

Taking L: W = 3:2

Let W = w

2w * 3w = 20.8

w = √ (20.8/6) = 2.0

W = 2*2 = 4 m

L = 2.0*3= 6.0 m

Vst (Volume of the sludge tank) = 4*6*2.5 = 60$m^3$

Sludge tank volume = 60$m^3$

### 5.4.6 Design of Sludge Drying Beds.

Water content in the sludge = 98%

Dry sludge = 2%

Volume of the sludge = 0.02*52 = 1.04 $m^3$

Taking the thickness H of the bed = 0.1m

A = Vs/H = 10.4 m

L: W = 3:1

Let W = a

$3a^2 = 10.4$

a = √ (10.4/3)

a = 2

W = 2

L = 6.0

Area of the Bed = 12 $m^2$

If the bed receives three dislodging intervals, the volume of the sludge on the bed =

1.04*3 = 3.12 $m^3$. ≈ 4 $m^3$

Maintaining the area, the thickness of the sludge = 0.3 m

### 5.4.7 Design of Anaerobic pond

The anaerobic ponds are basically designed according to the organic surfacing loading.

**Table 34 design parameters for anaerobic pond**

| Design parameter | Range |
|---|---|
| Length: width ratio (L: W) | 2 : 1, 3 : 1 |
| Depth (m) | 2 - 5 |
| Free board (m) (depend on site considerations) | 0.5 - 1 |
| Side slopes vertical: horizontal | 1 : 3 |
| Retention time in days | 1 - 4 |

*Source Mara and Pearson 1986 and mar et al 1997.*

**Design values of permissible volumetric loading and percentage BOD removal for anaerobic pond system.**

**Table 35 permissible design-loading values for anaerobic pond**

| Temperature °C | Volumetric loading $\lambda_v$ ($g/m^3.d$) | BOD removal (%) |
|---|---|---|
| < 10 | 100 | 40 |
| 10 - 20 | 20T - 100 | 2T + 20 |
| 20 - 25 | 10T + 100 | 2T + 20 |
| > 25 | 350 | 70 |

*Source Mara and Pearson 1986 and mar et al 1997.*

**Design parameters for anaerobic pond.**

Temperature = 27 ° C

Minimum temp. = 20 ° C

Q = 130 $m^3$/d.

BOD = 620 mg/l.

From the table above $\lambda_v$ = 300g/$m^3$.d

From equation 2.2,

$\lambda_v = LiQ/V_a$ ..... 2.2

Where;

$\lambda_v$ = Volumetric loading g/$m^3$d.

Li = influent $BOD_5$ concentration in g/$m^3$.

Q = influent flow rate $m^3$/d that comes into the pond.

$V_a$ = anaerobic pond volume $m^3$.

$V_a = (620*130)/300$

$V_a$ = 270 $m^3$

Taking into account sludge accumulation of 20%,

Design pond volume $V_{ad}$ = 1.2 * $V_a$

$V_{ad}$ = 1.2 * 270 = 324 $m^3$

Retention time (t) = $V_{ad}/Q$ = 324/130.

t = 2.5 days.

Taking a depth of 2.5 m to favour anaerobic conditions.

Mean depth area A = $V_a$/depth

$A = 324/2.5 = 130\ m^2$

Taking the anaerobic pond to be a rectangular,

The length: width ratio (L: W) = 2: 1 (from table 36)

$L = 2W$

$2W^2 = 130$

$W = \sqrt{(130/2)}$,

$W = 8.0\ m$

$L = 16\ m$

These dimensions are the mid depth dimension which need to be corrected for the slope of the embankment,

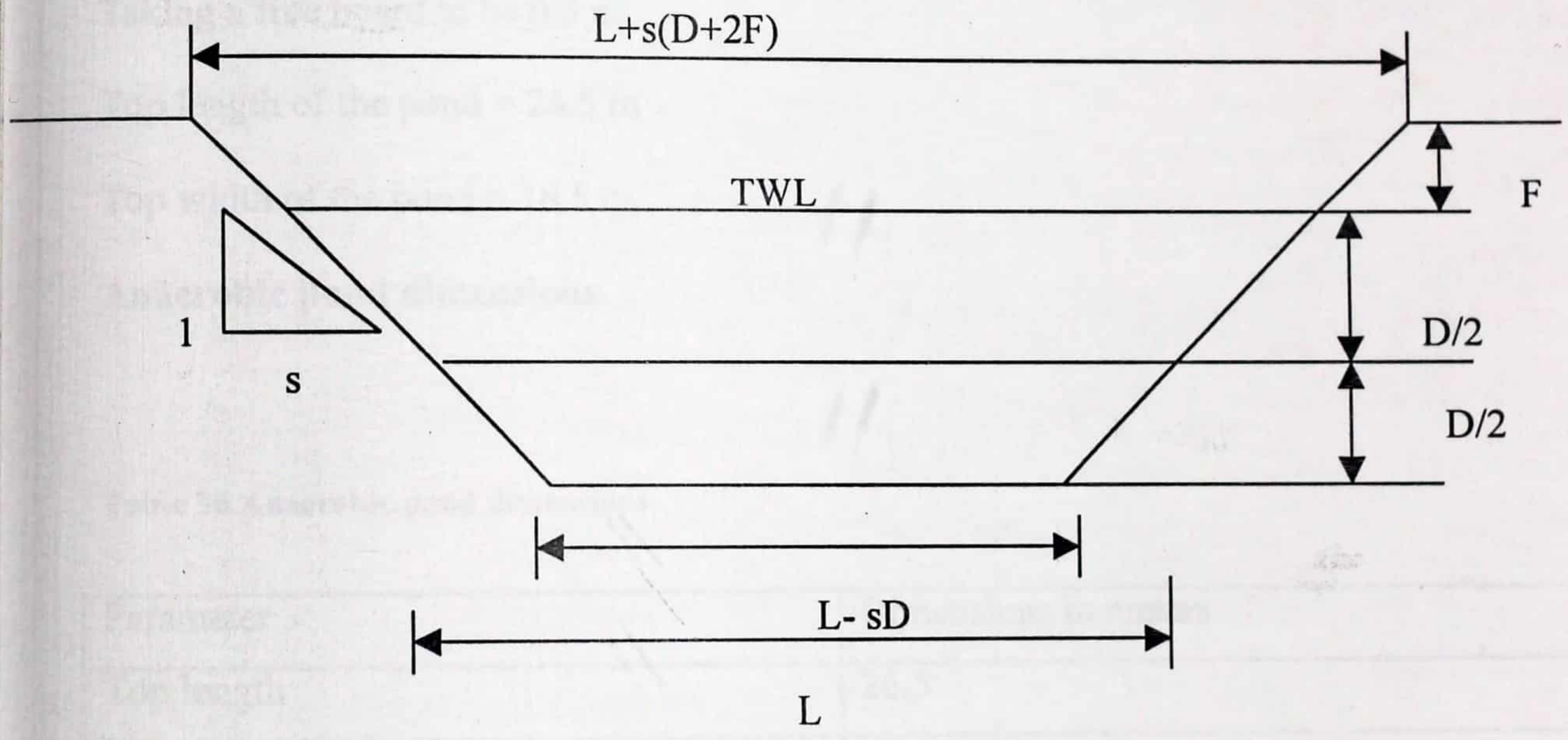



**Figure 30 calculation of Top and bottom width form those based on mid-depth**

TWL = Top water level

The Anaerobic pond volume is given by

$Va = [(LW) + (L - 2sD)\ (W - 2sD) + 4\ (L - sD)\ (W - sD)]\ [D/6]$ (EPA, 1983).

$Va$ = Anaerobic pond volume, $m^3$

L = Pond Length at TWL, m

W = Pond width at TWL, m

s = Horizontal slope factor (i.e. a slope of 1in s)

D = Pond liquid depth, m

F = Free board

Using a slope of 1: 3 for embankment

The Length at the Top water level = 23.5 m

The width at the Top water level = 15.5 m

The bottom width = 0.5 m

The bottom length = 8.5 m

Taking a free board to be 0.5 m.

Top length of the pond = 26.5 m

Top width of the pond = 18.5 m.

**Anaerobic pond dimensions**

**Table 36 Anaerobic pond dimensions**

| Parameter | Dimensions in meters |
|---|---|
| Top length | 26.5 |
| Top width | 18.5 |
| Bottom length | 8.5 |
| Bottom width | 0.5 |
| Embankment slope | 1:3 (vert: horiz.) |
| Free board | 0.5 |
| Pond volume $m^3$ | 360 |

(Source : Metcalf and Eddy).

### 5.4.8 Design of a cascade aerator.

A cascade aerator is designed to use the available discharge head to create turbulence as the wastewater falls in thin film over a series of steps. As the wastewater falls over the series of steps, there is an increase in the dissolved oxygen concentration of the wastewater under treatment.

The most common method required to determine the cascade height is based on the following equation.

$$H = \frac{R - 1}{0.361ab(1 + 0.046T)}$$ (Metcalf and Eddy 1995)

$R$ = deficit ratio

$$R = \frac{Cs - Co}{Cs - C}$$

$Cs$ = Dissolved oxygen saturation concentration of the wastewater at the temperature T, mg/l

$Co$ = Dissolved oxygen concentration of the influent, mg/l.

