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Comparative use of lime and moringa *oleifera* in removal of suspended solids from coffee processing effluent

By

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Declaration

This thesis is my original work and has not been presented for a degree in any other university.”

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F80/8390/2006

Approval

This thesis has been submitted for examination with my/our approval as university supervisor(s).

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Signature

Dedication

To

The coffee growers in Kenya for their loyalty to the coffee tree and diligent support to the coffee research in Kenya.

Acknowledgement

First I give glory to God for the opportunity and grace to undertake this study to completion. This I do in recognition that every good gift and every perfect gift is from above, and comes down from the father, to whom I am most grateful. I also sincerely feel indebted to my wife and our children for their sacrifice, bearing gracefully, encouraging praying, unflagging support, discerning advice and patience throughout the study period and as I went about my full paternal and mentorship role. For all their favours including as well this privilege to pursue this degree and standing by me tirelessly throughout this period, I wish to extend my special thanks to them.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

NOMENCLATURE (ACRONYMS AND NOTATIONS)

AGSM	Australian graduate school of management
Al_2SO_4	Aluminium sulphate
APC	Activated peel carbon
BAEN	Biological and Agricultural Engineering
Becolsub	**B**eneficio **Ecol**ogicos **Sub**-producto
BOD	Biochemical Oxygen Demand
C	Carbon
Ca	Calcium
CAC	Commercial activated carbon
$CaCO_3$	Calcium carbonate
$CaCO_3.MgCO_3$	Dolomite or Calcite
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium hydroxide
$CaSO_4.2H_2O$	Gypsum
CEW	Centre for education and work
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CRF	Coffee Research Foundation
DS	Dissolved solids
EC	Electrical conductivity
EPA	Environmental protection agency
FAO	Food and Agriculture Organization of the United Nations
$FeSO_4$	Ferrous sulphate
gm	grams
K	Potassium
kg	Kilograms
KSPCB	Kanataka State Pollution Control Board
N	Nitrogen
NEAP	Kenya National Environmental Action Plan
l	Liter
m	meter
mg	milligrams
$MgSiO_3$	Magnesium silicate (Diatomite)
NEMA	National Environmental Management Authority
OC	Organic carbon
P	Phosphorous
pH	Measure of acidity
S	Sulphur
t	Time

TS	Total solids
TSP	Triple superphosphate
TSS	Total suspended solids
UAF	Up-flow anaerobic filter
UASB	Up-flow anaerobic sludge blanket
VSB	Variable Sludge Blanket
WHC	Water holding capacity
WWF	World Wildlife Fund

ABSTRACT

In Kenya, coffee grows in only a small part of 20% of the whole country which is arable land. It grows well between 1200 m and 2100 m above sea level and an annual rainfall of more than 1000 mm. Besides that, coffee does well in areas with red roam soil which is deep and self-draining. It is grown by two economic sectors namely the small holder who are in cooperative societies and in small, medium and large estates. It has been identified with occasional environmental pollution threat in particular during the peak season. Such pollution has been attributed to the coffee processing wastes in particular the voluminous effluent. However, the final grading effluent which constitutes the largest component of the effluent has been recommended for recycling back to the pulping and washing operations. The washing effluent is also preferably mixed with the pulp which can subsequently be composted for agricultural use. Therefore, the pulping effluent remains as the only component in need of serious concern. Recent studies found minimization of water used for processing followed by treatment as the most practical solution towards alleviation of pollution from coffee pulping effluent. One of the postulated forms of treatment targets the removal of the suspended solids from the effluent prior to its discharge to the percolation disposal pits.

The first part of this study sought to relate the levels of suspended solids in the effluent to the specific amount of water used for processing the ripe coffee cherry. That was followed by evaluation of three options for removing suspended solids from the pulping effluent. The first trial degraded the raw effluent naturally by allowing it to remain resident under normal ambient laboratory conditions until no more solids precipitated out of the effluent. During that time the effluent was not disturbed except possibly slightly during measurements of the relevant parameters.

The second one involved application of lime at different rates to the effluent immediately after pulping. The third option treated the pulping effluent with different rates of dry and finely ground oil press cake from moringa *oleifera* seeds. In all these experiments, the pH, total and dissolved solids in the effluent were measured at preset intervals against time. The precipitated suspended solids from the effluent were also measured as well. Other remarkable observations were also made and recorded. Finally comparative seepage trials were conducted using the raw and treated effluent applied to the conventional percolation pit models.

Results of these trials were such that natural biodegradation caused the removal of solids from an initial concentration of 3 – 9 g/l to less than 2.0 g/l in 3 – 10 days. In general, between 50 to 90% of the solids were removed from the effluent within that period. However, addition of lime to the effluent even at its optimum rate of 2.0 g/l did not improve the rate or extent of the solids removal over the natural settlement. As for moringa *oleifera,* its optimum application rate was 1.0 – 2.5 g/l of effluent. That dosage consistently resulted with a distinct precipitation of solids from the effluent in 24 hours after treatment. Since pulping of coffee is a batch process at almost 24 hour intervals, the treatment of effluent with moringa would therefore be the most compatible to the locally practiced conventional coffee processing system.

As for the disposal of the effluent, percolation of the treated effluent from the pits was 1.66 – 3.75; 3.07 – 6.57 and 1.62 – 2.86 times faster than the raw effluent in 3 sites located at Kisii, Koru and Ruiru respectively.

Another dimension was that, the treated effluent had mainly two phases namely a solids free effluent and settled sludge. Occasionally, either some scum formed on the surface or/and some sludge dislodged from the bottom to the surface of the effluent. The sludge if from lime and moringa treatments has enhanced potential for economic utilization besides broadening the value addition options for these flocculants.

CHAPTER 1 INTRODUCTION

1.1 Background

In Kenya, arable land constitutes only 20% of land area and coffee grows in only a small part of that area. It grows well between 1,200 m and 2,100 m above sea level and an annual rainfall of more than 1,000 mm. Besides that, coffee does well in areas with red roam soil which is deep and self-draining. It is grown by two economic sectors consisting of the small holder farmers grouped in various societies and small, medium and large estates. Coffee in Kenya is mainly harvested in 2 seasons, each of which last about 3 months and the major of which accounts for 60% of the annual production. Otherwise, a few regions have only a one continuous 6 month season. Although the production is now about 40,000 metric tons of clean coffee, the established coffee can produce more than 100,000 metric tons of the same from 600,000 metric tons of coffee cherry in a peak year.

After harvesting, coffee is subjected to processing which generally, revolves itself into the best method of separating the coffee bean from the surrounding organic matter, so that it can retire from active to passive life, in which dry state it will keep. Coffee is either processed by the wet or dry method. The first part of the wet method procedure uses water to assist pulping ripe coffee cheery, pre-grading the mixture of cherry and parchment, intermediate washing, final washing and grading as well as transportation of coffee from stage to stage along the wet processing chain. The second part is devoted to drying of the parchment after which is milled in the dry secondary processing phase. In Kenya, the coffee cherry is preferably wet processed because it reportedly produces superior quality coffee compared to the dry and semi washed coffee processing methods (Shanmukhappa et. al., 1998 and Gonzalez-Rios *et* *al.*, 2006)***.*** Since the legal limit for processing water use is 22.5 m^3 per ton of dry parchment (Kenya water act, 1974), 2.7million cubic meters of water would be required to transform cherry from a peak season to clean state. However, the water used for processing is on average in excess of 4 to 5 times the stipulated limit. But pressure is urging coffee processors to keep within the law. Compared to pulping and final grading, the water used for transportation, intermediate washing and final washing is of no environmental consequence.

Coffee processing by the wet method is also characterized with the generation of considerable amounts of pulp and waste water referred to as coffee processing effluents or simply coffee effluent depending on the magnitude of the prevailing cherry production and the rate of water used to process a unit weight of cherry. Therefore, because of the excessive consumption of water, discharged effluents are similarly high. That is so in spite of the existing control measures in terms of water recirculation during pulping and final grading as well as limited intermediate washing and conveyance using pumps. Although pulping and final grading effluent are substantial recent studies have found use for the largest water output namely the final grading effluent with respect to its suitability for recycling for pulping and intermediate washing (Mburu, 2010). As such, pulping water is the only processing effluent worth of concern since the amounts of intermediate effluent are minimal and rather too concentrated for solids removal for the sake of only easing disposal.

Unfortunately, seepage of contaminated leachate from decomposing pulp heaps and inappropriate design and location of waste treatment pits can cause drainage and seepage of raw effluents to contaminate the environment in particular the surface water ways. The contamination of surface water with coffee processing effluent has always culminated with far reaching adverse consequences to other social and economic activities which depend on quality water for their normal operation. These include, other primary coffee processing factories downstream along the same river, rural and urban domestic water requirements, industries, agriculture, livestock and to a limited extent fish culturing among others.

In order to alleviate the occasional pollution of the surface waterways and land degradation identified with peak production, there is need to manage the coffee wastes effectively. Otherwise, without due care of the environment, there can be no sustainable development. Especially when expanding wet coffee processing or setting up new large scale processing operations, treatment of coffee effluent needs to be considered. The most viable option for coffee processing waste management lies in minimization followed by treatment (Wood *et al.*, 2000 and Mburu 2001). Minimization can be achieved by more intensive water re-circulation and recycling during wet processing. Alternatively, most of the mucilage can be removed mechanically as well as pulp disposal through a press screw conveyor a combination which uses significantly minimal water.

The strain on seepage pit disposal system by coffee processing effluent cannot be attributed to the volume factor only but also to the mucilaginous pectin in suspension. These suspended solids, are relatively slow to break down and some either float to the surface or settle as sediment to the bottom of the pit even after standing for several days. The floating matter probably impairs any evaporation of water from the pit while the sediment with the assistance of the weight of the effluent load in the pit is likely to clog the pit surfaces and thereby prevent any further seepage of the effluent out of the pit. It is desirable therefore to remove them from the effluent before they reach the effluent discharge pit. Firstly, the amount of solids contributing to COD loading of coffee effluent needs to be lowered if possible. However, the gelatinous texture of the mucilage makes it infeasible to filter it out of coffee effluents except possibly by other treatment mechanisms. Further to that simple, low cost methods for removing sugars and organic acids from coffee effluent are unavailable, so these must be treated by percolation trenches or other systems. The solids removal will reduce the potential for pit clogging and improve its action as a percolating filter or digester of organic compounds.

The conventional means for removing suspended materials in coffee effluent has been by the addition of flocculants like aluminium sulphate, ferrous sulphate or lime, which when added to water, produce a coagulating precipitate, which entrains suspended materials and results in sedimentation. However, ferrous sulphate is an expensive flocculant while aluminium sulphate in a water system has been linked with Alzheimer's disease. Although lime is readily available in Kenya, it has been reported to produce a partial flocculation and slow sedimentation of the suspended mucilage solids (Wood, *et al.,* 2000). However, as reported from the same study, the most successful flocculant was found to be a combination of lime and silicaceous clay in the form of Portland cement. From the foregoing, the search for other cheaper and effective flocculants was deemed essential. While doing so, it was important to consider that the output of effluent from a primary coffee processing factory fitted well to a 24 hour cycle.

For that purpose, current and alternative practices of coffee effluent treatment were evaluated against that background to establish which would be most cost effective and technically efficient. Wood *et al.* (2000) had dismissed lime as a coagulant to produce expected instant results however it could be used with processing cycle time frame. Lime was reported as slow in precipitating suspended solids from the effluent (Wood *et. al*., 2000), but it was still considered worthwhile to complement the natural process with it because of its ability to neutralize the pH paving way for enhanced action by the microorganisms responsible for the biodegradation of the effluent. Notwithstanding the fact that lime had been perceived slow as far as expedient removal of the suspended solids was concerned, assuming that the most frequent coffee pulping schedule has a 24 hour interval, it was deemed worthwhile to confirm whether lime could perform within such a period. That would guarantee effective treatment of a batch of effluent before the next one is due for release. Moreover, lime is attractive to use because it is locally available and hence bound to be cheap while the end treatment by-products i.e. sludge would be useful in farming. All the the treatment trails were preceded by some rapid experiments to establish the optimum dosage rates.

The treatment of the effluent for this purpose can also yield potential products for economic utilization together with the pulp. In view of that the main objective of this study was to precipitate the suspended solids from coffee effluent treatment system and to verify how easily the treated effluent seeped out of the seepage pit in comparison with the raw effluent. The results were expected to facilitate in the sustenance of the production of high quality coffee besides availing high quality water for other uses. The main focus is then not only to remove the suspended solids from the effluent towards enhancement of seepage in order to alleviate environmental pollution from the effluent but also to facilitate the separation of the 2 phases (solid and liquid) for alternative utility. It is in essence difficult to make use of them when combined. Besides, flocculants/coagulants which are capable of adding value to the end by-products would be rated highly. Ways and means should be explored towards economic exploitation of its contents washed off from the beans.

Since it would therefore be really worthwhile to test the possibility of using moringa oleifera to settle solids from the processing effluent, the main aim of this project was to evaluate moringa *oleifera* press seed cake powder and other natural substances in cost effective coagulation and/or flocculation for clarification of polluted coffee processing effluent. This study aimed at identifying and verifying the efficacy of the locally available coagulation agents in situ for immediate practical relevance. If successful, the cake would otherwise serve an alternative role besides its current usage as an animal feed thereby creating a spiralling social economic effect. That would by implication enhance the growing of the plant all the more and consequently enhancing the farmer's incomes.

The broad objective of this study was to enhance the infiltration of the effluent into the soil by removing the suspended solids within a specified coffee processing cycle. Therefore, although the Lime, performance on the coffee processing effluent in general was rated dismal by Wood *et. al.* (2000), the local availability of calcium stimulated interest in further studies using other calcium affiliated compounds like limestone, calcite, magmax, and $Ca(OH)_2$. The pulping effluent is normally realized from late in the afternoon while the output of effluent from washing and grading occurs generally in the morning. This requires an agent that can effectively treat the effluent batches within 24 hours. In addition to that, a substance which will enhance the value of the resultant sludge with respect to the likely options for its economic utilization will be preferentially considered. The selection criterion was based on the available knowledge about the potential of each substance considered to clarify water and/or agro processing effluents. The other aspect used to merit the selection of the flocculants was their expected value addition to the resultant by products of the effluent treatment. Since the economic means and the attitude of the rural coffee processors are somehow limited and ambivalent, the most preferred coffee processing effluent treatment method was limited to those which are cheap, effective and requiring minimal attention after application. The performances of the flocculants were then evaluated in experimental trials using coffee processing effluent.

1.2 Objectives

The main objective of the planned investigations was to alleviate pollution of the surface water ways by transformation of the effluent to ease its disposal or value addition.

The specific objectives were:

i. To establish the characteristics of the coffee processing effluent in relation to the corresponding specific water used (m^3/ton of cherry),
ii. To identify water clarifiers that can rapidly remove suspended solids from the effluent and compare their performance to the natural settlement of solids from the effluent.
iii. To postulate the most appropriate method for separating the sediment from the treated effluent,
iv. To compare the percolation of the raw and treated effluent using a model of the improved seepage pit design.
v. To explore options for economic utilization of the treated coffee processing effluent and the separated solid waste.

CHAPTER 2. LITERATURE REVIEW

2.1 Spatial distribution of coffee production and demand for coffee processing.

Coffee (Plate 2.1) grows well in areas with red roam soil which is deep and self-draining situated between 1200 m and 2100 m above sea level and an annual rainfall of more than 1000 mm (Wintgens, 2004).

Plate 2.1: Coffee tree in production

The main coffee growing areas in Kenya are as shown Fig. 2.1. As indicated, production of is distributed widely from east to west within the southern half of the country in areas providing suitable conditions for its establishment. The shown coffee growing regions are part of the arable land which only 20% of the whole country.

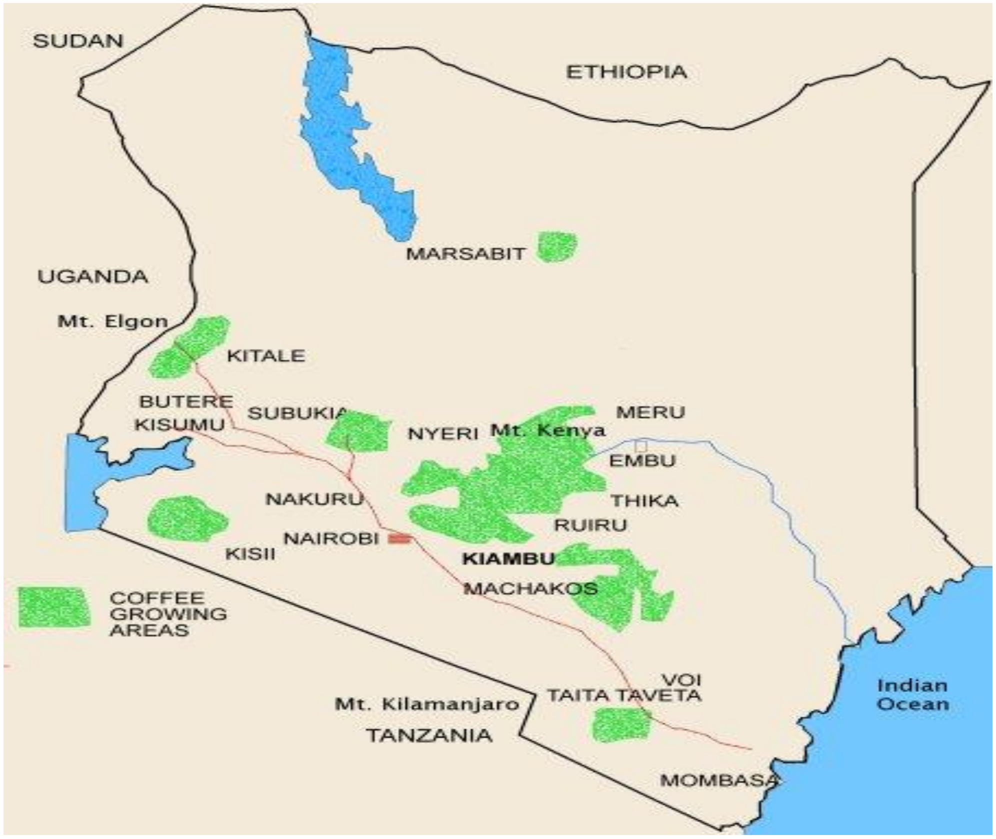

Figure 2.1: Map of coffee growing areas in Kenya

In Kenya, coffee is major source of employment and contributes significantly as a source of foreign exchange earner. It is also a cash crop for many small scale farmers who are mainly in the rural areas. It is grown by either the small holder farmers who are in cooperative societies or in small, medium and large estates. The coffee that was produced from each of the region in 2012 and the corresponding area from which the indicated coffee was produced was as shown next to each other in Fig. 2.2. It appeared clearly that most of the coffee in the country came from the central region followed by the Mount Kenya region which neighbour each other. A similar scenario was observed with respect to the area under coffee establishment. Another important observation was that the coffee production per unit area in the central region was bound to be higher than in all the other regions.

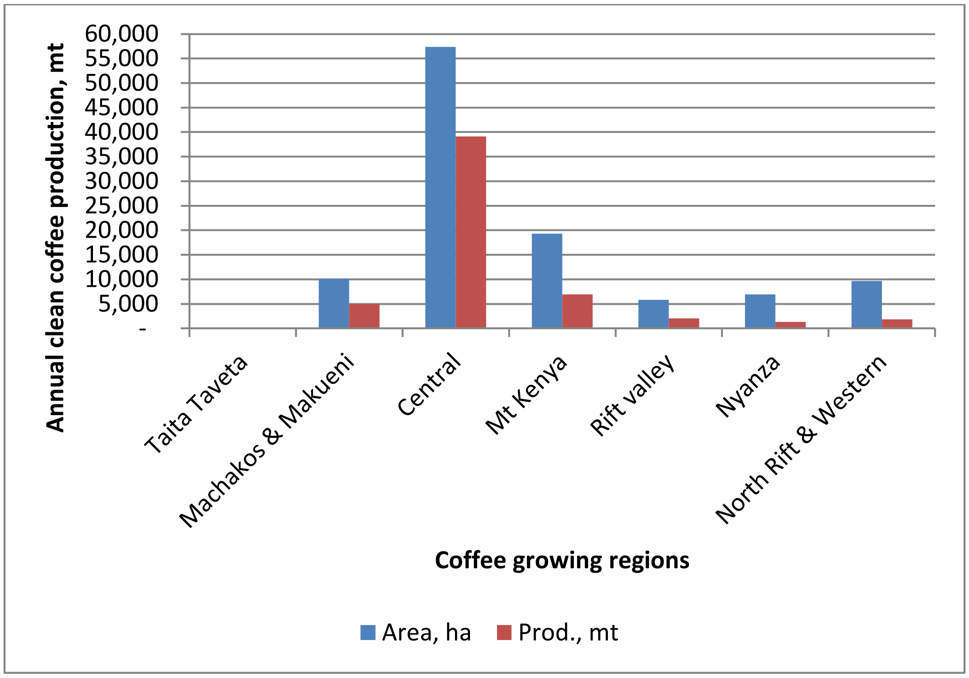

Figure 2.2: Coffee production and the occupied area in each region.

Source of data: Kenya Coffee Traders Association (KCTA), 2012

For the sake of further details spatial distribution of coffee production by the estates and the cooperative sectors in each coffee growing region was as show in Table 2.1. According to the presented information, about 68% of the coffee was produced in central Kenya in which 47% of that was from Kiambu County. The second in rank in terms of production was Eastern province which produced 21% of the national output and 80% of that was again from the cooperative sector. On the other hand, the cooperative sector produced about 57% of the national output. Except in Central Kenya where the estates produced more than the cooperatives and coast where there were no estates, the cooperative sector generally produced more coffee than the estates in all the other provinces.

Table 2.1: Production of clean coffee in the main growing regions in Kenya

Coffee Growing Area	Annual Production (Metric Tons)		
Province	Estates	Small holders	Total Production
Central	21123	17985	38785
Coast		5	5
Eastern	2343	9625	11968
Nyanza	32	1280	1312
Rift valley	1465	1577	3042
Western	34	1266	1300
Total	24997	31738	56412

NB: Production was based on a normal year data collected of 2008 - 2012

Source: KCTA, 2012

In a nutshell therefore, coffee production in Kenya is generally concentrated in a small region comprising the Central and Eastern provinces. And since almost all the coffee is produced by the wet method, the spatial demand for coffee processing is similarly distributed.

As concerns coffee production trends, the annual production of more than 130,000 metric tons of clean coffee reported in 1988/89 was not correct. Instead, it was an elevated production comprising the actual local production combined with a carryover stock and Ugandan coffee which was channeled through the mainstream marketing system. Otherwise, a more realistic annual production of 100,000 metric tons was recorded in 1998 arising from the weather induced Elnino effect. Except for such impromptu peak production incidences, coffee production has been on the decline since 1988. For instance, the country has been producing on average about half of that amount for the last nine years (Fig. 2.3) but last year (2012) realized only 32,000 metric tons of clean coffee.

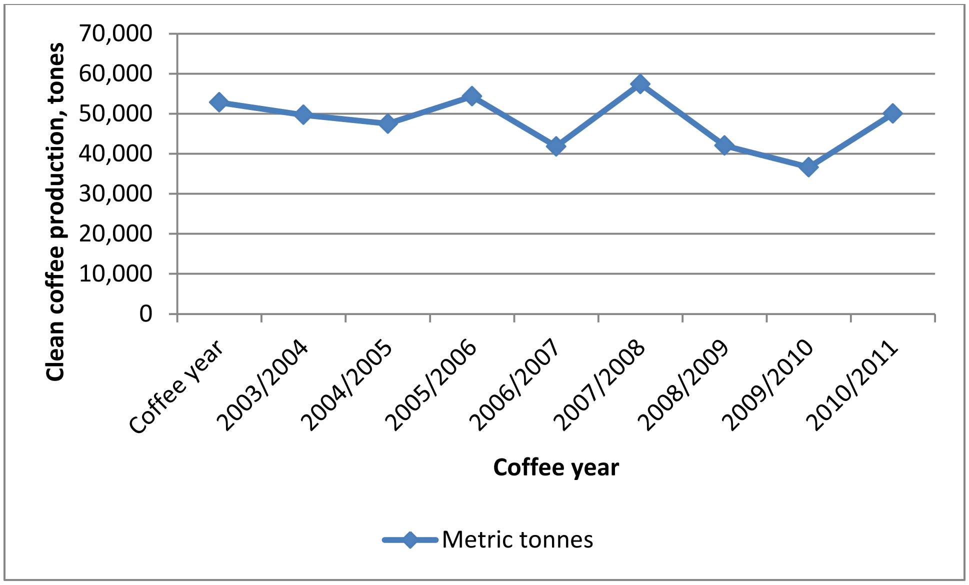

Figure 2.3: Table Total coffee export available for the last 9 years

Source: Kenya Coffee Traders Association, 2012

One of the factors responsible for the low coffee production has been the reduction of coffee establishment area from 170,000 ha to 110,000 ha due to its substitution with other crops and real estates. Coffee production has also declined to about 2 kg/tree or less attributed to erratic weather as related to climate change, social economic aspects like intercropping, abandonment and poor crop husbandly. The coffee industry has encountered poor support systems like infrastructure, marketing system (cooperative model), inputs and labour issues. The adverse impact from coffee marketing price volatility due to high costs of production and processing has further been increased by the emerging coffee mills. Such a scenario might persist for long because the current recovery of established area at 400 ha per annum may not offset the loss in the foreseeable future remembering that the lost land is not static but also increasing.

Unfortunately, there is lack of a clear/real policy on the way forward since coffee matters are like a back banner for the national government. However, the counties seem to have a policy but lack the technical basis. Their intention for instance to roast and market coffee might be a mistake having not considered how and where to market the finished product. Despite such initial shortcomings, frantic efforts are still actively involved in seeking for appropriate interventions to restore coffee production status to even a higher level than it has ever been before.

2.1.1 **Demand for coffee processing**

Coffee picking starts with fly picking which increases to a peak before tailing off. During harvesting, the ripe coffee cherry (Plate 2.2) is selectively picked targeting the just ripe coffee cherry from the coffee tress at about fortnightly intervals.

Plate 2.2: Coffee tree with ripe coffee cherry ready for harvesting

In some regions particularly to the east of the rift valley, there are 2 coffee harvesting seasons annually, each lasting for about 3 months out of which one is the main and the other one minor. As for the regions with only one season, harvesting lasts for 3 – 7 months. In regions with 2 coffee seasons per year about 60% and 40% of the annual crop is harvested in the main and minor season respectively. But in either case 20% and 15% of the cherry is ready for harvesting within 2 and 1 week of the peak of the season respectively. In Mount Kenya region, the main season comes first in the year followed by the minor season while it is the other way round in central Kenya.

Arabica coffee and Robusta coffee are grown in Kenya and after harvesting, the ripe coffee cherry passes through a long process in which it is converted to green beans. The Arabica type is predominant and is best processed by the wet method except for the small amounts of cherry sorted from the good ones which is dry processed. The wet method of processing can be achieved through three different processing techniques: dry, semi-washed, and fully washed. Wet process produces mild/washed coffee and dry process the natural or cherry coffee. The natural or dry processing is more straight forward, usually more ecological and is simplest of all (jayaprakash, 1999). It is however, practiced where the climate is consistently warm and dry following harvest and where copious quantities of water required for the wet method is available (Jayaprakash, 1999). Almost all the coffee in Kenya is fully washed as the later method is just entering into the local coffee industry.

The primary processing chain of operations to transform ripe coffee cherry to dry parchment is shown in Fig. 2.4. The coffee processing by-products namely fresh pulp and waste water are also included.

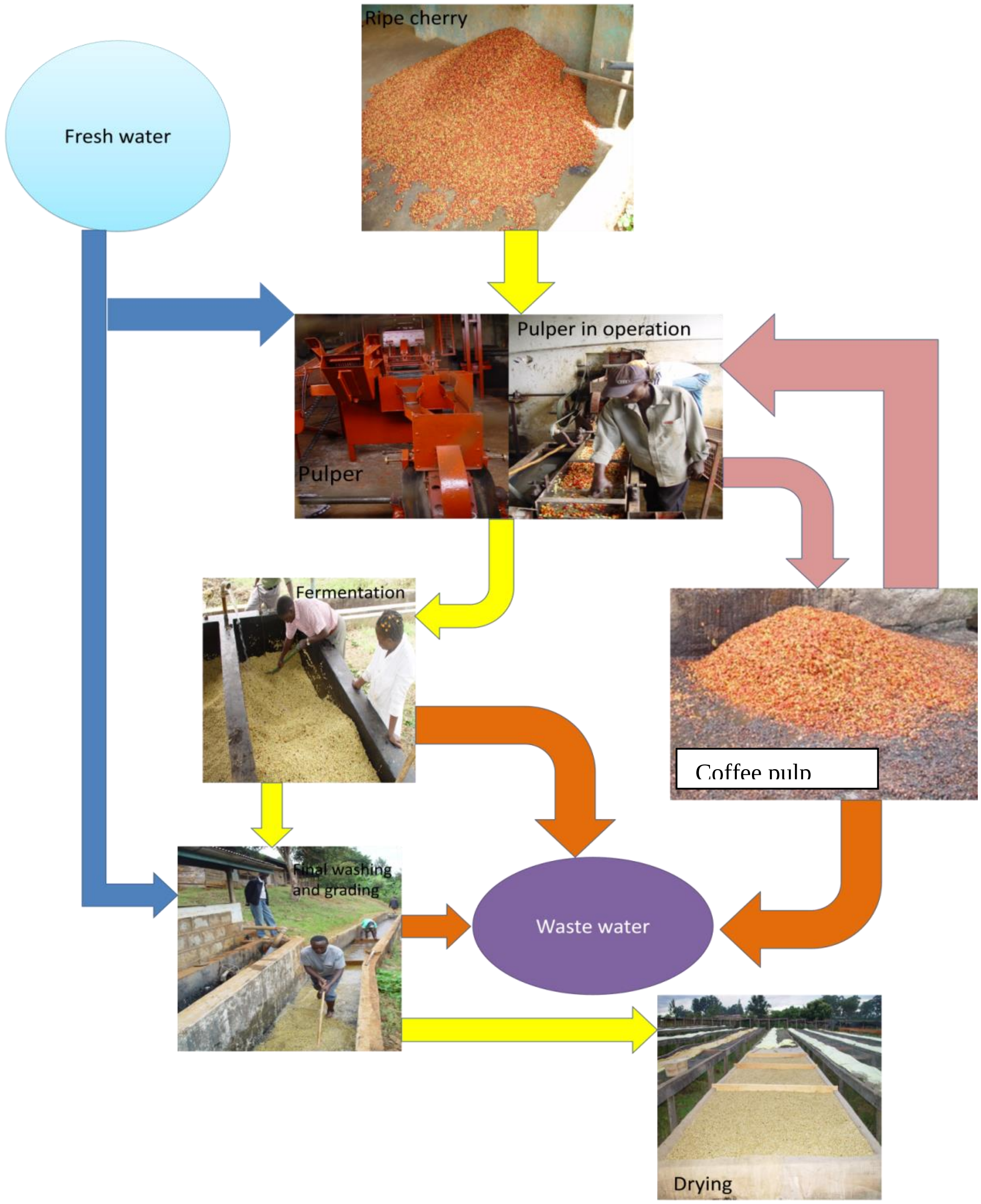

Figure 2.4:The Stages in the primary coffee processing chain.

The first operation in this fully washed option is pulping to remove the outer skin from the cherry to produce parchment. This is synchronized with pre-grading of the resultant parchment and cherry mixture into 3 main classes. The fermentation stage then follows to remove the mucilage covering the parchment in 12 - 36 hours. During fermentation mucilage is broken down by the action of enzymes and bacteria after which it is washed 3 - 4 times. In the course of fermentation, an intermediate washing of the fermenting parchment is preferred to enhance fermentation and sustain the quality of coffee (Gonzalez-Rios *et al.*, 2006). Fermentation causes development of the coffee flavor partially due to the microbiological processes. That is perhaps why wet processing is believed to yield higher quality coffee than the other processes (Gonzalez-Rios *et al.*, 2006). After fermentation, the broken down mucilage can also be removed mechanically from the parchment thereby reducing water requirements. After complete fermentation, beans are washed thoroughly to remove fermentation residues and any remaining mucilage. It is also graded, according to their density in water, into at most 4 classes of mucilage free coffee parchment. Although soaking is only recommended for class one parchment and strictly using clean water (Mburu, 1995 and), the prevailing practice soaks all the parchment for 24 hours between intermediate and final washing. Incidentally, Parchment coffee can be soaked for 7 days without adverse effect on coffee cup quality or loss in dry matter (Mburu, 1997). Such a possibility can be used to extend the factory processing capacity. Class one parchment is therefore no longer soaked after final grading as it used to be. The parchment is then dried and stored before dispatch to the mills for secondary processing at a later date.

2.1.2 **The amount of coffee processed in coffee factories**

Except for the emerging small holder planters, almost all the coffee produced in Kenya is processed in central coffee processing units. In the cooperative sector small scale farmers are grouped in a farmers society which is further divided into smaller sub group who operate a common centrally located processing unit. A society therefore consists of a number of coffee processing plants. On the other hand small, medium and large estates operate private pulping units. The most common pulping unit has 3 pulping disc followed by a 4 disc pulper whose respective coffee processing capacities are 750,000 and 1,200,000 kg coffee annually respectively. Since 1000 kg heavy cherry yields 160 kg clean (Anon., 1991) the total national annual production of 56,412 kg (Table 2.1) had come from 352,575 kg cherry. That was the amount of coffee cherry processed in 2012. There are 740 primary coffee processing factories in the cooperative sector, 337 in the large and 376 in small estates sector (KCTA, 2012). These were distributed among the coffee growing regions as shown in Fig 2.5.

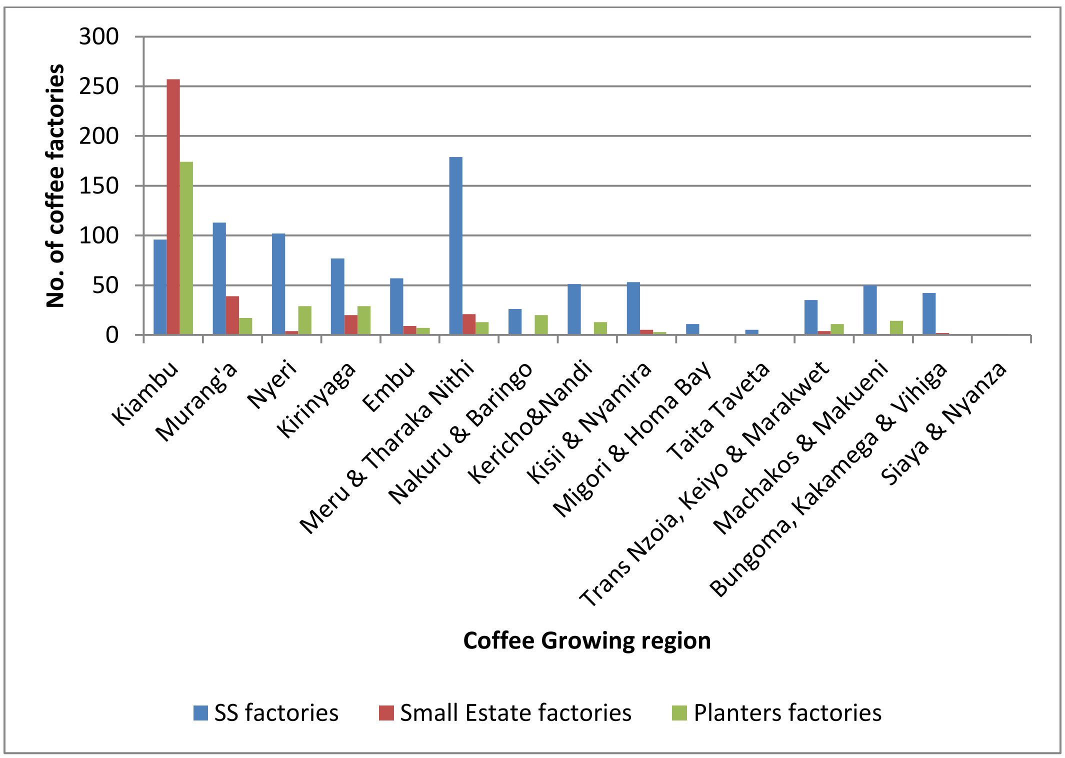

Figure 2.5: Coffee factories for the various coffee sectors in Kenya

Water requirement for processing

The most practiced fully washed method in Kenya uses water from pulping to final and grading after which it is discharged out through separate streams of effluent. The recommended processing water use along the coffee processing is limited to 22,500 lt/ton of coffee processed nil (0) of which should be returned to the surface water source (Holme, R.V., 1961; Aagaard, 1961 and Anon., 1981). Since 13200 kg coffee cherry were pulped with 2270 lt water , 352,575 kg cherry would be pulped with 60,632 lt of water would have been used for that purpose. However, since copious quantities of water are used for processing than that, (Mburu et al., 1994 and Wood et al. 2000) a challenge exists seeking to reduce the volume of water used in the coffee process from current levels to that of the limit set by legislation. Besides the eminent of environmental constraints related to the wet method of processing, another aspect is that where climate is consistently warm and dry following harvest, required for the wet method may not be available.

The method used to process coffee cherries is important to the determination of the type of waste stemming from coffee processing. Therefore, as the method used to process the coffee fruits into bean has not changed over the years so have been the wastes. But at the same time little attention has been given to the use of by-products of coffee processing industry. That could possibly be because, in the earlier days, there was less coffee production and abundant quantity water available for effluent disposal by dilution (Jayaprakash, 1999). The increased coffee productions lead to excessive waste water generation, which cannot be discharged directly into surface water ways without polluting them. Out of environmental concern, the conventional full washed processing system has therefore been equipped with a water re-circulation system comprising a rotary feeding system, recycling systems at pulping and final grading stage. Water recirculation systems have been in practice since 1977 to comply with the legislation. Interest in coffee processing by-products has been stimulated by factors like their disposal problems; contamination of the environment and possible alternative options for their utilization.

The semi washed system is equipped with minimal water use coffee pulpers and mechanical mucilage remover machines. After mechanical removal of mucilage, the parchment can either be committed to drying or soaked overnight prior to drying. This option therefore avoids the fermentation stage which goes well with a lot of parchment washing. In both cases, parchment is committed to the drying immediately after the final stage of the wet process. On the other hand, the dry method involves committing the mature and ripe cherry directly to a drying process until they attain a moisture content of 12% (wb. Parchment husks arise later on milling the dry parchment to produce clean coffee (green beans) and parchment husks as waste.

The operations between pulping and final grading are executed with the assistance of water for it eases processing. More often than not, processing coffee by the wet method and particularly the fully washed system requires large amounts of water (Enden and Calvert, 2002; Mburu *et al*., 1994). Currently, the fully washed system is synonymous with the coffee processing practice in Kenya though the semi washed system is gradually being adopted particularly with new installations. However, due to the capital investment involved in replacing the existing machines with new ones, the fully washed system is bound to last into the unforeseeable future. In the conventional system, water use for processing coffee is limited by legislation to not more than 22,500 litres per ton of coffee processed (Anon., 1981). But elsewhere, 59020 - 61290 litres is required to produce 1 ton of washed coffee (Mathew, 1978). The water used for de-pulping of the cherries is referred to as pulping water. It accounts for just over half of the water used in the process. The processing of coffee cherries is a batch process and regarding water flows, two processes can be determined: de-pulping and fermentation/washing.

As such, it is imperative to re-circulate pulping and final grading water in compliance with set limit in order to avoid compromising the environment as well as checking the cost of supplying water for processing. According to Anon (1981), Aagard (1961) and Holme (1961), water recirculation can make it possible for a coffee factory to use 22,500 lt/ton of coffee processed. However, Wood *et al.* (2000) found combining recirculation with recycling of grading water back to pulping and intermediate washing to make it possible to consume 1.5 m^3/ton of water per ton of cherry. However, recirculation systems are not commonly used unless in an environmental crisis threat. At the same time the water used for processing is not metered in proportion to the amount of cherry to be processed. Consequently, usage of water for processing varies greatly from one factory to another and exceeds the recommended limit (Mburu *et al.,* 1994).

Coffee processing wastes

The primary by-products from the fully washed coffee processing system are coffee pulp and effluent otherwise known as coffee effluent. Pulp is 432 per ton of coffee cherry processed (Braham and Bressani, 1979). The actual effluent output reflects the water used for processing which is generally too high compared to the recommended 22.5 m^3 per ton of coffee processed (Wood et al, 2000). For every tone of green bean prepared for export, the local country side and its waterways have to reabsorb around 3 tons of wet fruit pulp, 150 kg of dry hulls or husks (Calvert, 1999[a]). There are basically different types of effluent arising from pulping, pre-grading, transport; intermediate washing, final washing, final grading and soaking operations. The effluent from pulping and pre-grading is raw and can be reused during the de-pulping of the harvest of one day. The fermented effluents are outputs from the intermediate washing of the fermenting parchment, final washing, final grading and soaking. The final grading effluent constitutes the largest output stream and together with soaking effluent are the least loaded (i.e. relatively clean) with coffee processing residues compared to the other preceding stages such that they have been recommended for recycling for pulping, pre-grading and intermediate washing (Wood *et al.*, 2000 and Mburu, 2010).

Intermediate and final washing effluents constitute relatively limited volumes compared to the rest but are generally highly loaded with residue solids and other extracts from washing the coffee. Otherwise, they can be of interest in terms of their content for further economic utilization. As such, the pulping effluent therefore stands out as the main concern with respect to environmental conservation.

The semi washed system produces another by-product in form of raw and thick mucilage laden effluent from demucilager (Jayaprakash, 1999) besides the others identified with the fully washed system. The secondary processing transforms the dry parchment into clean coffee (green beans) and parchment husks. As for the dry method, coffee husks are the only by-products and come about during the hulling of the dry cherry which removes the dry outer skin and the endocarp simultaneously.

2.2 Characteristics of Coffee processing effluent

During coffee pulping and mucilage removal, the water accumulates mainly organic matter in suspension as well as inorganic compounds in solution among other contaminants (Murthy *et. al.,* 2004, Enden and Calvert, 2002). Where the water is recycled during pulping, the effluent becomes highly organic as reflected in its chemical oxygen demand (COD) volume of 20—50 g/lt (Braham and Bressani, 1979). In view of that the coffee pulping effluent is generally dark brown in colour. However, most of the organic matter in the wastewater is highly resistant (Enden and Calvert, 2002 and Treagust, 1994). Besides, mucilage, the processing effluent has coffee pulp and skins, prior to the screening out of the relatively large solid aggregates (Mathew, 1978). The pulp also consists to a large extent of proteins, sugars some which end up in the effluent during pulping. The pulp for instance absorbs water while parts of its solids migrate into the pulping water such that, the longer the close pulp-water contact the more the solids transferred into the water (Shanmukhappa *et al.,* 1998). Re-circulation of pulping water leads to increased organic matter and drop in pH attributed to the start of fermentation of the pulping water. Therefore, it is not only necessary to reduce water consumption during the different stages of the process but also the duration that the pulp should remain in contact with water as well. In any case, the organic load of the effluent increases as well as deterioration of pulp quality (Wintgens, 2004).

The organic matter in the effluent is rich in total suspended and dissolved solids as the major constituents of the effluent and the suspended pectins comprise approximately 50% of the effluent. These solids are biodegradable in nature while their concentrations vary with the quantity of water used per unit weight of the cherry processed (Enden and Calvert, 2002; Shanmukhappa *et al.,* 1998 and Selvamurugan *et al.*, 2010). Therefore, the effluent is not a constant flow of water with uniform loadings of contamination. The dissolved solids comprise acids, toxic poly-phenolic compounds like tannins, alkaloids e.g. caffeine, pectins, proteins and sugars (Enden and Calvert, 2002).

Coffee pulp and mucilage consist to a large extent of proteins, sugars and pectins i.e. polysaccharide carbohydrates (Avellone *et al.,* 1999) some of which end up up in the effluent during processing. Consequently, pulping effluent consists of quickly fermenting sugars from both of the coffee processing by-products (Enden and Calvert, 2002). The sugars in the effluents ferment in the presence of yeasts to Ethanol and CO2 (Enden and Calvert (2002)). However, in this situation Ethanol in the fermented pulping effluent is quickly converted to vinegar or acetic acid after reaction with oxygen. This acidification of sugars lowers the pH in the effluent to around 4 or even less (Calvert, 1999[a] and Jayaprakash, 1999) signifying the end of fermentation. At the same time, the digested mucilage will be precipitated out of solution and will build a thick crust on the surface of the waste water, black on top and slimy orange/brown in colour underneath (Calvert, 1999[a]). If not separated from the waste water, this crust will quickly clog up waterways and further contribute to anaerobic conditions in the waterways.

Mucilage in the pulping water is an insoluble gelatinous colloidal substance consisting of hemicellulose compounds including polysaccharide carbohydrates, sugars, poly-phenols, proteins and pectin i.e. polysaccharide carbohydrates (Avellone, *et al.* 1999). For that reason, the effluent from mechanical removers has an apparent gel like texture comprising segments of undigested mucilage and pectic substances from the parchment (Enden and Calvert, 2002). Therefore, it is at least not feasible to filter mucilage out of the coffee effluents due to such a texture while the mucilage pectin is slow to breakdown. Washing of the fermented beans also produces wastewater containing mainly hydrolyzed pectin from the mucilage, proteins and hydrolyzed sugars from fermentation and washing. During fermentation the mucilage texture is partly disintegrated first. Thereafter, long chain pectin substances undergo fermentation by pectinase and pectase resulting in short chain pectin Oligosaccharides. Oligosaccharides are soluble in alkaline and neutral solution. In acid conditions they float out of solution as pectic acid. The chemical or microbiological breakdown of the slippery mucilage to simple non-polluting substances is difficult (Shanmukhappa *et al.,* 1998) or as described by Calvert (1999[b]) very indigestible biologically.

Having started with fresh water with a pH of 6.6-7.9, the effluent from the wet processing method and a hydro pulping technique had a pH of 3.5-4.5 (Hue, 2006). Reuse of pulping effluent during the pulping of the harvest of one day results in an increase in organic matter and a decrease in pH. The effluent from the wet method and a hydro pulping technique requiring more water but no fermentation produced an effluent with reduced solids to300 mg/l after sand filtration (Hue, 2006) in both cases.

For every ton of green bean prepared for export, the local country side and its waterways have to reabsorb up to 6 tons of high BOD heavily polluted water (Calvert, 1999[a]). The biological oxygen demand (BOD) in the coffee pulping and washing effluent as reported by Mburu *et al.* (1994) range from 1,800 to 9,000 mg/l and 1,200 to 3,000 mg/ l and 1,800 to 2,900 and 1,250 to 2,200 mg/l (Mathew, 1978) respectively. However, Anon, (2009) and Enden and Calvert (2002), the BOD from biodegradable organic material in the coffee pulping and washing effluent could rise up to 20,000 mg/l and 8,000 mg/l respectively. Other reported BOD values for the general effluent include 8,000 to 11,500 mgl^{-1} (Hue *et al.*, 2006) having started with fresh water with BOD of 12mg/l, 15000 mg/l (Murthy *et al.*, 2004) and 20,000 mg/l (Droste, 1997 and Jayaprakash, 1999) On the other hand, the effluent from a hydro pulping technique but no fermentation produced an effluent with BOD of 800 mg/l (Hue *et a*l., 2006).

The chemical oxygen demand (COD) values of the organic matter in the effluent make up 80% of the pollution load (De Matos *et al.,* 2001) with values as high as 50 g/l (Treagust, 1994) and also Jayaprakash (1999); De Matos *et al.,* 2001 and; Enden and Calvert, 2002 and). COD Values in the effluent have been found to range from 3 to 5 g/l (Wikimedia, 2009). Although, Mburu *et al.* (1994) found the COD of the effluent from pulping with and without re-circulation to vary from 3,000 to 20,000 mg/l and 20,000 to 30,000 mg/l respectively, Murthy *et al.* (draft) reported that it could be between 15,000 to 25,000 mg/l. Reuse of pulping effluent during the pulping of the harvest of one day results in increased COD averages from 5,400 mg/l up to 8,400 mg/l with most of the pulp removed (Michael *et al.*, 2012).

During washing, there is a clear decrease in contamination of the coffee effluent accompanied by a drop in the COD values from 7,200 mg/l to less than 50 mg/l (De Matos *et al*., 2001). As for the pre-wash effluents the COD ranged between 1,200 and 4,500 mg/l where this operation was completed in the fermentation tanks though the level was as high as 11,000 mg/l where pre-washing was completed in channels. The final wash waters showed less COD variation in the range of 1,200 to 1,700 mg/l with the exception where beans had been previously pre-washed in grading channels releasing an effluent with a lower demand of 600 mg/l. Specifically, the wet processed coffee effluent accounts for 330 g COD/kg of green beans otherwise known as clean coffee (AYA, Accessed in Mar.

2010). The wastewater during the washing process of fermented coffee was found to have a clear decrease in contamination (Wikimedia, 2009) while the COD values drop from an average of 7,200 mg/l to less than 50 mg/l. The final washing and grading effluent has a COD of less than 50 mg/l which is less than 200 mg/l being the limit for discharge to the surface waterways in Nicaragua but it was not to be disposed directly as such because COD levels cannot be determined onsite during washing process and discharge of the wastewater into surface waters is based on visual inspection (Wikimedia, 2009). Locally, the effluent discharge standards limit the pH, BOD, COD and TSS 6.5 – 8.5, 30 mg/l (max), 50 m/l (max) and 30 mg/l (max) respectively (NEMA, 2006). When the water is "clear" it is considered to be clean enough but the COD value measured during a research study showed that discharge generally was too soon (Grendelman, 2006), resulting in waste water with higher levels of COD than permitted. Therefore, it is instructive to divert the wastewater to a treatment system for the sake of dilution of the wastewater which enables better treatment by anaerobic bacteria due to more favourable pH values and better post treatment due to lower concentrations of ammonium (Grendelman, 2006). Reuse of pulping water results in an increase in organic matter and a decrease in pH. Research in Nicaragua showed COD averages rising from 5,400 mg/l up to 8,400 mg/l with most of the pulp removed (Wikimedia, 2009).

However, as reported by Jayaprakash (1999), the coffee pulping waste contains low amounts of nutrients like nitrogen and phosphorous. In addition to these nutrients, Enden and Calvert (2002) expanded the list to include flavonoid and elevated levels of potassium in the dissolved solids of the coffee effluent. Specifically, the total nitrogen (TN) concentration in the wastewater stemming from washing ranged from 40 to 150 mg/l with an average over all samples of 110 mg/l. Total phosphorous (TP) concentration in the samples ranged from 7.8 to 15.8 mg/l with an average over all samples of 10.7 mg/l. Further to that, the nutrient content of the pulping water at the maximum COD load can also be considered to reflect maximum pollution and was indicated by a TN concentration in the effluent of 50 - 110 mg/l with an average over all samples of 90 mg/l while TP concentration was 8.9 - 15.2 mg/l with an average over all of 12.4 mg/l (Enden and Calvert, 2002). As for the washing effluent TN levels ranged from 40 to 150 mg/l with an average over all samples of 110 mg/l while TP concentration in the samples ranged from 7.8 to 15.8 mg/l with an average over all samples of 10.7 mg/l (Enden and Calvert, 2002). Coffee processing effluent has high P, Mg and K and some Ca and micronutrients (Cu, Mn and Zn). As such, the organic P values which were as much as 62 mg/l might need to be reduced if the processing water is to be discharged off the farm, as the EPA standard for total soluble P in water is 1.0 mg/l (Hue *et. al.,* 2006).

The water is also characterized by the presence of flavonoid compounds, coming from the skin of the cherries. Flavonoid compounds result in dark colouration of the water at a pH = 7 or higher, but they do not add to BOD or COD levels of the wastewater, nor have major environmental impacts. Therefore, main component of the coffee effluent is organic matter which is responsible for its high pollution potential.

2.3 Impact of the coffee effluent on the Environmental

Although the quality of river water has been rated generally as good, there have been cases of local pollution, particularly where there are intensive industrial, agricultural or human settlement activities (NEAP, 1994). As reported by Marder (1992) the pollution load from wet coffee processing is estimated to be 80 kg BOD/tone of dry parchment coffee regardless of the water consumed. Day to day variability in production and seasonality of the crop militates against the effective utilization and economic viability of conventional biological treatment systems. Pollution in terms of BOD arising from processing one ton of washed clean coffee is equivalent to that caused by the domestic wastes of about 2,000 people per day (Mathew, 1978). Here in Kenya, coffee processing effluent can flow into the surface water ways via direct discharge during processing, discharges from decomposing coffee pulp, rapid seepage from pits close to the rivers, overflow from seepage pits and mole tunnels from the pits (Mburu *et al.*, 1994).

The pollution potential of the processing effluent has also been reported to arise mainly from the large amounts of effluents disposed in water courses rather than its inherent toxicity (Adams *et al.* (1987). A study in Central America in 1988 showed that processing about 550,000 metric tons of coffee generated 1.1 million metric tons of pulp and polluted 110,000 m^3 of the region's waterways per day. This was equated with a city of 4 million people dumping raw sewage into the region's waterways (NRDC, Accessed in Nov 2012 and WWF[a], 2007). Ideally however, the coffee processing effluent from a factory producing 1.0 ton of parchment coffee per day has been reported to have pollution potential in terms of BOD, comparable to that caused by 2,000 people (Mathew, 1978 and Anon., 1981) if raw effluent is discharged to water courses without proper treatment. In addition to that, coffee processing plants have also been found to represent a major source of river pollution because of generating enormous volume of pulp besides the residual effluents (NRDC, Accessed in Nov. 2012). In Costa Rica, coffee processing residues account for 2/3 of the total biochemical oxygen demand in the country's rivers. When washed or semi washed coffee is processed in large quantities, untreated effluents greatly exceed the self-purification capacity of natural waterways.

The sugars, pectin, phenolics among other biodegradable components of the coffee effluent contain a high BOD/COD load which poses significant threat to manmade and natural ecosystems. By virtue of their presence in the effluent, an organic load of 35 kg BOD/tonne of fruit processed is released to natural and man-made water bodies (Deepa *et al.*, 2002). Pollution by the coffee effluent is therefore attributed to the organic matter especially the mucilage whose chemical or microbiological breakdown to simple non-polluting substances demands more oxygen than available dissolved in the recipient water course (Shanmukhappa *et al.,* 1998). The presence of some toxin chemicals like alkaloids, tannins and poly phenols in the effluent make the environment for biological degradation of organic material in the coffee effluent more difficult. Consequently, the BOD of the effluent increases to 2.5 – 12 g/l per COD load and provided the self-purification of the water course is exceeded, anaerobic conditions are ultimately created under which no higher aquatic life is possible (Enden and Calvert, 2002). Besides that, the sugars contained in the mucilage surrounding the bean ferment though with difficult, into organic and acetic acids making the waste very acidic with pH as low as 3.8, a condition in which higher plants and animals can hardly survive (Murthy et al., 2004). The ecological impact of discharge of organic pollutants to waterways lies in its robbing aquatic plants and wildlife off essential oxygen (NRDC, Accessed in Nov. 2012). Moreover, the high total suspended solids in the effluent and in particular the digested mucilage, when precipitated out of solution, builds a crust on the surface, clogging up waterways and further contributing to the anaerobic conditions. Besides, the bacteria cause health problems if the wastewater seeps into a source of potable water (Murthy *et al.*, 2004). In a nutshell then, the pollution of natural water bodies will have an adverse effect on domestic users, irrigation, fish and livestock and coffee processing units in the downstream (Shanmukhappa *et al.*, 1998)***.***

Under such circumstances, the coffee processing effluent poses serious disposal related problems (Braham and Bressani, 1979). However, the extent to which coffee processing effluents pollute the environment can also be aggravated by occasional low levels of water in rivers arising from low rainfall coincidence of coffee processing with the dry season (Anon 1974) and abstraction of water for local activities. Such natural water resources when at low ebb are effectively rendered more sensitive to even low contamination. Incidentally though the effluents generally cause local ecological effect of organic pollution which can be fatal to aquatic creatures and bad odour in a water course into which they have been discharged except in some cases which have been found to extend all the way to the ocean where they could even harm marine life.

According to Jayaprakash (1999) and Enden and Calvert (2002), the disposal of water used for pulping and washing of fermented coffee beans poses serious problems mainly where primary coffee processing takes place in centralized mills. However, a solution to that rest on installation and operation of minimal coffee processing water use equipment. In line with that, a successful case was reported (NRDC, Accessed in Nov. 2012) where the coffee processing systems were upgraded, with the objective of cutting organic pollutant discharges to surface waters by 80% within 5 years. Here in Kenya, the small holder coffee planters sector is also gradually becoming entrenched. Based on the small amounts of coffee that each small unit processes and the fact that they are located in the farmsteads which are well spread tend to diminish the pollution threat from their respective processing wastes.

From a chemical point of view, the presence of nutrients in the effluent may be beneficial if it suits re-use for irrigation or detrimental with respect to disposal constraints. For instance, on application of the processing water back to the orchard after treatment, some problems were encountered with including death of some trees while odour and nuisance (flies, insects) were also of noticeable concern (Hue and Bittenbender, 2003; Hue et al., 2006). Otherwise, only the potassium level in the soil was found to increase among the major nutrients (Velmourougana *et al.*, 2008). Further to that, the micro flora and fauna population recorded higher levels in the top soil compared to the sub soil section where the effluent was applied at an optimal rate of 25 l/m^2 (Velmourougana *et al.*, 2008). Else, from a pollution perspective, the nutrient content of the pulping water at the maximum COD load is considered to reflect maximum pollution.

Flavonoid compounds result in dark colouration of the water at a pH = 7 or higher, but they do not add significantly to BOD or COD levels of the coffee effluent, nor have major environmental impacts. Lower levels of transparency, however, can have a negative impact on photosynthetic processes and growth and nutrient transformations by (especially) rooted water plants. Many efforts in olive and wine processing industries, with relatively large funds for research, have been trying to find a solution for this problem.

Currently, the effluent is conveyed immediately to pits as it is discharged from primary coffee processing factories from where it is expected to seep into the ground gradually. After disposal into seepage pits, the effluent eventually biodegrades and the resultant solids either float on the effluent surface to a limited extent as scum or precipitate out of the solution to build a crust on the pit surface particularly at the bottom. Locally, sludge is scooped out of the seepage pits during the offseason maintenance. The presence of sludge confirms the prior settlement of suspended solids out of the effluent after being in the seepage pits for several months during the coffee harvesting season. Therefore, failure to frequently clear the scum from the surface of the effluent in a pit, de-sludge the pits seasonally, operate the water saving re-circulation systems and poor design and maintenance of skin towers (Mburu *et al.*, 1994), can contribute greatly to river pollution as well via overflow from the pit. Further to that, the pits have been occasional recipients of surface run off from the nearby rain water catchment area. These factors perhaps combine to give the pits a decimal the performance contrary to the expected. Consequently, large areas than necessary are normally required for the disposal of the effluents even if the provided pit capacity was adequately catered for at the design stage but without factoring in the impact of such a constraint. This happens at the expense of the coffee drying requirements with which it is normally in competition for the limited available land.

Besides that, seepage pits are still generally located below the factory contrary to recommendations and hence close to the rivers. That is so where water recirculation systems are absent or hardly used except when overcoming a pollution crises. Otherwise, water recirculation systems were also meat to enable the relocation of the pits to convenient sites above the factory and further away from the river. Where pits are below the factory, they are in some cases located too close to the river or marshy areas where flow of water is only possible into instead of out of the pit. Other areas might be rocky such that seepage does not occur at all. That is partly why, drainage, seepage or even overflow of raw effluent into natural water courses occurs from existing treatment pits under varying circumstances (Kamau, unpublished; Mburu *et al.,* 1994; Mburu and Mwaura, 1998 and Wood *et al.*, 2000).

It was found, from the present investigation, that the wastewater from coffee processing plant was heavily polluted with organic matter as it showed high concentration of COD (upstream 25,600 mg/l and downstream 15,780 mg/l), BOD (upstream 14,200 mg/l and downstream 10,800 mg/l), phosphate (upstream 7.3 mg/l and downstream 4.6 mg/l), nitrate (upstream 23 mg/l and downstream 10.5 mg/l) and suspended solids (upstream 5870 mg/l and downstream 2080 mg/l) and these concentrations were much higher than the permissible limits prescribed by WHO (1995). It was also found, from this study, that the people residing in the vicinity of this plant were consuming this polluted water and as a result suffered from many diseases like skin irritation, stomach problem, nausea and breathing problem (Haddis, 2007).

The problem of coffee processing effluent was not relevant in the distant past as there was abundant quantity of water available to dilute it upon disposal. In any case, there was less production of coffee. Besides, the method used to process the coffee cherry into green beans has mainly remained the same despite increased coffee production over the years. As coffee production increased later on, excessive waste water was generated which could not be discharged directly into the water. The need to economize on water usage in primary coffee processing factories has apparently not been considered by the operators and the entire stakeholders (Mburu *et al*., 1994). In practice, therefore, the quantities of water use are still too high for ease of disposal due to the persistence of some undesirable factors (Finney, 1990 and Mburu *et al.*, 1994).

In spite of water recirculation therefore, the increased coffee production can still cause excessive generation of coffee effluent, which cannot be discharged directly into the surface waterways (Jayaprakash, 1999). Consequently, large effluent volumes have been issued from the primary coffee factories in the absence of appropriate methods to treat such high strength waters due to high cost of treatment. Wambui et al. (2011) tested physico-chemical parameters included pH, temperature, Chemical Oxygen Demand(COD), Biochemical Oxygen Demand(BOD), Conductivity, Total Dissolved Solids(TDS), total solids(TS), total suspended solids(TSS), salt, Nitrate, Phosphate, Sulphate and potassium of pulping and recipient river water samples and the results were compared whether they met the WHO (1995) quality for domestic or fit for drinking. The results indicated that coffee processing effluent affected the Physico-chemical parameters (of river water within the coffee growing regions. Rise in BOD and COD of the effluent to values greater than 10mg\l respectively confirmed that coffee effluent in the main growing areas contribute to pollution problems and increasing trend of TDS and TS were also a confirmatory. Effluent disposal seepage pits were also found sited very close to water courses mostly on sloppy ground as a conveyance of effluent into them is dependent on gravity. That posed a threat to the ecosystem since the effluent discharged from the coffee factories could easily reach the rivers whenever there was overloading of seepage pits during the peak season or runoff during heavy rains.

In summary then, coffee production wastes are ruining the fresh water environment in some coffee growing regions of the world (Anon., 1990). In addition to that, polluted water can and in fact has, found its way into the underground reservoirs. Few notice this invisible pollution. But it exists and it is almost impossible to clean up.

2.4 Alleviation of pollution from the coffee effluents

2.4.1 Processing water minimization

Arising from the adverse impacts by coffee production and processing in most coffee producing countries practicing the wet method of processing, ICO (1996) recommended that a global study be conducted to document and review all the existing regulations and standards concerning coffee and the environment. It was further echoed that the need to ensure that coffee produced under environmentally sound conditions, particularly with organic certification, should receive a price which permits such conditions to be observed. Specifically it was reported by the German coffee association that the market would indeed pay the necessary premiums provided that a high quality level was maintained. The coffee processing effluent is classified as a non-domestic effluent in Hawaii (Hue, 2006) and it is hence illegal to discharge it to the public sewer systems because of its potential to damage the environment. Coffee processing by the fully washed processing techniques as practiced in Kenya often entails the usage of massive amounts of water and the production of considerable amounts of both solid and liquid waste. The processing wastes have persistently tended to compromise the environment particularly at peak seasons (Anon, 1990). Utmost importance should therefore be given to water conservation during processing by recirculation and to convert the ripe cherry to green bean recycling of the processing (FAO, accessed in October 2013) water as well as using pulping and washing equipment which require less consumption of water for the process (Jayaprakash, 1999). For instance, advanced machinery which adopts recycling system at pulping stage can reduce water usage by 80-90% compared to conventional method. In Kenya, water re-circulation during pulping, grading and transportation of coffee is currently a legal requirement to mainly minimize the processing water requirement but also speed up fermentation of parchment after pulping. Therefore, all the primary wet coffee processing factories are required to install water re-circulation systems while the resultant waste should be disposed strictly on land (Mburu and Mwaura, 1996). Another strategy by anon (1994) vouched for the reduction of the quantity of waste water for subsequent treatment by segregating strong wastes, which might allow the bulk of relatively unpolluted waste water to be discharged without treatment.

However, since recirculation only served as a partial solution, the concept of water minimization followed by treatment (Mburu, 2001) or containment has been identified as the most effective approach for effective alleviation of pollution from coffee processing effluents (Wood *et al.*, 2000). For that purpose, further water minimization options were identified in the pressing of the pulp prior to its disposal and the recycling of grading water for pulping, pre-grading, conveyance and intermediate washing on the same day. Since then, the practical viability in terms of quality improvements derived from such an improvement has also been verified (Mburu, 2010). Results of the verification trials found that, not only did recycling of grading water contribute appreciably in reducing the process water use to 1.86 lt/kg of cherry but improved the overall coffee quality.

The water usage can be reduced by using advanced machinery which adopts recycling system at pulping stage (Shanmukhappa, 1998). As such, modification in processing machinery and introduction of recycling system has reduced the water usage by 80-90% compared to conventional method. It was also confirmed that processing water recirculation and recycling can enhance fermentation (to produce easy to wash parchment) and minimize water use. Further to that, fermentation of pulped beans prior to aqua washing can contribute towards lesser production of effluent (up to 30% of total water usage) as washing is quicker compared to direct washing of beans. The measures to reduce the effluent include reduction of the consumption of water by adopting recycling in the pulping section; and minimizing contact between pulp and water as well as avoiding transportation of pulp using water (Shanumkappa, 1998). Besides that, there are other ongoing research studies intended to not only shorten the parchment fermentation duration but also enhance its efficiency in order to ease the removal of mucilage with less water (Mburu, 2010) during intermediate and final washing. The recent times have also seen a dramatic increase in small holder private pulping stations. The effect of that has been to relief the environment of the pollution pressure by way of limited effluent discharge from such pulping stations which are more spread compared to the central cooperative based pulping stations.

Alternatively, coffee can be processed by either dry or semi-washed techniques comprising pulper with inbuilt demucilages which are synonymous with minimal water use.

Figure 2.6: A coffee pulper with an inbuilt demucilager

Dry pulping for instance can enhance fermentation and produce easy to wash parchment in order to minimize water use. In any case, effluent minimization is one of the most important considerations towards reduction of the size of treatment plant and investment cost (Shanmukhappa *et al.*, 1998). The merits of this system otherwise known as semi washed processing system over the conventional system were also confirmed in Rwanda by Finney (2008). Such modern practices require only 1 m^3 of water per ton of fresh cherry while the traditional full washed technique without recycling uses 20 m^3 of water per ton of cherry. Besides that, fermentation of pulped beans prior to aqua washing according to CCRI (1997-98), contribute towards lesser production of effluents by up to 35% of total water usage as washing is easier, quicker resulting in complete removal of mucilage compared to direct washing of beans and in turn upgrading the coffee quality. Fermentation prior to demucilaging also lowers water requirement.

Semi washed parchment is produced from pulping cherries followed by mechanical mucilage removal. Most of the mucilage is removed except the small amount at the centre cut of the beans. This technique is used in order to reduce the water consumption from the long fermentation process and the extensive washing. While semi-washed processing requires less time than washed processing and is thus economically advantageous, the quality of the end product is regarded as inferior (Anon, 2009). The aim of semi-washed processing is to reduce the contamination generated by the wet process of coffee fruits by a developed technology that avoids using water when it is not needed and uses the optimal amount when it is needed. A fermenting process takes between 14 to 18 hours, to degrade the mucilage until it can be easily removed with water. Washing fermented mucilage requires, in the best case, 5.0 l/kg of dry parchment coffee (DPC). A Deslim system consists of a mechanical demucilager, washer plus a cleaner and removes more than 98% of the total mucilage to the same extent as a well conducted fermentation but using only 0.7 l/kg of DPC.

The concept of ecological coffee processing methods entails a rational and ecological handling of pulp, mucilage and effluent including use of effluents and by products (Wintgens, 2004). It is well demonstrated by a technology known in Colombia as Becolsub (Roa *et al*., 2000). The main function of the technology hinges on remove flouting fruits and light impurities, as well as heavy and hard objects, pulping without water otherwise referred to as dry pulping, mechanical demucilaging and simultaneous mechanical conveyance and mixing of the pulp and mucilage in a screw conveyor. Dry pulping was preferred because a coffee fruit has mucilage unlike immature and dry fruits. In addition to the mucilage it also has enough water inside for the skin and seeds to be separated in conventional pulping machines without water. In any case more water is only required as a conveying means. Pulping in the absence of water avoids 72% of the potential contamination as well.

This system uses sieves in all phases of the process, a technique that has mainly been capable of minimizing the volume of water needed by up to 90% compared to the traditional processing. For instance, Becolsub (Roa *et al.,* 2000) has a cylindrical screen to remove the fruits whose skin is not separated in the pulping machine. While such a screen provides a rough but expedient screening other components of the system ensure a rapid removal of the pulp as well as avoiding long pulp-water contact time which minimizes the transfer of solids to the water used. Besides minimizing water usage therefore, ecological processing avoids more than 90% of the contamination generated by its predecessor. The system also practices mechanical mucilage removal which reduces water by skipping the fermentation stage as well as the subsequent washing water requirements.

Consequently, COD, BOD values and in essence the load of other pollutants in the effluent decrease considerably down to 3 - 5 g/l and 1.5 – 3 g/l respectively. The quality of the coffee processed by this way was the same as the one for coffee processed by natural fermentation. In Tanzania, Maro and Teri (2010) similarly found ecological pulpers being more efficient than disc pulpers, though an increase in hopper size could improve efficiency them even more. They were particularly suitable for reducing water use, as an adaptation to climate change whereby water is becoming an increasingly scarce resource. However, to get the best cup, under water soaking of 6 hours is recommended.

Besides, despite the occurrence of pollution to the surface water ways now and then it can still be concluded that seepage pits have temporarily abated the problems to some extent, through a fairly simple measure. However, their performance can no longer cope effectively with the increased coffee production and pollution of adjacent water courses appears to remain a problem. The extent of the problem was confirmed by a recent survey which found BOD values in some local rivers ranging between 14 and 55 mg/liter (Mburu and Mwaura, 1998) instead of a maximum of 6 mg/liter (WHO, 1995).

In Guatemala for instance, It was estimated that over a 6 month period during 1988, the processing of 547,000 tons of coffee in Central America generated 1.1 million tons of pulp and polluted 11,000 m^3 of water per day, resulting in discharge to the region waterways equivalent to raw sewage dumping from a city of 4 million people (NRDC, Accessed in Nov. 2012). For that reason, adverse impact from coffee processing wastes has been reported in some countries of Central America. The solution has been witnessed in terms of important progress in the development of pollution control technologies with respect to reducing volume of water used in wet processing coffee which reduces the amount of water used requiring treatment before discharge from the processing facilities. Other alternatives include composting husks mixed with farm animal manure to use as organic fertilizer on crops; digesters that produce methane gas that can be used for practical applications like powering processing plant. Success has been demonstrated with the measures in various parts of North America. Without a concerted regional investment plan in improved technology, however, pollution prevention will remain the exception to the rule in this part of Latin America.

The large effluent volume has been mainly resorted to because of the absence of appropriate methods to treat high strength waters as well as the high cost of treatment. If water use in processing is reduced, a thick and concentrated effluent is produced which is difficult to treat in the conventional lagoon systems (Deepa, *et al.*, 2002). However, It is possible to improve the quality of both water and coffee bean, through adoption of (improved ecological plants) processing systems consisting of centralizing coffee processing medium sized modern plants with pollution reducing technologies featuring water recycling, effluent treatment, composting of organic byproducts, rapid fermentation, improved depulping and low energy use (Barbier B et al 2003).

2.4.2 Treatment of the effluent

The treatment and disposal of the coffee processing effluent is an important environmental consideration for the coffee industry and is regarded seriously. In India for instance, coffee plantations must seek permission from state control boards for wet processing of coffee with an undertaking that the effluents will be treated to the standards prescribed or stored within their premises (Shanmukhappa *et al.,* 1998). For that purpose, the ultimate aim of effluent treatment should be to reduce the BOD down to 200 mg/l before letting it into natural waterways to (Enden and Calvert, 2002) or to 100 mg/l which is acceptable for irrigation/discharge purposes is (Shanmukhappa *et al.,* 1998).

Although the coffee effluent can be disposed into, conventional lagoons lagoon systems their performance is limited to less than 50% BOD removal if often improperly operated. As a result of that a load of 10-18 kg BOD/tone of fruit is let into water bodies inadvertently (Deepa, *et al.*, 2002). Such a combination results in more than 95% BOD removal while less than 1 kg BOD enters the water bodies for every ton of fruit processed. However, a twin pilot scaled bio-digester using cow dung and neutralized coffee factory waste was able to reduce significantly the organic pollutants of the coffee factory waste as indicated by its low COD/BOD values of the slurry out of the digester (Sri-Mulato and Suharyanto, 2010). Otherwise, in the absence of the aerated lagoon the resultant effluent is best diluted to 1:10 with fresh water to facilitate its utilization for agricultural purposes only. Towards that, a rough screening during pulping and removal of pulp can considerably lower BOD to 1,578 – 3,242 mg/l respectively (Wikimedia, 2009). BOD_5 values in the range of 1.5 – 3 g/l were found in the effluent (Wikimedia, 2009). Remove the fruit skin from the effluent using appropriate screens (Shanmukhappa *et al.,* 1998).

Ecologically benign and efficient treatment and disposal of wastewater from wet coffee processing is a problem that has to be solved in coffee processing regions. An industrial effluent is generally treated chemically and biologically (Mathew, 1978). If waste water is fermented, solids come out of solution. Although the acid water then appears clear the organic pollution in it still extremely high. Toxicity in coffee effluent is not a severe problem because there are only little tannins, polyphenols and caffeine. The high acidity can negatively affect the treatment efficiency of treatment facilities treating the coffee wastewater like an anaerobic reactor or constructed wetlands and is considered to be detrimental for aquatic life when discharged directly into surface waters. The treatment of the coffee pulping effluent by the biological method which transform it to a more environmentally friendly status have been referred to as the most viable (Jayaprakash, 1999) compared to other available technologies. Under such circumstances, the effluent undergoes through a natural biodegradation process on its own which mainly facilitates the breakdown of organic matter given time under suitable ambient conditions.

Any water into public streams should not contain more than 30 mg/l of BOD. However, double that quantity of pollutants gets into the water within the first 15 seconds of contact with the pulp. Pulp, therefore, has to be separated from the water as quickly as possible (Mathew, 1978). Treatment of Biodegradable pollutants can be by filtration, anaerobic digestion followed by aerobic decomposition (Mathews, 1978). In estates, purification plants could be constructed to successfully tackle the problem. Provisional measures include impounding coffee pulp water mixed with lime in tanks of convenient sizes to hold water for 40 days (Mathews, 1978). The effluent can be released after 35-40 days as it is expected to be sufficiently pure to be let out.

However, the effluent’s high sugar content and BOD prevents good mixing with sewage water as well. Since the coffee processing effluent is highly charged with pollutants, it can be a threat to the environment unless it is treated to render it harmless to the environment. Fortunately, shortly after pulping, a large part of the organic matter comprising mainly pectins precipitates as mucilated solids and could be taken out of the water (Enden and Calvert, 2002). That is accompanied with a drop in pH attributed to the start of fermentation of the pulping water and continues until fermentation is finished and pH levels of around 4 are reached. When these solids are not removed and pH values rise, an increase in COD can be observed. The constitution of the effluent is also an important factor worth consideration because it influences the technical solutions for coffee effluent treatment.

For instance, since coffee pulping effluents are generally loaded with fresh organic matter with some sugar, rapid fermentation starts immediately subject to suitable temperature. The fermentation of the sugars namely the disaccharide carbohydrates into ethanol and CO_2 leads to acid conditions in the washing water. The high acidity can negatively affect the treatment efficiency of the facilities like an anaerobic reactor or constructed wetlands and is considered to be detrimental for aquatic life when discharged directly into surface water. The breakdown of the coffee processing effluent being a fermentation process depends on the concentration of the relevant inherent ingredients, and temperature.

Re-circulation of the pulping water is bound to achieve such convenient conditions just like when it hastens the fermentation of parchment. The BOD of effluent and water treated samples varied significantly and high BOD recorded with water treated samples. The high acidity can negatively affect the efficiency of facilities treating the coffee wastewater like an anaerobic reactor or constructed wetlands and is considered to be detrimental for aquatic life when discharged directly into surface waters. During the washing process in Nicaragua (WIKIMEDIA, 2009), there is a clear decrease in contamination of the effluent. The COD values drop from an average of 7,200 mg/l to less than 50 mg/l. But even though the effluent with COD values below 200 mg/l is allowed to be discharged into the natural waterways it is advisable to redirect all the effluent to the treatment system. This is because COD cannot be determined onsite during the washing process and discharge of the effluent into surface water ways is based on visual inspection. In support of that necessity, measured COD values of water which had been considered to be clean enough by virtue of being "clear" showed that discharge generally was too soon since the discharged effluent had higher levels of COD than permitted (WIKIMEDIA, 2009). Another positive effect of diverting the effluent to a treatment system was its dilution which enabled better treatment by anaerobic bacteria due to more favourable pH values and better post-treatment due to lower concentrations of ammonium.