$C$ = Required dissolved oxygen level after aeration, mg/l.

$a$ = water quality parameter equal to 0.8 for wastewater treatment plant effluent.

$b$ = Weir geometry ( for stepped weir $b = 1.1$).

$T$ = wastewater temperature in $^{o}$C.

$H$ = height through which the wastewater falls (m).

## Typical design information for a cascade aerator system

**Table 37 Design information for a cascade aerator**

| Item | Range | Typical |
|---|---|---|
| Hydraulic loading rate at average design flow $m^3/m.d$ | 1240 - 6200 | 2976 |
| **Step dimension** | | |
| Height (m) | 0.15 – 0.30 | 0.2 |
| Length (m) | 0.3 - 0.60 | 0.45 |
| Cascade height (m) | 1.8 - 5.0 | |

Determination of cascade height.

Design parameters.

T = 27 ° C.

Cs = 8.07

C = 6.0

Co = 0.14

b = 1.1

a = 0.8

$$R = \frac{8.07 - 0.14}{8.07 - 6.0} = 7.93/2.07 = 3.83 \text{ mg/l.}$$

$$H = \frac{3.83 - 1}{0.361 * 0.8 * 1.1\,(1 + 0.046 * 27)}$$

$H$ = 4 meters

**Number of steps.**

Choosing a height of step to be 0.3 m

Number of steps = total height of cascade/height of one step.

No. of steps 4/0.3 = 13 steps.

**Cascade length.**

Choosing the length of one step to be 0.45 m

Length of the cascade 0.45 * 13 = 5.9 ≈ 6.0 m

**Width of the step/cascade.**

Selecting the hydraulic rate to be 1240 $m^3$/m width/d (from table 37).

Hr = 0.014 $m^3$/m/sec.

Width of the cascade = volumetric flow rate / hydraulic loading

Q = 130 $m^3$

Q = 130/10*3600 = 0.0036 $m^3$ /sec (for ten hours of working).

W = Q/Hr

W = 0.0036/0.014 = 0.26 m ≈ 0.3 m.

### 5.4.9 Final settling tank

Let the retention time be 30 minute.

Q = 13$m^3$ /hr

Volume if the liquid in the tank = 0.5hrs * 13 = 6.5 $m^3$

Let the depth be 2m

Area = 3.25

Let L: W = 2:1 , Let w = W

$2w^2 = 6.5$

w = √ (3.25/2) = 1.62 ≈ 1.5 m

W = 1.5 m

L = 3 m

D = 2 m

**Table 38 Cascade aerator dimensions**

| Parameter | Dimension in meters |
|---|---|
| Cascade | |
| Length | 6.0 |
| Height | 4.0 |
| **Width** | 0.3 |
| Steps | |
| Length | 0.45 |
| Height | 0.3 |
| Width | 0.3 |

**Table 39 Capacity and dimensions of the treatment units**

| Unit | Capacity | Dimensions in (m) | Surface Area |
|---|---|---|---|
| RE-CIRCULATION TANK | 12 $m^3$ | L = 4.0 | 13 $m^2$ |
| | | W = 3.0 | |
| | | H = 1.0 + 0.5 (free board) | |
| DOSING CHAMBER | 1.5 $m^3$ | L = 1.5 | 1.5 $m^2$ |
| | | W = 1.0 | |
| | | H = 1.0 + 0.5(free board) | |
| MIXING CHAMBER | 1 $m^3$ | L = 1 | 1 $m^2$ |
| | | W = 1 | |
| | | D = 1 + 0.5 free board | |
| SEDIMENTATION TANK | 50 $m^3$ | L = 5.0 | 10 $m^2$ |
| | | W = 2.0 | |
| | | H = 4.0 +0.5 (free board) | |
| ANAEROBIC POND | 320 $m^3$ | L = 14.0 | 98 $m^2$ |
| | | W = 7.0 | |
| | | H = 2.5 | |
| CASCADE AERATOR | - | L = 6.0 | 1.8 $m^2$ |
| | | H = 4.0 | |
| | | W = 0.3 | |
| STEPS | - | L = 0.45 | - |
| | | W = 0.3 | |
| | | H = 0.3 | |
| FINAL SETTLING TANK | 8$m^3$ | L = 4 | 8 $m^2$ |
| | | W = 2 | |
| | | H = 1 + 0.5 (free board) | |
| SLUDGE TANK | 60$m^3$ | L = 6 | 24 $m^2$ |
| | | W = 4 | |
| | | H = 2.5 +0.5 free board | |
| SLUDGE DRYING BEDS | 3.84 $m^3$ | L = 6.5 | 13 $m^2$ |
| | | W = 2 | |
| | | H = 0.3 | |
| **Total Surface area** | | | **172.8 $m^2$** |

## 5.3 Conclusions

- Characteristics of the wastewater from wet coffee processing station has been done and found to be unacceptable for discharge into the environment.
- Primary and secondary treatment have been proposed and designed.
- After the primary treatment which consists of cement dosing, mixing and sedimentation, the effluent quality with respect to pH, SS, Turbidity, PO43- Colour, was found to be good and satisfied the GH-EPA standards.
- The settled mucilage after the primary treatment was found to have high pH and could therefore be applied to acidic soils.
- The final effluent quality after the secondary treatment met the GH-EPA standards for wastewater disposal into the environment.
- The effluent from the treatment plant can be used for fish raring to help the project in self-economic sustainability since the dissolved oxygen of 6.0 mg/l of the final effluent quality can sustain aquatic life.
- The treatment plant units can be constructed with locally available materials.
- The TDS present in the effluent are due to formation of flavanoic acids, which may impose an increase in colour but these do not pose any harm to the environment nor add significantly to BOD or COD.

## 5.4 Recommendations.

- For effective mucilage removal by cement treatment, wastewater from all different stages of processing must be mixed.
- The application of mucilage as fertilizer or soil conditioner has to be further investigated by agronomists.

- A cheap and simple method of yeast disposal to the environment has to be further investigated before it can be used for treatment of coffee wastewater.
- There should be flow meters at each point of wastewater treatment unit to monitor the discharge.
- Sample testes should be carried out at exit of each unit.
- Provision for sample collection at each treatment unit should be provided.
- A pilot plant should be constructed and run for 2 consecutive coffee processing seasons in order to verify the results of the bench test and also to verify the need for any design review.
- The effluent quality monitoring from the plant should be carried out at least three times a week.

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# APPENDICES

# APPENDEX A

## LABORATORY RESULTS OF THE RAW SAMPLES

| | TDS ( Total dissolved solids) | | | SUSPENDED SOLIDS | | | TURBIDITY | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | TDS 1 | TDS 2 | TDS average | SS 1 | SS 2 | SS Average | TURBIDITY 1 | TURBIDITY 2 | URB. Averag |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FAU | FAU | FAU |
| SS1 | 1100 | 1082 | 1091 | 800 | 780 | 790 | 500 | 424 | 462 |
| SS2 | 400 | 254 | 327 | 120 | 158 | 139 | 100 | 132 | 116 |
| SS3 | 700 | 632 | 666 | 1200 | 1120 | 1160 | 2300 | 1748 | 2024 |
| SS4 | 250 | 236 | 243 | 98 | 108 | 103 | 120 | 182 | 151 |
| SS5 | 600 | 464 | 532 | 400 | 112 | 256 | 300 | 348 | 324 |

| | COLOUR | | CONDUCTIVITY | | | SALANITY TEST | | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | Colour 1 | Colour 2 | Colour avaerage | Conductivity 1 | Conductivity 2 | Cond. average | Salinity 1 | Salinity 2 | Salinity avaerage |
| | APH | APH | APH | µs/cm | µs/cm | µs/cm | | | |
| SS1 | 3000 | 4220 | 3610 | 1100 | 1086 | 1093 | 0.3 | 0.3 | 0.3 |
| SS2 | 350 | 346 | 348 | 400 | 252 | 326 | 0 | 0 | 0 |
| SS3 | 480 | 502 | 491 | 700 | 630 | 665 | 0.1 | 0.1 | 0.1 |
| SS4 | 320 | 338 | 329 | 250 | 236 | 243 | 0 | 0 | 0 |
| SS5 | 1000 | 890 | 945 | 600 | 466 | 533 | 0 | 0 | 0 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX A

## LABORATORY RESULTS OF THE RAW SAMPLES

| | TEMPERATURE | | | BOD | | | COD | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | temp 1 | temp 2 | temp average | BOD 1 | BOD 2 | BOD average | COD 1 | COD 2 | COD Avaerage |
| | $^0C$ | $^0C$ | $^0C$ | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| SS1 | 23.4 | 23.4 | 23.4 | 2400 | 1400 | 1900 | 10000 | 8934 | 9467 |
| SS2 | 24.7 | 24.9 | 24.8 | 1600 | 1800 | 1700 | 8000 | 7210 | 7605 |
| SS3 | 26.9 | 27.3 | 27.1 | 2600 | 2000 | 2300 | 6400 | 5860 | 6130 |
| SS4 | 30 | 31.8 | 30.9 | 350 | 450 | 400 | 2000 | 1724 | 1862 |
| SS5 | 27.7 | 28.1 | 27.9 | 2500 | 1500 | 2000 | 6000 | 3468 | 4734 |

| | PHOSPHATES | | | NITRATES | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | $PO_4^{3-}$ | $PO_4^{3-}$ | $PO_4^{3-}$ average | $NO_3^{2-}$ | $NO_3^{2-}$ | $NO_3^{2-}$ | pH 1 | pH 2 | pH Average |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | | |
| SS1 | 47.5 | 39 | 43.25 | 10 | 9.6 | 9.8 | 5.2 | 5.74 | 5.47 |
| SS2 | 8.7 | 6.5 | 7.6 | 1.6 | 1.2 | 1.4 | 6.7 | 6.26 | 6.48 |
| SS3 | 3.8 | 2.8 | 3.3 | 2 | 1.6 | 1.8 | 4.8 | 5.46 | 5.13 |
| SS4 | 20 | 15 | 17.5 | 2.2 | 1.4 | 1.8 | 6.5 | 7.08 | 6.79 |
| SS5 | 26.4 | 24 | 25.2 | 5 | 3 | 4 | 4.8 | 5.76 | 5.28 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX B

## AVERAGE LABORATORY RESULTS OF THE RAW SAMPLES FROM WET COFFEE PROCESSING

| sample | pH | TDS | SS | TURBIDITY | COLOUR | CONDUCTIVITY | SALNITY | TEMP | BOD |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | APH | µs/cm | | 0C | mg/l |
| SS1 | 5.47 | 1091 | 790 | 462 | 3610 | 1093 | 0.3 | 23.4 | 1900 |
| SS2 | 6.48 | 327 | 139 | 116 | 348 | 326 | 0 | 24.8 | 1700 |
| SS3 | 5.13 | 666 | 1160 | 2024 | 491 | 665 | 0.1 | 27.1 | 2300 |
| SS4 | 6.79 | 243 | 103 | 151 | 329 | 243 | 0 | 30.9 | 400 |
| SS5 | 5.28 | 532 | 256 | 324 | 945 | 533 | 0 | 27.9 | 2000 |

| sample | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|
| | mg/l | mg/l | mg/l |
| SS1 | 9467 | 43.25 | 9.8 |
| SS2 | 7605 | 7.6 | 1.4 |
| SS3 | 6130 | 3.3 | 1.8 |
| SS4 | 1862 | 17.5 | 1.8 |
| SS5 | 4734 | 25.2 | 4 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX C

## Determination of the optimum dosage of portland cement.

SAMPLE SS5

| TME IN MINS | CONCETRATIONS | | | | |
|---|---|---|---|---|---|
| | 1g/l | 1.5g/l | 2.0g/l | 2.5g/l | 3.0g/l |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 20 | 40 | 80 | 300 | 320 |
| 10 | 40 | 60 | 120 | 400 | 430 |
| 15 | 60 | 80 | 200 | 470 | 470 |
| 20 | 100 | 300 | 300 | 520 | 540 |
| 25 | 160 | 400 | 400 | 560 | 600 |
| 30 | 240 | 420 | 460 | 580 | 620 |
| 35 | 260 | 440 | 480 | 600 | 650 |
| 40 | 260 | 460 | 500 | 620 | 660 |
| 45 | 300 | 480 | 560 | 640 | 680 |
| 50 | 300 | 520 | 600 | 660 | 720 |
| 55 | 300 | 560 | 620 | 700 | 800 |
| 60 | 300 | 600 | 640 | 800 | 800 |
| 12 Hrs | 300 | 600 | 640 | 800 | 800 |
| 14 Hrs | 300 | 600 | 640 | 800 | 800 |
| 16 Hrs | 300 | 600 | 640 | 800 | 800 |

SS1 : WATER FROM THE PULP
SS2 : GRADING WATER
SS3 : WASTEWATER FROM 24hr FERMENTATION
SS4: WASTEWATER FROM 48hr FERMENTATION
SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4

# APPENDEX D

## PERCENTAGE( %) SETTLEMENT OF SS5 TO BTAIN OPTIMUM DOSE

| CONCENTRATIONS | | | | | |
|---|---|---|---|---|---|
| TME IN MINS | | | | | |
| | 1g/l | 1.5g/l | 2.0g/l | 2.5g/l | 3.0g/l |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 2 | 4 | 8 | 30 | 32 |
| 10 | 4 | 6 | 12 | 40 | 43 |
| 15 | 6 | 8 | 20 | 47 | 47 |
| 20 | 10 | 30 | 30 | 52 | 54 |
| 25 | 16 | 40 | 40 | 56 | 60 |
| 30 | 24 | 42 | 46 | 58 | 62 |
| 35 | 26 | 44 | 48 | 60 | 65 |
| 40 | 26 | 46 | 50 | 62 | 66 |
| 45 | 30 | 48 | 56 | 64 | 68 |
| 50 | 30 | 52 | 60 | 66 | 72 |
| 55 | 30 | 56 | 62 | 70 | 80 |
| 60 | 30 | 60 | 64 | 80 | 80 |
| 12 Hrs | 30 | 60 | 64 | 80 | 80 |
| 14 Hrs | 30 | 60 | 64 | 80 | 80 |
| 16 Hrs | 30 | 60 | 64 | 80 | 80 |

SS1 : WATER FROM THE PULP
SS2 : GRADING WATER
SS3 : WASTEWATER FROM 24hr FERMENTATION
SS4: WASTEWATER FROM 48hr FERMENTATION
SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4

# APPENDEX E

## SETTLEMENT OF THE MUCILAGE OF 1 LITTRE SAPMLE

| TME IN | SS1 | SS2 | SS3 | SS4 | SS5 |
|---|---|---|---|---|---|
| MINS | ml | ml | ml | ml | ml |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 100 | 40 | 400 | 100 | 300 |
| 10 | 120 | 50 | 560 | 100 | 400 |
| 15 | 150 | 100 | 600 | 120 | 470 |
| 20 | 160 | 120 | 660 | 125 | 520 |
| 25 | 162 | 150 | 680 | 128 | 560 |
| 30 | 165 | 160 | 684 | 130 | 580 |
| 35 | 170 | 162 | 694 | 130 | 600 |
| 40 | 180 | 165 | 700 | 150 | 620 |
| 45 | 184 | 170 | 710 | 200 | 640 |
| 50 | 190 | 180 | 720 | 220 | 660 |
| 55 | 195 | 200 | 721 | 230 | 680 |
| 60 | 198 | 200 | 725 | 240 | 700 |
| After 12 Hrs | 300 | 250 | 800 | 400 | 800 |
| 14 Hrs | 300 | 250 | 800 | 400 | 800 |
| 16 Hrs | 300 | 250 | 800 | 400 | 800 |

SS1 : WATER FROM THE PULP
SS2 : GRADING WATER
SS3 : WASTEWATER FROM 24hr FERMENTATION
SS4: WASTEWATER FROM 48hr FERMENTATION
SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4

# APPENDEX F

## PERCENTAGE (%) SETTLEMENT OF THE MUCILAGE AFTER THE ADDITION OF 2.5g/l OF CEMENT

| TIME IN MINS | SS1 | SS2 | SS3 | SS4 | SS5 |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 10 | 4 | 40 | 10 | 30 |
| 10 | 12 | 5 | 56 | 10 | 40 |
| 15 | 15 | 10 | 60 | 12 | 47 |
| 20 | 16 | 12 | 66 | 12.5 | 52 |
| 25 | 16.2 | 15 | 68 | 12.8 | 56 |
| 30 | 16.5 | 16 | 68.4 | 13 | 58 |
| 35 | 17 | 16.2 | 69.4 | 13 | 60 |
| 40 | 18 | 16.5 | 70 | 15 | 62 |
| 45 | 18.4 | 17 | 70.2 | 20 | 64 |
| 50 | 19 | 18 | 70.25 | 22 | 66 |
| 55 | 19.5 | 20 | 70.5 | 23 | 70 |
| 60 | 19.8 | 20 | 80 | 24 | 80 |
| 12 Hrs | 30 | 25 | 80 | 40 | 80 |
| 14 Hrs | 30 | 25 | 80 | 40 | 80 |
| 16 Hrs | 30 | 25 | 80 | 40 | 80 |

SS1 : WATER FROM THE PULP
SS2 : GRADING WATER
SS3 : WASTEWATER FROM 24hr FERMENTATION
SS4: WASTEWATER FROM 48hr FERMENTATION
SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4