The effluent can be treated by aerobic and/or anaerobic methods using an equalization tank using lime to correct the pH to neutral followed by anaerobic process in 1 or 2 consecutive lagoons and an aerobic unit order to stabilize the organic matter preferably in lagoons (Shanmukhappa *et al.,* 1998; Jayaprakash, 1999; Adams and Dougah, 1981). This system requires cow dung in the anaerobic as well as Urea and TSP fertilizer at different rates in both the anaerobic and aerobic phases. Since the pH of coffee pulping water is low and contains low levels of nitrogen and phosphorous content the minimum recommended BOD:N:P ratio of 100:2.5:0.5 for all anaerobic treatment processes (Jayaprakash, 1999) can only be maintained by addition of urea and super phosphate to anaerobic lagoon daily to hasten the process of degradation of organics (Shanmukhappa *et al.* (1998).

According to *Shanmukhappa et al.* (1998), the effluent was neutralized by addition of spray lime at the rate of 1.5 – 2.0 g/l of effluent after which it was allowed to stand overnight. In order to optimize the anaerobic processing of the wastewater, pH values should be between 6.5 and 7.5, instead of the generally present values of pH = 4, which is highly acidic. That was obtained by adding calcium hydroxide ($CaOH_2$) to the wastewater and results in a regained solubility of the pectins, raising COD from an average of 3.7 g/l to an average of 12.7 g/l (Anon., 2009). The scum is thereafter removed periodically using a bamboo basket and the solids separated from the effluent while discharging the effluent to anaerobic lagoon. Available information as reported by Murthy et al. (2004) indicated that the standard of the treated effluent for irrigation or land disposal permits 200 mg/l of suspended solids, pH of 6.0 – 9.0 and a BOD, 3 days at 27^{o}C not exceeding100 mg/l. Besides that it was required that colour and odour be removed.

Another attractive innovation considered to execute the anaerobic phase of the effluent treatment at minimal operating costs was the biomass immobilized bioreactors (Deepa, *et al.*, 2002) which when coupled to aerobic lagoons removed more than 95% BOD and produced biogas at the rate of 10 m^3 per ton of coffee processed. Further, as the bioreactor can handle a high concentration of effluents, the quantity of water used per ton of coffee could be reduced thereby reducing the size of the bioreactor as well (Murthy *et al.,* 2003). Installing a biogas reactor or bioreactor is an alternative option for the anaerobic phase of the effluent treatment (Murthy *et al.,* 2004). The bioreactor not only reduces the BOD and COD levels of the effluent, but releases biogas that can be used for the generation of electricity through a dual fuel engine.

The same author reported that the accepted effluent quality standard include TSS 200 mg/l, pH 6.6 to 9.0 and BOD_5 at 27^oC 100 mg/l. In some cases, pits are often dug without any formal design and effluent usually receives no pre-treatment before discharge into pits. Under such circumstances, the option in large farms is a carefully designed anaerobic digestion which captures biogas for farm fuel (Michael, 2012) provided the treatment was neither too expensive nor too difficult to implement and maintain.

In Nicaragua Michael (2012) identified the conventional effluent treatment system to consist of three settling pits to provide water improvement through filtration, neutralization and microbial decomposition of organic matter before infiltration to the nearby stream. The wastewater was neutralized by use of CaO ostensibly Hydrated to $Ca(OH)_{2.}$ from an initial pH of 4.2 to approximately 7 in order to provide an optimal pH range of 6.5 - 7.7 for biodegradation of the nutrient by diverse microbial populations. Three other alternatives to that were studied, the first of which had a plastic lined settlement basin plus 3 parallel rock-media infiltration pits which used CaO for neutralization of the effluent. The second alternative had a settlement basin, a horizontal flow anaerobic basin and a hand excavated shallow sinusoidal channel with crops like corn between the channel loops. This alternative lowered BOD_5, neutralized pH to 7 and removed TSS, phosphorous and nitrogen from the effluent into the soil. Ultimately, the nitrogen and phosphorous were removed from the soil by corn whose harvest was finally transferred as usual from there and by so doing aiding in the wastewater treatment.

The third alternative had a primary treatment in a settling basin with pH neutralization common to all alternatives coupled to a secondary treatment in an up flow anaerobic sludge blanket (UASB) to replace the “Growth” anaerobic basin and a finishing step by either subsurface infiltration or a final deposition in an overland channel. This alternative similarly removed BOD5 (85-95%), Nitrogen and phosphorous. Biogas was also produced but not in attractive quantity because of need to transport gas across some distance from the farm to kitchen and existence of adequate fuel wood. At the same time a nonstop year round operation could not be guaranteed. Neutralization of the wastewater, which is to be used for irrigation as in the second and third alternative can also provide healthy soils and robust vegetative growth.

Among the various technologies available for treating the effluent, only the 2 stage biological method has particularly been found effectively useful and most economical for treating effluent because of its ability to treat high strength organic coffee effluents with high quantity of solids (Shanmukhappa *et al.,* 1998). The method consists of screens, neutralization tank, either aerobic or anaerobic lagoons or a combination of both followed by polishing (Jayaprakash, 1999). But, the resulting thick and concentrated effluent from coffee processing systems using minimal water has been found difficult to treat in the conventional lagoon system (Hue *et al.*, 2006). That might seem to demonstrate the importance of dilution of the coffee effluent for it enables better treatment by anaerobic bacteria due to more favourable pH values and better post treatment due to lower concentrations of ammonium.

In order to optimize the anaerobic degradation of the wastewater it is necessary to raise the pH from 4 to between 6.5 and 7.5, by adding calcium hydroxide [$Ca(OH)_2$] to the wastewater. That results in a regained solubility of the pectins, raising COD from an average of 3.7 g/l to an average of 12.7 g/l. Therefore, the basic model has 4 tanks with different capacities including a neutralization/equalization tank which receives 1 day's effluent from pulping, washing and soaking for homogenizing pollution load. A bottom drain should be provided to remove the sludge; anaerobic, aerobic and settling (which is optional for small growers) tanks with 21, 7 and 1 day's effluent capacity respectively. Sizes of the tanks are arrived at on the basis of processing water input in l//kg cherry.

After treatment to the stipulated standards (Shanmukhappa, 1998) the effluents can be used for irrigation within the coffee estates (Jayaprakash, 1999). Treatment of the effluent can however be enhanced by *n*utrient additives (Shanmukhappa *et. al*., 1998). After reviewing various biological treatment methods, Adams and Dougah (1981) found that only stabilization ponds provided a near practical solution. However, the pond design being derived from the organic surface load often required a surface area that was simply not available besides other operational and maintenance constraints. Besides that, other reports showed that anaerobic ponds were least suitable despite the high COD and suspended solids (TSS) removal rate due to difficulties in maintaining the pH level and mosquito infestation on the higher hydraulic retention time (HRT).

After confirming that anaerobic digestion technology could achieve a high performance for treatment of coffee effluent, Gathuo (1995) suggested that features of VSB and a solid reactor be combined to develop a high performance reactor that can be operated all year round due to the seasonality of coffee processing. These would then constitute a more innovative approach which was well designed and engineered. In another study, Zuluanga *et al.*, (1987) found that, a UAF system was capable of effectively removing more than 70% of the COD contained in the coffee effluent from the wet processing of coffee. However, the reactor had to be carefully constructed to ensure an even plug flow apparently required for it to function effectively without the necessity to correct the pH of the coffee effluents. Otherwise, the absence of a simple means of removing an excess of solids leading to the accumulation of biomass and solids in the reactors eventually resulted in blocking the system (Zuluanga *et al.*, 1987). The reactor needs to be seeded with the effluent from an anaerobic digester used for treatment of pig manure; Correction of the influent pH with concentrated NaOH encouraged a rapid aerobic fermentation of the stored influent.

Lime sprays on the effluent facilitate anaerobic digestion (Wiki media, 2009). However, treatments of the effluent with 1% lime and aeration for 7 days was found to significantly lower both the BOD down to 300 mg/l and phosphorous (Hue *et al.,* 2006). This was because of increased pH of effluent which has been saturated with lime ($CaCO_3$) and then aerated to 8.0 which would stimulate microbial growth. (Hue *et al.,* 2006). The results were a rapid conversion of organic carbon (BOD/COD) to CO_2 and mineralization of organic P to orthophosphate (mostly HPO_4^{2-}. Therefore increase of microbial growth and acidity for decreasing BOD, pH upward adjustment must be considered. Sand filtration was found unsuitable for that because the pH of the effluent went up to only 5.07. Ca levels in saturated effluent (600 mgL^{-1}) would precipitate most soluble P as Ca-P either as amorphous or minerals, depending on time and other solution conditions (e.g. ionic strength, competing ions, soluble organic molecules).

Elsewhere, Chandrasekhar (1989) treated coffee pulping waste using up flow anaerobic sludge blanket (UASB) which was cheaper compared to conventional methods. In addition to that the average efficiency of UASB reactor was 64% reduction in COD with mean organic loading and COD removal efficiency of 89.52 kg of COD/m_3-day and 24 hours respectively. It is also reported that over all, COD removal efficiency of 95% was achieved using UASB process followed by extended aeration process

(Jayaprakash, 1999). Combined coffee pulping waste water can be treated by anaerobic lagoon with an overall retention period of 5 days with BOD removal efficiency in the range of 27.20% to 57.40%; aerated lagoon with an overall aeration of 22 hours with BOD and COD removal efficiency of 89.52% and 89.31% respectively and oxidation ditch with a detention time of about 48 to 60 hours with BOD and COD removal efficiency in the range of 97.6% to 98.2% and 94.1% to 96.0% respectively (Jayaprakash, 1999). Generally, treatment of the coffee processing effluent has hitherto concentrated on the reduction of COD by an up flow anaerobic sludge blanket (UASB) reactor (Jayaprakash, 1999) alone or followed by an aeration process to improve the efficiency.

In Papua New Guinea a UASB reactor was used for treating coffee effluent along with a biological filter system (Calvert, 1997). Although the UASB technology is central in the treatment process (Enden and Calvert, 2002), a more comprehensive approach to coffee effluent treatment include acidification pond; neutralization tank filled with ground limestone; a UASB with methanogenic bacteria; wetland planted with macrophytes for secondary treatment and tertiary treatment using water hyacinth (Eichorniacrassipes) pond (Enden and Calvert 2002). After full acidification, the clear, acid water can be treated by natural limestone to lift the pH from around 4 to around 6. Only at this pH level, a UASB digestion and constructed wetlands will achieve optimal results (Enden and Calvert, 2002). The key characteristics of such a system included methane gas from the UASB suitable for the coffee driers, BOD and TSS reduction by 49-81% and 36-70% respectively using rushes and reeds (Phragmitisaustralis) in the hyacinth pond and the removal of bacteria and heavy metals in the wet land.

According to Selvamurugan *et al.* (2010), a newer technology lies in the up flow anaerobic hybrid reactor (UAHR) configuration which has combined the advantages of both UASB) and UAF while minimizing their specific limitations. Such a reactor is efficient in the treatment of dilute to high strength coffee effluent at high organic loading rates (OLR) and short hydraulic retention times (HRT). However, an up-flow anaerobic hybrid reactor (UAHR) configured by combining the advantages of both the up-flow anaerobic sludge blanket (UASB) and up-flow anaerobic filter (UAF) while minimizing their limitation was found efficient in treatment of dilute to high strength coffee effluents by reducing the BOD, COD and TS by 66% 61% and 58% respectively as well as biomethanation of the coffee processing waste water (Selvamurugan *et al.*, 2010). While doing that, it was prudent to observe that biological treatment of the coffee processing wastes has been preferred for a long time. But, this method takes quite long and may not therefore constitute a practical solution to the problem at hand.

According to (Devi *et al.*, 2009), the maximum percentage reduction of COD and BOD concentration in coffee waste water under optimum operating conditions using avocado peel carbon (APC) was 98.20% and 99.18% respectively. That was comparable to the performance of commercial activated carbon (CAC) whose reduction of the same parameters in that order was 99.02% and 99.35% respectively. As the adsorption capacity of APC was comparable with that of CAC for reduction of COD and BOD concentration, it could be a lucrative technique for treatment of domestic wastewater generated in decentralized sectors. Application of another commercial product with activated carbon (the Netherlands) as the active ingredient has also been reported as capable of restoring the desired level of performance of a biological coffee effluent treatment method by facilitating adsorption of non-biodegradable and toxic compounds, which inhibit biological activity.

There are some products in the market which have been advanced as capable of rapidly reducing organic loads of pollution causing entities in the coffee effluent. One such product described as 100% natural, high quality and eco-friendly has been alleged to improve the clarity of water satisfactorily for usage in irrigation as well as eliminating the foul odor near the effluent treatment tanks in an economical way.

Effective microorganisms are also being introduced directly into the processing stream in order to mainly digest the waste and speed up overall decomposition of the organic matter in the effluent before it is discharged from the processing plant. By so doing, biological oxygen demand of the effluent was appreciably reduced prior to their release into local waterways (WWF[b], 2007). After treatment, post-fermented effluent becomes clearer than treated pulping water since the colour of pulping water attributed to that of the pulp persists. Fermentation attributed to enzymes and microorganisms for instance biodegrades the effluent as well and although it can facilitate flocculation it is not efficient for raw effluent like pulping water. Otherwise, some other enzymes can be used to treat the coffee processing effluent including that from the pulping of coffee berries resulting in the reduction of organic load in the effluent. Elsewhere, there exist some novel enzymes for industrial processes and degradation of solid wastes from agro-industries.

Remains are highly resistant materials like acids and flavanoids colour compounds from the cherry. At a pH greater than 7, flavanoids are dark green to black. After degradation of organic matter remains resistant organic materials which can be broken down by chemical means account for 80% of the pollution load in terms of COD equal to and greater than 50,000 mg/l. Other small amount substances are toxic and include tannins, alkaloids (Caffeine) and polyphenols mainly remain in the effluent (Shanmukhappa *et al.,* 1998). Calvert (1997) cited research done into the removal of polyphenolics and flavonoid compounds by species of wood digesting fungi (basidiomycetes) in a submerged solution with aeration using compressed air. These complex processes apparently seemed to remove the colour compounds while simplified and cheaper techniques using other types of fungi like geotrichum, penicilium, and aspergillus only thrived in highly diluted coffee effluents.

Although a wide range of technologies are available that can treat coffee processing effluent, many of these technologies are capital intensive, require sophisticated operating and monitoring regimes and necessitate a high level of infrastructural support (Wood *et al.,* 2000). Besides that, different technologies can give a limited degree of effluent treatment, independently or in combination to generate a much improved effluent quality with varying cost implications. However, as treatment system engineering became complex, its performance improves while its cost increases (Wood *et al.,* 2000). Based on these technical outcomes, an improved seepage pit system, designed according to known parameters, was recommended for rural coffee processors in Kenya despite being only a partial solution to the problem (Wood *et al.,* 2000). That is because of the potential for pit clogging instead of serving effectively as a percolating filter or digester of organic compounds.

Due to the suspended solids which are the larger part of organic matter of the effluent, (Wood *et al.*, 2000), seepage pits can hardly cope effectively with the disposal of the effluent within the limited availability of land. Many pits are then not only necessary but preferably sited and operated in a series in which the first receives the heavily laden effluent from which suspended solids settle before the slightly clarified effluent overflows progressively into the other pits. A similar serial set up of long channels can also be used in which solids settle at the entry section of the first channel while the rest of the channel receives effluent with diminishing solids along its length and which progressively overflows to the other channels. Whichever the case may be the off season maintenance would however be mainly required in the first and maybe the 2nd pit or channel.

2.4.3 TSS removal from the effluent

Since the suspended pectins are responsible for the high COD and pit clogging, the potential for mucilage removal from effluent streams is therefore the prime option towards easing disposal of the effluent. To achieve that expediently and effectively, however, encounters a challenge. First, the mucilage pectin is relatively slow to break down and sometimes may not settle from suspension even after standing for several days. Secondly, it is even not feasible to filter the mucilage out from coffee effluents due to its texture.

Physical

In spite of the difficulties which tend to inhibit removal of suspended solids from the effluent, a rough screening during pulping and fast separation of fresh pulp from the pulping effluent can considerably lower COD of the latter to 3,429 – 5,524 mg/l (De Matos, 1001). Similarly, very fine screens with openings of 0.2 to 1.5 mm laced after coarse or fine screens (1.5 to 6 mm) can reduce suspended solids to levels near those achieved by primary clarification (EPA, Accessed in July 2012). However, although mechanical removal is effective, it is not necessarily the most viable option.

Combination of different effluent treatment options

Another method which can decimate the level of suspended solids from the effluent comprises a preliminary mechanical removal of solids in suspension by filtration, centrifuging or by sedimentation. That is followed by a 3 stage secondary chemical process in which sedimentation occurs in the first stage which is accelerated in the second stage after which the effluent exits to the 3^{rd} anaerobic stage in a pond (Wintgens, 2004). The anaerobic processing of coffee effluent slightly lowers its suspended solids. Besides that other separation techniques that facilitate recovery of suspended solids from wastewater stream are being developed including acoustic separation and electro-osmotic dewatering. These technologies use an applied acoustic, electrical, or combined field to enhance the rate and efficiency of separation. They can reduce wastewater generation by making it more economically viable to recover solids from high solids streams (Philips, 1997).

One of the discouraging reasons against chemical coagulation and centrifugation is that these methods can only remove approximately 25% of the solids, leaving the balance in the solution and therefore not amenable to removal by filtration methods (CEW, Accessed in2007). Worse still, a study to cleanup coffee effluent by coagulating and removing the suspended solids was not successful in handling the mucilage problems and proved costly on a large scale (Calvert, 1977). The removal of the natural organic matter present in coffee processing wastewater through chemical coagulation-flocculation and advanced oxidation process (AOP) were studied under acidic conditions (Teresa *et al.*, 2007). The results obtained when the most efficient combination of a coagulant and flocculant was applied to the raw coffee wastewater showed that the greatest reduction in COD was 55% - 60% at pH 4.6. In addition to that, it was found that a reduction in COD of 67% could be realized when the coffee wastewater was treated by chemical coagulation in combination with flocculation with lime (1.0 g/l) at pH 4.6 (Teresa *et al.*, 2007). When chemical coagulation-flocculation treatment was used in combination with UV/H_2O_2 photo oxidation, a COD reduction of 86% was achieved, although only after prolonged (120 min) UV irradiation. Of the three advanced oxidation processes considered including (UV/H_2O_2, UV/O_3 and $UV/H_2O_2/O_3$), application of UV photo oxidation in the presence of H_2O_2/O_3 to industrial coffee effluent was the most efficient approach for reducing COD, and consequently the amount of organic material as well as colour and turbidity of the coffee wastewater. For instance, the $UV/H_2O_2/O_3$ process was capable of reducing the COD content of the wastewater by 87% in 35 min at pH 2.0 compared to approximately 84% by the UV/H_2O_2 and UV/O_3 treatment under the same conditions (Teresa *et al.*, 2007).

Conventional water treatment

During natural acidification of sugars, the digested mucilage (pectin oligosaccharides) is subsequently precipitated out of solution as mucilated solids to build a thick crust on the effluent surface, black on top and slimy orange/brown in colour underneath from where they can be taken out of the effluent (Enden and Calvert, 2002). Such a byproduct of acidification of the effluent can be either be raked off the surface of the trough or separated from the treated fluid by any other suitable method.

In connection to this, the reagents for removing suspended materials in coffee effluent include ferrous sulphate, ferric sulphate, lime, activated silica, alum, aluminum, other inorganic aluminium polycation salts or coagulants and low molecular weight synthetic polyelectrolytes. Ferrous sulphate is expensive while aluminum sulphate in water systems has been linked with incidences of Alzheimer 's disease (Wood *et al.,* 2000). Towards activating biodegradation of the nutrients by diverse microbial populations (Michael et al., 2012) the waste water can be corrected with lime applied at the rate of 1.5 – 2.0 g/l (Shanumkhappa, 1998) or 1.0 mg/l (Hue *et. al.*, 2006, Murthy *et al.,* 2003 and Zuluanga *et. al.*, 1987) to raise the pH from 3.5 - 4.5 to 6.5 - 7.5. Neutralization of the effluent with a lime spray results in precipitation/settling of suspended solids as sludge consisting dark coloured tannins and polyphenols (Shanumkappa, 1998; Calvert 1999 and Wood *et. al.,* 2000) which can be removed by drains from the neutralization tank (Wintgens, 2004 and Shanmukhappa et. al., 1998). Besides that, spraying coffee effluent with lime results in regained solubility of the pectins which raises the COD from an average of 3700 mg/l to an average of 12,650 mg/l.

When calcium oxide is added to processing effluent, calcium or other multivalent ions and pectic acid fragment are cross linked into a non-soluble gel of calcium pectate (Enden and Clavert, 2002). Therefore, besides the observed rise in pH to 12 (Bressani, Orozo 1973), calcium oxide coagulated the pectin substances and caused them to sediment as calcium pectate, which was separated by filtration. Nevertheless, the degree of settling was insufficient even after 18 days standing, to make a great impact on the separation of mucilage insoluble solids from effluent. Similar findings were reported by wood *et al*. (2000) indicating that lime produce only a partial flocculation and slow sedimentation of the suspended mucilage solids while natural magnesium silicate clay (Sepiolite) improved the rate of sedimentation though neither were effective enough in terms of rate of reaction or efficiency of sedimentation.

The most successful flocculantion resulted from a combination of lime and silicaceous clay in the form of Portland cement applied to the post fermentation wash water at 1.5 kg/m^3 (wood *et al*., 2000). Such a rapid precipitation process would require smaller storage tanks for post fermentation than is the case currently. Another important aspect arising from that is either the pulping effluent will be fermented prior to treatment or further investigation on treatment of the pulping effluent with cement will still be necessary. The only drawback with respect to that proposal despite the local availability of cement was that it is expensive. Besides that, a new technology for the flocculation process using cement will require the installation of a complex system which will highly unlikely appeal to adoption by the Kenya coffee industry in general. Based on these findings, Wood *et al.* (2000) recommended the consideration of cheaper, effective and locally available materials to in particular render even the resultant sludge rather economically utilizable.

In line with that, some potential compounds for treating coffee processing effluents have been identified to include calcium oxide, calcium carbonate, lime, limestone (crude), dolomite otherwise known as magmax in the trade, Calcite which is an agricultural Lime with low magnesium, gypsum which is also known as plaster of Paris, calcium hydroxide and, sepiolite, diatomite all of which tend to neutralize the pH of the effluent for ease of bio-digestion (Hue *et al.*, 2006). Others include pectic and other enzymes, biological waste degraders, commercial water treatment Polymers and Moringa oleifera. Considering calcium based compounds which are locally available with ease; calcium oxide for instance is insoluble in water. When it is mixed with water, it forms slaked Lime which is slightly soluble, Quick lime, burnt lime. Calcium carbonate is also insoluble because it is extremely stable, as a solid and water does not have enough solvating capability to dissociate the elements. Calcium hydroxide being a strong base is slightly soluble in water to some extent to the tune of 0.185 g/100 cm^3 of water. It is however important to note that all metal sulphates are soluble in water except Pb, Ca and Ba (Sulphates) while all oxides are insoluble in water except Ca, Ba and Alkali metals (group 1)

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Polymers

High molecular weight synthetic polymers of acrylamide are also conventionally used as flocculants in water and dilute mineral wastes suspensions treatment. Starch, polysaccharide and guar gum based polymers from natural resources, such as corn potatoes and legume seeds, have been used as flocculant in industrial dewatering processes. Both the synthetic and natural dewatering aids induce aggregation of suspended colloidal to fine particles dispersed in water through a dominant particle bridging mechanism. Consequently, particles settling rate are dramatically amplified to produce optically-clear supernatant and compact sediment. Whilst the application of such synthetic additives has experienced dramatic growth and significant commercial success in recent years, their overuse and failure to degrade rapidly in aqueous media may lead to undesirable water pollution (CEW, Accessed in 2007)). Alternatively, the use of novel, natural flocculants which are not only bio-degradable but also reasonably cheap and readily available is attractive if their flocculation performances and efficacies can be demonstrated to be good enough for a range of particulate matter found in aqueous suspensions. In any case, with the current, extremely high demand for corn and potato as food for human consumption, their use in the manufacture of natural starch-based polymeric products is becoming less attractive (CEW, Accessed in 2007). Without original structural modification, however, most of the natural polymers have been generally found to be less effective than the synthetic poly-acrylamide based flocculants, on equivalent dosage basis.

Moringa *Oleifera*

Another attractive plant with respect to many potential options of usage including human food (Gamatie, 2001), livestock forage, medicine, dye, and water purification is moringa *oleifera* (Palada and Chang, 2003). Moringa tolerates a wide range of environmental conditions. It grows best between 25 to 35^{o}C, but will tolerate up to 48^{o}C in the shade and can survive a light frost. The drought-tolerant tree grows well in areas receiving annual rainfall amounts that range from 250 to 1500 mm. Although moringa *oleifera*, can be grown best locally at an altitude of 200 m to 600 m above sea level, this adaptable tree can also grow in altitudes up to 1200 m in the tropics. Moringa prefers a well-drained sandy loam or loam soil, but tolerates clay. It will not survive under prolonged flooding and poor drainage. Moringa tolerates a soil pH of 5.0–9.0.

The fruits of moringa oleifera are of industrial importance in terms of edible oil production with oil press cake as a by-product. Currently, edible oil is extracted from the moringa o*leifera* seeds by earth oil refineries (Nairobi, Kenya) while the oil expellant press cake has been considered for use as an animal feed. In connection to that, further research is ongoing but certain anti-nutritional factors must be dealt with before it is used for feeding livestock (Price, 1985). The seed cake left over after the oil extraction process can also be used as soil fertilizer or in the treatment of turbid water (Price, 1985). But viewed in detail, some gathered anecdotal evidence indicates that both the seed and the press cakes, or more particularly the protein extract from the press cake (Phytofloc), undoubtedly have very positive flocculant and coagulating properties for water clarification (Price, 1985).

Previously, the idea of dealing with industrial sediments using moringa had been explored in Argentina. There is also a water treatment system in one village in Nicaragua using Moringa seed powder (Price, 1985). It could also be that, the removal of suspended solids from the effluent could be accompanied by a decrease in both BOD and COD while separate solid and liquid phases availed for other uses (Anon, 2009). The active ingredient in form of a polyelectrolyte which has been isolated in the laboratory indicates that 100 kg of moringa kernels will produce about 1 kg of almost pure polyelectrolyte (Price,1985). However, the level of the polyelectrolyte present in the kernels is substantially less during the wet season. For that reason, a water treatment experiment (Senegal) done last Sept failed to work. Therefore, seed harvested for water treatment should be harvested during the dry season only. In relation to that there has been marked interest in the development of bio-flocculant from moringa *oleifera* plant seeds. Therefore, it is worth considering the cake as well as the moringa seed (if finely ground) for cleaning coffee processing effluents. Grinding makes the protein readily available for its work as a floculant.

Since the protein activity within the press cake is important, the temperature of the press cake has to be kept low enough during pressing to avoid denaturing it. However, at earlier times, there was a significant difficulty in keeping the temperature of the press cake low enough. As such, the sufficiency of protein balance in the oil press cake is limited by the tolerable impact on the oil extraction process. Such difficulties have been overcome by newer press which permits the cooling of the press surfaces, and thus to preserve the activity of the press cake. However, there is a further difficulty in the successful extraction of the oil which has to be aided by the heating of the seed before and during pressing, bearing in mind that the main purpose is to maximize the recovery of oil. So the production of an "active" flocculant cake would probably act against that of maximized oil extraction. It may be that the available (standard) press cake is sufficiently active for treating coffee processing effluent. On the other hand, a specially prepared "low temperature" press cake could be produced, but there would be a cost factor to determine depending upon the quantity required because of the loss of efficiency in oil extraction. Amidst all that, in the end, it becomes a question of the dose rate of this material which will determine its economic usefulness, together with the preparation necessary to prepare the seed, or the press cake, for this end use.

The doses of moringa required for coagulating the solid matter in water so that it can be easily removed and can also remove a good portion of the suspended bacteria did not exceed 250 mg/l (Price, 1985). Neutral or synthetic organic poly-electrolytes rapidly adsorb on the surface of the particulates, accelerating the rate at which the particles aggregate. Aggregates are then removed from the water by physical means e.g. gravity sedimentation, floatation or filtration through granular media. Otherwise a general rule of thumb is that the powder from 1 moringa kernel when added to 2 liters of water is a good amount when water is slightly turbid, and to 1 liter when water is very turbid (Price, 1985). Alternatively, two (2) heaped teaspoons or 2 grams of the powder were mixed with a small amount of clean water in a bottle. The water and the moringa kernel powder were shaken for 5 minutes to form a paste. This paste is then poured through a cloth strainer into the water to be purified. The water is stirred rapidly for two minutes, and then slowly for 10-15 minutes. Leave the bucket of water undisturbed for at least an hour. Impurities will then sink to the bottom. The water should be strained again into a storage container for use. The seeds and powder can be stored but the paste needs to be fresh for purifying the water (Price, 1985). This process removes 90-99% impurities (Price, 1985). All the same, good clarification is obtained if a small cloth bag filled with the powdered seeds of the benzolive is swirled round in the turbid water.

Electric endosmose or cataphoresis is the often observed phenomenon of the migration or flow of a fluid, under the influence of potential difference, through the diaphragm separating the cathode and anode chambers (Lob, 1906). Flow or transportation of fluid always occurs in a certain direction, either to the anode or to the cathode, depending upon the nature of the substances and the diaphragm. If the rigid diaphragm is replaced by fine suspensions which act like movable diaphragm, the fluid remains at rest, but the suspended particles migrate towards the electrode. This directed movement depends undoubtedly upon a polar charge of the suspended particles contrary to that of the water. Since organic colloids act as extremely fine suspension, cataphoresis also possesses great importance to the organic substances with respect to their suspension, coagulation and sedimentation phenomenon. The direction of albumen depends upon the chemical composition of the fluid, for instance, whether the aqueous medium is alkaline or acid.

2.5 Possible uses of the effluent and its post treatment by-products

The method used to process the coffee fruit commonly known as cherry into beans has not been changed over the years and at the same time little attention has been given to the use of by-products of coffee processing industry (Jayapralash, 1999). Although there are several effluent treatment processes, the investment in these processes can be made attractive through pecuniary returns instead of being forced through environment protection laws (Naramha *et al.* 2004). Precipitation of suspended pectins out of the effluent will avail the separated effluent and solids for further economic utilization (Wood *et. al.*, 2000).

The waste to energy conversion route for coffee effluent by bio digestion can generate biogas (Calvert, 1997; Calvert, 1999[a] and Murthy *et al.*, 2004). The gas has also been profitably used in dual fuel engines for the generation of electricity (Murthy *et al.*, 2004). Locally, methane installations were found viable using cultivated vegetable matter like grass (Boshoff, 1965). However, due to land limitation it was felt necessary to explore the possibilities of utilizing the vegetable wastes from agro based factories. According to Boopathy (1989) a project of setting up a biogas plant based on solid wastes in a coffee estate was found feasible both technically and economically. The theoretical work on economics of anaerobic digestion also proved that this enterprise of anaerobic digestion in coffee estate is highly profitable.

Recently a twin pilot scaled bio-digester using cow dung and neutralized coffee factory waste produced substantial biogas for domestic cooking for a family unit in Indonesia (Sri-Mulato and Suharyanto, E, 2010). The biogas technology is intended to help coffee farmers to conserve their energy need for the daily cooking as well as running the house hold industry.

The additional benefit is that the slurry has a potential use for being recycled as organic fertilizer to coffee plants (Sri-Mulato and Suharyanto, E, 2010). Currently some operational biogas systems can be found in the rural areas while this dimension gaining momentum. Therefore, in the absence of adequate ‘cost’ imposed on polluted effluent discharge and on the use of water, positive returns on investment are obtained through replacement of diesel. Lagoons -The reduction in operating costs and gaseous fuel is an attractive bonus especially to small and medium plantations (Deepa, *et al.*, 2002).

Bioreactor system also include provision for a part of the water content to be recycled for non-potable uses which constituted a tangible benefit that could be included in the reckoning. According to Velmourougane *et al.* (2008), application of the effluent to the soil increased its electrical conductivity and water holding capacity significantly compared to water treated soil while the pH remained more or less the same. The treated coffee processing effluent may be used for only agricultural purposes (Shanmukhappa et. al., 1998) like irrigation of Napier grass and grass mulch. Specifically though Hue *et al. (*2006) indicated that the presence of elevated levels of K and P in the effluent make it beneficial for irrigation reuse. However, re-use of some coffee effluents for irrigation can be more environmentally friendly in terms of BOD and plant nutrients than others because of the differences in processing techniques used. For instance, the effluent from hydro pulping without fermentation had different impacts compared to the wet fermentation technique to remove the mucilage from the parchment coffee (Hue *et al.*, 2006). In spite of these attractive utility options, some trees died from the processing water application while bad odour and nuisance (flies, insects) were of noticeable concern (Hue, 2006).

Treatment of the effluent with lime results in a sludge that is attractive as a soil ameliorant if the use of lime in agriculture is any experience to lean on. Since the press oil cake is used as an animal feed it hence ends up as one of the constituents of manure. Therefore, if the same is successful as an effluent clarifier, the value of the solid by-products of the effluent treatment would be appropriately boosted for further economic usage. It is also possible to develop a granular sludge with excellent sedimentation characteristics in a USB reactor which can be put into further usage (Jayaprakash, 1999). The sludge from offseason maintenance of the empty seepage pits by scraping the walls to remove all the deposit solids material can be utilized as a fertilizer. Besides the sludge, enhanced attention to the use of coffee pulp can avoid pollution causing discharges from it. Hither to, the two by-products have been widely used as substrate for worms to produce natural fertilizers.

(Braham and Bressani, 1979) reported about studies in progress to use the coffee processing waste water as a substrate for microbial growth that in turn would be used as protein rich animal feed.

Coffee pulp can be composted easily into a fine compost within 3 week (Mburu 2001). During composting, the rise of the pH to a maximum and a similar rise in temperature to a peak dropping to the ambient temperature as well as shrinkage of the pile size to a minimum coincided with respect to time. As such, the possibly signified the end of the composting process. However composting was also dependent on the weather particularly due to loss or gain in moisture. The high concentration of the mucilage obtained from the demucilager leads to the opportunity of industrializing the by-product. The resulting highly concentrated mixture of water, mucilage and impurities is for instance very viscous and can be added to the separated fruit skin in a screw conveyor, obtaining a great retention in the solid. The screw conveyor is as well a mixer whose retention is greater than 60% leading tp an additional 20% control of the potential contamination.

CHAPTER 3. METHODOLOGY

3.1 Introduction

First and foremost, a survey on the specific water used for processing coffee cherry was conducted in which the discharged effluent at each level was characterized. The survey findings were to inform on whether the rest of the study will rely on samples from simulation processes or on random sampling from primary coffee factories in the coffee growing regions. The selection of potential substances for removing suspended solids from the effluent then followed. Having selected the solids removal agents, their performance were evaluated in experimental trials using coffee processing effluent. Mathematical expressions for describing the treatment process were then derived from the analytical data. The last component of this study compared the seepage of the treated effluent with that of the raw effluent. The results of this work were used to derive predictive seepage models for the raw and treated effluent.

3.2 Measurement of processing water use and sampling of effluent

On the day of coffee harvesting and prior to the commencement of coffee pulping, the diameter of the fresh water supply tank and the distance of the water level from the top of the tank were measured and recorded. The routine preparatory procedure for the coffee processing equipment was then conducted. The processing equipment was then started and the water supply adjusted as required. Thereafter and prior to commencement of pulping, the effluent flow rate was measured by simultaneously timing the filling of a bucket of known volume with effluent abstracted from a convenient point along the processing line. This procedure was repeated 5 times. Coffee cherry was then allowed into the processing system and timing of the process started simultaneously using a stop watch.

Where re-circulation of pulping water was in practice, sampling of effluent for analysis was done at the end of a pulping cycle for a specified batch of coffee cherry. Besides that the quantity of the processed coffee cherry and the corresponding water used to process it were measured and recorded. Otherwise, in the absence of re-circulation, samples were drawn from the effluent streams at predetermined time intervals during pulping based on the available quantity of cherry for pulping and pulping rate. These samples were progressively combined to form a bulk sample from which representative sub-samples were removed for further analysis.

At the end of pulping, both the water supply and timing of the process were terminated and the latter recorded. The water level in the water supply tank was then measured again and the amount of cherry processed recorded.

The water used as measured by the 2 methods was calculated as follows:

i. Method 1:Water removed from the storage/supply tank

$$V = \pi(D/2)^2(H_f - H_i)$$

Where:

V = Volume of water used for entire process, m^3

D = Diameter of the fresh water tank

H_i = Initial water level in the tank from the top

H_f = Final water level in the tank from the top.

ii. Method 2: Timing of processing system flow rates

$$F = (V_b/S)*60$$

$$V = FT\ (60/1000)$$

V = Volume of water used for entire process, m^3

F = Average processing water flow rate, lt/min

v_b Volume of the bucket, lt

S Time taken to fill the bucket with processing water, seconds

T = Processing time, hr.

From the collected data, the, specific water use in terms of m^3 per ton of processed cherry was calculated as quotient of the water used (m^3) to process a certain batch of coffee cherry and its own weight (tones).

3.3 Sampling and preservation

The coffee processing effluent samples for this study were sourced from selected primary coffee processing factories in representative parts of the coffee growing regions. For each experiment, coffee effluent samples were separately drawn at random from pulping streams in each factory. Where pulping water was re-circulated, sampling of the effluent for analysis was done at the end of a pulping cycle for a specified batch of coffee cherry. Otherwise, in the absence of re-circulation, samples were drawn from the effluent streams at predetermined time intervals during pulping. These samples were progressively bulked in one container from which representative 1 litre sub-samples were drawn for further analysis. Since the effluent contains biologically degradable suspended matter, each of them was acidified to pH≤2 with 2.0 ml concentrated sulphuric acid per litre to prevent degradation (was preserved) between sampling and analysis. The effluent samples were immediately after transferred in plastic containers to the laboratory at the Coffee Research Station (CRS) for further analysis and experimental treatments.

3.3.1 Selection criteria of the flocculants

The selection criterion was based on the available knowledge about the potential of each substance considered to clarify water and/or agro processing effluents. The other aspect used to merit the selection of the flocculants was their added value to the resultant by products of the effluent treatment. Since the economic means and the attitude of the rural coffee processors are somehow limited and ambivalent, the most preferred coffee processing effluent treatment method was limited to those which are cheap, effective and requiring minimal attention after application.

3.3.2 Data analysis

Finally, all the measured parameters were compiled and the data analysed to determine the relationship between the water used per unit weight of cherry processed and the effluent characteristics.

3.4 Measurement of parameters in the effluent.

Immediately after sampling, the initial characteristics of the effluent including the pH, temperature (T,^{o}C) and dissolved solids (DS) were measured in situ using electronic meters while the Total Solids (TS) was determined by Reference procedure in accordance with Standard Methods, Section 2540 B., Total Solids Dried at 103 – 105^{o}C (APHA, 1995). Standard Methods does recommend that the sample volume should be selected to ensure a residue of 2.5 to 200 mg even if it is necessary to dispense successive sample portions to the dish following evaporation. Additionally, it is specified that the cycle of drying, cooling, desiccating, and weighing should be continued until a constant weight is obtained or until the weight loss is less than 4% of the previous weight or 0.5 mg, whichever is less. Such measurements were similarly made during the conduct of the experimental trials.

3.5 Experimental trials on removal of solids from the coffee processing effluents.

3.5.1 Experiment 1: Natural settlement.

The natural biological settlement of solids from the effluent by was investigated by filling 5 clear plastic buckets of 20 liters each with the effluent shared out from a bulk sample. The experimental set up was left at laboratory conditions and daily samples drawn from 3 positions in each bucket namely the top (But beneath the scum), middle and above the sludge. Those 3 samples were immediately thereafter thoroughly mixed into one (1). The effluent status in terms of Temperature (T,^{o}C), acidity (pH), dissolved solids (DS, g/lt) and, total solids (TS, g/lt) was assessed by measuring these parameters against time from the initial conditions until consecutive records were not significantly different.

3.5.2 Experiment 2 Lime treatments.

In another experiment, 5 buckets full of effluent were set up in the laboratory similarly to biological treatment trial. A sample of 100 ml of effluent was drawn from each bucket into a beaker. Lime powder was then applied to the effluent sample at the rate of 1.0 g/lt (Wood *et. al.*, 2000.) and stirred up thoroughly before returning the solution back into the respective bucket. The effluent in the bucket was then stirred for thorough mixing with lime. The progress of the treatment against time was tracked by measuring T, pH, DS, and TS until 3 consecutive constant readings were recorded.

3.5.3 Experiment 3 Moringa treatments.

First, different weights of moringa powder ranging from 1 to 5 g at a constant incremental from one treatment to the other were premixed in separate beakers with a sample of effluent from each bucket. The resultant solutions were returned back to the respective buckets while stirring the effluent vigorously. By so doing, the optimum application rate of Moringa o*leifera* was determined by applying it in solution form, at different rates to the effluent in separate buckets. At the beginning and end of the treatment process, the final effluent characteristic parameters were measured.

The experiment set up for the treatment of the effluent with Moringa was similar to experiment 2 except that moringa o*leifera* was applied at the optimal rate to every bucket full of the effluent. To start with samples were drawn from the effluent to determine the initial characteristics before treatment. The moringa powder was mixed with a small amount of clean water in a bottle and shaken for 5 minutes to form a uniform paste. This paste was then purified by pouring it through a cloth strainer into the effluent. The effluent was then stirred rapidly for 2 minutes and then slowly for 10-15 minutes. The buckets with the treated effluent were left undisturbed until the effluent clarified and the time taken recorded. Samples were drawn from the effluent to determine the final characteristics of the clarified treatment.

3.6 Seepage of treated and untreated effluent in pit models.

The experimental trials for this study were sited in areas where the soil type was in conformity with specifications for coffee cultivation (Michori and Kimeu, 1980). The experimental pit model was adapted from the improved pit design (Wood *et. al.*, 2000) and modified into a scaled down model with a diameter of 1.0 m and a depth of 1.25 m comprising the actual depth of filling the effluent, 1.0 m and a free board, 0.25 m. At each site, model pits were dug 10 m apart along a contour and used to study the seepage of raw and treated effluent. The pits were also protected from surface runoff arising from the water catchments above them.

Plate 3.1: Model seepage pit.

To start with the characteristics of the input clean water, raw and treated effluent were then measured. These pits were filled with clean water, treated effluent and raw effluent respectively separately and at random. Immediately after that, changes in effluent surface level in each pit with respect to a reference datum at the top of the pit were measured at 15 -

30 min intervals. Seepage out of each pit was measured nonstop except when refilling and at night. The pit was always refilled with effluent as it tended to drain out completely. The refilling volume/marks against time were also documented accordingly. Each set of experiment was repeated in different sites within the coffee growing regions. Using the collected data a general model expressing the seepage of effluent from a pit as a function of time was developed.

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1 Water use for pulping coffee cherry and the TSS and pH in the resultant effluent

4.1.1 Demand for water during pulping coffee cherry.

In Fig. 4.1, classification of coffee factories based on their respective processing water usage is shown. In each category, the number of coffee factories fitting within the specified water use range is indicated. It can be inferred from these results that out of all of the considered coffee factories, about 64% used between 4 to 7 m^3 of water for pulping a ton of ripe coffee cherry. Another observation was that, 86.36% and 95.46% out of 22 coffee factories operated with less than 10 and 15 m^3/ton respectively. It was also noted that most of the coffee factories covered by this study pulped less than 10 tons of coffee cherry per day. Finally, all the factories pulped coffee with more than the recommended 0.533 m^3 of water.

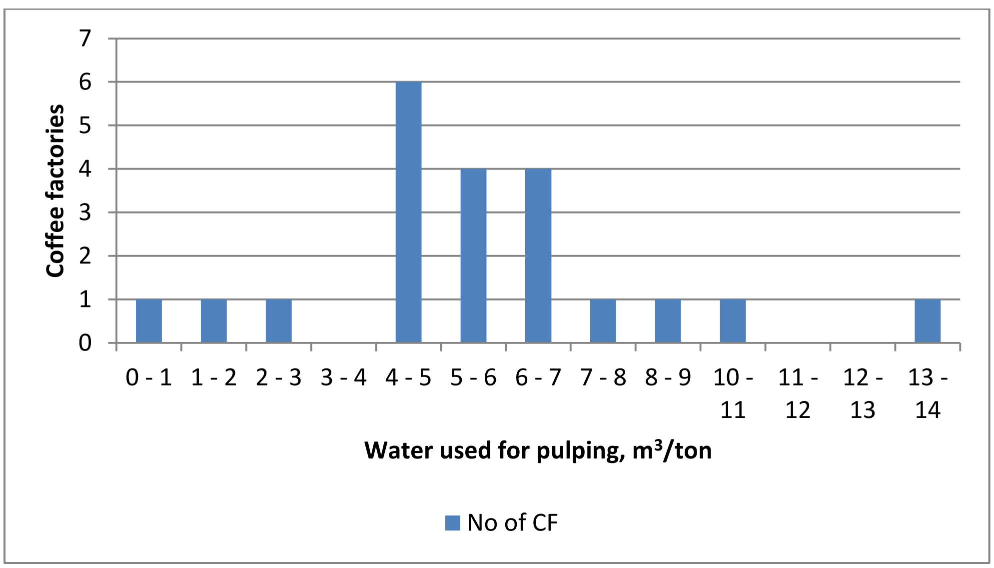

Figure 4.1: Coffee factories within specified pulping water use ranges

Fig. 4.2 shows the amount of water in m^3/ton used to pulp 22 batches of coffee cherry whose weights ranged from 1 to 22 tons. According to the results very high 13 and 24 m^3/ton were used to pulp 4 and 16 tons of coffee cherry respectively while all the other coffee factories used less than 10m^3/ton. It was noted that just over half (12) of the coffee factories pulped more than 5m^3/ton. It was also noted that 6 coffee batches of coffee cherry of different weights were pulped coffee with about 5 m^3 of water per ton of coffee cherry. This implied that cases existed where usage of nearly the same amounts of water to pulp different weights of cherry and vice versa. These results reflected the realty in terms of water used not only for pulping but the entire wet processing chain.

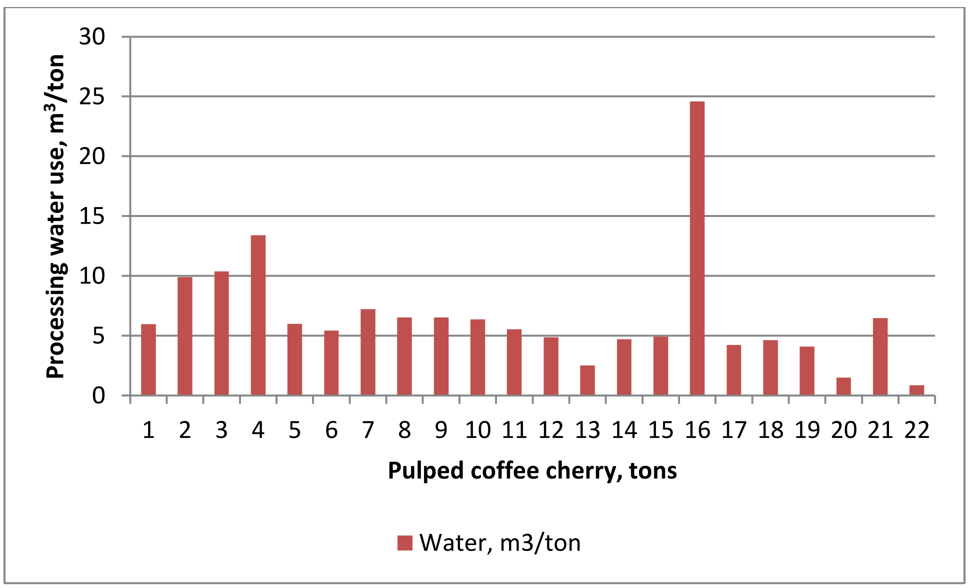

Figure 4.2 : Water use during pulping of coffee cherry

The factors contributing to that have been reported to include factory layout, lack of water meters and the fact that processing water minimization does not feature highly during primary coffee processing (Mburu, et al., 1994). As such pulping water use levels were not only inconsistent but mostly exceeded the recommended 2.25 m^3/ton of coffee cherry produced (Aagaard, 1961).

Although there was no general trend in water use against increased cherry pulped (Fig. 4.3), the consistence observed between 0.25 and 8.0 tons attracted further analysis. That was because the remaining coffee factories except one within that range had an almost directly proportional relationship between the amount of coffee processed and the water used. That was further demonstrated by superimposing the ideal water use trend over practical water use (Fig. 4.3). It then emerged that the practical and the ideal water use trends compared well in factories which processed less than 10 tons of coffee cherry per day except in one factory.

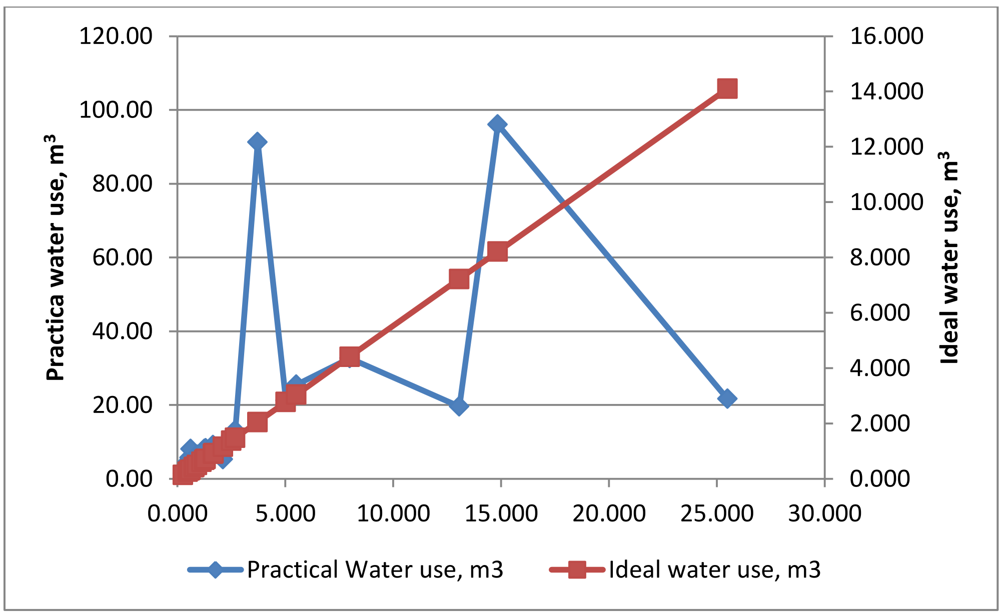

Figure 4.3 : Practical and ideal quantities pulping of water used for

Fig. 4.4 focused more closely on the bulk (m^3) and specific water used for pulping a ton (m^3/t) of coffee cherry. The bulk water used appears quite proportional to the pulped coffee cherry. As such, the plotted data of the bulk water use could be fitted well with a regression line as shown in Fig.

4.4 (R^2=0.993). From the gradient of the regression line, water us was 3.8 m^3/ton of pulped coffee cherry. However, the water use per ton as calculated from the same data decreased at a decreasing rate contrary to the ideal water use which is supposed to be 0.553 m^3/ton of coffee cherry pulped (Aagard, 1961). That sort of signified economic gains in water use against increasing quantities of pulped cherry albeit at a diminishing rate.

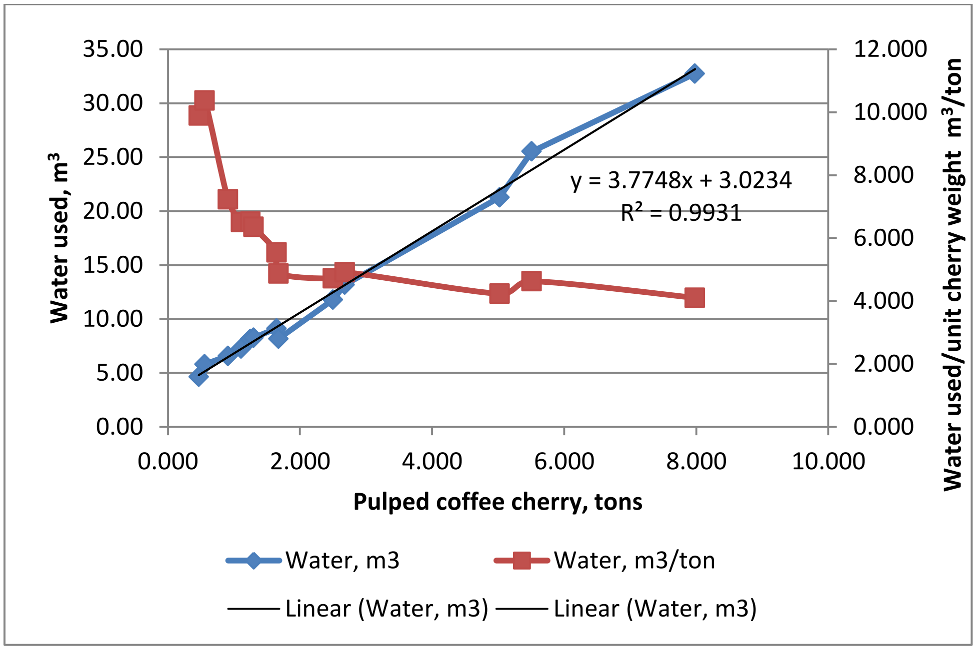

Figure 4.4: Bulk and specific water used to pulp coffee cherry.

Due to the variation in the specific water use as was demonstrated in Fig. 4.4, the same data was further analysed by the following method. In Table 4.1 the sum of the cherry pulped by all the 13 coffee factories and the corresponding water used were calculated and were 32.614 tons and 162.415 m^3 respectively. The average amount of water used for pulping as calculated from these two parameters was 4.98 m^3/ton. This value was used to estimate the average water use in each coffee factory and listed in the column headed “average, m^{3}” as shown. Similarly, the ideal water use per factory were estimated using the standard recommended pulping water use rate of 0.533 m^3/ton and the values were also shown in the column headed “Ideal, m^3”.

Table 4.1 : The actual pulping water use compared to the average and recommended rates.

Pulped cherry, tons		Water used, m^3	Calculated water use	
			Average, m^3	Ideal, m^3
	0.469	4.640	2.336	0.250
	0.559	5.796	2.784	0.298
	0.910	6.579	4.532	0.485
	1.112	7.237	5.535	0.592
	1.248	8.138	6.215	0.665
	1.300	8.260	6.474	0.693
	1.646	9.119	8.197	0.877
	1.677	8.169	8.351	0.894
	2.500	11.791	12.450	1.333
	2.679	13.173	13.341	1.428
	5.024	21.263	25.020	2.678
	5.510	25.515	27.440	2.937
	7.980	32.735	39.740	4.253
Total	32.614	162.415		
Average, m^3/t		4.980		

The actual pulping water used to pulp various batches of coffee cherry was compared to the average and recommended rates (Fig. 4.5). The results show the trend of the actual water as compared to the average and the ideal water use. As indicated in Fig. 4.5, coffee cherry batches of less than 2 tons were pulped with more than the average water used while bigger batches than 2 tonnes were pulped with less than the average pulping water used. Further to that, each of the coffee factories used more than the ideally recommended water for pulping a batch. These results tally with earlier findings which found the practical water used for processing being excessive of the recommended amounts (Wood et al., 2000). The excess in water use are magnified even more where there only too small coffee batches to process. The primary cause of this problem is lack of water meters and the will to process coffee rationally.

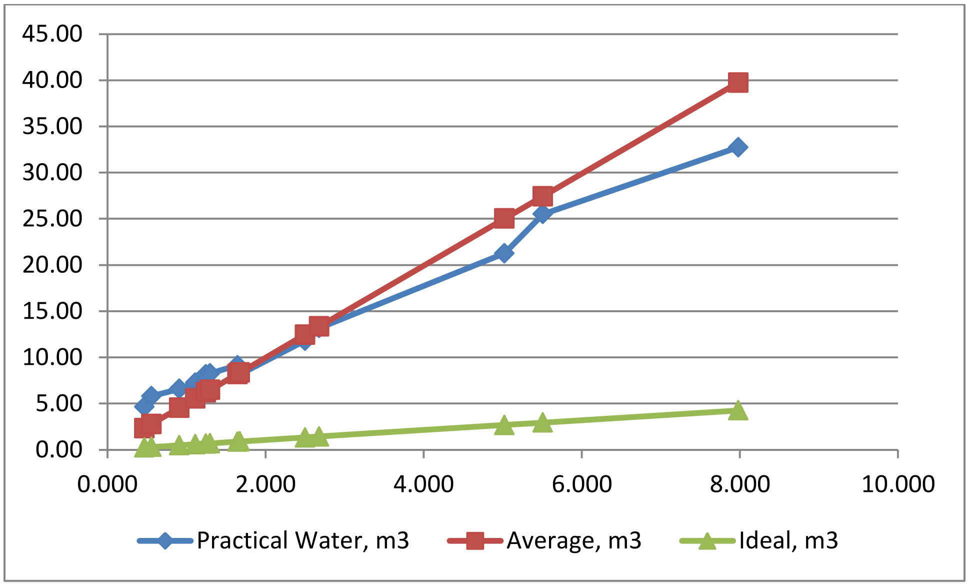

Figure 4.5 : Comparison of the actual, average and ideal water use for pulping coffee cherry.

4.1.2 Effect of water used for pulping on TSS and pH in the effluent.

Calculation of the total suspended solids (TSS)

The total suspended solids (TSS) in the effluent were measured by an indirect method because of the nature of the effluent characteristics in particular the gelatinous nature of the mucilage component in the coffee processing effluent. In view of that, it generally seals the filter members whenever the removal of solids by filtration is attempted. For that reason, the TSS values reported in this study were derived from the measured DS and total solids TS. This was done by assuming that the TS could be expressed in terms of DS and TSS as in equation 1 (AGSM 337, Accessed in Oct. 2013).

TS = DS + TSS [4.1]

The concentrations of solids in the effluent and its pH after pulping coffee with different amounts of water per ton of coffee cherry were as shown in Fig. 4.6. The TDS component varied to a rather limited extent regardless of the specific water used for processing. On the other hand, TSS varied erratically and broadly between 0 to 8.00 g/l. Such a range of TSS was almost comparable to 2.30 - 8.794 g/l of TSS in pulping effluent which was reported by wood *et al.* (2000).

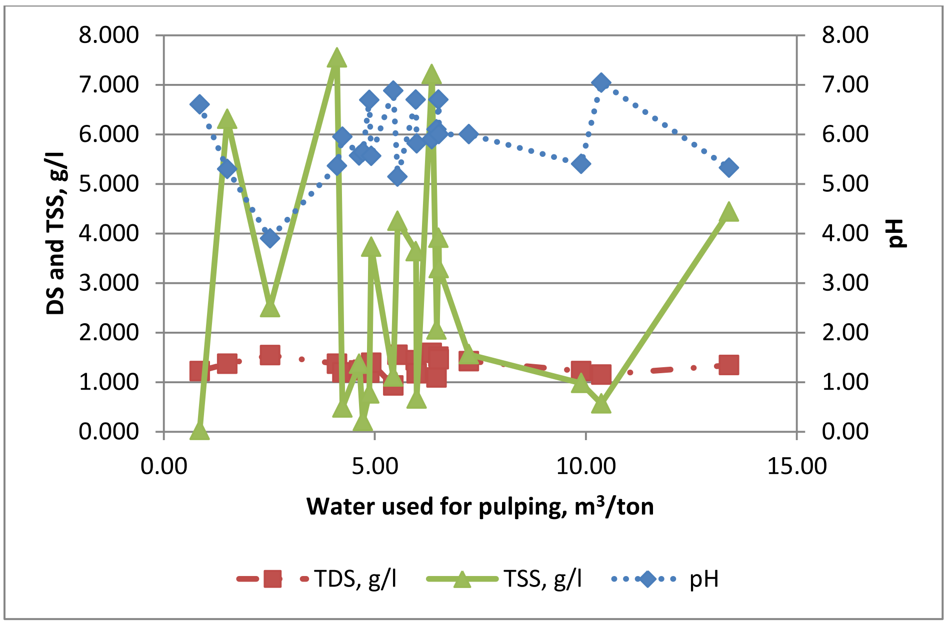

Figure 4.6: Solids in the effluent in relation to the water used to pulp a ton of coffee cherry.

The implication of these results was that water use levels could not be relied on to predict the solids in the effluent. Another important inference was that, very high levels of total solids lying between 6.0 and 8.0 g/l were recorded in 3 coffee factories out of 13 with low water use ranging from 1.50 to 6.35. However, high processing water usage did not necessarily translate to the dilution of the TSS in the effluent and instead could easily facilitate the access of the increased effluent volumes to the vulnerable environment in particular the surface waterways with possibly even higher loads of solids.

The unpredictable variation of the effluent solids (Fig. 4.6) could possibly be attributed to inhomogeneity of coffee cherry processed in terms of their degree of ripeness, coffee production factors and the extent of maceration by the pulper among other processing equipment factors. Succulent coffee cherries for instance were easier to pulp resulting in more pulverized and hence fibrous pulp from which more solids were likely to migrate into the effluent. On the other hand, cherry from droughty conditions was harder to process and its pulp remained more or less intact with even less transfer of solid materials into the effluent. Besides that, failure to subject the pulper to scheduled service and maintenance could introduce variations as observed because the cherry sizes keep on changing throughout the harvesting season. Hence, the characteristics of the effluent from even the same pulper let alone from one pulper to another are bound to keep on changing during the coffee harvesting season.

As for the pH of the effluent, it varied mainly from 5 to 7 except for only one case where it was about 4 within the covered water use range (Fig. 4.6). Since a pH of 7 is fairly neutral while 4 is fairly acidic that variation of 3 orders of magnitude was a wide range. Consideration of pH was deemed important due to its influence in the degradation of the effluent by microbes. In essence the higher the pH, the more the conditions are expected to become favourable for microbial action.

According to these findings, the TSS in the effluent was not a function of processing water use. In view of that, these results did not support the generation of effluent samples by simulating the process such that the characteristics of the output effluent was controlled by varying the input factors. Instead the effluent samples for the rest of the study were randomly drawn from primary coffee processing factories during pulping. While doing so, the target scope of coverage limit of suspended solids in the effluent was as identified in Fig. 4.6 to ensure that the effluent treatment was as comprehensive as possible.

Some parameters of the coffee effluent which were monitored in this study were as shown in Table 4.2. The samples responsible for this data were sourced on the indicated dates from various coffee factories (CF) located in some parts of the coffee growing regions.

Table 4.2: Some characteristics of the coffee effluent

Date	**CF**	**Location**	**pH**	**TDS, g/l**	**TS, g/l**	**SS, g/l**	**COD, g /l**
27.04.09	Gacibi	Kiambu	3.31	1.090	1.610	0.520	4.000
13.05.09	Gathage	Kiambu	3.96	1.154	8.490	7.336	24.250
25.06.10	Gathiruini	Kiambu	3.72	1.136	2.490	1.354	1.120
11.01.10	Githongo	Kiambu	5.95	1.262	2.600	1.338	17.500
04.01.10	kamuchege	Kiambu	5.40	1.222	2.200	0.978	15.500
26.01.10	Kanake	Kiambu	5.14	1.550	5.800	4.250	11.000
08.04.09	Karakuta	Kiambu	6.30	1.144	4.590	3.446	0.660
13.05.09	Karangi	Kiambu	4.33	0.968	2.670	1.702	5.750
03.08.10	Kisii	CRISC[a]	6.37	1.470	8.170	6.700	32.000
22.10.09	Kitale	CRISC[b]	6.00	1.460	4.760	3.300	2.020
10.09.09	Koru	CRISC[c]	6.88	0.929	2.040	1.111	1.660
10.05.09	Mariene	CRISC[d]	6.49	1.248	2.530	1.282	1.080
24.11.09	Ndia-ini	Nyeri	3.27	0.958	1.560	0.602	4.750
24.06.10	Rukera	CRI[e]	4.40	0.859	6.700	5.841	17.500
14.11.09	Tabaya	Nyeri	6.38	0.996	3.090	2.094	9.250
30.11.09	Thunguri	Nyeri	3.90	1.540	4.050	2.510	7.450

Key: CRISC – Coffee Research Institute, Sub center

CRI – Coffee Research Institute, Ruiru *(Source: This research)*

According to Table 4.2, the pH of the raw effluent varied from 3.27 to 6.88 while TDS, TS, TSS and COD were 0.859 - 1.550, 1.5660 - 8.490, 0.520 - 7.336 and 0.660 – 32.000 g/l respectively. These findings confirmed some of the characteristics of the effluent samples used for this study.

4.2 Removal of TSS from the coffee pulping effluent.

4.2.1 Natural solid sedimentation.

The status of the effluent in terms of pH, TS, DS and consequently the derived TSS in the pulping effluent against time from the day of pulping to the end of such a natural phenomenon was as shown in Fig. 4.7. The end of the process was signified by there being no further change in levels of these effluent characteristics. The outlined trend for each of these parameters represented the general behaviour of pulping effluent in all the conducted experiments.

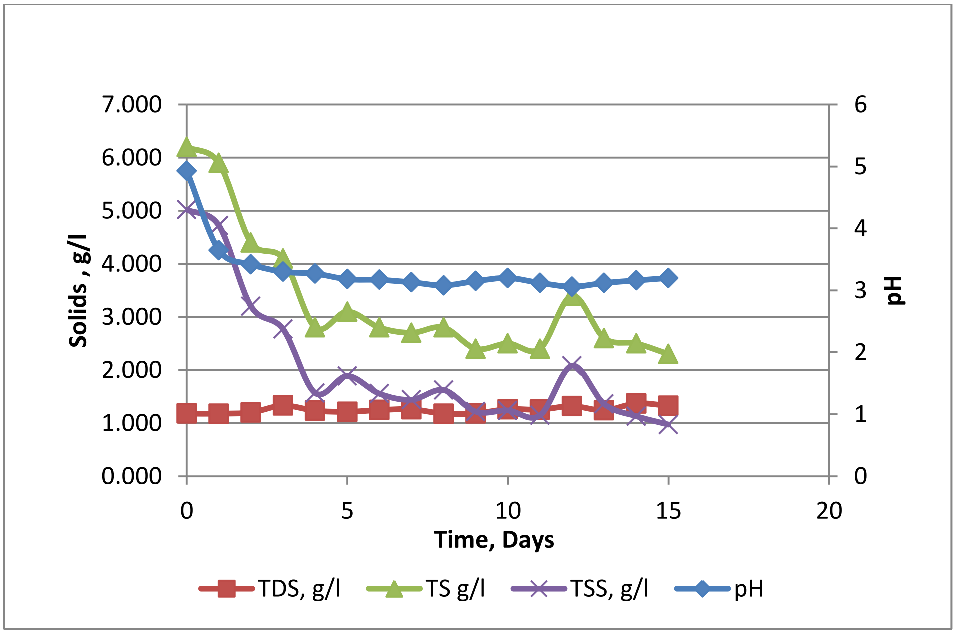

Figure 4.7:Solids and pH levels in the effluent against time after pulping.

The TSS profile in fig. 4.7 was also akin to the natural changes that the raw pulping effluent goes through after its disposal into the pits without any form of treatment. The biodegradation of the effluent depends on the conditions conducive for the bacteria for the bacterial activity. That process takes long and releases solids from the effluent mainly to the bottom of the pit while some float to the surface as scum but only to limited extent. The formed sludge is normally the concern of the offseason maintenance schedule in which it is removed. According to their respective curve profiles, the pH and TS decreased progressively in the course of the given process time while the concentration of TDS in the effluent remained relatively constant.

For that reason, the decrease in TS could be attributed to the sedimentation of the TSS out of the effluent by a similar margin except in some rare cases where effluent formed three phases as illustrated in Plate 4.1 including the clarified effluent, substantial sediment and some floating matter.

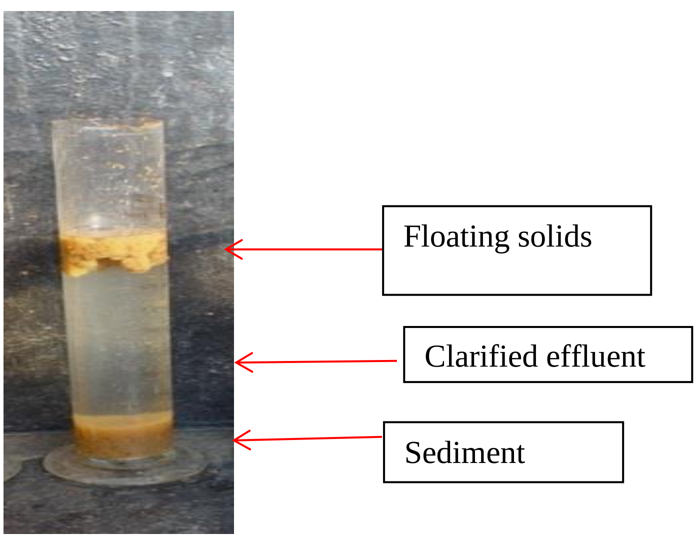

Plate 4.1: Solid and liquid phases of the treated pulping effluent

The existence of the floating matter was however more temporarily than the sediment. In both cases some of the removed TSS eventually dissolved back into the effluent or migrated from the top to the bottom and vice versa. The formed sludge was for instance rather unstable from the 4th day (Fig. 4.7) and could at times return back to the effluent or even pop up to the surface of the effluent or vice versa without being prompted by any disturbance at all. In connection to that, it was worth noting that TSS in the effluent decrease from about an initial of 5.8 to 1.5 by the 4th day. Immediately thereafter and until the 15th day (Fig. 4.7) the transfer of TSS entered an unstable phase characterized by solid movement from and back into the both the effluent and the sludge. In other words, there existed a state of equilibrium during that period in which the solids moved from and into either phase. Consequently, only about 0.5 g/l of TSS move out of the effluent during that period of 11 days (Fig. 4.7). Those findings indicated that the practical treatment process time was about 4 days.

In order to conceptualize and analyze the changes in the effluent during treatment, the daily pH and solid levels in the effluent committed to a natural degradation process after pulping were as tabulated in Table 4.3. Although the TSS in the effluent reduced by 4.049 g/l (i.e. 5.021 to 0.972) within 15 days, the first 4 days were responsible for the removal of 3.455 g/l (68%) of the solids. That could have been as a result of a rather rapid degradation of some of the organic matter including fermentation of sugar in the pulping effluent. As the sugars are fermented down to alcohol and then vinegar, the acidity or pH drops to 3.8 and that will throw all the mucilage/pectins out of solution to float on the surface as an orange yellow scum Calvert (1999[a]). As the active ingredients propelling the process forward diminished, further removal from then declined suddenly to only 0.35 g/l (6.97%) from the 4th to the 9th day, 0.07 g/l (1.39%) from 9th to 11th day.

Table 4.3: pH and solids in the effluent (Rukera estate, Ruiru) given time after pulping.

Days	pH	TDS, g/l	TS g/l	TSS, g/l
0	4.93	1.179	6.200	5.021
1	3.65	1.178	5.900	4.722
2	3.42	1.200	4.400	3.200
3	3.30	1.330	4.100	2.770
4	3.27	1.234	2.800	1.566
5	3.18	1.213	3.100	1.887
6	3.17	1.246	2.800	1.554
7	3.13	1.260	2.700	1.440
8	3.08	1.178	2.800	1.622
9	3.15	1.184	2.400	1.216
10	3.20	1.262	2.500	1.238
11	3.12	1.254	2.400	1.146
12	3.06	1.320	3.400	2.080
13	3.12	1.240	2.600	1.360
14	3.16	1.370	2.500	1.130
15	3.20	1.328	2.300	0.972

However, increase of 0.214 g/l (4.26%) from 11th to 13th day followed by further decrease of 0.388 g/l (7.73%) from 13th to the 15th day were recorded. Table 4.3 also shows that TSS in the effluent decreased continuously from the beginning to the seventh day. After that, there occurred to cases between the 7th and 8th as well as the 11th and 12th days in which TSS increased from the previous day's record. In each case then the effluent regained some of the TSS it had previously given out. In view of all that, TSS removal could be safely assumed to have ended on the 7th day for practical purpose. That was just before a state of instability started between the effluent and sediment interface.

In addition to that, the pH decreased from an initial 4.93 to 3.08 by the 8th day (Table 4.3). From then to the 15th day, the pH kept varying between 3.06 and 3.20, incidentally, that was also more the same period that the

TSS in the effluent was behaving similarly. That is each parameter was swing up and down within a narrow range without any directional change. The pH on the 8th day supported the conclusion made with respect to the TSS on the 7th day as signifying the end of the treatment process.

During the period between the 7th and the 15th day, some dislodged sludge in form of a fluffy mass kept disintegrating easily while on transit from the sediment to the surface through the effluent. Entrainment of some traces gas within the settled sludge was advanced by Calvert, (1999[a]) as the prime reason behind such a phenomenon. As such, the entrained gas though insignificant to measure or identify made the affected portion buoyant enough to dislodge itself from the sludge. Its undoing however was the reversal of solids removal from the effluent as detected through some odd measurements in terms of increased solids (Table 4.3) between two consecutive days like 4th – 5th (0.321 g/l), 7th – 8th (0.182 g/l), 9th – 10th (0.022 g/l and 11th – 12th (0.934 g/l). In spite of that, the general trend of diminishing TSS in the effluent against time still persisted. Incidentally, such cases were commonly encountered after the solids removal curve reached a turning point and after the TSS concentrations were less than the recommended safe effluent disposal limit of 2 g/l. Therefore, the turning point as well as the state of instability could perhaps be taken to signify the end of the solids removal process. That being the case, the effluent could have been considered safely treated for disposal on the 4th day when the TSS in the effluent reached 1.556 g/l.

Expression of TSS in the effluent as a function of time.

In order to derive an expression of TSS in the effluent as a function of time, it was considered that the discharge of the effluent from coffee factories was in batches instead of continuous flow. Such an assumption was important towards the development of a mathematic model capable of predicting the status of the TSS in the affluent at any time during the removal process. For that purpose, the rate of removal of TSS (r_{TSS}) from the effluent as a function of time was established by postulating a rate expression and applying it to a batch reactor mass balance equation as follows.

$$\frac{\mathrm{d(TSS)}}{\mathrm{dt}} = \mathrm{f(TSS)} \qquad (4.2)$$

Since the settlement of solids constitutes a first order reaction where Reactant (A) → product, the rate of solids removal was expressed as;

$R_{TSS} = k*TSS_t$

Where,

R_{TSS} was the rate of solids removal,

TSS_t was the concentration of suspended solids at any time (t) from the beginning of settlement and

K was the reaction rate constant

Thus,

$$\frac{d\mathrm{(TTSS)}}{dt} = -k\mathrm{(TSS)} \qquad (4.3)$$

$$\frac{d\mathrm{(TTSS)}}{\mathrm{(TSS)}} = -k.dt$$

The analytical integration of equation 4.3 gives:

$$\int_{\mathrm{TSSo}}^{TSS} \frac{d\mathrm{(TSS)}}{(TSS)} = -k\int_0^t dt$$

Therefore,

$$ln\left(\frac{TSS}{TSSo}\right) = -kt$$

Therefore,

$$TSS=TSS_0e^{-kt} \quad (4.4)$$

Putting equation 4. 2 into a linear form,

$$Ln(TSS) = – ln(TSS_0)-kt \quad (4.5)$$

The transformed ln(TSS) data was then plotted on the y-axis against t on the x-axis and a regression line fitted through the plots (Fig 4.8).

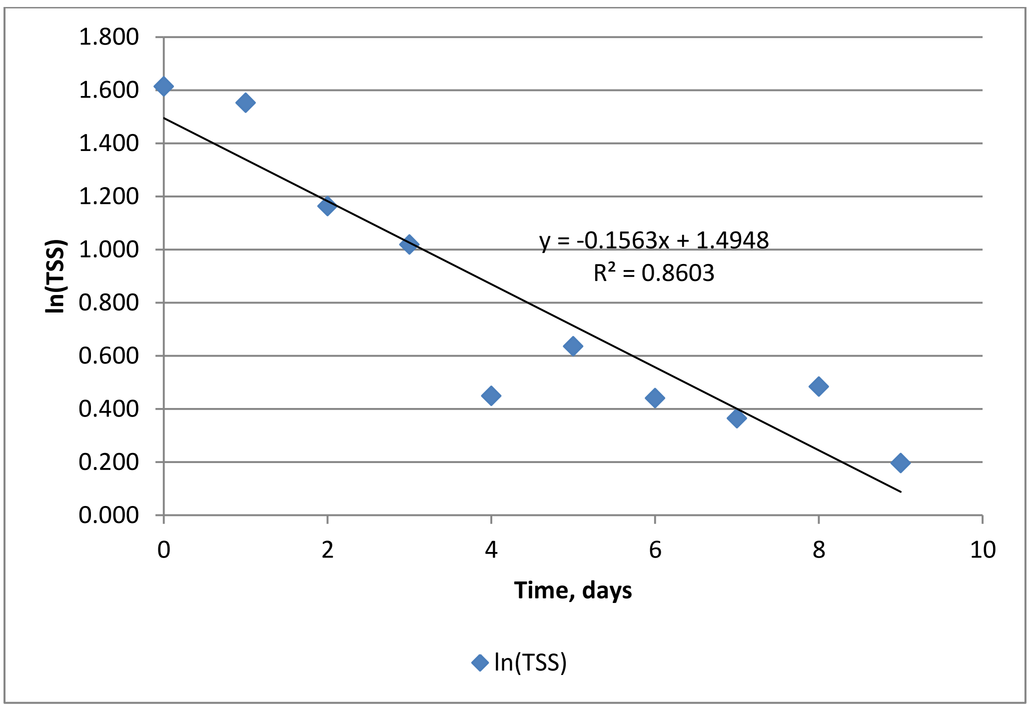

Figure 4.8: Regression of ln(TSS) on retention time (t) for pulping effluent.