# APPENDEX G

## RESULTS OF THE SUPERNATANT AFTER ADDITION OF 2.5g/l OF CEMENT

| TDS (TOTAL DISSOLVED SOLIDS | | | SUSPENDED SOLIDS | | | | TURBIDITY | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | TDS 1 | TDS 2 | TDS Average | SS 1 | SS 2 | SS Average | turbidity 1 | truburdity | turb. Average |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FAU |
| SS1 | 2300 | 1900 | 2100 | 65 | 77 | 71 | 100 | 130 | 115 |
| SS2 | 650 | 590 | 620 | 0 | 0 | 0 | 7 | 5 | 6 |
| SS3 | 1300 | 1188 | 1244 | 85 | 75 | 80 | 100 | 90 | 95 |
| SS4 | 900 | 424 | 662 | 13 | 17 | 15 | 27 | 33 | 30 |
| SS5 | 900 | 1028 | 964 | 7 | 3 | 5 | 5 | 13 | 9 |

| | COLOUR | | | CONDUCTIVITY | | | SALANITY TEST | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | Colour 1 | Colour 2 | Colour avaerage | Conductivity 1 | Conductivity 2 | Cond. average | Salinity 1 | Salinity 2 | Salinity avaerage |
| | APH | APH | APH | µs/cm | µs/cm | µs/cm | | | |
| SS1 | 700 | 764 | 732 | 2300 | 1900 | 2100 | 0.9 | 0.9 | 0.9 |
| SS2 | 2 | 4 | 3 | 650 | 590 | 620 | 0 | 0 | 0 |
| SS3 | 350 | 434 | 392 | 1300 | 1188 | 1244 | 0.3 | 0.5 | 0.4 |
| SS4 | 13 | 19 | 16 | 900 | 424 | 662 | 0.1 | 0.1 | 0.1 |
| SS5 | 90 | 104 | 97 | 900 | 1028 | 964 | 0.2 | 0.2 | 0.2 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX G

## RESULTS OF THE SUPERNATANT AFTER ADDITION OF 2.5g/l OF CEMENT

| | BOD | | | COD | | | PHOSPHATES | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | BOD 1 | BOD 2 | BOD average | COD 1 | COD 2 | COD Avaerage | PO43- 1 | $PO_4^{3-}$ 2 | $PO_4^{3-}$ average |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| SS1 | 900 | 924 | 912 | 3000 | 2120 | 2560 | 0.9 | 85.6 | 43.25 |
| SS2 | 320 | 280 | 300 | 1200 | 800 | 1000 | 0.4 | 14.8 | 7.6 |
| SS3 | 500 | 540 | 520 | 900 | 500 | 700 | 0.5 | 6.1 | 3.3 |
| SS4 | 420 | 180 | 300 | 1300 | 636 | 968 | 0.2 | 34.8 | 17.5 |
| SS5 | 700 | 540 | 620 | 1200 | 776 | 988 | | 50.4 | 25.2 |

| | NITRATES | | | pH | | TEMPERATURE | | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | $NO_3^{2-}$ 1 | $NO_3^{2-}$ 2 | $NO_3^{2-}$ Average | pH 1 | pH 2 | pH Average | temp 1 | temp 2 | temp average |
| | mg/l | mg/l | mg/l | | | | $^0C$ | $^0C$ | $^0C$ |
| SS1 | 10 | 4 | 7 | 7.2 | 6.7 | 6.95 | 20 | 24 | 22 |
| SS2 | 4 | 0.4 | 2.2 | 7.9 | 8.6 | 8.25 | 24 | 22 | 23 |
| SS3 | 10 | 2 | 6 | 7.6 | 7.22 | 7.41 | 23.2 | 23.6 | 23.4 |
| SS4 | 3 | 0.4 | 1.7 | 8 | 7.78 | 7.89 | 20.5 | 22.9 | 21.7 |
| SS5 | 4 | 1.2 | 2.6 | 67 | -53 | 7 | 21 | 23 | 22 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX H

## AVERAGE RESULTS OF THE SUPERNATANT AFTER ADDITION OF 2.5g/l OF CEMENT.

| sample | pH | TDS | SS | TURBIDITY | COLOUR | CONDUCTIVITY | SALNITY | TEMP | BOD |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | APH | µs/cm | | $^0$C | mg/l |
| SS1 | 6.95 | 2100 | 71 | 115 | 732 | 2100 | 0.9 | 22 | 912 |
| SS2 | 8.25 | 620 | 0 | 6 | 3 | 620 | 0 | 23 | 300 |
| SS3 | 7.41 | 1244 | 80 | 95 | 392 | 1245 | 0.4 | 23.4 | 520 |
| SS4 | 7.89 | 662 | 15 | 30 | 16 | 662 | 0.1 | 21.7 | 300 |
| SS5 | 7 | 964 | 5 | 9 | 97 | 964 | 0.2 | 22 | 620 |

| sample | COD | $PO_4^{3-}$ | $NO_3^{2-}$ |
|---|---|---|---|
| | mg/l | mg/l | mg/l |
| SS1 | 2560 | 0.61 | 7 |
| SS2 | 1000 | 0.6 | 2.2 |
| SS3 | 700 | 0.69 | 6 |
| SS4 | 968 | 0.73 | 1.7 |
| SS5 | 988 | 0.42 | 2.6 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX I

## RESULTS FROM THE YEAST TREATMENT

| | TDS (TOTAL DISSOLVED SOLIDS | | | SUSPENDED SOLIDS | | | TURBIDITY | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | TDS 1 | TDS 2 | TDS Average | SS 1 | SS 2 | SS Average | TURBIDITY 1 | TURBIDITY2 | TURB. Averag |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FAU | FAU | FAU |
| SS2 | 500 | 460 | 480 | 40 | 22 | 31 | 86 | 64 | 75 |
| SS3 | 680 | 404 | 542 | 170 | 136 | 153 | 200 | 172 | 186 |
| SS5 | 640 | 436 | 538 | 120 | 150 | 135 | 220 | 132 | 176 |

| | COLOUR | | | CONDUCTIVITY | | | SALANITY TEST | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | Colour 1 | Colour 2 | Colour avaerage | Conductivity 1 | Conductivity 2 | Cond. average | Salinity 1 | Salinity 2 | Salinity avaerage |
| | APH | APH | APH | µs/cm | µs/cm | µs/cm | | | |
| SS2 | 100 | 116 | 108 | 520 | 444 | 482 | 0 | 0 | 0 |
| SS3 | 1280 | 1220 | 1250 | 600 | 484 | 542 | 0 | 0 | 0 |
| SS5 | 1500 | 1230 | 1365 | 560 | 516 | 538 | 0 | 0 | 0 |

| | TEMPERATURE | | | BOD | | | COD | | |
|---|---|---|---|---|---|---|---|---|---|
| sample | temp 1 | temp 2 | temp average | BOD 1 | BOD 2 | BOD average | COD 1 | COD 2 | COD Avaerage |
| | $^0$C | $^0$C | $^0$C | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| SS2 | 19.7 | 20.8 | 20.25 | 1000 | 600 | 800 | 500 | 430 | 465 |
| SS3 | 30.2 | 36 | 33.1 | 1400 | 1200 | 1300 | 1200 | 972 | 1086 |
| SS5 | 20.4 | 18.8 | 19.6 | 1350 | 1050 | 1200 | 550 | 380 | 465 |

| | PHOSPHATES | | | pH | | |
|---|---|---|---|---|---|---|
| sample | PO43- 1 | $PO_4^{3-}$ 2 | $PO_4^{3-}$ average | pH | pH | pH |
| | mg/l | mg/l | mg/l | | | |
| SS2 | 1.04 | 1.02 | 1.03 | 5.5 | 5.9 | 5.7 |
| SS3 | 0.98 | 0.96 | 0.97 | 4.2 | 4.6 | 4.4 |
| SS5 | 0.96 | 0.98 | 0.97 | 3.8 | 4.4 | 4.1 |

# APPENDEX J

**AVERAGE RESULTS AFTER SEEDING 200ML OF THE SAMPLE WITH 5ML OF YEAST FOR 2 DAYS INCUBATION**

| sample | pH | TDS | SS | TURBIDITY | COLOUR | CONDUCTIVITY | SALNITY | TEMP | BOD |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | FAU | APH | µs/cm | | 0C | mg/l |
| SS2 | 5.7 | 480 | 31 | 75 | 108 | 482 | 0 | 20.25 | 800 |
| SS3 | 4.4 | 542 | 153 | 186 | 1250 | 542 | 0 | 33.1 | 1300 |
| SS5 | 4.1 | 538 | 135 | 176 | 1365 | 538 | 0 | 19.6 | 1200 |

| sample | COD | $PO_4^{3-}$ |
|---|---|---|
| | mg/l | mg/l |
| SS2 | 465 | 1.03 |
| SS3 | 1086 | 0.97 |
| SS5 | 465 | 0.97 |

**SS1 : WATER FROM THE PULP**
**SS2 : GRADING WATER**
**SS3 : WASTEWATER FROM 24hr FERMENTATION**
**SS4: WASTEWATER FROM 48hr FERMENTATION**
**SS5 : COMPOSITE SAMPLE OF SS1+SS2+SS3+SS4**

# APPENDEX K TREATMENT ALTERNATIVES AFTER DOSING WITH CEMENT.

## APPENDEX K1

**RESULTS FORM ANAEROBIC PROCESS FOR ALTERNATIVE ONE**

| | 2 DAYS | | | 6 DAYS | | | 8 DAYS | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1st test | 2nd test | Average | 1st test | 2nd test | Average | 1st test | 2nd test | Average |
| pH | 7.6 | 6.72 | 7.16 | 7.1 | 6.26 | 6.68 | 6.4 | 6.6 | 6.5 |
| conductivity | 850 | 950 | 900 | 900 | 908 | 904 | 960 | 922 | 941 |
| TDS | 850 | 950 | 900 | 900 | 908 | 904 | 960 | 922 | 941 |
| BOD | 350 | 144 | 247 | 200 | 268 | 234 | 220 | 138 | 179 |
| COD | 700 | 986 | 843 | 520 | 364 | 442 | 400 | 334 | 367 |
| Temp | 26 | 27.6 | 26.8 | 26 | 26.4 | 26.2 | 26.2 | 27.6 | 26.9 |
| DO | 0.1 | 0.18 | 0.14 | 0.1 | 0.12 | 0.11 | 0 | 0 | 0 |
| Salinity | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |

## APPENDEX K 2

**AVERAGE RESULTS FOR ANAEROBIC PROCESS FOR ALTERNATIVE ONE**

| Parameter | raw sample | effluent from cement | 2days | 6days | 8 days |
|---|---|---|---|---|---|
| pH | 5.28 | 10.89 | 7.16 | 6.68 | 6.5 |
| conductivity | 533 | 964 | 900 | 904 | 941 |
| TDS | 533 | 964 | 900 | 904 | 941 |
| BOD | 2000 | 620 | 247 | 234 | 179 |
| COD | 4734 | 988 | 843 | 442 | 367 |
| Temp | 27.1 | 28.3 | 26.8 | 26.2 | 26.9 |
| DO | 0.07 | 1.51 | 0.14 | 0.11 | 0 |
| Salinity | 0 | 0.3 | 0.1 | 0.2 | 0.2 |

# APPENDEX K 3

## AERATION PROCESS OF THE COMPOSITE SAMPLE FOR ALTERNATIVE TWO

| | 2 HOURS AEARTION | | | 4 HOURS AERATION | | | 6 HOURS AERATION | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average |
| pH | 9.4 | 10 | 9.7 | 8.4 | 8.84 | 8.62 | 6.8 | 7.6 | 7.2 |
| conductivity | 820 | 1008 | 914 | 870 | 1034 | 952 | 870 | 1034 | 952 |
| TDS mg/l | 820 | 1008 | 914 | 870 | 1034 | 952 | 870 | 1034 | 952 |
| BOD mg/l | 350 | 450 | 400 | 340 | 432 | 386 | 320 | 258 | 289 |
| COD mg/l | 500 | 806 | 653 | 520 | 708 | 614 | 450 | 240 | 345 |
| Temp °C | 26.2 | 26.4 | 26.3 | 26.4 | 27.2 | 26.8 | 26.5 | 28.3 | 27.4 |
| DO mg/l | 3 | 3.96 | 3.48 | 4 | 5.6 | 4.8 | 6.4 | 6.66 | 6.53 |
| Salinity | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

| 8 HOURS AERATION | | | 10 HOURS AERATION | | | |
|---|---|---|---|---|---|---|
| Parameter | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average |
| pH | 7.1 | 7.5 | 7.3 | 6.9 | 7.3 | 7.1 |
| conductivity | 900 | 1020 | 960 | 1000 | 930 | 965 |
| TDS mg/l | 900 | 1020 | 960 | 1000 | 930 | 965 |
| BOD mg/l | 300 | 200 | 250 | 250 | 150 | 200 |
| COD mg/l | 350 | 250 | 300 | 270 | 250 | 260 |
| Temp °C | 28.3 | 28.5 | 28.4 | 27.5 | 29.7 | 28.6 |
| DO mg/l | 2 | 11.6 | 6.8 | 6.8 | 7.6 | 7.2 |
| Salinity | 0 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 |

# APPENDEX K 4

**AVERAGE RESULTS FOR AERATION PROCESS (ALTERNATIVE TWO)**

| Parameter | raw sample | effluent from cement | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|---|
| pH | 5.28 | 10.89 | 9.7 | 8.62 | 7.2 | 7.3 | 7.1 |
| conductivity | 533 | 964 | 914 | 952 | 952 | 960 | 965 |
| TDS | 533 | 964 | 914 | 952 | 952 | 960 | 965 |
| BOD | 2000 | 620 | 400 | 386 | 289 | 250 | 200 |
| COD | 4734 | 988 | 653 | 614 | 345 | 300 | 260 |
| Temp | 27.1 | 28.3 | 26.3 | 26.8 | 27.4 | 28.4 | 28.6 |
| DO | 0.07 | 1.51 | 3.48 | 4.8 | 6.53 | 6.8 | 7.2 |
| Salinity | 0 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

# APPENDEX K 5

## RESULTS OF ANAEROBIC FOLLOWED BY AERATION PROCESS (ALTERNATIVE THREE) FOR COMPOSITE SAMPLE

| 2 DAYS ANAEROBIC | | | 2 HOURS AEARTION | | | 4 HOURS AEARTION | | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1st test | 2nd test | Average | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average |
| pH | 6.95 | 7.37 | 7.16 | 8.2 | 9.2 | 8.7 | 8.5 | 9.16 | 8.83 |
| conductivity | 850 | 950 | 900 | 1000 | 1118 | 1059 | 1090 | 1166 | 1128 |
| TDS | 850 | 950 | 900 | 1000 | 1118 | 1059 | 1090 | 1166 | 1128 |
| BOD | 350 | 144 | 247 | 170 | 76 | 123 | 74 | 90 | 82 |
| COD | 700 | 986 | 843 | 420 | 302 | 361 | 300 | 314 | 307 |
| Temp | 26 | 27.6 | 26.8 | 26.7 | 28.5 | 27.6 | 27.4 | 28.4 | 27.9 |
| DO | 0.1 | 0.18 | 0.14 | 1.2 | 1.14 | 1.17 | 2.17 | 5.35 | 3.76 |
| Salinity | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.2 | 0.4 | 0.3 |

| 6 HOURS AEARTION | | | 8 HOURS AEARTION | | | 10 HOURS AEARTION | | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average | 1st Aeration | 2nd Aeration | Average |
| pH | 8.5 | 8.82 | 8.66 | 8.2 | 8.8 | 8.5 | 8.1 | 8.4 | 8.25 |
| conductivity | 1200 | 1182 | 1191 | 1100 | 1140 | 1120 | 1050 | 1128 | 1089 |
| TDS | 1200 | 1182 | 1191 | 1100 | 1140 | 1120 | 1050 | 1128 | 1089 |
| BOD | 67 | 69 | 68 | 55 | 47 | 51 | 52 | 38 | 45 |
| COD | 260 | 262 | 261 | 220 | 240 | 230 | 220 | 140 | 180 |
| Temp | 27.6 | 28.4 | 28 | 27.6 | 28.6 | 28.1 | 28 | 29.2 | 28.6 |
| DO | 4.8 | 4.04 | 4.42 | 4.3 | 6.1 | 5.2 | 5.8 | 6.34 | 6.07 |
| Salinity | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.2 | 0.4 | 0.3 |

## APPENDEX K 6

### AVERAGE RESULTS FOR ANAEROBIC FOLLOWED BY AERATION PROCESS ALTERNATIVE THREE

| | | Anaerobic | | Aeration | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | raw sample | effluent from cement | 2 days | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
| pH | 5.28 | 10.89 | 7.16 | 8.7 | 8.83 | 8.66 | 8.5 | 8.25 |
| conductivity | 533 | 964 | 900 | 1059 | 1128 | 1191 | 1120 | 1089 |
| TDS | 533 | 964 | 900 | 1059 | 1128 | 1191 | 1120 | 1089 |
| BOD | 2000 | 620 | 247 | 123 | 82 | 68 | 51 | 45 |
| COD | 4734 | 988 | 843 | 361 | 307 | 261 | 230 | 180 |
| Temp | 27.1 | 28.3 | 26.8 | 27.6 | 27.9 | 28 | 28.1 | 28.6 |
| DO | 0.07 | 1.51 | 0.14 | 1.17 | 3.76 | 4.42 | 5.2 | 6.07 |
| Salinity | 0 | 0.3 | 0.1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 |