Since a reasonably straight line was drawn through the plotted ln(TSS) versus time, it could be similarly assumed that the postulated solids settlement rate expression was the proper one for modeling the experimental data. In addition to that, since the regression line fitted the transformed data well (R^2 = 0.8603), then equation 4.3 was verified to express the trend of TSS variation against time correctly. The slope of the straight line was –k=0.1563 (0.16) being the TSS removal rate and the intercept ln(TSSO)=1.4948 from which TSS_o= 4.458.

Although the TSS removal process was demonstrated to extend up to 14 - 15 days (Fig. 4.7), the derived expression of TSS in the effluent at any time during the treatment process was only applicable within a certain range. In this case for instance, it was applicable up to 9 days (Fig. 4.8). In addition to that, the values closest to the lowest limit of solids removal curve (Fig. 4.9), indicate that the treatment process took not more than 6 days after which the interphase between the solids and the effluent became unstable.

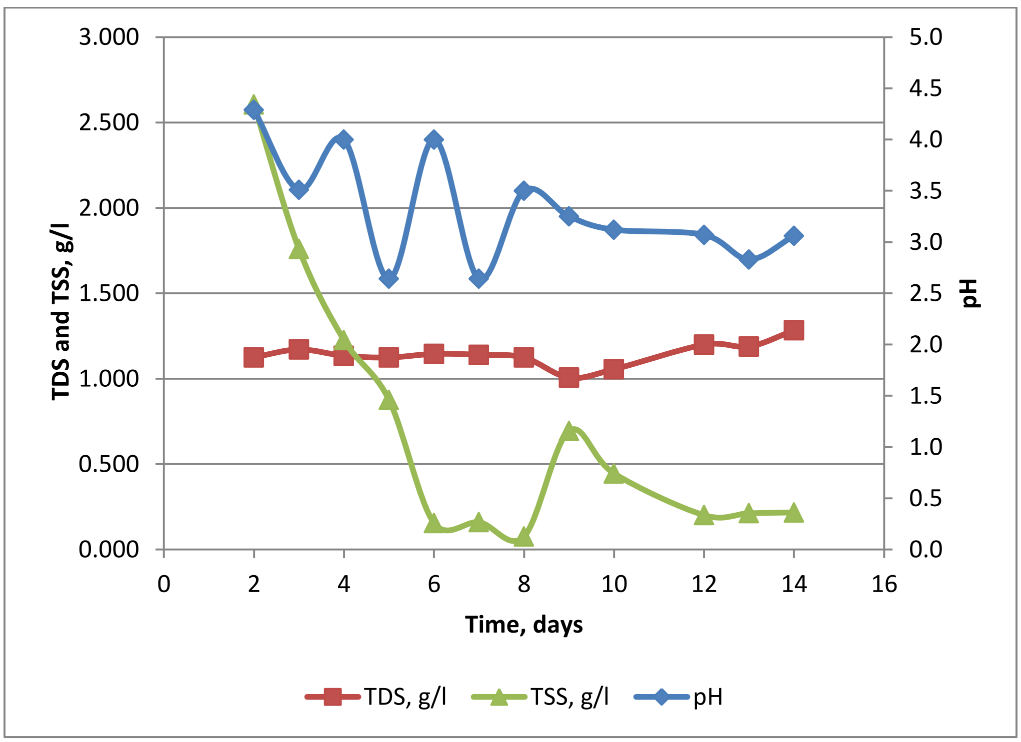

Figure 4.9: The DS, TSS and pH of effluent with time after pulping.

At such a time, some solids could detach from the sediment and return back to the effluent and vice versa. As such, the lower limit of the range namely retention time (RT) for stability could be taken as the end point of the treatment process. However, the effluent could only be considered to have attained full treatment status for seepage purpose, if the balance of TSS was 2 g/l or less.

Therefore such retention times were located and are as shown in Table 4.4 as RT for ≤ 2 g/l. Based on these values, the treatment process could be terminated earlier than or at the same time with the equation's lower limit. It was also found worth considering the first phase of this process for the design of an effective effluent treatment.

Table 4.4: TSS for the raw and treated effluent and the retention times.

TSS_r, g/l	TSS_p, g/l	$\left(\frac{TSSf}{TSSr}\right)\%$	RT_p, Days	TSS_{sp}<2 g/l	RT_{sp}, Days
2.605	0.155	5.950	6	1.769	3
2.820	0.155	5.496	5	1.769	2
5.021	1.566	31.189	4	1.566	4
2.092	0.840	40.153	4	1.540	1
3.524	1.694	48.070	3	1.694	3
4.756	1.140	23.970	5	1.969	3
3.769	1.498	39.745	1	1.498	1
4.756	1.622	34.104	6	1.622	6
3.446	1.580	45.850	4	1.580	4
1.327	0.739	55.690	1	0.739	1
1.741	0.760	43.653	1	0.760	1
4.101	1.798	43.843	5	1.798	5
3.585	1.971	54.979	1	1.971	1

Key: Retention times for practical/optimal (RT_p) and seepage (RTsp) purpose.

That was because of the rapid TSS removal that took place down to the acceptable standard level below which further removal was not appreciable beyond that phase. Such a critical time limit in the process could be taken to suffice for the purpose of the projected enhancement in seepage of the effluent.

The derived expression was further tested more comprehensively in other similar experiments which used different batches of pulping effluents. The regression parameters of the resultant expressions were as shown in Table 4.5.

Table 4.5: The k values for raw effluent with different TSS.

Actual TSS_o	K	$\ln(TSS_o)$	Predicted TSS_o	R^2
2.092	0.158	0.740	2.096	0.898
2.605	0.182	0.534	1.706	0.420
2.820	0.172	0.405	1.499	0.466
3.446	0.204	1.333	3.792	0.967
3.524	0.206	1.235	3.438	0.966
3.585	0.282	1.286	3.618	0.680
3.769	0.335	1.113	3.044	0.848
4.101	0.177	1.478	4.384	0.981
4.756	0.282	1.511	4.531	0.996
5.021	0.088	1.251	3.493	0.700
5.705	0.392	1.627	5.089	0.751

Further to that, the relation between k and TSS was sought by plotting the respective values as shown in Fig. 4.10. Although k varied with TSS in the raw effluent, the variation was not consistent. This is strongly confirmed by the small value of $r^2 = 0.347$ which signified a rather poor correlation. That was so despite the observed strong tendency of k to decrease with increased TSS except for a few values in between the given range which decreased from the previous ones instead. That could be attributed to other factors inherent to the effluent which were not controlled in this study.

The increased in values of k imply that the TSS in the effluent decreased with time and was in agreement with the derived equation 4.4. In essence, that was an indication that the equation could be used to design an effective coffee effluent treatment plant.

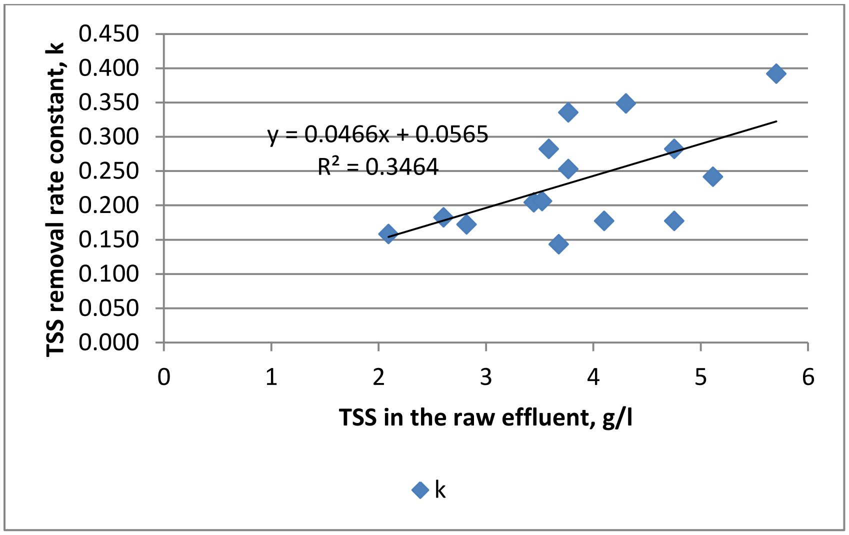

Figure 4.10: Variation of k with TSS in the raw effluent.

Table 4.6 shows the TSS and pH in the raw and treated effluent for various samples and the time taken transform the effluent as such. According to the results given in Table 4.6, the full treatment of the effluent took 4 to 12 days which was too long. That was because of the generation of the effluent at 24 hour intervals which implied that the effluent discharges on the next 2 days after the 1st discharge would find the treatment equipment still not ready to receive more. Otherwise, the pH changed from 4.25 - 6.44 to 3.12-4.01 g/l. However, the solids removal of between 53.831% and 97.305% indicated that the treatment was very effective.

Table 4.6: TSS and pH in the raw and treated effluent and retention time.

Initial solids and pH		Time taken	Final solids and pH		SR%
TSS_i	pH_i	Days	TSS_f	pH_f	
1.026	4.25	5	0.350	3.92	65.887
2.605	4.29	8	0.076	3.50	97.083
2.820	5.80	8	0.076	3.50	97.305
3.446	6.30	5	1.371	3.26	60.215
3.524	4.55	5	1.627	3.12	53.831
3.769	6.28	4	0.812	3.59	78.456
4.101	6.37	5	1.798	3.20	56.157
4.756	6.44	3	0.981	3.39	79.373
5.021	4.93	9	1.216	3.15	75.782
5.705	6.43	4	0.812	3.59	85.767
6.136	6.14	12	1.380	4.01	77.510

Key: TSS_i / Ph_i and TSSf / pH_f are the TSS and pH in the raw and treated effluent respectively. SR Solids removal

Further to the results given in Table 4.6 plots of the initial and final TSS in the effluent together with the time taken to lower the concentration of the TSS in the effluent as such were as shown in Fig. 4.11. It was observed that, the time taken to remove the TSS from the effluent was not related to the starting TSS concentration. However, except in two cases when the time increased significantly with increase in initial TSS, the rest of the trend was a decrease in time up to slightly over 3 g/l of TSS after which the time taken remained relatively constant.

As for the TSS the final values bore not proportionality to the initial TSS. Instead, some initial factors inherent to the effluent like sugars, extent of coffee ripening among others could have been responsible for such an anomaly. At the same time, the condition of the ripe cherry changes continuously from the beginning to the end of the harvesting season.

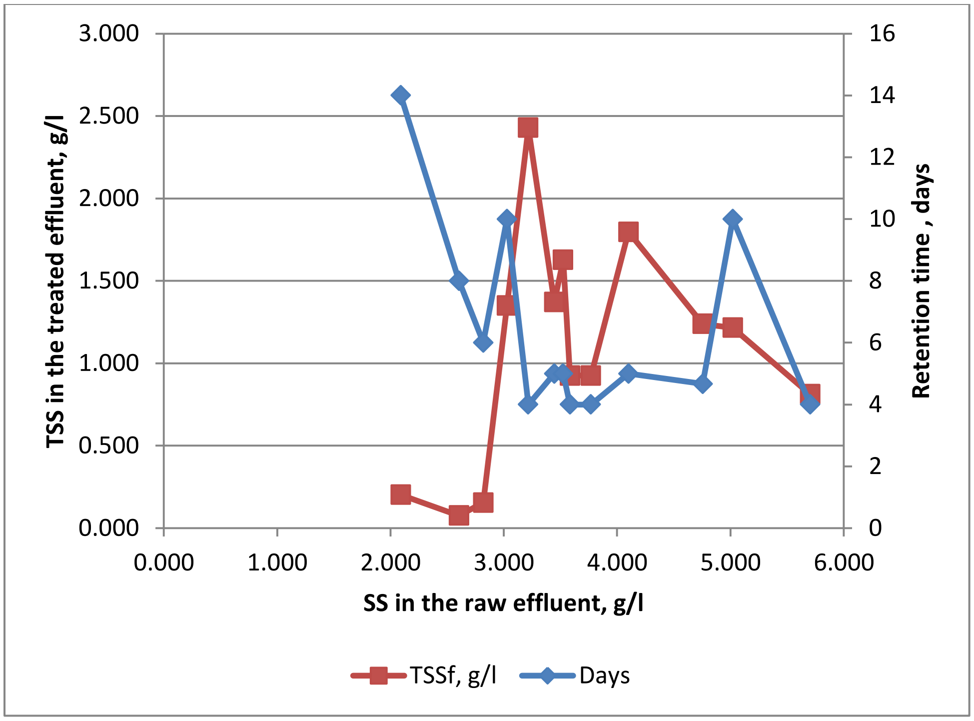

Figure 4.11: The TSS in the treated effluent and retention time for raw effluent with different TSS.

Generally, over ripe coffee cherry for instance normally starts fermenting before they are picked from the tree already. Failure to sort out the over ripe cherry prior to pulping could hence affect the solids removal process. Besides that, differences in sugar concentration would have induced even more variance in the TSS. Such factors among others could have served to distort any likely relationship between the TSS in the raw and treated effluent.

The pH of the raw effluent was found rather inconsistent (Table 4.6) and varied between 4 and 6.5 (Fig. 4.12). But after treatment the pH, of the effluent fell to between 3 and 4. Therefore, the pH of 2.5 in the raw effluent was limited to 1 after treatment of the effluent which could then be taken as an indicator of stabilization. At the same time, the pH decreased gradually to a minimum as the TSS in the raw effluent increased from 1 g/l to 3.5 g/l but then started increasing from 5 g/l. All the same, the variation of TSS in the treated was only between 3 and 4 and hence less than for the raw effluent.

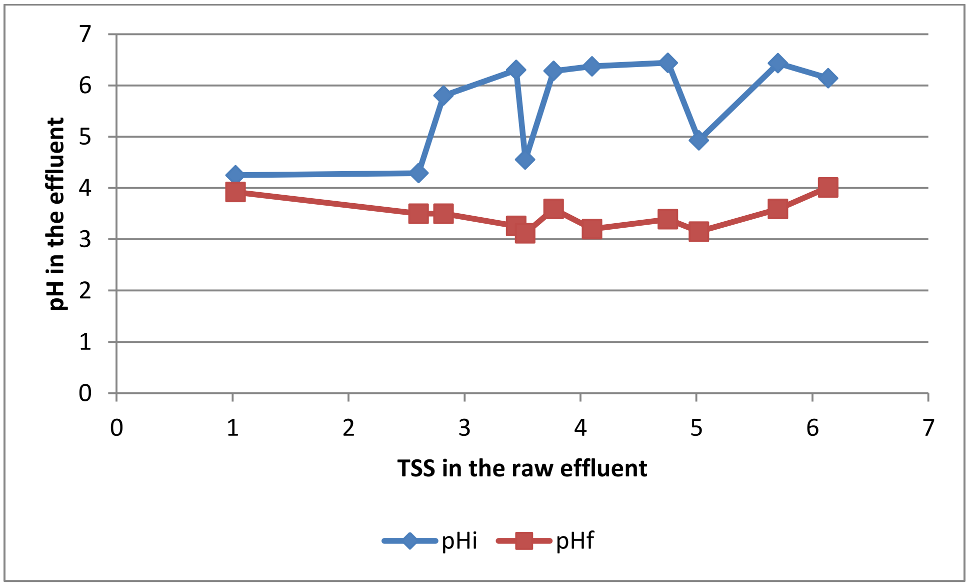

Figure 4.12: The pH in the raw and treated effluent

4.2.2 TSS removal from the coffee processing effluent using lime.

The solids balance in the effluent after treatment

When treating the pulping effluent with lime at a general rate of 1.5 g/l irrespective of the initial TSS content, the representative trends of solids and pH in the effluent against time were as shown in Fig. 4.13. According to these results, the TSS profile could be described to conform to two sections, the first of which extended to the 6^{th} day and the 2^{nd} on from there to the 15^{th} day. As indicated the TSS in the effluent decreased at a diminishing rate for about 6 days. Immediately thereafter the effluent reached a state of instability.

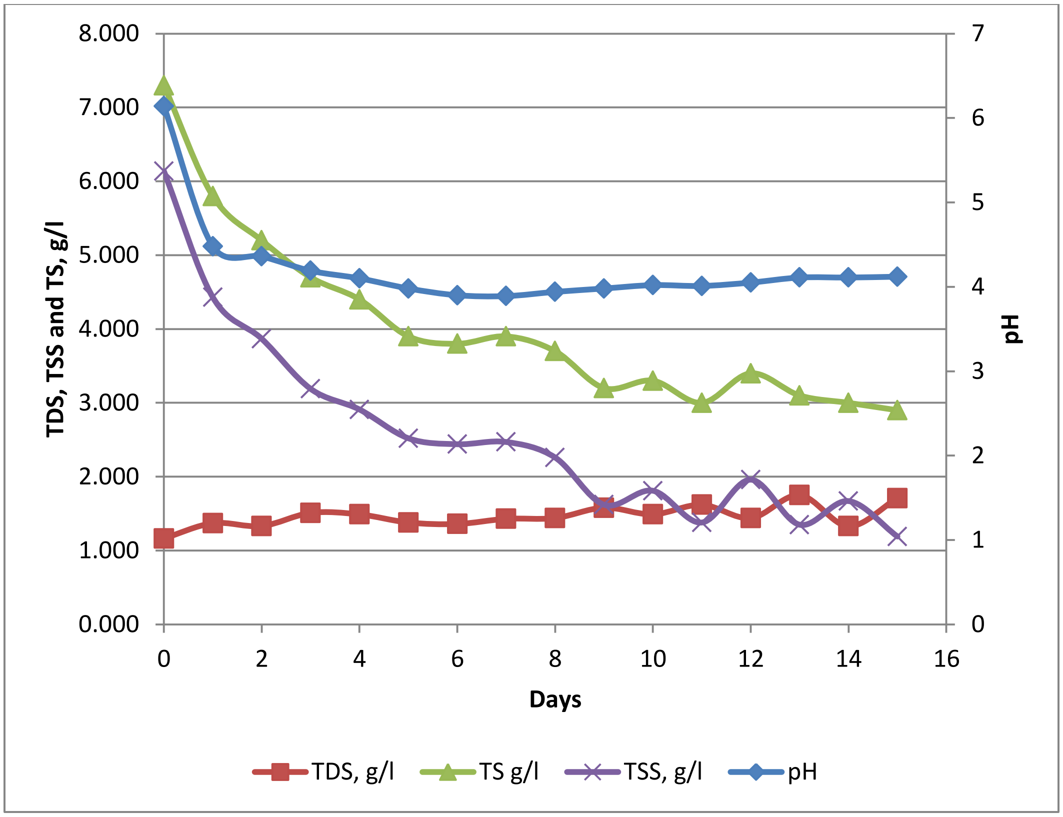

Figure 4.13: The solids and pH in the pulping effluent treated with lime.

During the 2nd section, the TSS tended to vary more against time than prior to the 6th day. The TSS trend also a slow and unpredictable transformation sometimes even increasing unexpectedly.

It could also be inferred from these results that between the 9th to the 15th day; the recorded TSS in the effluent fluctuated such that it appeared as if some solids were returning back to the effluent and removed on alternate consecutive days. Just like for the natural process, such inconsistences could be attributed to the return of some solids back to the liquid phase from the settled sludge phase. Fig 4.13 also shows that TSS in the effluent decreased steadily from 6 to 2.5 g/l within 6 days from the day of pulping. After that the process stalled for a day before advancing further until the 9th day from when TSS removal process slowed down greatly. That was so such that by the 11th day, the rate of solids removal had even diminished almost to zero. For that reason, the process could have been considered completed on 9th day when TSS in the effluent was 1.5 g/l. Compared to the 1st section in which 3.5 g/l of TSS left the effluent, the 2nd section accounted for decrease of only about 1.3 g/l of TSS in 9 days. Considering the pH profile in the effluent Fig 4.13 shows that it decreased from 7 to about 4 by the 7th day when the TSS level was 2 g/l after which about 0.5 g/l were removed by the 9th day. Therefore, stagnation of pH drop at 4 sort of signified the end of the process and any further removal between then and the 9th day was a consequence of lag in response time of the process to the changes in pH.

The main objective ought to establish whether treatment of the effluent with lime posted a significant performance and in particular a hydraulic retention time compatible with the effluent issuance protocol from a primary processing factory. Ideally, the treatment capacity would then sort of tend to tally with the rate of the effluent production from the coffee processing system. However, since the treatment with lime generally took 9 – 11 days, it was then not a better option than the natural settlement. Instead the only benefits would simply accrue from enriching the sludge with lime to enhance its usage in agriculture. For that reason, the natural TSS settlement process can be supplemented with lime based treatment to add value to the sludge and the clarified effluent.

Expression of TSS as function of time

In order to develop a function to describe the trend of removal of TSS (r_{TSS}) from the effluent shown in Fig. 4.13 as a function of time the settlement of solids was assumed to constitute a first order reaction i.e. Reactant (A) $\rightarrow$ product. As such a function was established by postulating a rate expression and applying it to a batch reactor mass balance equation as follows.

$$\frac{d(TSS)}{dt} = f(TSS)$$

This function was integrated following the same procedure which was applied in section 4.2.1. The result was the following linear expression (Equation 4.7) which was similar to equation 4.5.

$$Ln(TSS) - \ln(TSS_o) = -kt \qquad (4.7)$$

Therefore,

$$TSS = TSS_o e^{-kt}. \qquad (4.8)$$

Where:

TSS The total suspended solids in the effluent any time after treatment

TSS_o The total suspended solids in the raw effluent

K Solids precipitation rate constant

t time in hours from the beginning of solids precipitation.

To verify whether such a linear relationship applied to the removal process of TSS from the effluent treated with lime, Ln (TSS) was plotted against time (t) (Fig. 4.14). The results indicate that, the ploted data tended to fit quite well to a regression line of ln(TSS) on t except $\ln(TS_0)$. That apparently seemed to imply that, the reaction for the first day was very abruptly right from the beginning but slowed down rather abruply by the 2^{nd} day and remained consistent to the end of solids removal. In essence there was some rather active ingredient in the raw effluent which were exhausted after only 1 day.

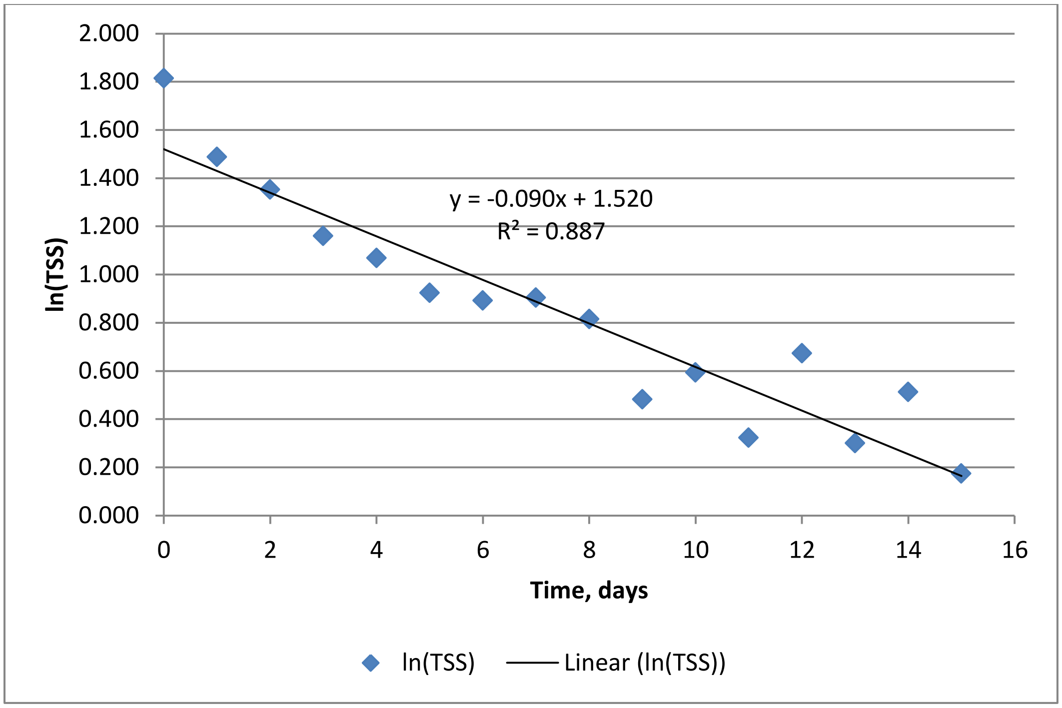

Figure 4.14: Regression of ln(TSS) on retention time (0 to 15 days) for lime treated pulping effluent.

That refleted well to the presence of sugar and other rapidly degrading biological matter to which the rapid reaction can be attributed. Since the available amounts are just enough to sustain the relevant rection for one day, that perhaps can be the cause of the observed difference. Further that was a common characteristic of all the conducted experiments using stand alone effluent or effluent with lime.

For that reason, $\ln(TSS_0)$ was omited as shown in (Fig. 4.15) though that did not change the coffeficient of corretion 0.887. However, the next suspect cause for any likely error in deriving the envisaged relation could lie in the range of the treatment period.

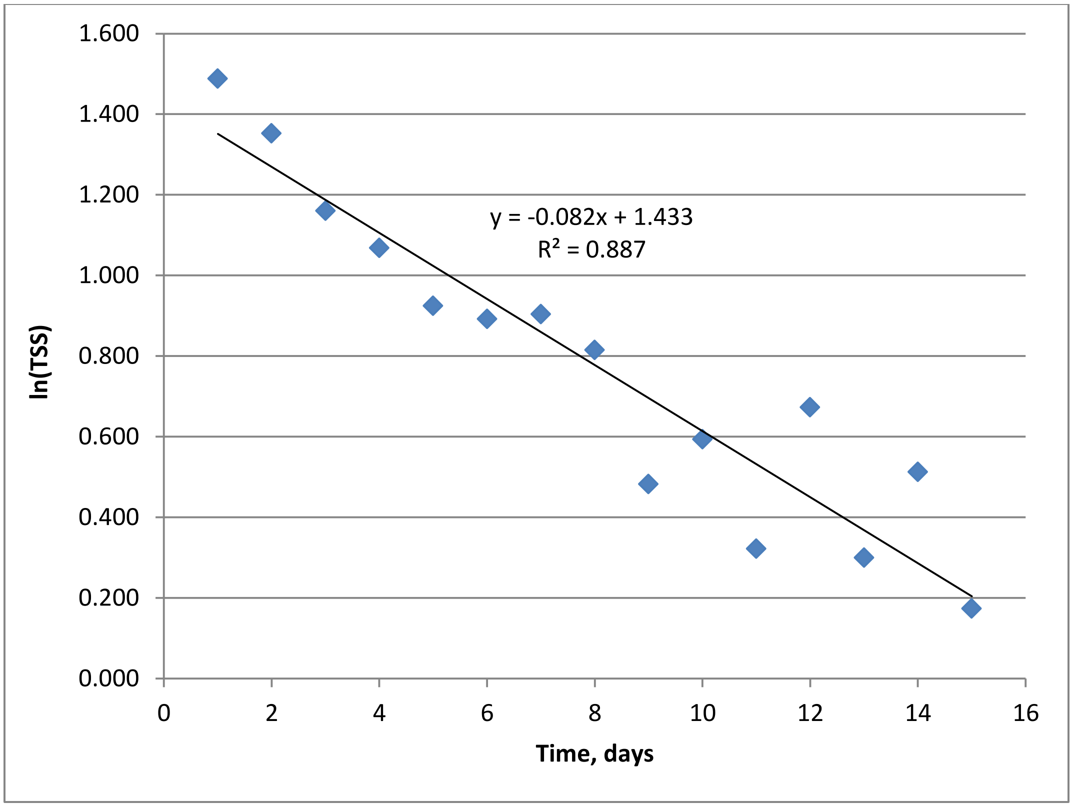

Figure 4.15: Regression of ln(TSS) on retention time (1 to 15 days) for line treated pulping effluent.

As was the trend with the solids removal profile, the end of the process was anticipated after all the settleable matter was exhausted by the degradation process. That could be easily approximated by inference (Fig. 4.13) to be from the 9th to 12th day from the beginning.

As such, the next test involved limiting the data to between day zero and the 11th day (Fig. 4.16). By so doing, there was a large improvement in the R^2 from 0.887 to 0.938. That signified that, the reaction had more or less come to an end by the 11th day.

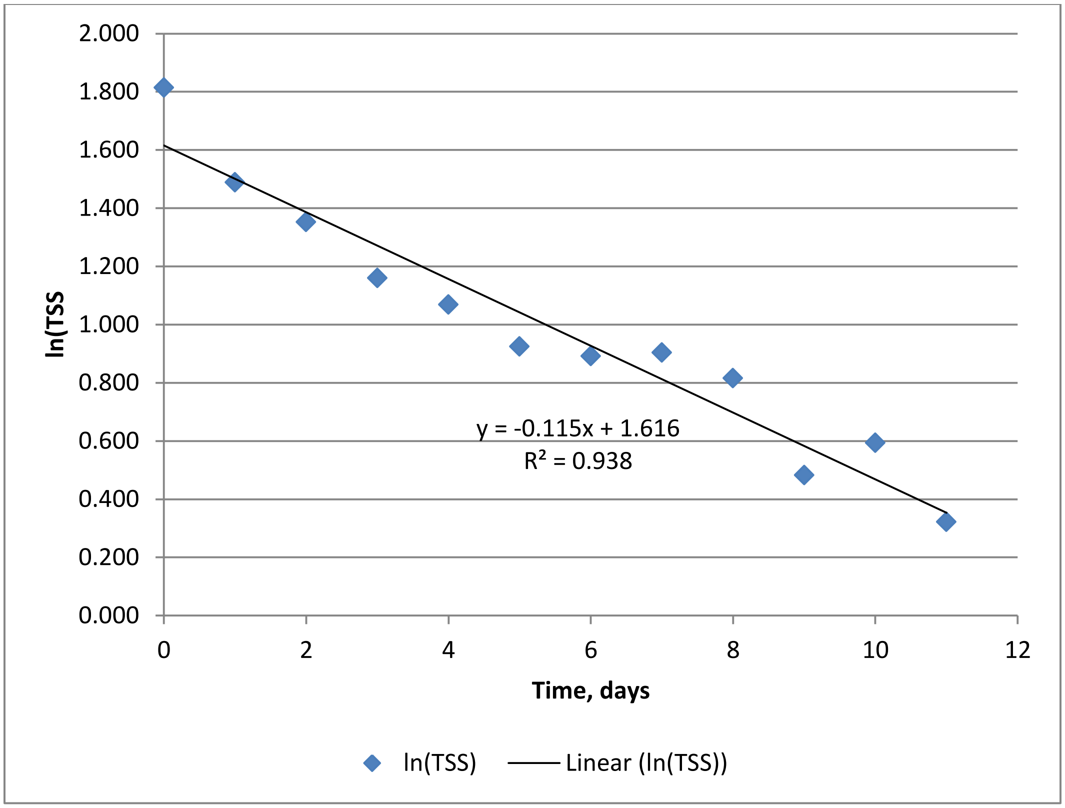

Figure 4.16: Regression of ln(TSS) on retention time (1 to 11 days) for line treated pulping effluent.

That could possibly explain why the data beyond that day was not consistent with the rest. It also indicated that, inclusion of any post reaction data introduced a bigger error than including that from the raw effluent immediately after treatment. All the same, it was deemed necessary to evaluate whether there was any more improvement in correlation by omitting the lower and the upper limits of the range.

Fig. 4.17 shows the regression of t on ln(TSS) for the data ranging from day1 to day 11. It can be seen that omission of day 0 and any other data collected after the 11^{th} day improved the fitting just slightly from R^2=0.938 to R^2 = 0.945 i.e. by a margin of 0.007.

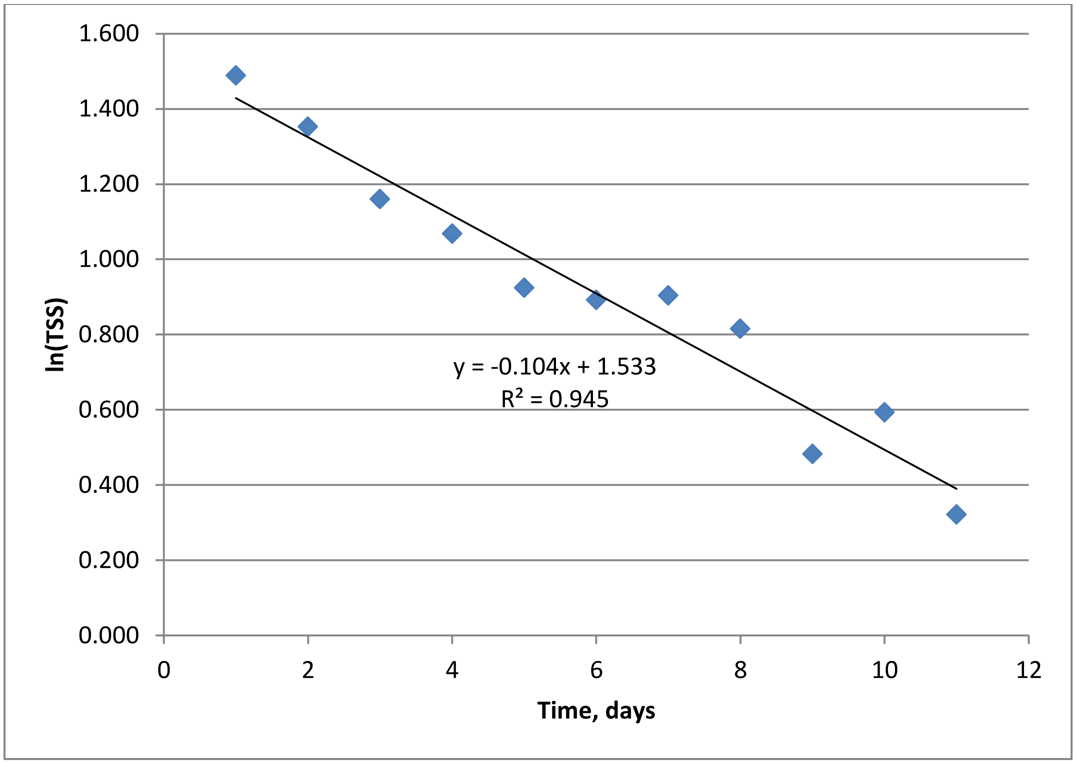

Figure 4.17: Regression of ln(TSS) on retention time (1 to 11 days) for lime treated pulping effluent.

That was not a significant difference which therefore means that the derived expression could be safely applied within the entire range of the suspended solids precipitation process. At the same time, it was also proved how critical it was to identify the end of the process to ensure that post reaction data was not considered. That was perhaps why omission of the data recorded from 11th to 15th day significantly improved the correlation coefficient for the remaining data. Therefore, it could be safely assumed that the practical process time in this case was 11 days within which the TSS in the effluent dropped from 6.0 to 1.5 g/l after which further TSS removal was not significant at all.

The regression lines in Fig. 4.18 and 4.19 demonstrates further how different the solids removal process was on the first day from the rest of the retention time.

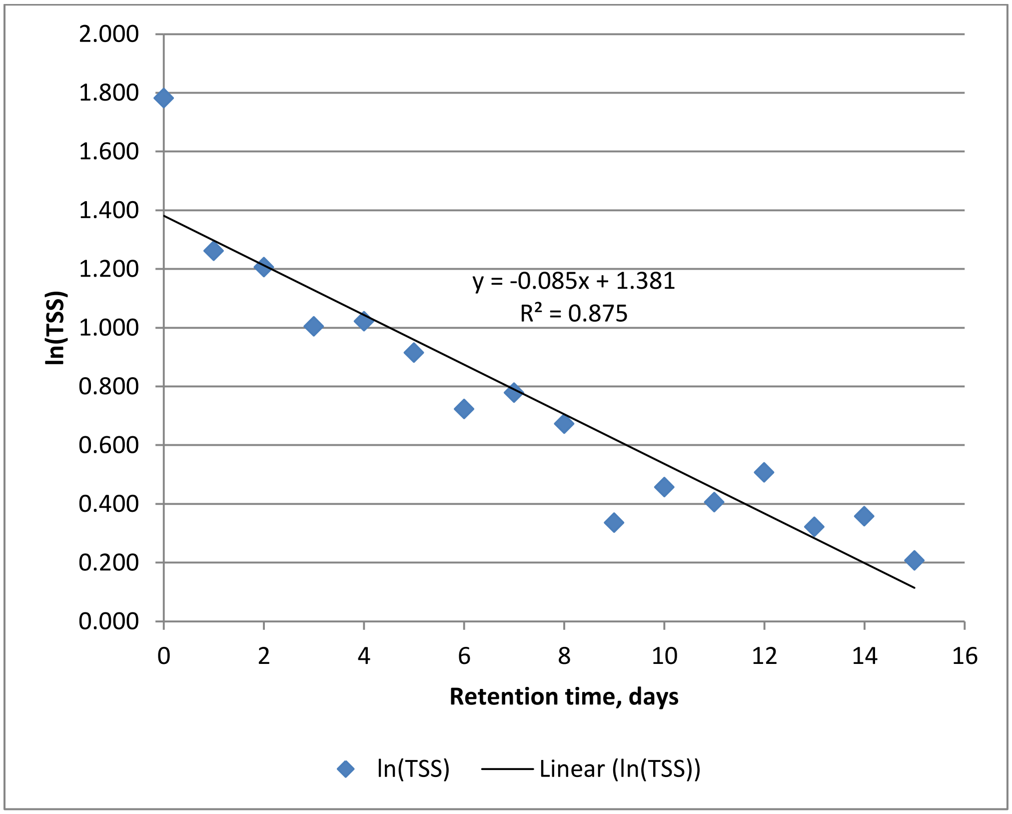

Figure 4.18: Regression of ln(TSS) on retention time (0 to 15 days) for lime treated pulping effluent.

As indicated in Fig. 4.18 all the data from the beginning of the treatment to the end were less correlated ($r^2 = 0.875$) than after isolating the initial (day 0 - 1) data from the rest of the data ($r^2 = 0.954$) as shown in Fig. 4.19. Such differences arose from the rapid initial solids removal which lasted for 1 day following treatment despite there being a very short reaction time lag immediately after treatment. Thereafter, the reaction slowed down gradually perhaps in response to diminishing active ingredient in the effluent with time.