## APPENDIX L: Concentration of dissolved oxygen at saturation for a range of temperature.

Equilibrium concentrations (mg/L) of dissolved oxygen* as a function of temperature and chloride

| Temperature, °C | Chloride concentration, mg/L | | | | |
|---|---|---|---|---|---|
| | 0 | 5,000 | 10,000 | 15,000 | 20,000 |
| 0 | 14.62 | 13.79 | 12.97 | 12.14 | 11.32 |
| 1 | 14.23 | 13.41 | 12.61 | 11.82 | 11.03 |
| 2 | 13.84 | 13.05 | 12.28 | 11.52 | 10.76 |
| 3 | 13.48 | 12.72 | 11.98 | 11.24 | 10.50 |
| 4 | 13.13 | 12.41 | 11.69 | 10.97 | 10.25 |
| 5 | 12.80 | 12.09 | 11.39 | 10.70 | 10.01 |
| 6 | 12.48 | 11.79 | 11.12 | 10.45 | 9.78 |
| 7 | 12.17 | 11.51 | 10.85 | 10.21 | 9.57 |
| 8 | 11.87 | 11.24 | 10.61 | 9.98 | 9.36 |
| 9 | 11.59 | 10.97 | 10.36 | 9.76 | 9.17 |
| 10 | 11.33 | 10.73 | 10.13 | 9.55 | 8.98 |
| 11 | 11.08 | 10.49 | 9.92 | 9.35 | 8.80 |
| 12 | 10.83 | 10.28 | 9.72 | 9.17 | 8.62 |
| 13 | 10.60 | 10.05 | 9.52 | 8.98 | 8.46 |
| 14 | 10.37 | 9.85 | 9.32 | 8.80 | 8.30 |
| 15 | 10.15 | 9.65 | 9.14 | 8.63 | 8.14 |
| 16 | 9.95 | 9.46 | 8.96 | 8.47 | 7.99 |
| 17 | 9.74 | 9.26 | 8.78 | 8.30 | 7.84 |
| 18 | 9.54 | 9.07 | 8.62 | 8.15 | 7.70 |
| 19 | 9.35 | 8.89 | 8.45 | 8.00 | 7.56 |
| 20 | 9.17 | 8.73 | 8.30 | 7.86 | 7.42 |
| 21 | 8.99 | 8.57 | 8.14 | 7.71 | 7.28 |
| 22 | 8.83 | 8.42 | 7.99 | 7.57 | 7.14 |
| 23 | 8.68 | 8.27 | 7.85 | 7.43 | 7.00 |
| 24 | 8.53 | 8.12 | 7.71 | 7.30 | 6.87 |
| 25 | 8.38 | 7.96 | 7.56 | 7.15 | 6.74 |
| 26 | 8.22 | 7.81 | 7.42 | 7.02 | 6.61 |
| 27 | 8.07 | 7.67 | 7.28 | 6.88 | 6.49 |
| 28 | 7.92 | 7.53 | 7.14 | 6.75 | 6.37 |
| 29 | 7.77 | 7.39 | 7.00 | 6.62 | 6.25 |
| 30 | 7.63 | 7.25 | 6.86 | 6.49 | 6.13 |

* Saturation values of dissolved oxygen in fresh water and sea water exposed to dry air containing 20.90 percent oxygen by volume under a total pressure of 760 mm of mercury.

*Source*: G. C. Whipple and M. C. Whipple: Solubility of Oxygen in Sea Water, *J. Am. Chem. Soc.*, vol. 33, p. 362, 1911. Calculated using data developed by C. J. J. Fox: On the Coefficients of Absorption of Nitrogen and Oxygen in Distilled Water and Sea Water and Atmospheric Carbonic Acid in Sea Water, *Trans. Faraday Soc.*, vol. 5, p. 68, 1909.

# APPENDIX M: ANALYTICAL METHODS

The laboratory analysis is carried out using "Standard Methods for the Examination of Water and Wastewater" Greenberg *et al* 1995). The following parameters were analysed:

BOD

COD

pH

Temperature

Dissolved oxygen

Conductivity

TDS

Salinity

Suspended solids

Nitrate

Phosphorus

A summary of the methods used for the laboratory analysis is given below.

**Biochemical Oxygen Demand (BOD):**

The BOD test is carried out using the Winkler Modification Method for oxygen determination.

**Chemical Oxygen Demand (COD):**

The Open Reflux method using potassium dichromate for oxidation is used in the calculation of the COD.

**pH and Temperature:**

For the measurement of pH and temperature, a pH meter is used

**Dissolved Oxygen (DO):**

A digital oximeter kit (WTW OXI 323-B / Set) is used. The kit has a probe connected to it .The sample under test is well shaken, and the probe inserted. There is a digital read-out when the probe is inserted in the sample.

**Electrical conductivity, TDS and Salinity:**

A meter consisting of a digital measuring kit with a probe is used for the measurement of Conductivity, TDS and salinity

**Suspended solids:** Photometric Method (also Non filterable Residue). Using HACH DR/2010 SPECTROPHOTOMETER.

**Phosphates:** Ascorbic Acid Method (Phos Ver 3 Powder Pillows). Using HACH DR/2010 SPECTROPHOTOMETER.

**Nitrates:** Cadmium Reduction Method (NitraVer 6 Powder Pillows). Using HACH DR/2010 SPECTROPHOTOMETER.

**Detailed laboratory analysis**

Reagent and apparatus

Distilled water

Borate buffer

Indicating boric acid

6N Sodium hydroxide solution

0.1031N Hydrochloride acid

pH

Volumetric flask

Kjeldahl (Distillation) flask

Burrette

Pipettes

Erlenmeyer flask

Heating device

Distillation apparatus.

**PHOSPHATE**

(Phos Ver 3 (Ascorbic Acid) Method using Powder Pillows)

Apparatus

ISO 9001 Certified

HACH DR/2010 Portable Data logging Spectrophotometer

**Procedure**

Using powder pillows

1. Enter the stored program number for reactive phosphorus, ascorbic acid method powder pillows. Press: **490 ENTER** the display will show: **Dial nm to 890**
2. Rotate the wavelength dial until the small display shows: **890nm** when the correct wavelength is dialed in, the display will quickly show: **Zero Sample** then **mg/L $PO_4^{3-}$ PV**.
3. Insert a 10-ml Cell Riser into the cell compartment.
4. Fill a sample cell with 10 ml of sample.
5. Add the contents of one PhosVer 3 Phosphate powder pillow for 10-ml sample to the cell (the prepared sample). Swirl immediately to mix.
6. Press: **SHIFT TIMER**. A two-minute reaction period will begin.
7. Fill a second 10-ml sample cell with 10ml of sample (this is the blank).



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8. When the timer beeps, the display will show: mg/L $PO_4^{3-}$ **PV**. Place the blank into the cell holder. Close the light shield.
9. Press zero. The display shows zeroing then 0 mg/l $PO_4^{3-}$ **PV**.
10. Place the prepared sample into the cell holder. Close the light shield.
11. Pres read then the results will be displayed. In mg/L $PO_4^{3-}$

The procedure is repeated using demineralised water.

Calculation

$PO_4^{3-}$ - P (mg/l) = CF-D

Where:

C = $PO_4^{3-}$ - P value obtained for the diluted sample.

D = $PO_4^{3-}$ - P value obtained for the demineralised water

F = dilution factor of sample.

**NITRATE**

**Apparatus:**

ISO 9001 Certified

HACH DR/2010 Portable Data logging Spectrophotometer

Cadmium Reduction Method using powder pillows (NitraVer 5).

**Procedure:**

1. Enter the stored program number for low range nitrate nitrogen ($NO_3^-$ - N).

Press: 353 ENTER. The display will show: Dial nm to 400.

2. Rotate the wavelength dial until the small display shows: 400 nm when the correct wavelength is dialed in, the display will quickly show: Zero sample then: mg/l $NO_3^-$ - N MR
3. Fill a sample cell with 25 ml of sample (the prepared sample).

4. Fill another cell with 25ml of demineralised water (the Blank).
5. Add the contents of one NitraVer 5 Reagent Powder pillow to each cell. Stopper.
6. Press: SHIFT TIMER. A one-minute reaction will begin. Shake until the timer beeps.
7. When the timer beeps. Press SHIFT TIMER. A five-minute reaction period.
8. When the timer beeps, the display will show: mg/l $NO_3^-$ - N MR remove the stopper and place the blank into the cell holder. Close the light shield.
9. Press ZERO the display will show 0.0mg/l $NO_3^-$ - N
10. Place prepared sample into the cell holder. Close the light shield.
11. Press: READ the display will show the results in mg/l nitrate expressed as nitrogen ($NO_3^-$ - N).

pH AND TEMPERATURE

A digital pH measuring kit with a probe (WTW pH 323-B/ Set-2) is used. The pH meter is calibrated before use. The kit measures both the pH and temperature of the sample. The sample under test is well shaken, and the probe is inserted.

ELECTRICAL CONDUCTIVITY, TDS AND SALINITY

A digital conductivity measuring kit (WTW LF 323-B/Set) is used. The kit has a probe connected to it. The conductivity meter is calibrated before use. The sample under test is well shaken, and the probe inserted. There is a digital read-out when the probe is inserted.

## SUSPENDED SOLIDS (SS)

### Photometric Method (Also Non-filterable Residue).

Apparatus

**ISO 9001 Certified**

**HACH DR/2010 Portable Data logging Spectrophotometer.**

Procedure

1. Enter the stored program number for suspended solids. Press: **630 ENTER**. The display will show: **Dial nm to 810.**
2. Rotate the wavelength dial until the small display shows: **810 nm** when the correct wavelength is dialed in, the display will quickly show: **Zero Sample** then: **mg/L SUSP.SOLIDS.**
3. Blend 500ml of sample in a blender at a high speed for exactly two minutes.
4. Pour the blended sample into a 600-ml beaker
5. Stir the sample and immediately pour 25 Ml of the blended sample into a sample cell (the prepared sample).
6. Fill a sample cell with 25ml of tap water or demineralised water (the blank).
7. Place the blank in the cell holder: close the light shield.
8. Press ZERO the display shows zeroing then **0 mg/l SUS.SOLIDS**.
9. Swirl the prepared sample cell to remove any gas bubbles and uniformly suspended any residue.
10. Place the prepared sample into the cell holder. Close the light shield.
11. Press READ. The display will show the result in **mg/l suspended solids.**

## BIOLOGICAL OXYGEN DEMAND (BOD)

### Instruments and Laboratory Equipment:

BOD bottle, 300ml

Incubator (controlled at $20 \pm 1^{O}C$)

Burette

Pipettes

Measuring cylinder –100ml

Conical flask-250ml

Volumetric flask-100ml

Aspirator Glass container (10 Litres) for Aeration.

### Reagents:

Distilled Water

Magnesium sulphate solution ($MgSO_4$)

Phosphate buffer solution

Calcium chloride solution ($CaCl_2$)

Iron (III) chloride solution ($FeCl_3$)

Manganese (II) sulphate solution ($MnSO_4$)

Alkali-iodide-azide reagent

Conc. Sulphuric acid ($H_2SO_4$)

0.025M Sodium thiosulphate solution ($Na_2S_2O_3$)

Starch solution

## Procedure

In preparing the dilution water, a pre-determined volume of distilled water is poured into the glass container. For each 1litre of distilled water is poured into the glass container. For each 1litre of distilled water in the glass container, 1ml $MgSO_4$, 1ml Phosphate buffer, 1ml $CaCl_2$ and 1ml $FeCl_3$ were added. The vacuum pump is applied and the distilled water is aerated for 1 hour. The sample is well shaken and 100ml portion of it is diluted to 1litre. The diluted sample is well shaken and 1ml of it is pipetted into volumetric flasks, and diluted to 1litre with the dilution water. For each dilution, two 300ml BOD bottles were carefully filled with the diluted sample excluding air bubbles. For one of the bottled samples, the dissolved oxygen content is determined immediately. The other is incubated at 20oC for 5 days after which the dissolved oxygen content is determined. In determining the dissolved oxygen content, 1ml $MnSO_4$ followed by 1ml alkali-iodide0azide reagent were added to the diluted sample in the BOD bottle and closed carefully to exclude air bubbles. The bottle is inverted several times for the manganese hydroxide precipitate formed to mix evenly, and then allowed to settle. When the precipitate has settled to approximately half the bottle volume, 1ml conc. $H_2SO_4$ is added and the bottled closed. The bottled is inverted several times for complete dissolution of the precipitate, which gives intense yellow colour. 200ml of the solution is decanted into a conical flask. This is titrated with the 0.025 M $Na_2S_2O_3$ to a pale yellow colour. 1ml of starch solution is added and the titration continued to the first disappearance of the blue colour.

Calculation

$$BOD5\ (mg/l) = [(Di - Df)/p] \times F$$

Where:

Di = volume of 0.025 M Na2S2O3 used for 200ml of the original dilution (ml)

Df = volume of 0.025 M Na2S2O3 used for 200ml of the incubated dilution (ml)

P = decimal volumetric fraction of sample used

F = dilution factor

**CHEMICAL OXYGEN DEMAND (COD)**

The sample, with the organic matter to be measured, is oxidized under reflux with a known amount of dichromate in concentrated sulphuric acid with silver sulphate as a catalyst. Part of the dichromate is reduced by organic matter and the remainder is determined by titration with ferrous ammonium sulphate using ferrous as indicator.

**Instruments and Laboratory Equipment:**

Measuring cylinder

Volumetric

Reflux flask

Burette

Pipettes

Heating device

Condenser

Reagents

Distilled water

0.25N Potassium dichromate

Mercury (II) sulphate

Silver sulphate solution

Conc. $H_2SO_4$

Ferroin indicator

Ferrous ammonium sulphate

Procedure

About 1g mercury (II) sulphate is placed in the reflux flask. The sample is well shaken and a 100ml portion taken. This portion is diluted with distilled water to 1litre. The diluted sample is well shaken and a volume of 10ml of it is pipetted into the flask. 10ml of 0.25N Potassium dichromate followed by 20ml of concentrated sulphuric acid were added to the flask. The flask is then cooled under running water, and 1ml of silver sulphate solution is added. The process is repeated using 10ml of distilled water instead of sample as blank. The content of each flask is mixed well and the flasks fitted to the condenser with the bottom of the flasks resting on the heaters. The heaters were switched on and the mixtures boiled under open reflux for 2 hours. Flasks were removed and of distilled water added to each flask. Flasks were cooled under running water and 3 drops of ferroin indicator were added producing a light blue-green colour. The residual solution is then titrated with ferrous ammonium sulphate to a reddish-brown end-point.

**Calculation:**

$$COD\ (mg/l) = [(A-B) \times N \times 8000/] \times F$$

Where:

A = volume of ferrous ammonium sulphate used for the blank titration (ml)

B = volume of ferrous ammonium sulphate used for the sample titration (ml)

V = volume of diluted sample used (10ml)

N = normality of ferrous ammonium sulphate

F = dilution factor (10)

Standardization of ferrous ammonium sulphate

The normality of ferrous ammonium sulphate is not stable; it changes with time. Thus for a COD test on any particular day, the normality is checked as illustrated below.10ml of the standard Potassium dichromate solution is diluted with distilled water to about 100ml. 30ml of conc. Sulphuric acid is added cooled under running water. The (3) drops of ferroin indicator is added and titrated with the ferroin ammonium sulphate to reddish-brown end-point.

Normality = (C x 0.25)/D

Where:

C = volume of Potassium dichromate (10ml)

D = volume of ferroin ammonium sulphate (ml)

0.25 = normality of the standard Potassium

# APPENDIX M: ANALYTICAL METHODS

The laboratory analysis is carried out using "Standard Methods for the Examination of Water and Wastewater" Greenberg *et al* 1995). The following parameters were analysed:

BOD

COD

pH

Temperature

Dissolved oxygen

Conductivity

TDS

Salinity

Suspended solids

Nitrate

Phosphorus

A summary of the methods used for the laboratory analysis is given below.

**Biochemical Oxygen Demand (BOD):**

The BOD test is carried out using the Winkler Modification Method for oxygen determination.

**Chemical Oxygen Demand (COD):**

The Open Reflux method using potassium dichromate for oxidation is used in the calculation of the COD.

**pH and Temperature:**

For the measurement of pH and temperature, a pH meter is used

**Dissolved Oxygen (DO):**

A digital oximeter kit (WTW OXI 323-B / Set) is used. The kit has a probe connected to it .The sample under test is well shaken, and the probe inserted. There is a digital read-out when the probe is inserted in the sample.

**Electrical conductivity, TDS and Salinity:**

A meter consisting of a digital measuring kit with a probe is used for the measurement of Conductivity, TDS and salinity

**Suspended solids:** Photometric Method (also Non filterable Residue). Using HACH DR/2010 SPECTROPHOTOMETER.

**Phosphates:** Ascorbic Acid Method (Phos Ver 3 Powder Pillows). Using HACH DR/2010 SPECTROPHOTOMETER.

**Nitrates:** Cadmium Reduction Method (NitraVer 6 Powder Pillows). Using HACH DR/2010 SPECTROPHOTOMETER.

**Detailed laboratory analysis**

Reagent and apparatus

Distilled water

Borate buffer

Indicating boric acid

6N Sodium hydroxide solution

0.1031N Hydrochloride acid

pH

Volumetric flask

Kjeldahl (Distillation) flask

Burrette

Pipettes

Erlenmeyer flask

Heating device

Distillation apparatus.

**PHOSPHATE**

(Phos Ver 3 (Ascorbic Acid) Method using Powder Pillows)

Apparatus

ISO 9001 Certified

HACH DR/2010 Portable Data logging Spectrophotometer

**Procedure**

Using powder pillows

1. Enter the stored program number for reactive phosphorus, ascorbic acid method powder pillows. Press: **490 ENTER** the display will show: **Dial nm to 890**
2. Rotate the wavelength dial until the small display shows: **890nm** when the correct wavelength is dialed in, the display will quickly show: **Zero Sample** then **mg/L $PO_4^{3-}$ PV**.
3. Insert a 10-ml Cell Riser into the cell compartment.
4. Fill a sample cell with 10 ml of sample.
5. Add the contents of one PhosVer 3 Phosphate powder pillow for 10-ml sample to the cell (the prepared sample). Swirl immediately to mix.
6. Press: **SHIFT TIMER**. A two-minute reaction period will begin.
7. Fill a second 10-ml sample cell with 10ml of sample (this is the blank).