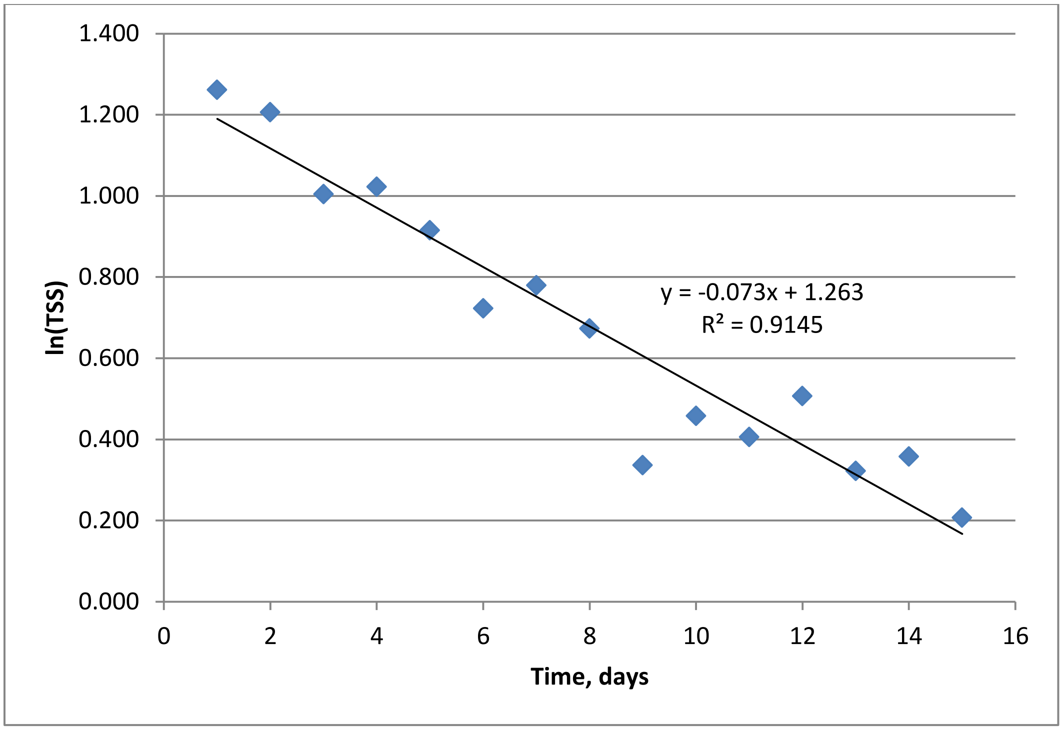

Figure 4.19: Regression of ln(TSS) on retention time after modifying Fig. by excluding day 0.

Finally as was common in these cases, there was a tendency of scattering of the data after the 9th day after treatment. That more or less confirmed that it was not viable to extend the treatment process beyond the 9th day.

The initial concentrations of total solids in the effluent were plotted against the reaction constant k (Fig. 4.20) from various experiments. The result was a scatter diagram in which the correlation between the initial TSS and k was r^2=0.208. That signified that the two parameters were poorly related despite there being a slight tendency of k to generally increase with increasing TSS. The implication of that was such that the higher the initial concentration of solids in the effluent, the higher the solids removal rate by lime. The variation in solids removal rate was hence not likely to be significant as inferred from the small variation in k.

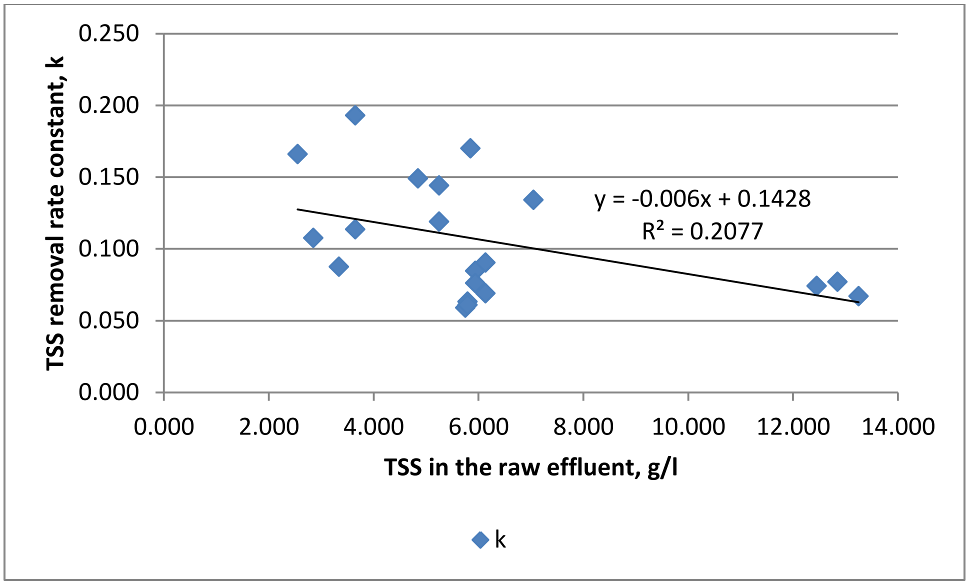

Figure 4.20: The initial TSS in the effluent versus the rate constant k.

Regarding the efficacy of treatment of pulping effluent with lime, Table 4.7 shows the TSS of the raw (TSS_r) and treated effluent.

Table 4.7: The TSS in raw and treated and the respective retention times.

TSS_r	TSS_p	Rt_p, days	TSS_f	Rt_f, Days
2.850	1.830	1	0.480	6
2.850	0.970	4	0.970	4
3.000	1.676	2	0.570	5
3.340	1.970	4	1.340	5
3.650	2.000	2	0.600	5
5.793	1.810	8	2.170	6
5.940	1.960	8	2.060	6
6.136	1.620	9	2.520	5
6.650	2.005	2	0.600	5
6.674	2.070	9	2.950	4

Key
Rt_p : Time taken to Reduce TSS_r to TSS_p
Rt_f : Time taken to Reduce TSS_r to TSS_f

The given TSS values in Table 4.7 were to the extent of satisfying the seepage requirements (TSS_p) and to also the derived equation's application range (TSS_f). As indicated, the TSS in the effluent took between 4 to 6 days to decrease to an equilibrium status such that no more significant removal occurred. However, considering the time taken to lower the TSS of the effluent to ≤ 2 gm which was considered practically acceptable for its easy disposal via seepage into the ground, 2 to 9 days were required for that purpose. However, there existed great variation in retention times in each case which once again could be attributed to factors inherent to the effluent.

Fig. 4.21 shows the TSS in the treated effluent, corresponding solids removal efficiency % and the retention time plotted against the TSS in the raw effluent.

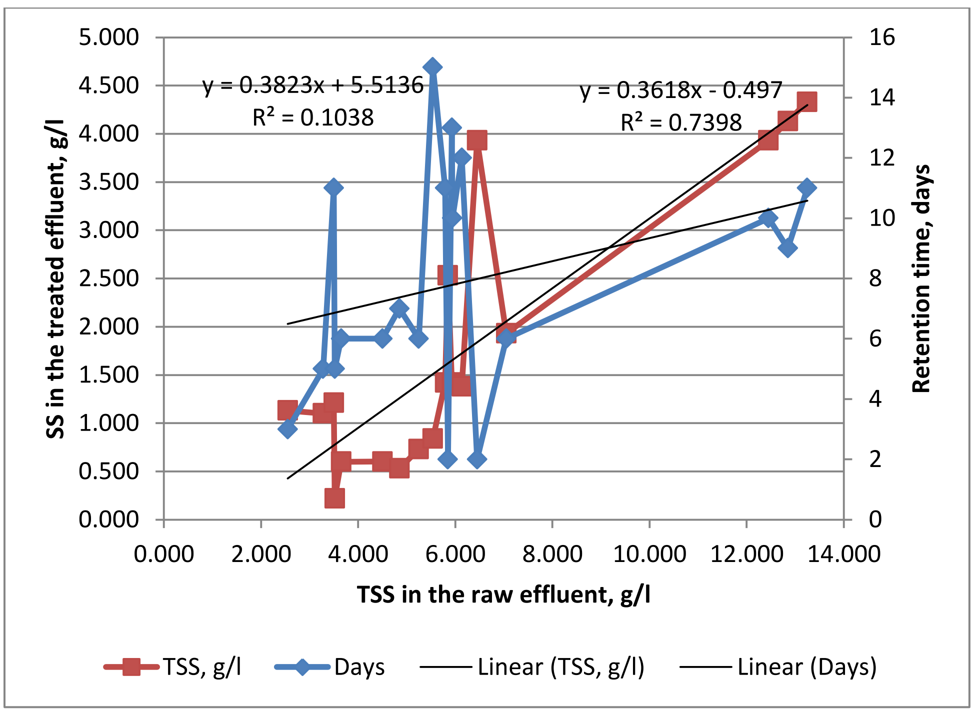

Figure 4.21: Effect of the TSS in the raw to the TSS in the treated effluent and the resident time for complete removal of the TSS.

As for the residue TSS in the effluent after treatment, there existed a general tendency for it to increase as the TSS in the raw effluent increased. That was further confirmed by a regression line through the data which showed that there was a positive correlation of r^2=0.740 between the initial and the residues TSS. That could have been due to the rather consistent removal of solids from the effluent by calcium at an average of 59% of the original concentration. While that was so, there was very poor correlation (r^2=0.104) between the TSS in the raw effluent and required retention time to effectively treat the effluent to the desired level of TSS. That implied that the TSS removal rate of processes in the different effluent samples were as diverse and unpredictable as the recorded retention times. That could have been attributed to differences in the original biological/chemical status of the effluent. As is commonly the case, the conditions of the processed cherry were generally diverse particularly with respect to the degree of ripeness. Noting that internal fermentation starts as cherry tends to over ripen, the natural sedimentation process in each effluent would have advanced to different extents by the time of treatment with calcium. Such a phenomenon could have distorted the effect of the chemical treatment.

pH of the raw and treated effluent

The pH of the raw effluent whose TSS ranged from about 3.5 to 6.5 varied between about 5 and 7 (Fig. 4.22). However, after treatment with $Ca(OH)_2$ pH of the fully treated effluent varied even more widely from 4 to 12 regardless of corresponding ph in the raw effluent.

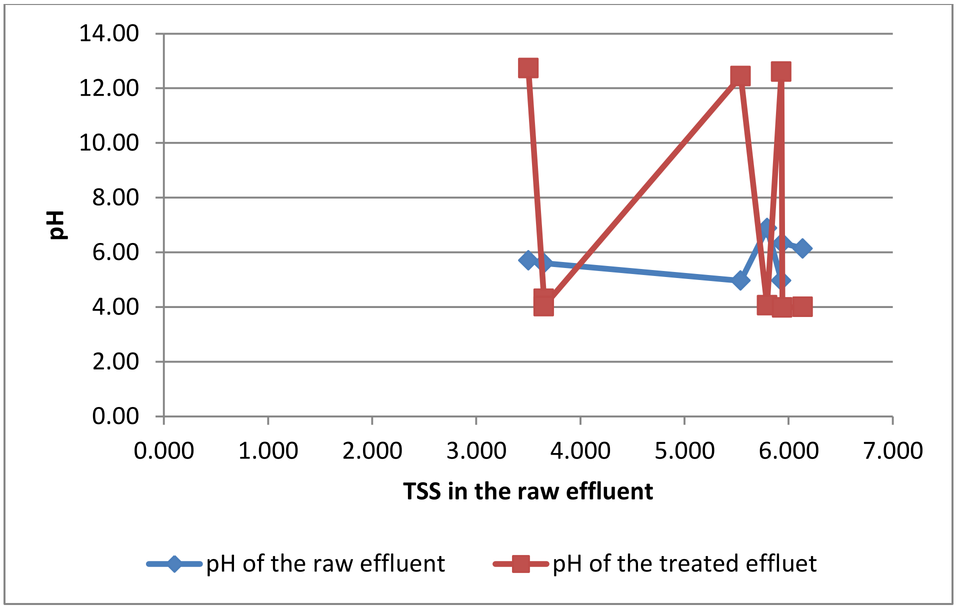

Figure 4.22: pH in the raw and treated effluent for different TSS.

That could be possibly attributed to variation in levels of other substances inherent in the effluent (e.g. sugar) and particularly those responsible for the degradation of the of the effluent besides the influence of $Ca(OH)_2$. These findings imply that $Ca(OH)_2$ is not alone in action on the effluent. Instead, the natural biodegradation of the effluent seems have been active as a complementary process to that of $Ca(OH)_2$.

Effect of pH on sedimentation of TSS from the effluent.

The profiles of pH of similar effluent treated with $Ca(OH)_2$ and lime against time respectively were as shown in Fig. 4.23. Treatment with $Ca(OH)_2$ elevated the pH to between 12 and 13 which thereafter decreased very gradually against time to less than 12 even after 15 days. As for lime the initial pH of the treated effluent was about 7 but dropped to 4 within 3 days and stagnated at that level for the rest of the treatment duration. These results implied that $Ca(OH)_2$ had a strong buffer capacity than lime against the acidity of the effluent.

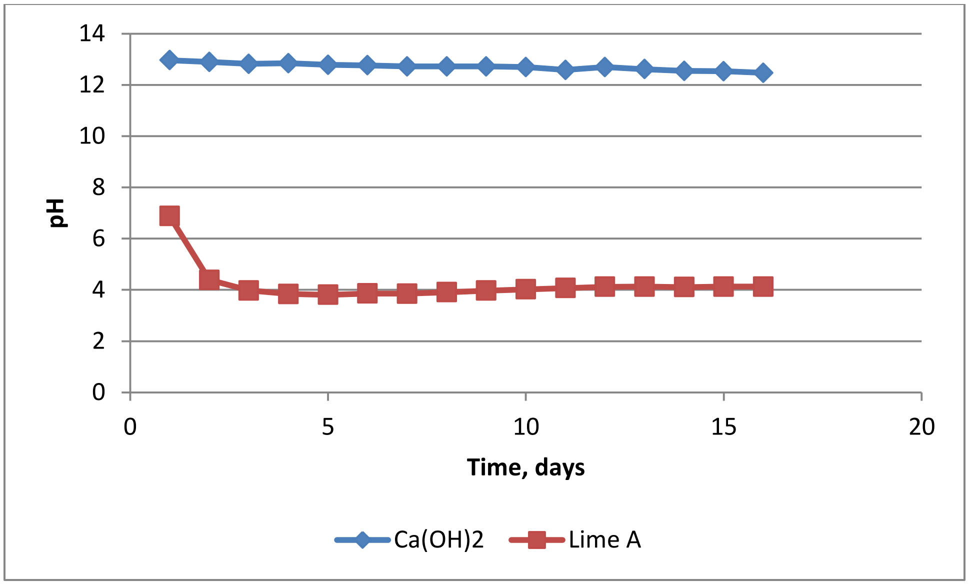

Figure 4.23: The pH of the effluent after application of Ca OH)$_2$ and lime

Treatment of the effluent with Calcium hydroxide

Some preliminary trials found TSS to precipitate out of the effluent rather so dynamically after being treated with $Ca(OH)_2$ that the migration was visible to the naked eye. For that reason, measurement of the volume of the sediment was preferred for assessing such a rapid removal of TSS from the effluent because the sampling and analysis steps involved in the conventional standard method for TSS determination could not cope with such a fast transformation. That was done on assumption that the quantity of the sludge formed was a reflection of the TSS removed from the treated effluent. It was also perceived as a rather straight forward method since the settlement values were measured and read off from the scale of a graduated measuring cylinder. This method was however not as accurate as the precise and direct measurement of TSS in the effluent using sensitive instruments.

After applying lime at different rates to 5 separate samples of pulping effluent in measuring cylinders, the trends of sludge settlement from the effluent against time were as shown in Fig. 4.24. The TSS precipitation curves demonstrate that that except for control (0 g/l) and the 1.0 g/l rates, the solids removed by the others by the end of treatment was within a very close range. According to these results, treatment of the pulping effluent with Lime at the rate of 2.0 g/l was as effective as for the 3 and 4 g/l rates.

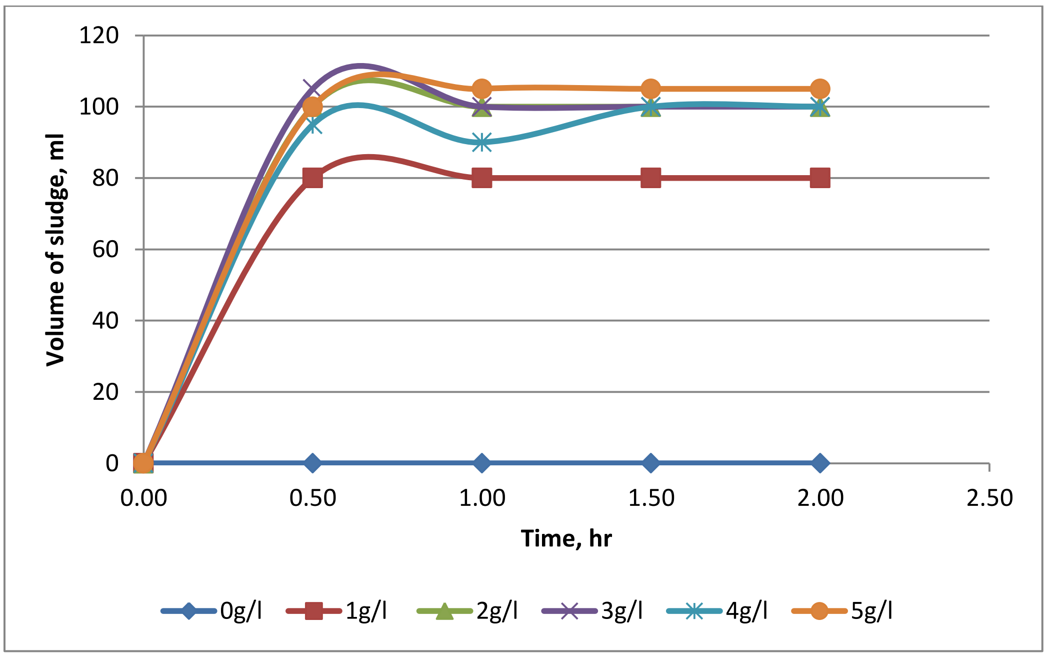

Figure 4.24: TSS removed from the pulping effluent treated with of Ca(OH)2 at different rates.

The performance of the 5 g/l rate was just slightly better than the 2, 3 and 4 g/l rates. As such the 2 g/l application rate was hence considered as the optimum dosage for the general effluent while preliminary evaluations found 1.0 g/l quite effective for the Intermediate effluent as long as it was not too concentrated as it quite often was.

Further, compared to the other treatment rates, 3.0 g $Ca(OH)_2$ reacted immediately on fresh pulping effluent but took some time to settle solids out of the fermented pulping effluent. Other results showed that about 30 minutes after treatment, the effluent with more than 1 g/l $Ca(OH)_2$ became clear while that with 1g did not show any clarity until after 3 hours when it started clearing slightly. The treatment of the effluent with $Ca(OH)_2$ at 3.0 g/l, was the fastest and 1g/l least effective. In the following morning after treatment, only the untreated effluent was still not clear while by the 2nd day, there was no further settling even in the slowest treatment. Besides that, the formation of sludge and scum was erratic and temporary due to migration of some portions from either phase to the other. On the other hand, the 2 day old pulping effluent responded rather slowly to $Ca(OH)_2$ at 3.0 g/l whereas, the 3 day effluent did not clear even after two hours. Besides, solids settled loosely at the bottom of the 3.0 g/l $Ca(OH)_2$ treatment.

The status of effluent after being left overnight after treatment with $Ca(OH)_2$ was as shown in plate 4.2. On the following morning, the effluent treated with 2 and 3 g/l had separated into a relatively clear but yellowish effluent and a sediment phase. At the same time the effluent treated with lime at the rate of 1 g/l and the control had not changed at all. These results implied that the optimum dosage of lime to the effluent was possibly between 1 and 2 g/l. That was the commonly the case with all the effluent treated with lime regardless of the initial concentration of the TSS in each sample of effluent.

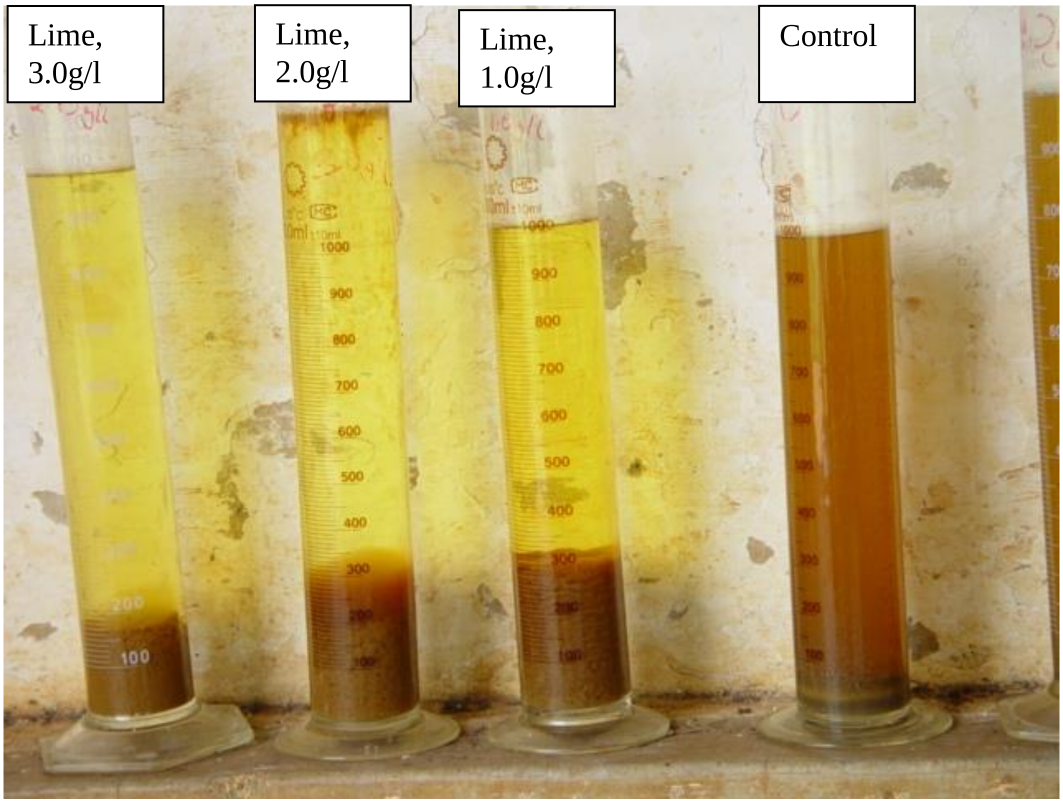

Plate 4.2: Removal of TSS from the pulping effluent using lime.

Fig. 4.25 traces how the sludge of suspended solids increased at the expense of the treated phase of the pulping effluent. That was why the trend curve for the precipitation of TSS from the effluent increased at a decreasing rate until no more change was observed signifying the end of the treatment process. It was also found that unlike for lime, TSS started settling rapidly from the pulping effluent immediately after applying $Ca(OH)_2$. Further to that most of the suspended solids were settled out of the effluent within 6 hours with very little more settling from then to 18 hours later. The cause of that was the elevated pH which provided an optimal pH range for biodegradation of the effluent by diverse microbial populations (Zuluaga et al., 1987 and Michael et al., 2012) which led to accelerated precipitation of the TSS.

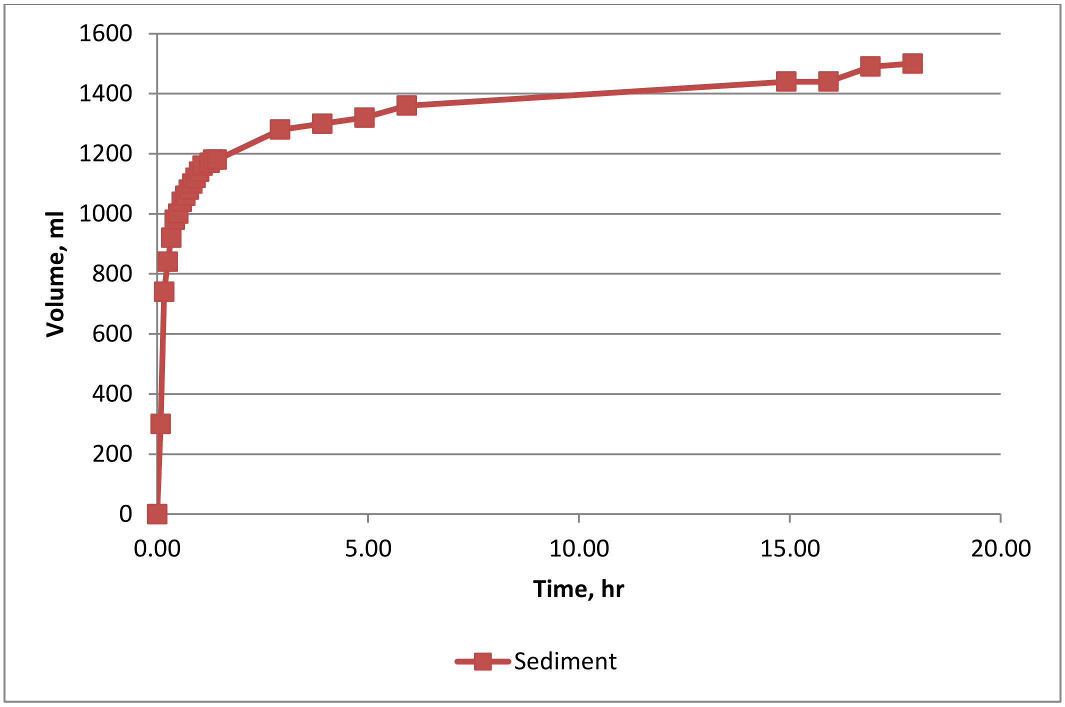

Figure 4.25: TSS settlement from the pulping affluent treated with Ca(OH)2 (anlar).

Hence the difference in performance between the effluent treated with lime and $Ca(OH)_2$. Another remarkable finding was that by the 6^{th} hour after treatment, the sludge occupied about 1350 ml out of the starting 2000 ml of effluent. However, that could not be taken as the actual amount of the settled sludge since the sediment was rather fluffy but consolidated to smaller volumes given time. All the same the results gave a clear indication of the settlement trend of the suspended solids from the effluent after treatment with $Ca(OH)_2$ anlar.

4.2.3 Treatment of pulping effluent with Moringa Oleifera

The pulping effluent samples which were treated with Moringa Oleifera at different rates were clarified to the extent shown in plate 4.3 after 24 hours. The TSS which was removed from the effluent was deposited at the bottom except for the control sample without moringa treatment.

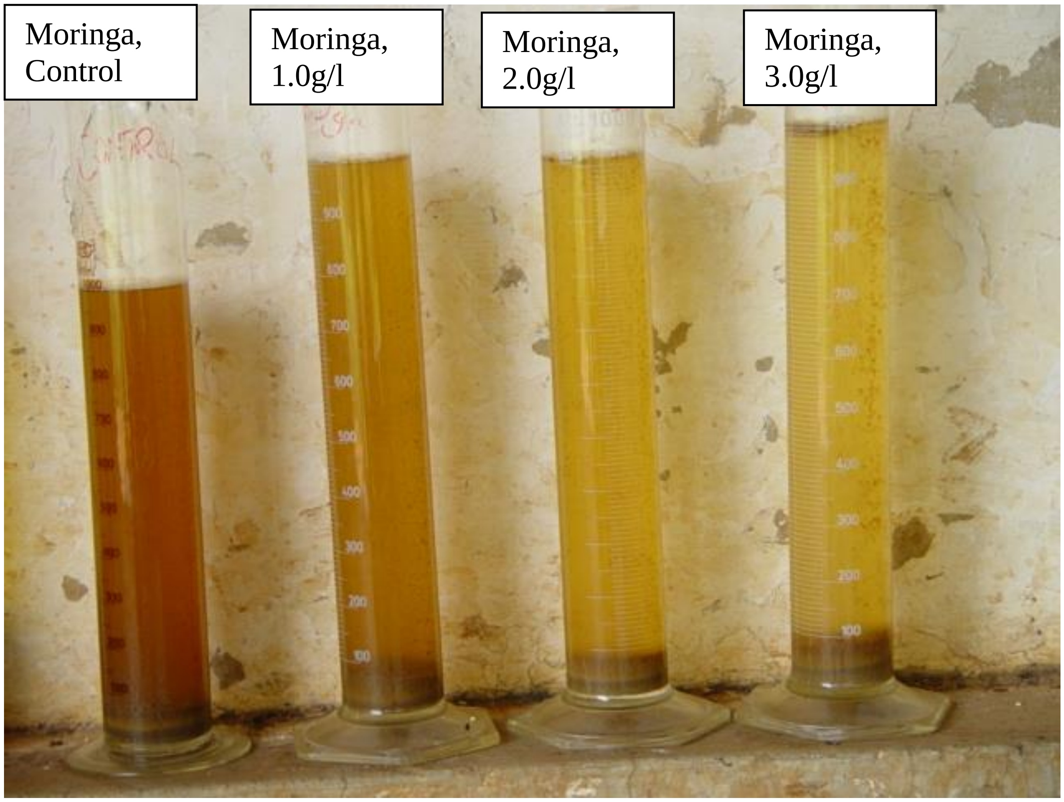

Plate 4.3: Pulping effluent treated with moringa Oleifera and a control.

It was also found that there were no advance signs of response by the effluent to the treatment until just close to 24 hours when the TSS settled to the bottom of the effluent instantaneously. There was also just a slight clarity of the effluent treated with 1.0 g/l compared to the control. However, the 2.0 and 3.0 g/l rates clarified the effluent more or less equally and significantly compared to the control. Therefore, the optimum application could lie between 1.0 and 2.0 g/l. Further to that, comparison between the performance of moringa and lime (Plate 4.4) demonstrated the superiority of the later with respect to effluent treatment.

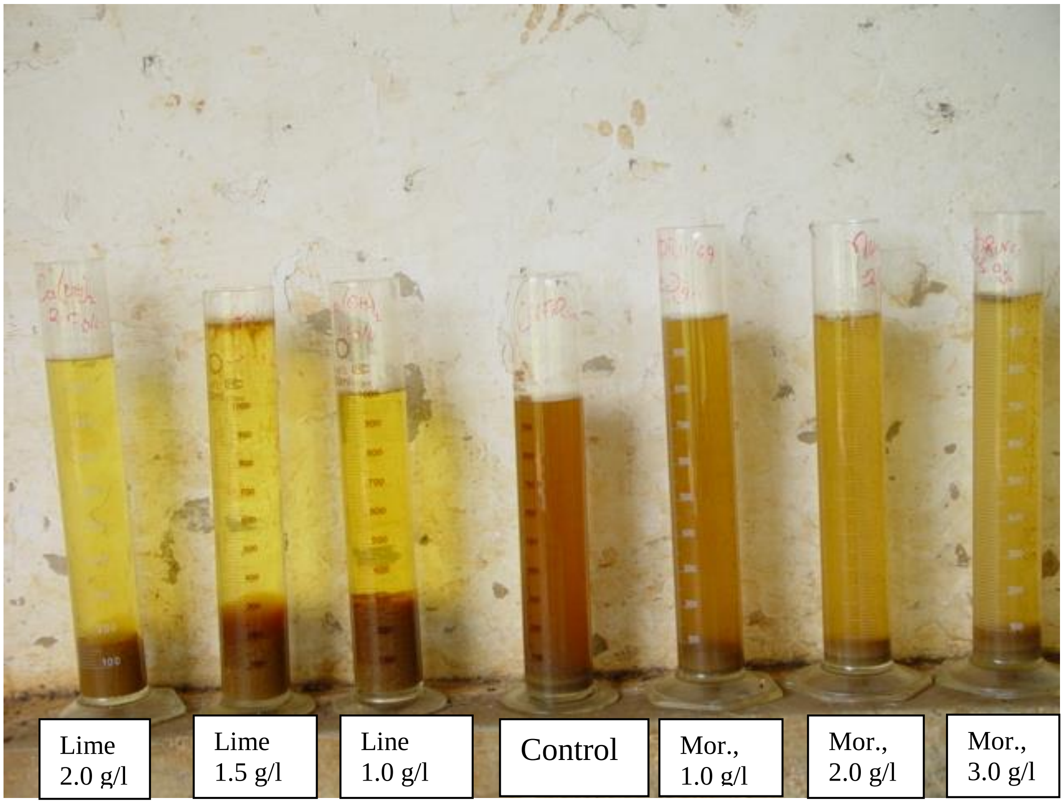

Plate 4.4 : Moringa oleifera and lime treated effluent as well as the control.

The results showed that based on equal application rates, lime performed better than moringa Oleifera such that application of lime at 1.0 g/l seemed to suffice while only a minimum of 2.0 g/l of moringa seemed viable. However, it took much longer for lime to act on the effluent than moringa oleifera.

In addition to the visual observations made after treatment of the pulping effluent with moringa oleifera, Fig. 4.26 and 4.27 shows that the solids removal increased though not proportionately to increased treatment rates. That was so such that the maximum solids removal occurred at an application rate of 3.0 beyond which no more suspended solids settled out of the effluent. That was then the optimum for the most effective removal of suspended solids from the effluent. However, such a rate was slightly higher than the 2.0 g/l required for clarification of turbid water using the same flocculant (Price 1985). According to Figs 4.26 and 4.27 application rates of 1.5 and 2.0 g/l lowered the level of suspended solids in the effluent to about 2 g/l respectively. In this case TDS values apparently seemed to decrease possibly because the TDS recorded in the sample treated with 1 g of moringa was erroneously high compared with the rest.

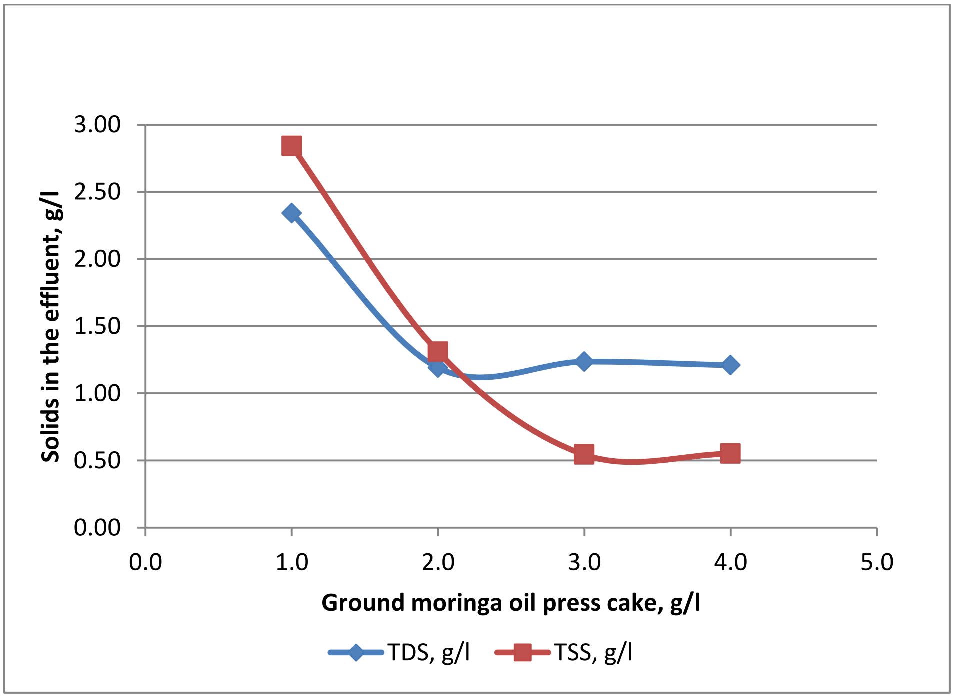

Figure 4.26: The concentration of TSS in the moringa treated effluent.

Such a concentration of TSS in the effluent sufficed towards enhancing seepage of the effluent into the soil. For that reason and as the appearance of effluent confirmed in Plate 4.3 and 4.4, TSS removal using between 1.5 and 2.0 g/l of moringa was considered acceptable for that purpose.

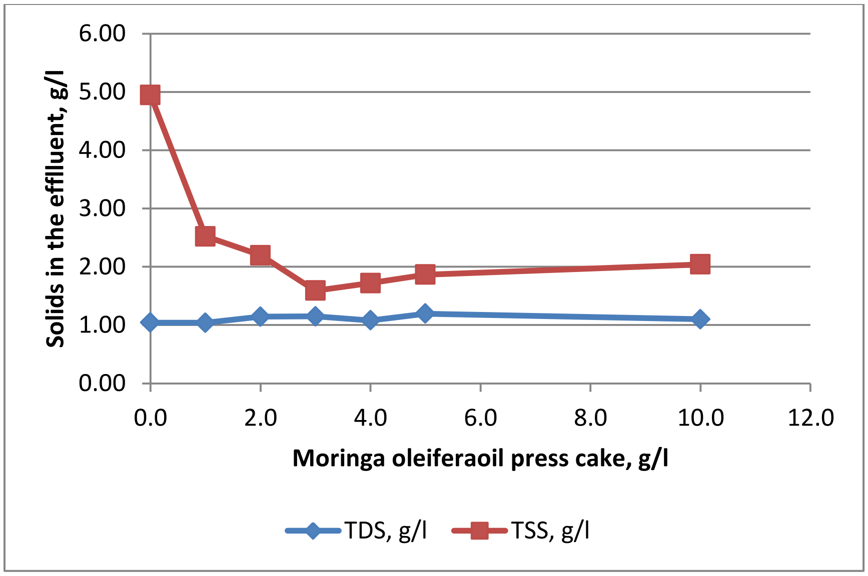

Figure 4.27 : The concentration of TSS in the moringa treated effluent.

Generally, the coffee pulping effluent had varying concentrations of TSS. Due to that, the TSS in the raw effluent and the corresponding treated effluent were compared to establish whether there existed a relationship between them (Fig. 4.28). The results show how the TSS in the effluent varied after treatment with 1.0 g/l as the TSS in the raw effluent increased.

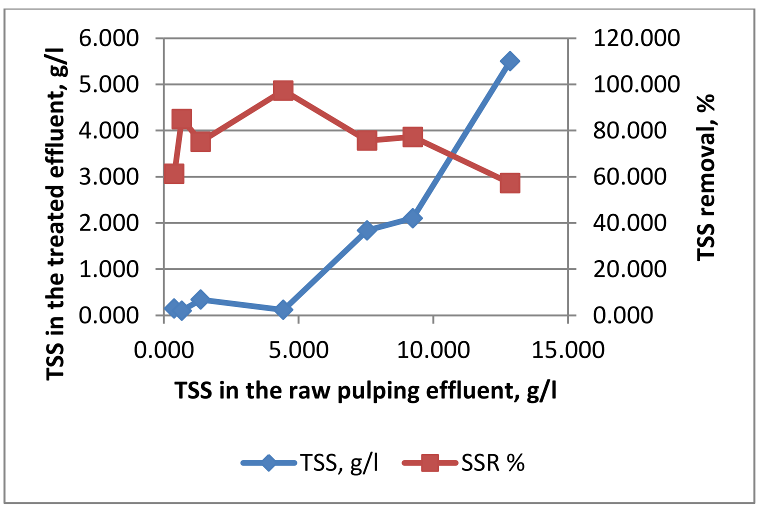

Figure 4.28: TSS removal using moringa at the rate of 1.5 g/l

It was noted that except the raw effluent whose TSS was less than 5 g/l, the TSS in the treated effluent generally tended to increase in response to increasing TSS in the raw effluent. But, the % TSS removal varied mainly between 60 and 80% regardless of the TSS in the raw effluent. These results show as well that treatment with moringa removed the solids from raw effluent with ≤ 10 g/l to mostly less than 2.0 g/l regardless of the initial solids concentration.

The pulping effluent is normally discharged from a primary coffee processing factory mostly late in the afternoon while the output of effluent from washing and grading occurs generally in the morning. An effluent treatment agent like moringa which can effectively treat the effluent batches within 24 hours is then very relevant to such effluent discharge schedule.

Discussion

Although the results show that Moringa oleifera oil press cake can remove suspended solids from the effluent to a level that enhances its seepage compared to the raw effluent it is worth noting that it was most likely complemented by the natural process in which the effluent degrades with the assistance of bacteria, yeast and enzymes. As such, two transforming operatives were likely to have caused that including chemical and a flocculation processes.

These findings on Moringa *oleifera* oil press cake's capability to remove the suspended are of practical importance to the Kenya coffee industry. That is because a treatment cycle of 24 hours would cope effectively with the normal pulping effluent discharges in the afternoon while washing and grading effluents arise in the morning. An effluent treatment system with 2 separate treatment lines would be required. Further to that such an option would be invaluable improvements to the system in which batches of effluent accumulate progressively in a current seepage pits as coffee processing continue.

The economic importance of Moringa oleifera’s oil press cake, is entrenched in the extraction of edible oil from its seeds and suitability of the oil press cake for animal feeding. However, an additional usage of the cake for effluent clarification is likely to broaden its value by diversifying its scope of utilization beyond its current local usage as an animal feed. The cake residues in the resultant liquid and sludge will also enhance their prospects for value addition investigations towards their further economic utilization. That would be expected to cascade the benefits by stimulating increased cultivation of the plant in the country and the accrued enhanced income to the farmers.

4.3 Synchronization of effluent treatment with the coffee processing cycle.

4.3.1 Natural and lime

In view of the recorded performance, a coffee harvesting schedule of 3 times per week, would require 3 pits of adequate daily capacity for receiving the raw effluent separately per day. The effluent would then be ready to exit from each pit to a common pit after a retention time of 3 days (Fig. 4.29) to overflow later to a 2^{nd} common pit if need be. By so doing the first receiving pit would be ready to receive another batch of fresh effluent on the fourth day and other 2 to follow in turn consecutively. Such a set up implies that the first set of pits would serve to settle the TSS while the common one would be for seepage of the partially clarified effluent.

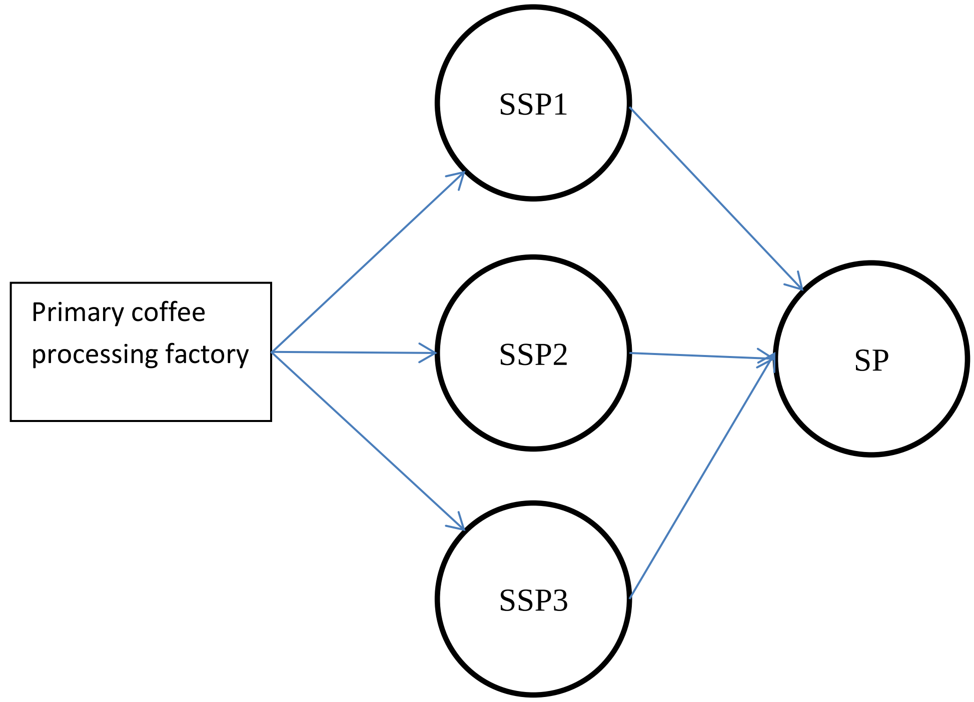

Figure 4.29: Flow of the effluent in parallel sedimentation pits and a common seepage pit

Such a setup is an improvement of some seepage pit system configurations which are practically in use in a few primary coffee processing factories besides the current effluent disposal pits. Alternatives to that configuration lie in a serial pit treatment system (Fig. 4.30) and seepage channels (Fig. 4.31).

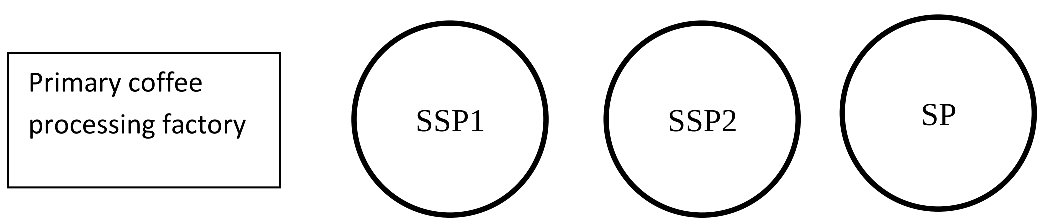

Figure 4.30: Treatment of effluent using serial pits

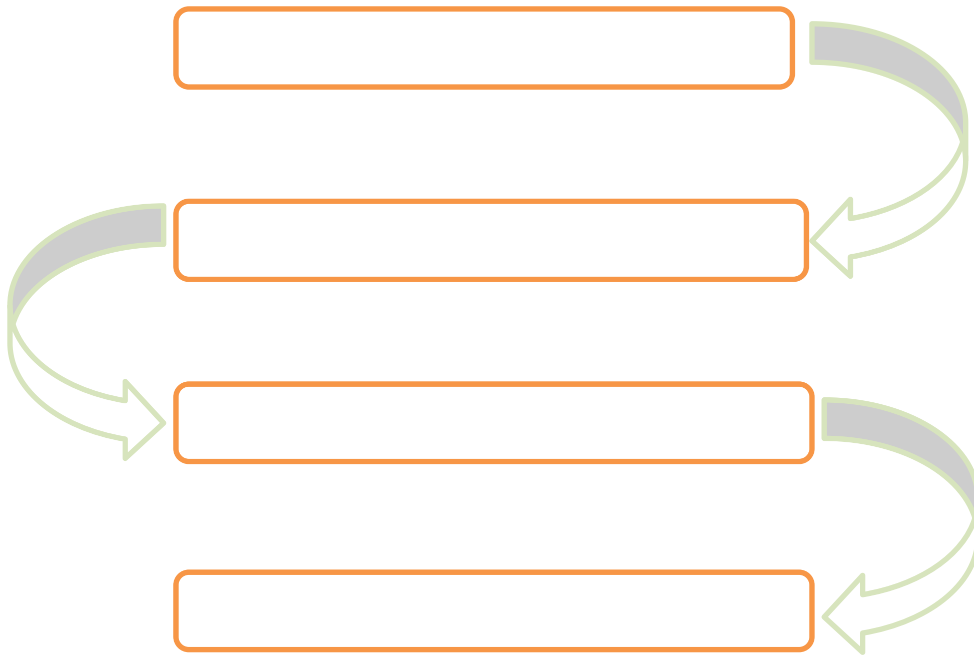

Figure 4.31: Flow of the effluent through a series of trenches

4.3.2 Moringa.

The ripe Coffee cherry is normally pulped in the afternoon immediately after harvesting and delivery to a primary coffee factory while the washing and grading of the parchment is done in the morning. During pulping on the first day, the ostensibly heavily loaded pulping effluent rises consequently followed by the 1^{st} washing effluent in the morning of the 2^{nd} day, while after approximately 24 hour later (in the morning of the 2^{nd} day since pulping), an enormous effluent component from the final washing and grading of parchment is discharged. That implies that the highest frequency of effluent discharge can only arise when coffee is harvested on consecutive days. In such a case, the frequency would be 24 hours. In reality therefore, a coffee processing cycle spans over 36 hours starting with pulping late on the 1^{st} day and ending with the final washing in the morning of the 3rd day (Table 4.8). Therefore, a cycle starting on Monday would be completed on Wednesday. Assuming that Sunday is a resting day, a week would accommodate only 4 coffee processing cycles.

Table 4.8: General coffee harvesting schedule in a week.

Process cycles	Mon day	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1							
2							
3							
4							

Therefore, the effluent batches arising from coffee harvested on different days per week overlap except on the first and last day. Ideally, the coffee processing effluents tend to arise almost daily from a primary wet process system but at varying amounts and times of the day. However, as if to naturally ease off the adverse effect on the environment, the generally enormous but least loaded final grading effluent in terms of pollution causing agents, may be left out of contention for it has already been proven fit for recycling during intermediate washing and pulping (Mburu, 2010). Therefore, the most viable effluent treatment cycle is that which can be fitted to such a schedule. By so doing, an effluent treatment regime at a frequency of 2 times per day and with an agent effective enough to completely act within 24 hours would be the most suitable.

4.3.3 The required effluent treatment capacity.

Generally, the ripening of coffee starts with a few cherries and progressively increases to a peak before tailing off again to the end of the season (Fig. 4.32). That takes place within a season of 3 months.

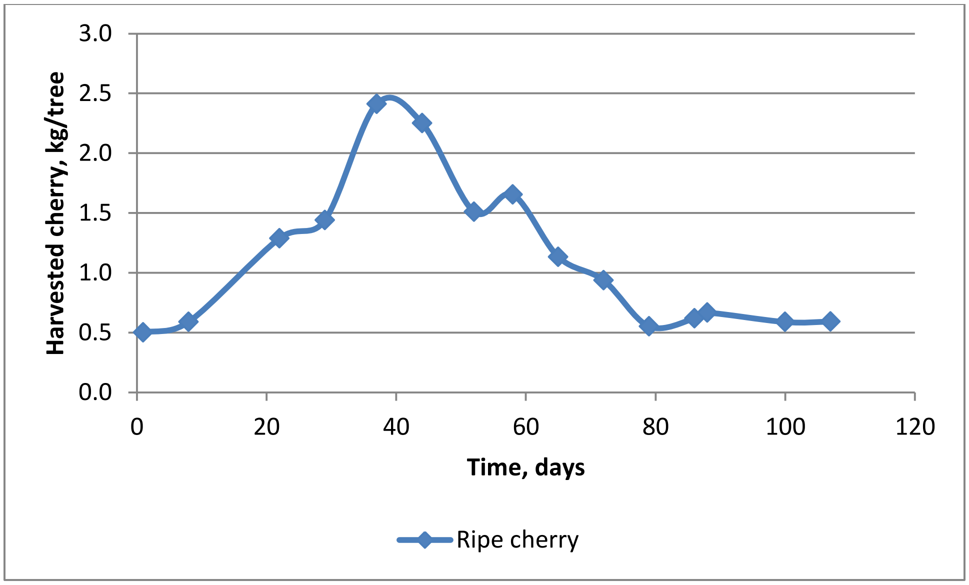

Figure 4.32 : Coffee ripening trend in a season.

There can either be one (uni-modal ripening) or two (bi-modal ripening) seasons in a year. Where two seasons prevail, there is a main and a minor season and depending on the coffee growing region, the early crop season may be the main followed by the minor one in the late crop season and vice versa. In some coffee growing regions, the ripening of coffee extends over a prolonged period to form one annual season.

The harvested cherry on any day in a season traces through a similar trend to that of coffee ripening if plotted against time and the same characteristic extends to the effluent arising from processing any available harvest. Consequently, there exists a challenge in providing an effluent treatment facility which will be of optimally adequate capacity without experiencing excesses prior and after the peak and deficiency at the peak. To surmount that obstacle and establish the most suitable process capacity with ease, it was deemed necessary to consider the following.

4.3.4 Assumptions

i. The ripening of coffee is such that approximately 20% of coffee is ready for harvesting within 2 weeks or 15% within 1 week at the peak of the season (Mburu and Kathurima, 2006)

ii. The annual coffee production is constituted by about 20% and 80% of coffee cherry from the minor and main seasons respectively (Whitaker *et al.*, 1984).

iii. The fermentation process to completely degrade the mucilage coating the parchment comprises an overnight dry fermentation followed by soaking for 24 hours as recommended (Mburu, 1997). Therefore, assuming that fermentation and soaking are done in separate tanks, the smallest coffee factory has a capacity for coffee harvested within a schedule of 4 days per week i.e. Monday – Thursday since Sunday is a reserved rest day. As such, the capacity of the coffee factory for can be increased by either increasing the volume of the tanks

iv. The coffee factory pulping capacity is depended on the number of discs (1 – 4)while the practical pulping time is 7¼hr,

v. The recommended water use is 22.5 m^3/ton of dry parchment derived from 5 ton of cherry i.e. 4.5 m^3/t cherry (Kenya water act, 1974). However, emerging findings indicate that recycling of processing water in the conventional system or the adoption of the minimal water use technologies can reduce the processing water demand to 3.56 l/kg of cherry.

4.3.5 Quantification of effluent production.

Design production is

C_s = *xp* kg

Where C_s is the coffee production per season, x is a factor of coffee production which is dependent on the number of seasons per annum and *p* is the annual coffee production in kg. For a region with only one season per annum, x = 1 while for a region with a main and a minor season x = 0.8 and 0.2 respectively.

Assuming a ripe cherry harvesting factor of 15%/week at the peak of a season, the design processing capacity (D_c) can be derived from,

$$D_c = \frac{15 \times xp}{100} \text{ kg},$$

$$= 0.15xp \text{ kg}$$

Therefore, daily processing capacity (y) becomes

$$y = \frac{0.15xp}{d} \text{ kg}$$

Where d is the number of picking days per week

Since 3.56 litres of water will be used to process 1 kg of ripe coffee cherry,

Effluent discharge/ day was given by,

$$Ev = \frac{0.15xp}{d} * 3.56 \text{kg lt.}$$

Since in practice, treatment with moringa *oleifera* takes full effect after 24 hours, a system with a treatment chamber for pulping effluent and another for the washing and grading effluent will be required. The capacity of each chamber will be commensurate with the respective maximum daily effluent capacity of each type. That will ensure a timely smooth displacement of the treated effluent by the incoming raw effluent with a stable interface at 24 hour intervals on consecutive processing days.

The design of the effluent treatment prototype can be informed by the outcome of the effluent treatment and the mode of effluent production. On treatment for instance, the effluent breaks down into 3 phases comprising a top scum, middle clean liquid and the settled sludge. The top scum is commonly insignificant compared to the settled sludge. However, the top sludge can easily disintegrate on slight disturbance and its fragments trans-located to the settled sludge. Likewise, parts of the sludge unpredictably break off from the settlement and floats up to the surface. During such translocations of matter, some residue solids remain in the middle phase. The slimy settled sludge is also very sensitive to any form of disturbance to the extent of mixing with the rest of the liquid. While the disturbance aspect of the effluent can be minimized if not prevented, the unpredictable and inherent agitation cannot be controlled though the extent to which they can cause changes in the concentration of solids in the middle layer may not be significant. The proposed equipment for separating the clear liquid from the other two phases would best have the outlet slightly below the surface such that the scum does not exit together with the overflow of the clear liquid.

4.4 Seepage of the treated and untreated effluent from pits.

When percolation values for batches of raw and treated effluent from separate but similar pits were plotted against time, each batch generated a curve bearing a general trend as shown in Fig. 4.33. The results show that although the seepage of raw effluent was 20.5 cm in 5.0 hours, half of it seeped through within the first 30 minute. That could have been caused by a rather rapid seepage of the raw effluent for a short time after which the pit is more or less partially sealed off thereby limiting the seepage to a low rate. As for the treated effluent, the seepage of effluent increased gradually and faster than the raw effluent but at a decreasing rate.

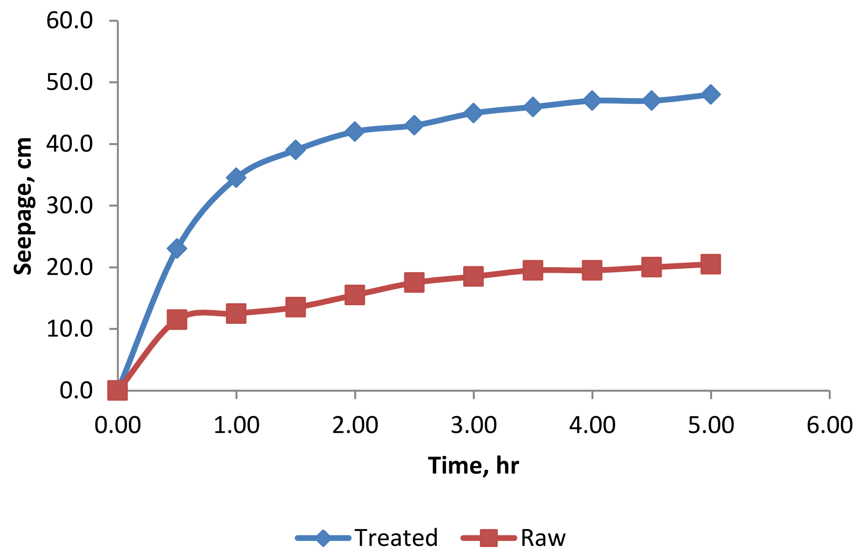

Figure 4.33: Location of the effluent surface from the top of the pit against time.

After 5.0 hours about 48.0 cm of the treated effluent had seeped out compared to about 20 cm of the raw effluent. Besides, while seepage of the raw effluent had stopped that of the treated effluent was still taking place albeit to a limited extent. Since the cumulative volume effluent that seeped out from a pit increased at a decreasing rate against time (Fig 4.33), then the level of the effluent surface inside the pit (z, cm) increased proportionately to a reference point at the top of the pit any time (t) after application of the effluent was into the pit. Therefore, that depth as expressed as z was proportional to t

Ideally, water seeps out of a pit along three dimensions namely horizontally through the entire circumference and vertically through the bottom of the pit. In this case however, the effluent has about 2 g/l of suspended solids which ultimately settles at the bottom of the pit against time. Suspend solids at the bottom of the pit would impair the vertical seepage of effluent from the pit significantly (Wood *et al.*, 2000). As such, almost all the seepage of effluent from the pit was assumed to occur horizontally. However, the available effective infiltration vertical surface of the pit decreases as the level of the effluent the pit drops against time. Together with that the depth of the effluent in the pit also provides a driving force for seepage of the effluent from the pit in all direction. That force is the product of the density (ρ) of the effluent, gravity (g) and the depth of the effluent (h). This force is technically referred as the head. The head therefore falls proportionately to the depth as the effluent seeps out of the pit. Under such varying factors the general trend of seepage of effluent (z) from a pit against time (t) was derived by curve fitting method (Little and Hills 1972).) and conformed to a general equation describing these curves as:

$$z = ct^k \qquad (6.1)$$

Where c and k are constants.

The curve expressed by Equation 6.1 can be transformed to a straight line by taking logarithms of z and t to get:

$$\log(z) = kLog(t) + \log(c) \qquad (6.2)$$

On applying the log – log transformation to the data responsible for the trend curves in Fig. 4.33, the resulting regression lines were as shown in Fig. 4.34.

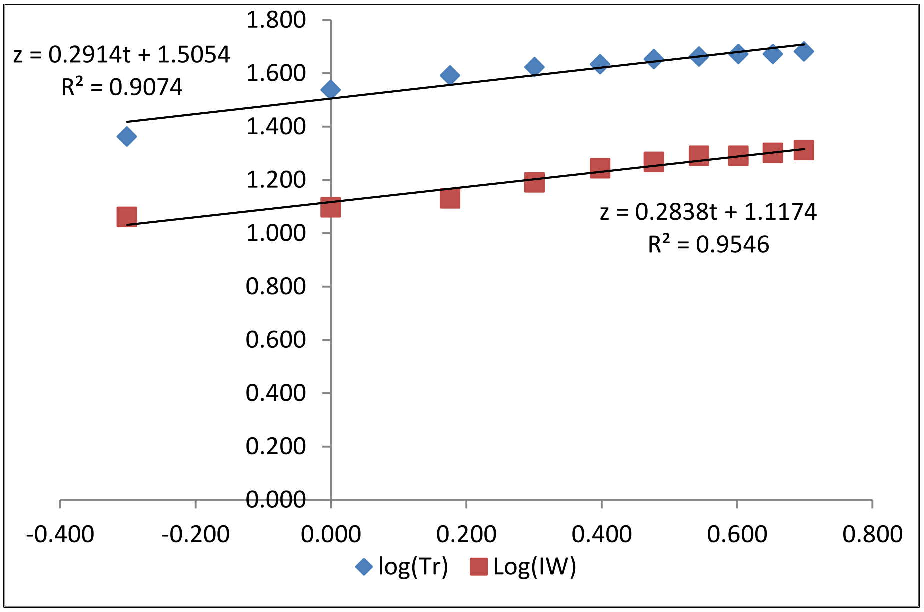

Figure 4.34: Fitting of straight lines to the transformed data.

As can be inferred from the regression lines, the correlation coefficients were close to unit in both cases. Besides, since $z = \text{antilog}(1.505)t^{0.291} = 31.989t^{0.291}$ and $z = \text{antilog}(1.117)t^{0.283} = 13.092t^{0.283}$ for the treated and raw effluent respectively, the value of z or seepage for the treated effluent was higher than that for the raw effluent at any time within the considered range of collected data. That explains why the trend of raw seepage is mostly differing only slightly to that of the treated effluent except for about 1 hour from the onset of the seepage process. Thereafter, the trends adopt only slightly small divergent slopes which rhymed with the small difference between k=0.291 and k=0.283 respectively.

The active area for seepage however, varies continuously because as the effluent seeps out it is accompanied by a decrease in its level in the pit (i.e. z_o -Δz). Once the coffee processing effluent has been relieved of most of the solids load as sludge and scum, the improved pit performance is attributed to that. This is as a result of uninhibited seepage and evaporation components. A well designed pit is supposed to be 1.5 m deep out of which 0.5 m constitutes the free board. As such, the size of the pit as dictated by the effluent generated per day can be varied by adjusting the diameter of the pit.

Seepage of the treated effluent starts off at a high rate than for the raw effluent with both diminishing to almost the same rate after only 1 hour. The seepage rate of the raw effluent from the pit progressively diminishes with time during the coffee processing season i.e. from batch to batch. As for the seepage of the treated effluents the rates remain almost constant with time. In comparison, the seepage of the treated effluent is initially 2 times faster than the raw effluent but the gap widens to 6 times after the 1^{st} 2 batches.

In Table 4.9, the c and k values of the regression lines fitted to the transformed data from consecutive seepage experiments were as shown. More often than not, the k values for the raw effluent were slightly higher than that for the treated effluent.

However, the c values for the treated effluent were higher than for the raw effluent. In effect, the k values refer to the rate of change in seepage with respect to time. Therefore, the k values imply the seepage of the treated effluent was increasing at a higher decreasing rate than the raw effluent. However, the c values expanded the z scale for the treated effluent more than that for the raw effluent by such an extent that outweighed the effect of k.

Table 4.9: Comparative seepage of raw and treated effluent.

Raw settlement				Treated			
k	log(c)	c	r^2	K	log(c)	C	r^2
0.31	0.813	6.501	0.974	0.25	1.272	18.707	0.952
0.36	0.662	4.592	0.959	0.24	1.068	11.695	0.987
0.50	0.468	2.938	0.981	0.34	0.73	5.370	0.949
0.44	0.468	2.938	0.989	0.52	0.571	3.724	0.980
0.68	0.213	1.633	0.972	0.27	0.785	6.095	0.948
0.72	0.157	1.435	0.948	0.53	0.442	2.767	0.979
0.88	0.041	1.099	0.964	0.47	0.463	2.904	0.985
1.11	-0.033	0.927	0.894	0.44	0.608	4.055	0.997
1.33	-0.319	0.480	0.940	0.50	0.485	3.055	0.971
1.16	-0.219	0.604	0.962	0.41	0.468	2.938	0.972
0.76	0.035	1.084	0.939	0.40	0.39	2.455	0.927
0.72	-0.008	0.982	0.963	0.50	0.312	2.051	0.990
0.69	-0.045	0.902	0.938	0.56	0.174	1.493	0.982
2.22	-1.226	0.059	0.742	0.73	-0.035	0.923	0.965
0.87	-0.142	0.721	0.946	0.78	0.012	1.028	0.946
1.07	-0.233	0.585	0.947	0.83	-0.01	0.977	0.979
1.04	-0.447	0.357	0.904	0.74	-0.011	0.975	0.972
0.91	-0.245	0.569	0.877	0.47	0.403	2.529	0.967
0.91	-0.027	0.940	0.984	0.48	0.531	3.396	0.960
0.81	-0.024	0.946	0.984	0.54	0.368	2.333	0.984
0.97	-0.252	0.560	0.944	0.73	0.077	1.194	0.887
0.64	-0.12	0.759	0.916	0.81	0.000	1.000	0.969
0.97	0.009	1.021	0.988	0.44	0.615	4.121	0.982
0.90	-0.011	0.975	0.993	0.30	0.965	9.226	0.952
1.13	-0.286	0.518	0.974	0.14	1.077	11.940	0.958
1.00	0.082	1.208	0.971	0.43	0.807	6.412	0.972
0.63	0.184	1.528	0.991	0.71	0.276	1.888	0.975
0.98	0.011	1.026	0.984	0.23	0.961	9.141	0.981
1.22	-0.376	0.421	0.952	0.28	0.868	7.379	0.987
0.84	-0.031	0.931	0.977	0.33	0.793	6.209	0.978

4.4.1 Sustainability of the improved seepage pit performance.

In order to assess how effluent would percolate out of a pit over some time, the pit was recharged with more effluent after the level had dropped to a preselected depth in the pit to start another timed cycle. The results from 5 cycles were as shown in Fig. 4.35. It was clear that, the cycles depicted more or less a common trend. That validated the application of the developed predictive equation for some time of usage. However, the percolation rate would obviously be expected to diminish with time thereby lengthening the every subsequent cycle. That was bound to happen until a significant change in percolation was detected after which the pit surfaces would be scrapped to restore the original performance. All the same the combination of solids removal and percolation of the treated effluent seems to be a more viable solution towards alleviation of pollution from the coffee processing than further treatment with the many conventional treatment processes such as the UASB, secondary (wetlands) and hyacinth ponds before letting the effluent back to the natural water ways. That was because the infrastructure demand by the extended treatment system is not available at the coffee factories.

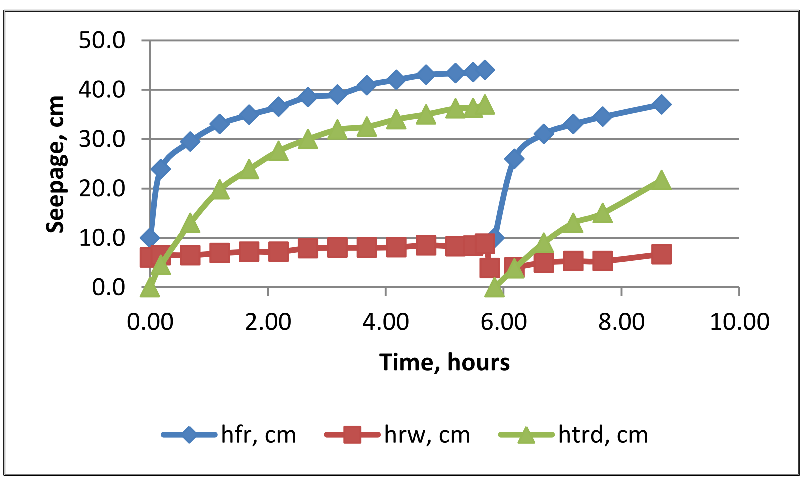

Figure 4.35: Two cycles of seepage of water, raw and treated effluent

After allowing the effluent to percolate through a pit and recharging to start another cycle from time zero the plot for 5 complete cycles at 1 cycle per day, the seepage trends are as shown in Fig. 4.36. It is apparent that the cycles were consistently displaying a similar trend.

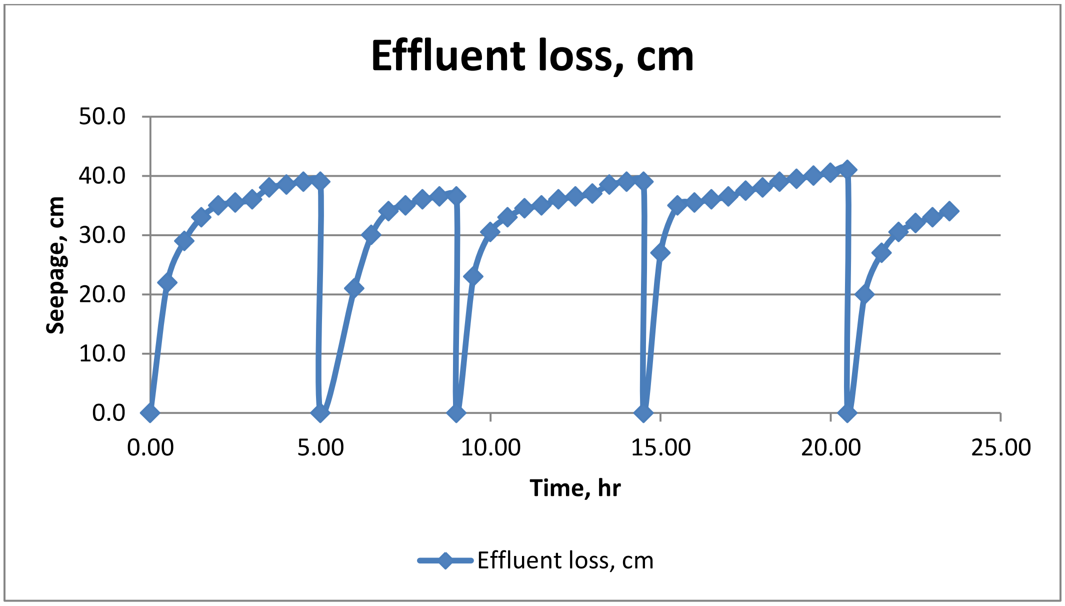

Figure 4.36: Pulping effluent seepage cycles

In addition to that, re-designing and scheduled protection of the pits from surface runoff water (prevention of any surface water run-off from entering the waste pits) to complement on that novel concept was viewed to constitute an even more viable option for the same purpose. Otherwise, other conventional complementary options, which can greatly check the adverse impact of the coffee processing effluent on the environment include frequent clearing of the scum from the surface of the effluent in a pit and, seasonal de-sludge of the pits (Mburu, 2010).

4.5 Engineering significance

The main benefit accrued from the treatment of the coffee pulping effluent lie in its impact with respect to effective environmental protection from coffee wastes. Therefore, having identified that the suspended solids can be removed from the effluent either naturally or by the application of moringa oleifera within 6 and 1 days per batch of effluent respectively, the effluent disposal systems can be redesigned for improved efficiency. The pits can for instance be arranged such that the incoming raw effluent into the treatment tank displaces the clarified effluent to the next pit in which the effluent percolates into the soil with ease. As such, a series of pits can be set up in a factory after the treatment tank such that depending on the harvesting frequency, serial displacements occur from one pit to another. The number of seepage pits required after the settlement pit would depend on the factory processing capacity and frequency of processing. It is expected that the level of clarification of the effluent increases along the series. Such an arrangement performs more efficiently than the disposal of the effluent through a single pit. Alternatively, the treated effluent may also be disposed into long channels in which the initial section handles the initial levels of the suspended solids which decline as the treated effluent is displaced along the channel. In practice very few coffee factories have such pits and channels in which the effluent is receive by the first pit or channel from which it is progressively passed on to the rest in series as coffee processing progresses.

Besides improving the efficiency of the current effluent disposal systems, the findings of this study will contribute to the design of new effluent plants. Successful design of new effluent plants shall lead to the adoption of the innovation and its mass production to satisfy the local and external coffee industries.

Another new dimension opened by this study arises from the resultant by-products consisting of the liquid and sludge phases. It is envisaged that once separated, such by products will be readily available for any viable proposition towards their economic utilization. If suitable utilization options for the clarified effluent and the sludge are found, that would open indirect new value addition avenues not only for them but also for the applied treatment agents like lime or moringa oleifera. In any case, any process that will avail by-products from effluent treatment will subsequently demand to be provided with equipment for process them into valuable products.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

This study found that most coffee factories not only exceeded the 1.25 m^3 recommended limit of water for pulping a tone of coffee cherry but use was inconsistent.

The water used was neither proportional to the amount of coffee cherry pulped nor the TSS in the discharged effluent in all the factories in this study. For that reason, the water use for pulping coffee cherry (m^3/ton) could not be a basis for predicting the TSS in the effluent. Despite these discrepancies, the results confirmed that coffee effluents have high organic loadings and acidity.

TSS can naturally settle from the effluent within 6 days. Such a TSS settlement profile would require a treatment system with a retention time of 6 days. Where for instance a coffee harvesting schedule of three times per week is practiced, such a system would be required 3 receiving/settlement pits for the raw effluent of separate days after which the fully treated effluent from each pit would overflow to a common pit. An alternative to that would be a series of 3 pits in which the first one receives raw effluent which is displaced into the next pits along the series as the effluent accumulates with pulping from day to day. In such a setup, percolation of the effluent into the soil would be expected to increase from one pit to the other along the series. In essence then the raw effluent receiving pit would serve purely as a sediment pit.

Application of lime to the effluent did not hasten the TSS removal process but just performed as good as the natural option within 6 days. For that reason, its use during the treatment of the effluent would only be considered based on the attractive economic merits by virtue of the value it would add to the solid by-products of the treated effluent. For instance, the role of lime in agriculture and its local availability at relatively cheap rates can stimulate interest towards using it for this purpose. That is because the resultant sediment can be easily recycled back to the farm as a soil ameliorant after becoming dry. As such treatment of the effluent with lime could then broaden its further application as such or otherwise. As for calcium hydroxide (anlar), it would be uneconomical to use it for effluent treatment despite its expedient action on the effluent within about 2 hours or so.

The most promising performance was found in moringa o*leifera* oil press cake powder with respect to effluent treatment. Moringa complemented the natural treatment process of the effluent to a great extent by reducing the retention time from 4 – 6 days to 1 day. Its capability to precipitate out the suspended solids out of the effluent within 24 hours therefore fitted well with the effluent production cycle such that, one day's batch would be fully treated just when the following day's batch is expected.

The treatment of the effluent removed the suspended solids and enhanced seepage of the effluent more efficiently through the pit walls compared to the raw effluent.

5.2 Recommendations

It will be necessary to study relationship of water used for processing coffee and the resultant TSS under controlled biological and experimental conditions.

Having established that Moringa *Oleifera* oil press cake can effectively treat the coffee effluent, design of a viable treatment plant deserves to be considered before anything else. For instance, the few local small grower planters would require small waste treatment units, which are simple and easy to operate and low in capital and recurring cost. For that purpose, reduction in the consumption of process water and development of low-cost water treatment systems are in essence some of the most important aspects in reducing the size of treatment plant and investment cost. But first, the water used for processing need to be minimized by proportionating water used to commensurate with the coffee to pulped. Other water minimization options worth of further evaluation include direct drying of ripe coffee cherry as well as parchment with mucilage, intensive re-circulation and recycling of coffee processing water dry pulping and eco-pulping in combination with mechanical mucilage removal.

There is need to consider shortening the pulp water contact time by for instance conveying the pulp by mechanical means like helical screws, conveyor belts or elevators and use of sieves in all phases of the process to eliminate organic matter in suspension.

The emerging small scale coffee processing plants are likely to impact positively towards offsetting the need for treating coffee effluent. Mobile pulping is another attractive option to consider because only the parchment woul be transported to a central processing unit. By so doing not only would the amounts of wastes produced be small per unit processing site but also too spread for any likely economic venture. By virtue of their importance in terms of environmental conservation such new developments need to be evaluated for effective adoption.

These improved coffee processing regimes generally output effluent with high concentration of solids. Such effluents are physically thick which makes them rather difficult to treat unless diluted. However, the high concentration of various forms of matter in the effluent can make it more valuable for further economic utilization. For instance, addition of microbial organisms to the effluent to expedite degradation of the solids and other pertinent component to soluble or separate sediments needs to be considered as well.

On other hand, treatment of the coffee effluent from the conventional processing systems would open new utility avenues for the clarified effluent and the separate solids. However, well-designed equipment for separating these phases completely will be required to facilitate translations of such suggestions into a practical value addition endeavour. After separation it woul be important to either evaluate their economic utilization like irrigation and application of sludge back to the farm as a soil ameliorant or research into other alternative options for their value addition.

Due to the encouragement encountered from use of moringa, there is need to try to extract suitable polymeric substances from its seeds and extracts for characterization of the polymer/extracts functionality, charge and molecular weight with simulated suspensions.

The effect some trees like the Eucalyptus and bamboo among others if planted next to the seepage pits with respect to aiding the transmission of the treated effluent out of the pits is need also to be studied.