8. When the timer beeps, the display will show: mg/L **$PO_4^{3-}$ PV**. Place the blank into the cell holder. Close the light shield.
9. Press zero. The display shows zeroing then 0 mg/l **$PO_4^{3-}$ PV**.
10. Place the prepared sample into the cell holder. Close the light shield.
11. Pres read then the results will be displayed. In mg/L **$PO_4^{3-}$**

The procedure is repeated using demineralised water.

Calculation

$PO_4^{3-}$ - P (mg/l) = CF-D

Where:

C = $PO_4^{3-}$ - P value obtained for the diluted sample.

D = $PO_4^{3-}$ - P value obtained for the demineralised water

F = dilution factor of sample.

**NITRATE**
**Apparatus:**

ISO 9001 Certified

HACH DR/2010 Portable Data logging Spectrophotometer

Cadmium Reduction Method using powder pillows (NitraVer 5).

**Procedure:**

1. Enter the stored program number for low range nitrate nitrogen ($NO_3^-$ - N).

Press: 353 ENTER. The display will show: Dial nm to 400.

2. Rotate the wavelength dial until the small display shows: 400 nm when the correct wavelength is dialed in, the display will quickly show: Zero sample then: mg/l $NO_3^-$ - N MR
3. Fill a sample cell with 25 ml of sample (the prepared sample).

4. Fill another cell with 25ml of demineralised water (the Blank).
5. Add the contents of one NitraVer 5 Reagent Powder pillow to each cell. Stopper.
6. Press: SHIFT TIMER. A one-minute reaction will begin. Shake until the timer beeps.
7. When the timer beeps. Press SHIFT TIMER. A five-minute reaction period.
8. When the timer beeps, the display will show: mg/l $NO_3^-$ - N MR remove the stopper and place the blank into the cell holder. Close the light shield.
9. Press ZERO the display will show 0.0mg/l $NO_3^-$ - N
10. Place prepared sample into the cell holder. Close the light shield.
11. Press: READ the display will show the results in mg/l nitrate expressed as nitrogen ($NO_3^-$ - N).

pH AND TEMPERATURE

A digital pH measuring kit with a probe (WTW pH 323-B/ Set-2) is used. The pH meter is calibrated before use. The kit measures both the pH and temperature of the sample. The sample under test is well shaken, and the probe is inserted.

ELECTRICAL CONDUCTIVITY, TDS AND SALINITY

A digital conductivity measuring kit (WTW LF 323-B/Set) is used. The kit has a probe connected to it. The conductivity meter is calibrated before use. The sample under test is well shaken, and the probe inserted. There is a digital read-out when the probe is inserted.

## SUSPENDED SOLIDS (SS)

**Photometric Method (Also Non-filterable Residue).**

Apparatus

**ISO 9001 Certified**

**HACH DR/2010 Portable Data logging Spectrophotometer.**

Procedure

1. Enter the stored program number for suspended solids. Press: **630 ENTER**. The display will show: **Dial nm to 810**.
2. Rotate the wavelength dial until the small display shows: **810 nm** when the correct wavelength is dialed in, the display will quickly show: Zero Sample then: mg/L **SUSP.SOLIDS.**
3. Blend 500ml of sample in a blender at a high speed for exactly two minutes.
4. Pour the blended sample into a 600-ml beaker
5. Stir the sample and immediately pour 25 Ml of the blended sample into a sample cell (the prepared sample).
6. Fill a sample cell with 25ml of tap water or demineralised water (the blank).
7. Place the blank in the cell holder: close the light shield.
8. Press ZERO the display shows zeroing then **0 mg/l SUS.SOLIDS**.
9. Swirl the prepared sample cell to remove any gas bubbles and uniformly suspended any residue.
10. Place the prepared sample into the cell holder. Close the light shield.
11. Press READ. The display will show the result in **mg/l suspended solids.**

## BIOLOGICAL OXYGEN DEMAND (BOD)

**Instruments and Laboratory Equipment:**

BOD bottle, 300ml

Incubator (controlled at $20 \pm 1^{O}C$)

Burette

Pipettes

Measuring cylinder –100ml

Conical flask-250ml

Volumetric flask-100ml

Aspirator Glass container (10 Litres) for Aeration.

**Reagents:**

Distilled Water

Magnesium sulphate solution ($MgSO_4$)

Phosphate buffer solution

Calcium chloride solution ($CaCl_2$)

Iron (III) chloride solution ($FeCl_3$)

Manganese (II) sulphate solution ($MnSO_4$)

Alkali-iodide-azide reagent

Conc. Sulphuric acid ($H_2SO_4$)

0.025M Sodium thiosulphate solution ($Na_2S_2O_3$)

Starch solution

**Procedure**

In preparing the dilution water, a pre-determined volume of distilled water is poured into the glass container. For each 1litre of distilled water is poured into the glass container. For each 1litre of distilled water in the glass container, 1ml $MgSO_4$, 1ml Phosphate buffer, 1ml $CaCl_2$ and 1ml $FeCl_3$ were added. The vacuum pump is applied and the distilled water is aerated for 1 hour. The sample is well shaken and 100ml portion of it is diluted to 1litre. The diluted sample is well shaken and 1ml of it is pipetted into volumetric flasks, and diluted to 1litre with the dilution water. For each dilution, two 300ml BOD bottles were carefully filled with the diluted sample excluding air bubbles. For one of the bottled samples, the dissolved oxygen content is determined immediately. The other is incubated at 20oC for 5 days after which the dissolved oxygen content is determined. In determining the dissolved oxygen content, 1ml $MnSO_4$ followed by 1ml alkali-iodide0azide reagent were added to the diluted sample in the BOD bottle and closed carefully to exclude air bubbles. The bottle is inverted several times for the manganese hydroxide precipitate formed to mix evenly, and then allowed to settle. When the precipitate has settled to approximately half the bottle volume, 1ml conc. $H_2SO_4$ is added and the bottled closed. The bottled is inverted several times for complete dissolution of the precipitate, which gives intense yellow colour. 200ml of the solution is decanted into a conical flask. This is titrated with the 0.025 M $Na_2S_2O_3$ to a pale yellow colour. 1ml of starch solution is added and the titration continued to the first disappearance of the blue colour.

Calculation

$$BOD5\ (mg/l) = [(Di - Df)/p] \times F$$

Where:

Di = volume of 0.025 M Na2S2O3 used for 200ml of the original dilution (ml)

Df = volume of 0.025 M Na2S2O3 used for 200ml of the incubated dilution (ml)

P = decimal volumetric fraction of sample used

F = dilution factor

**CHEMICAL OXYGEN DEMAND (COD)**

The sample, with the organic matter to be measured, is oxidized under reflux with a known amount of dichromate in concentrated sulphuric acid with silver sulphate as a catalyst. Part of the dichromate is reduced by organic matter and the remainder is determined by titration with ferrous ammonium sulphate using ferrous as indicator.

**Instruments and Laboratory Equipment:**

Measuring cylinder

Volumetric

Reflux flask

Burette

Pipettes

Heating device

Condenser

Reagents

Distilled water

0.25N Potassium dichromate

Mercury (II) sulphate

Silver sulphate solution

Conc. $H_2SO_4$

Ferroin indicator

Ferrous ammonium sulphate

Procedure

About 1g mercury (II) sulphate is placed in the reflux flask. The sample is well shaken and a 100ml portion taken. This portion is diluted with distilled water to 1litre. The diluted sample is well shaken and a volume of 10ml of it is pipetted into the flask. 10ml of 0.25N Potassium dichromate followed by 20ml of concentrated sulphuric acid were added to the flask. The flask is then cooled under running water, and 1ml of silver sulphate solution is added. The process is repeated using 10ml of distilled water instead of sample as blank. The content of each flask is mixed well and the flasks fitted to the condenser with the bottom of the flasks resting on the heaters. The heaters were switched on and the mixtures boiled under open reflux for 2 hours. Flasks were removed and of distilled water added to each flask. Flasks were cooled under running water and 3 drops of ferroin indicator were added producing a light blue-green colour. The residual solution is then titrated with ferrous ammonium sulphate to a reddish-brown end-point.

**Calculation:**

COD (mg/l) = [(A-B) x N x 8000/] x F

Where:

A = volume of ferrous ammonium sulphate used for the blank titration (ml)

B = volume of ferrous ammonium sulphate used for the sample titration (ml)

V = volume of diluted sample used (10ml)

N = normality of ferrous ammonium sulphate

F = dilution factor (10)

Standardization of ferrous ammonium sulphate

The normality of ferrous ammonium sulphate is not stable; it changes with time. Thus for a COD test on any particular day, the normality is checked as illustrated below.10ml of the standard Potassium dichromate solution is diluted with distilled water to about 100ml. 30ml of conc. Sulphuric acid is added cooled under running water. The (3) drops of ferroin indicator is added and titrated with the ferroin ammonium sulphate to reddish-brown end-point.

Normality = (C x 0.25)/D

Where:

C = volume of Potassium dichromate (10ml)

D = volume of ferroin ammonium sulphate (ml)

0.25 = normality of the standard Potassium