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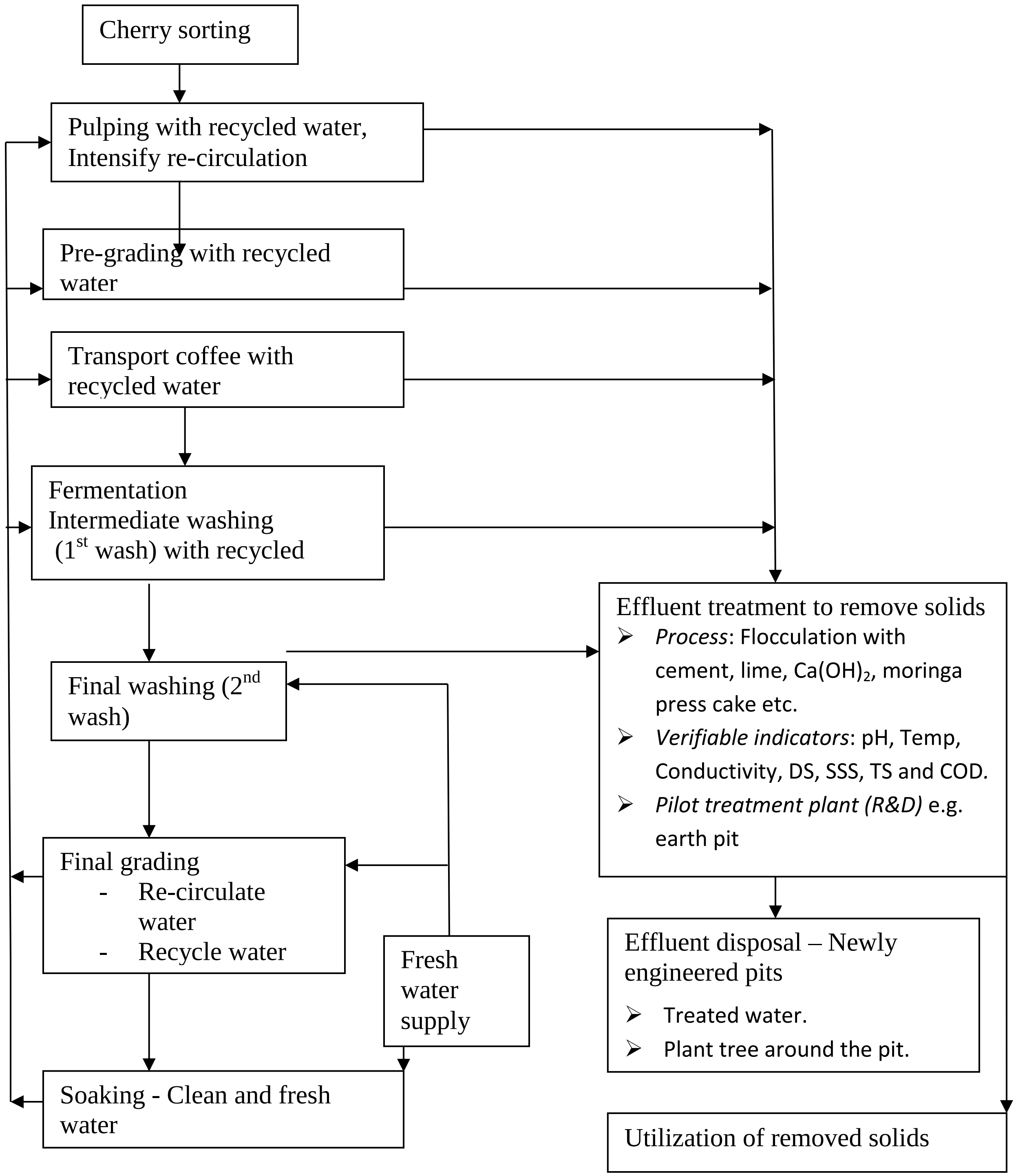
APPENDIX

APPENDIX A

COFFEE PRODUCTION AND PROCESSING



A1: The recommended coffee processing water flow cycle

A2. Conversion factors in coffee processing

A single disc of a pulper can process 1000 kg cherry per hour,

- An Aagaard pre-grader properly adjusted grades 300 kg cherry/hr
- Pulping 5 days per week for 7 hours per day, a disc pulper processes 105,000 cherry per week
- 1000 kg cherry give about 0.5^3 m wet parchment,
- 1000 kg cherry requires 0.6 m^3 of fermentation or soaking space
- 100kg cherry need 18 m drying space = 10 skin drying trays of 200 x 90 cm = 0.45 tables of 22 x 1.8m
- 1000 kg fresh pulped cherry requires 20 m^2 drying area at 2.5 cm depth.
- 1000 kg half dried cherry requires 10 m^2 drying area at 5 cm depth
- Cherry drying time: Approximate 3 week
- Parchment drying time, approximate 14 days in sun well managed this will handle 100 tones cherry per week
- A 3 disc pulper needs: 16 fermentation tanks, 20 skin drying tables 15 * 1.8 m and 80 drying tables 23 m * 1.8 m
- 1000kg good heavy cherry give $1000/_5$ = 200 kg dry parchments,
- 200 kg dry parchment require about 0.5 m bins or store space
- One bag of heavy parchment weights approx. 50kg net
- Bag of parchment stacked 8 bags need 0.1 m store space
- 10 bags of parchment requires a storage area of 1m^2 floor space
- 8 bags of parchment is the maximum height for stacking
- 200 kg dry parchment from 1000 kg heavy cherry give $1000/_6$ = 166 kg clean coffee,
- 1000 kg light cherry give$1000/_{10}$ = 100 kg clean coffee,
- One tone clean coffee (green coffee) = 16 ½ bags gross.
- One bag of clean (green) coffee weights 60kg net 60.5 kg gross
- Ripe cherry has 60-65% moisture content
- Washed undried parchment has 52-55% moisture after surface water drained off,
- Dry parchment coffee has an MC of 10 – 11% (On average 10.5%)
- Dry coffee cherry (buni) has an Mc of 12%
- Clean coffee has 12% moisture

Source: Anon. (1991).

A3: Water used to process cherry equivalent to 1t clean coffee

Method	Arabica	Robusta
Conventional Machine wash	80,000	1,000,000
Natural fermentation	70,000	NA
Dry pulper-cum-washer	8,000	30,000
Soaking	2,000	2,000

NA – Not available because most of the Robusta is washed mechanically.

Source:

A4: Water consumption/lt cherry

Processing activity	Gallons
Pulping	250
Factory cleaning	150
Pre-washing	560
Final washing and grading	1,750
Total	2710

Appendix A5: Water used (lt) in a 3 disc factory, Aagaard pre-grader processing 20,455 kg cherry in 1 day.

Operation	A	B	C	D	E
Pulping 20,455 kg=7½ hr	81,830	10,911	10,800	rw	Rw
Intermediate washing	8,182	8,183	8,100	rw	Rw
Transport from one stage to another	16,360	16,366	4,050	4,050	Rw
Transport to final washing channel	10,911	10,911	2,700	2,700	2,700
Final washing and grading	65,464	16,366	16,200	16,200	16,200
Soaking heavy coffee	6,365	6,365	6,300	6,300	6,300
Cleaning factory	4,546	4,546	4,500	4,500	4,500
Total	193,663	73,647	52,650	33,750	29,700
Water consumption/kg cherry	9.37	3.56	2.57	1.65	1.45

A - No circulation water
B - Full circulation water
C- Full circulation including transport water
D – Pulping and washing with recycled final grading and soaking water
E – Pulping, washing and transport from one stage to another with recycled final grading and soaking water

Appendix A6: Water used to process different amounts of coffee and the characteristics of the resultant effluent

Process input					Effluent characteristics			
Cherry, Kg	***Pulping, Kg/hr***	***Water, m^3***	***Water, m^3/ton***	***T, ^oC***	***pH***	***TDS, g/l***	***TS, g/l***	***TSS, g/l***
14,849	2620	96.042	6.47	25.7	6.1	1.094	3.150	2.056
3,716	2623	91.307	24.57	25.4	5.7	1.230	5.040	3.810
13,064	3015	19.643	1.50	25.7	5.3	1.370	7.680	6.310
25,495	3824	21.697	0.85	23.9	6.6	1.220	1.250	0.030
7,980	3925	32.735	4.10	31.7	5.36	1.370	8.920	7.550
469	4020	4.640	9.89	23.8	5.4	1.222	2.200	0.978
5,024	4433	21.263	4.23	22.7	5.95	1.194	1.680	0.486
5,510	4468	25.515	4.63	21.7	5.57	1.230	2.600	1.370
2,500	5172	11.791	4.72	23.0	5.64	1.247	1.460	0.213
2,679	2551	13.173	4.92	23.7	5.56	1.390	5.120	3.730
1,646	3086	9.119	5.54	23.2	5.14	1.550	5.800	4.250
761	1903	4.560	5.99	23.3	5.81	1.174	1.840	0.666
605	2269	8.106	13.40	23.7	5.32	1.340	5.780	4.440
2110	2751	5.31	2.52		3.90	1.540	4.050	2.510
1677	3106	8.17	4.87	23	6.69	1.190	1.960	0.770
780	3120	4.24	5.44	22.2	6.88	0.929	2.040	1.111
260	2680	1.55	5.97	33.3	6.70	1.440	5.080	3.640
1300	2230	8.26	6.35	26.4	5.90	1.590	8.800	7.210
1112	2292	7.24	6.51	23.9	6.70	1.510	5.420	3.910
1248	2148	8.14	6.52	24.2	6.00	1.460	4.760	3.300
910	2063	6.58	7.23	25.1	6.00	1.420	2.980	1.560
559	1694	5.80	10.37	24.7	7.04	1.152	1.720	0.568

Appendix A7: Some parameters of the coffee effluent source from Coffee factories (CF) in some parts of the coffee growing regions

Date	CF	Location	pH	TDS, g/l	TS, g/l	SS, g/l	COD, g /l
27.04.2009	Gacibi	Kiambu	3.31	1.090	1.610	0.520	4.000
17.05.2009	Gacibi	Kiambu	3.2	1.075	1.870	0.795	5.000
16.06.2009	Gacibi	Kiambu	3.4	1.064	1.400	0.336	6.250
27.06.2009	Gacibi	Kiambu	3.23	1.066	1.750	0.684	8.750
13.05.2009	Gathage	Kiambu	3.96	1.154	8.490	7.336	24.250
14.05.2009	Gathage	Kiambu	3.3	1.204	6.600	5.396	15.750
15.05.2009	Gathage	Kiambu	2.97	1.246	6.070	4.824	13.500
16.05.2009	Gathage	Kiambu	2.82	1.224	5.000	3.776	15.000
17.05.2009	Gathage	Kiambu	2.73	1.265	5.050	3.785	14.000
25.06.2010	Gathiruini	Kiambu	3.72	1.136	2.490	1.354	1.120
13.07.2010	Gathiruini	Kiambu	5.27	0.871	5.280	4.409	0.027
11.01.2010	Githongo	Kiambu	5.95	1.262	2.600	1.338	17.500
12.01.2010	Githongo	Kiambu	5.57	1.230	2.600	1.370	12.600
18.01.2010	Githongo	Kiambu	5.64	1.247	1.460	0.213	8.900
26.01.2010	Githongo	Kiambu	5.3	1.262	2.180	0.918	17.500
02.02.2010	Githongo	Kiambu	5.68	1.214	2.020	0.806	9.500
04.01.2010	kamuchege	Kiambu	5.4	1.222	2.200	0.978	15.500
04.1.2010	Kamuchege	Kiambu	5.40	1.222	2.200	0.978	14.000
14.07.2010	Kamuchege	Kiambu	5.71	0.320	5.420	5.100	30.000
15.07.2010	Kamuchege	Kiambu	6.14	0.193	1.880	1.687	17.000
26.01.2010	Kanake	Kiambu	5.14	1.550	5.800	4.250	11.000
01.02.2010	Kanake	Kiambu	5.81	1.174	1.840	0.666	12.500
02.02.2010	Kanake	Kiambu	5.32	1.340	5.780	4.440	7.500
08.04.2009	Karakuta	Kiambu	6.3	1.144	4.590	3.446	0.660
14.04.2009	Karakuta	Kiambu	6.43	1.155	6.860	5.705	1.480

27.04.2009	Karakuta	Kiambu	6.43	1.155	6.860	5.705	18.500
13.05.2009	Karangi	Kiambu	4.33	0.968	2.670	1.702	5.750
14.04.2009	Karangi	Kiambu	6.28	1.101	4.870	3.769	1.340
15.05.2009	Karangi	Kiambu	3.54	0.984	1.250	0.266	4.500
16.05.2009	Karangi	Kiambu	3.42	0.965	0.970	0.005	4.250
17.05.2009	Karangi	Kiambu	3.37	0.986	3.860	2.874	3.500
03.08.2010	Kisii	CRISC[a]	6.37	1.470	8.170	6.700	32.000
21.10.2009	Kisii	CRISC[a]	6.00	1.600	8.020	6.420	2.720
24.10.2009	Kisii	CRISC[a]	6.00	1.420	2.980	1.560	2.040
02.11.2010	Kisii	CRISC[a]	6.39	0.790	14.020	13.230	2.120
22.10.2009	Kitale	CRISC[b]	6.00	1.460	4.760	3.300	2.020
25.10.2009	Kitale	CRISC[b]	6.70	1.440	5.080	3.640	1.880
03.11.2010	Kitale	CRISC[b]	6.6	0.756	13.620	12.864	1.830
10.09.2009	Koru	CRISC[c]	6.88	0.929	2.040	1.111	1.660
19.10.2009	Koru	CRISC[c]	6.70	1.510	5.420	3.910	2.280
23.10.2009	Koru	CRISC[c]	5.90	1.590	8.800	7.210	2.720
01.11.2010	Koru	CRISC[c]	6.58	0.742	12.220	11.478	1.950
04.11.2010	Koru	CRISC[c]	6.72	0.730	12.640	11.910	1.680
21.04.2009	Koru	CRISC[c]	6.78	1.033	1.420	0.387	8.250
10.05.2009	Mariene	CRISC[d]	6.49	1.248	2.530	1.282	1.080
24.11.2009	Ndia-ini	Nyeri	3.27	0.958	1.560	0.602	4.750
24.06.2010	Rukera	CRI	4.40	0.859	6.700	5.841	17.500
25.06.2010	Rukera	CRI	4.39	0.799	4.400	3.601	14.000
14.11.2009	Tabaya	Nyeri	6.38	0.996	3.090	2.094	9.250
30.11.2009	Thunguri	Nyeri	3.90	1.540	4.050	2.510	7.450

Appendix A8: Characteristics of Coffee processing effluent.

Parameter	Pulping	Pre-washII	Pre-wash II	Final wash	R. sample
COD (mg/l)	3,000-28,000	1,280-11,000	2,000-4,560	600-1,600	100-600
DO (mg/l)	0.00-0.12	0.02-0.15	0.07-0.24	0.07-0.45	0.39-0.58
pH	6.17-5.03	4.59-3.99	5.00-4.61	6.49-5.34	6.19-6.97
TSS	2,301-8,794	727-2,493	923-1,764	115-541	50-126
DS, mg/l	6889-31506	1201-3962	1298-2356	230-559	79-250

COD = Chemical Oxygen Demand; DO = Dissolved Oxygen; TSS = Suspended Solids

Source: Mburu et al., 1994.

Appedix A9: Characteristics of coffee effluent

Characteristics	Recycling pulping water	No recycling
pH	4.0-4.5	4.0-4.5
COD g/l	18.0-23.0	7.2-14.8
BOD g/l	10.0-13.0	2.3-5.0
Suspended solids	7.0-10.9	2.0-3.3

Source: Wood *et al.*, 2000

Appendix A10 Composition of mucilage

Component	Percent , %
Water	84.20
Protein	8.90
Sugar	4.10
Pectic acid	0.91
Ash	0.70

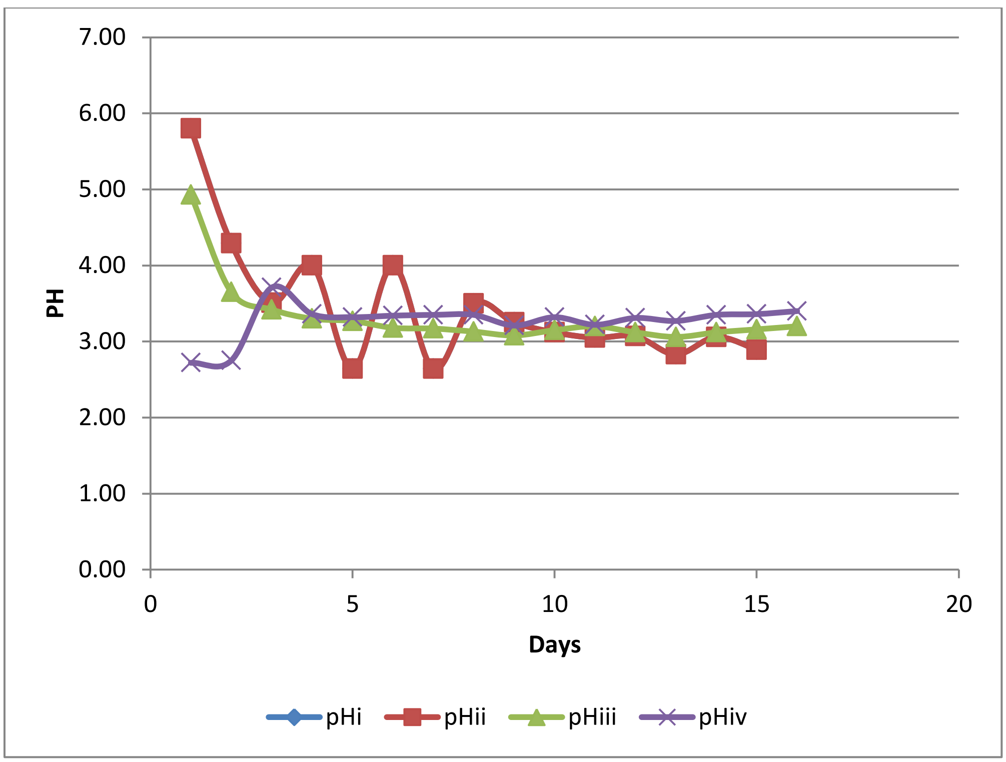
Appendix A11: Main coffee growing areas.

Coffee growing area		Annual production (Metric tons		
Province	Count/Area	Estates	Small holders	Total
Central	Kiambu	15,623	2,560	18,193
	Kirinyaga	2,194	5,870	8,064
	Murang'a	1,662	2,925	4,264
	Nyeri	1,634	6,630	8,264
	Sub total	***21,123***	***17,985***	***38,785***
Coast	Taita Taveta		5	5
	Sub total		***5***	***5***
Eastern	Embu	397	2,268	2,665
	Machakos	1,443	2,803	4,246
	Makueni		763	763
	Meru	328	2,624	2,952
	Tharaka-Nithi	175	1,167	1,342
	Sub total	***2,343***	***9,625***	***11,968***
Nyanza	Kisii & Nyamira	29	1,174	1,203
	Migori & Homa Bay	3	106	109
	Sub total	***32***	***1,280***	***1,312***
Rift Valley	Baringo	25	115	140
	Kericho, Nandi Hill	298	1,238	1,536
	Nakuru	705	111	816
	Trans Nzoia, Keiyo	437	113	550
	Sub total	***1,465***	***1,577***	***3,042***
Western	Bungoma	34	1,246	1,280
	Kakamega & Vihiga		20	20
	Sub total	***34***	***1,266***	***1,300***
	National total	**24,997**	**31,738**	**56,735**

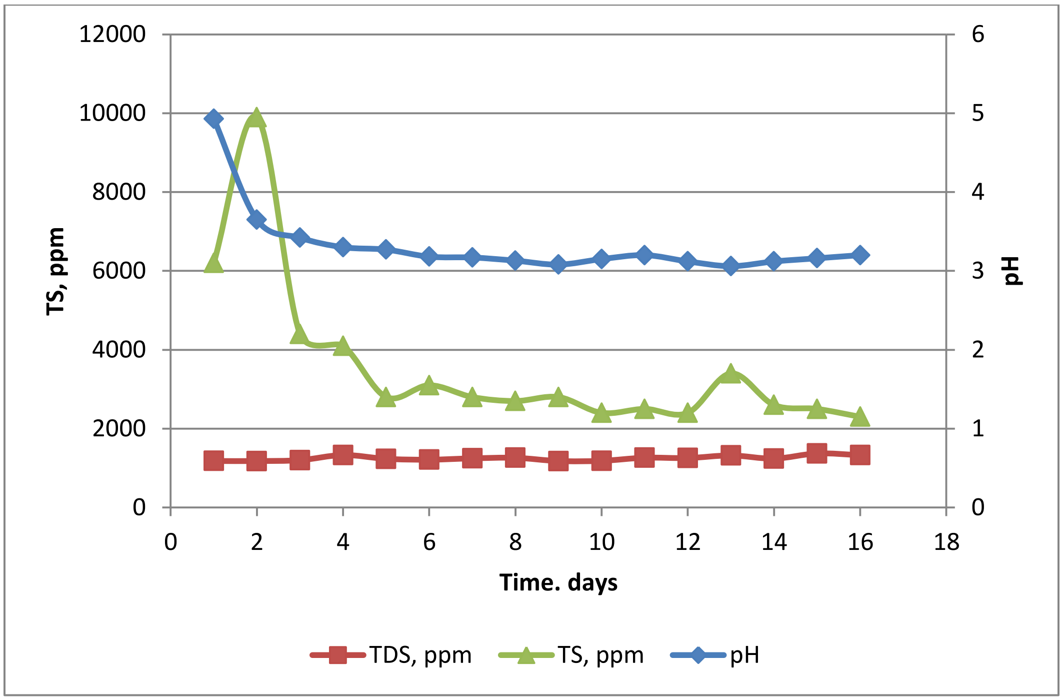
Appendix A12:Distribution of primary coffee factories in Kenya.

Coffee growing area	Annual production (Metric tons)		
		Estates	
County	Cooperative	Large	Small
Baringo	4	2	-
Embu	57	7	9
Kericho/Nandi Hills	16	13	6
Kiambu	94	174	261
Kirinyaga	77	29	20
Kisii & Nyamira	41	3	5
Machakos	29	14	4
Meru	122	9	21
Murang'a	111	17	39
Nakuru	-	18	1
Nyeri	95	29	4
Siaya/Nyanza	-	1	-
Tharaka-Nithi	54	4	-
TransNzoia, Keiyo & Marakwet	6	11	2
Kakamega/Vihiga	4	-	2
Uasin Gishu	-	-	2
Bungoma	16	-	-
Makueni	6	-	-
Migori & Homa Bay	3	-	-
Taita Taveta	5	-	-
Total	740	331	376

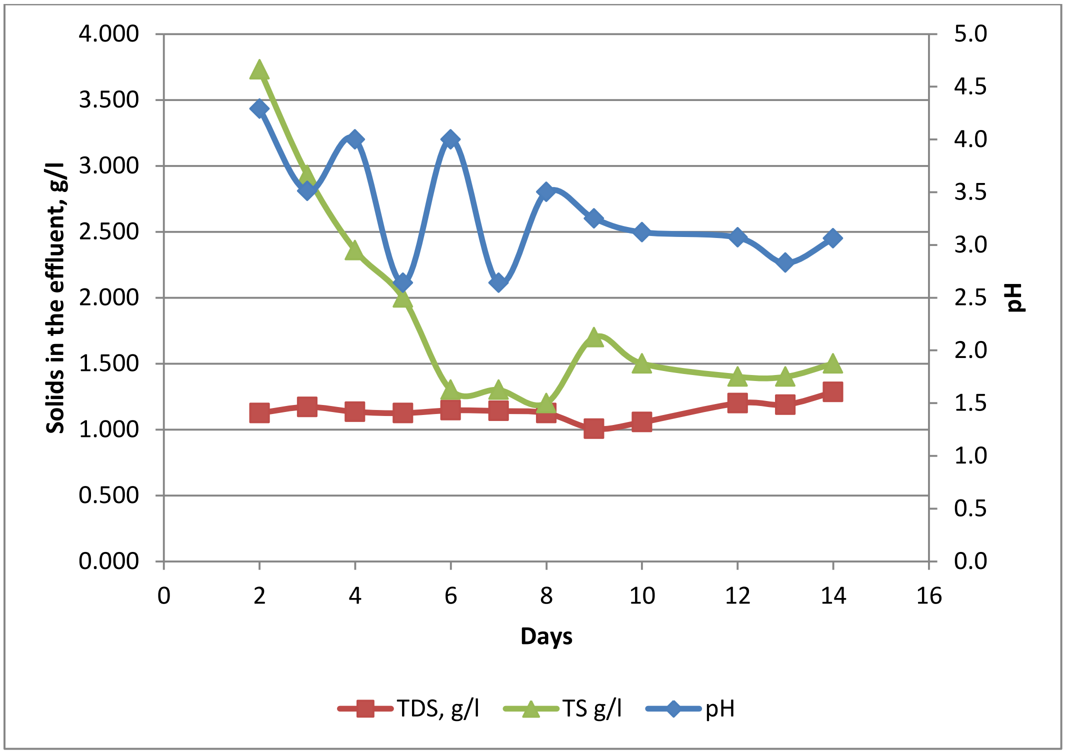
APPENDIX B
TREATMENT OF THE COFFEE EFFLUENT



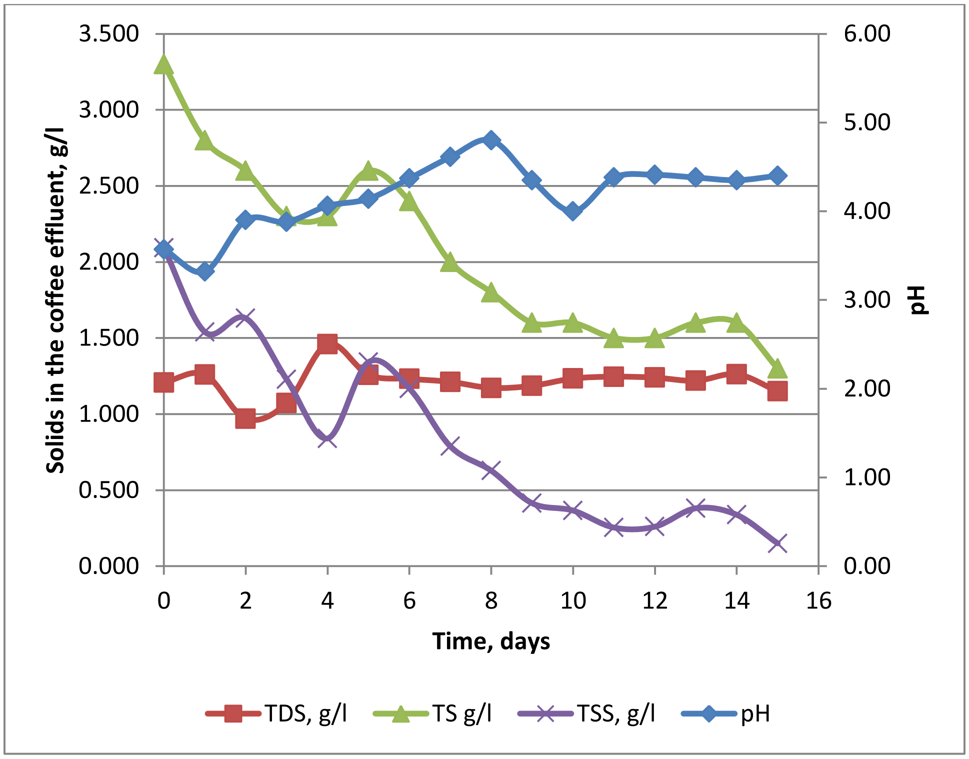
Appendix B1: Decay of pH in 3 batches of pulping effluent against time after pulping



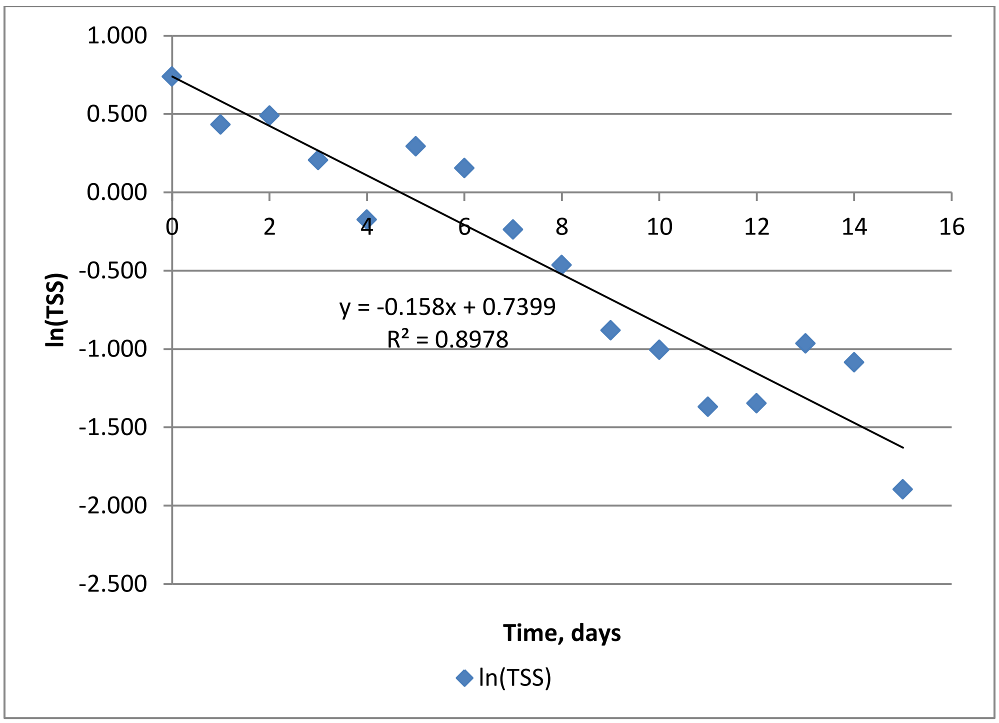
Appendix B2: Changes in solids and pH levels in an effluent batch against time after pulping.



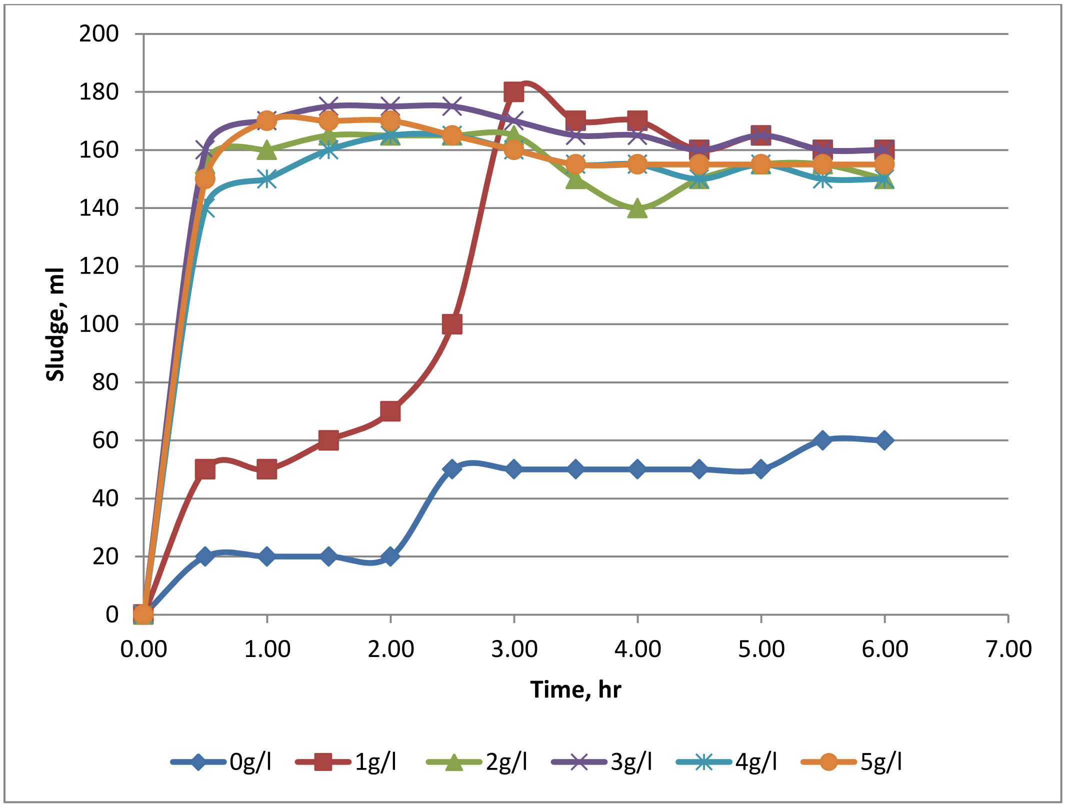
Appendix B3: Solids and pH levels the pulping effluent against time after pulping.



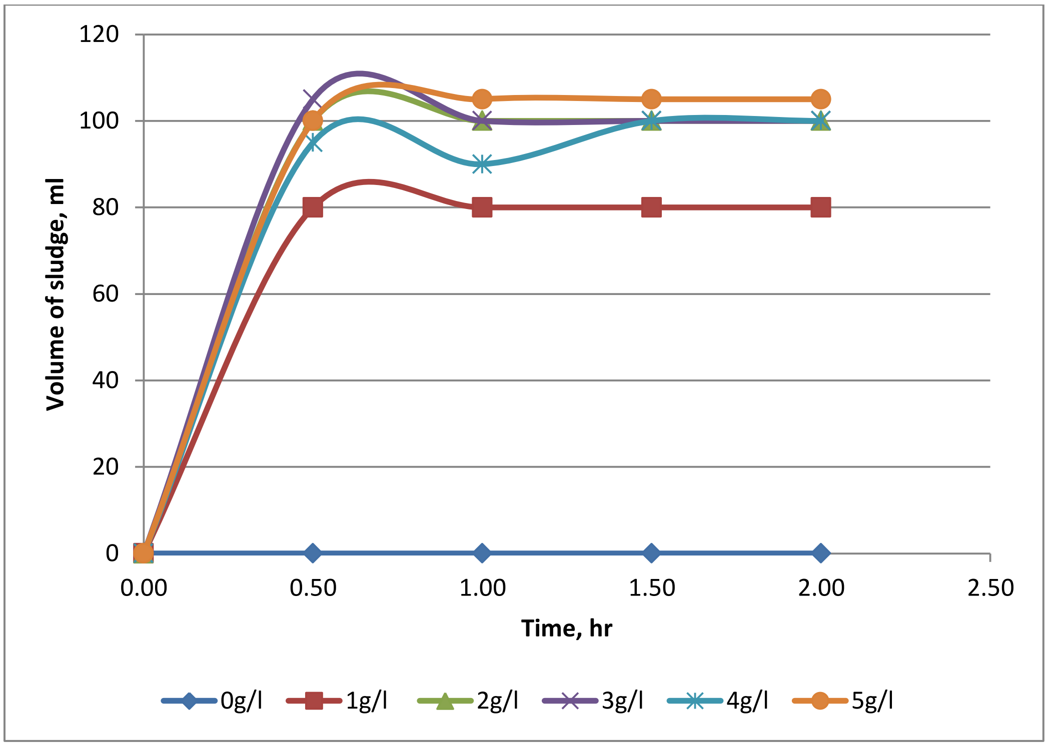
Appendix B4: Solids and pH in the effluent against time after pulping.



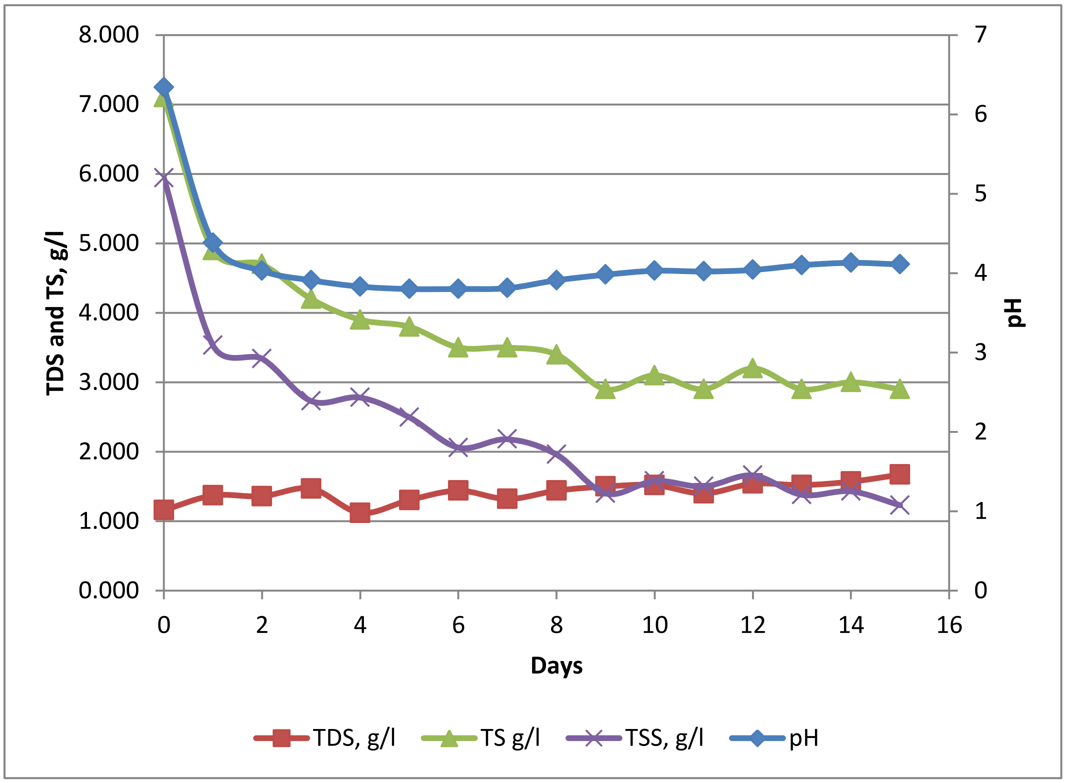
Appendix B5: Regression of ln(TSS) on time (t, days) after pulping



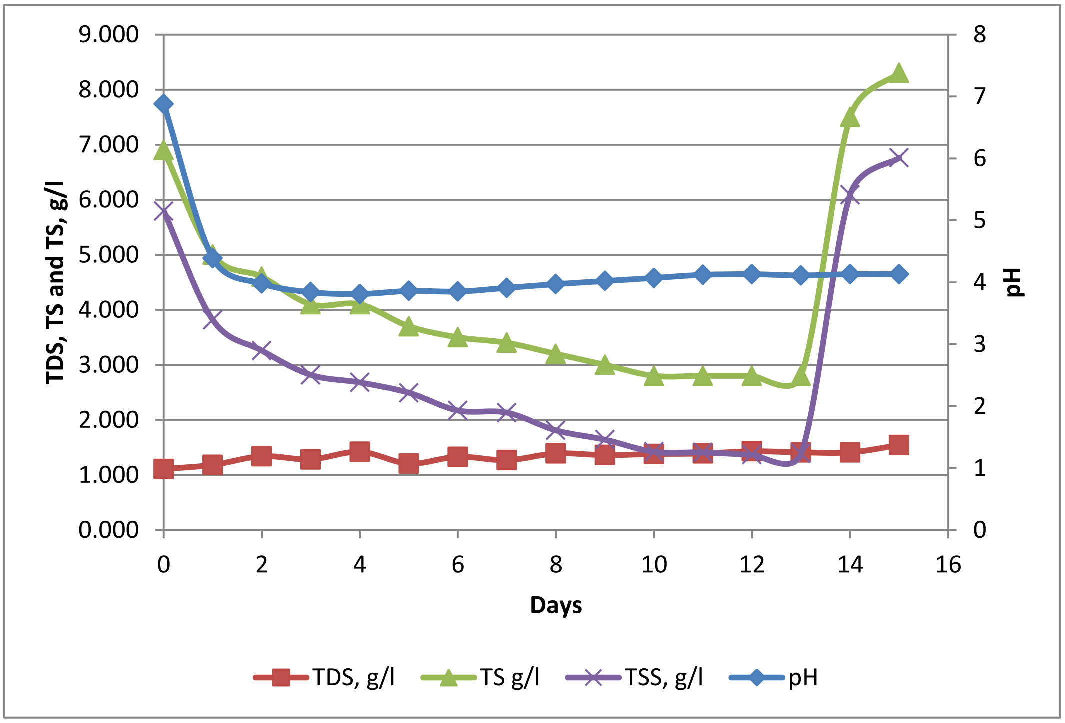
Appendix B6: Removal of solids from the pulping effluent after treatment with lime at different rates



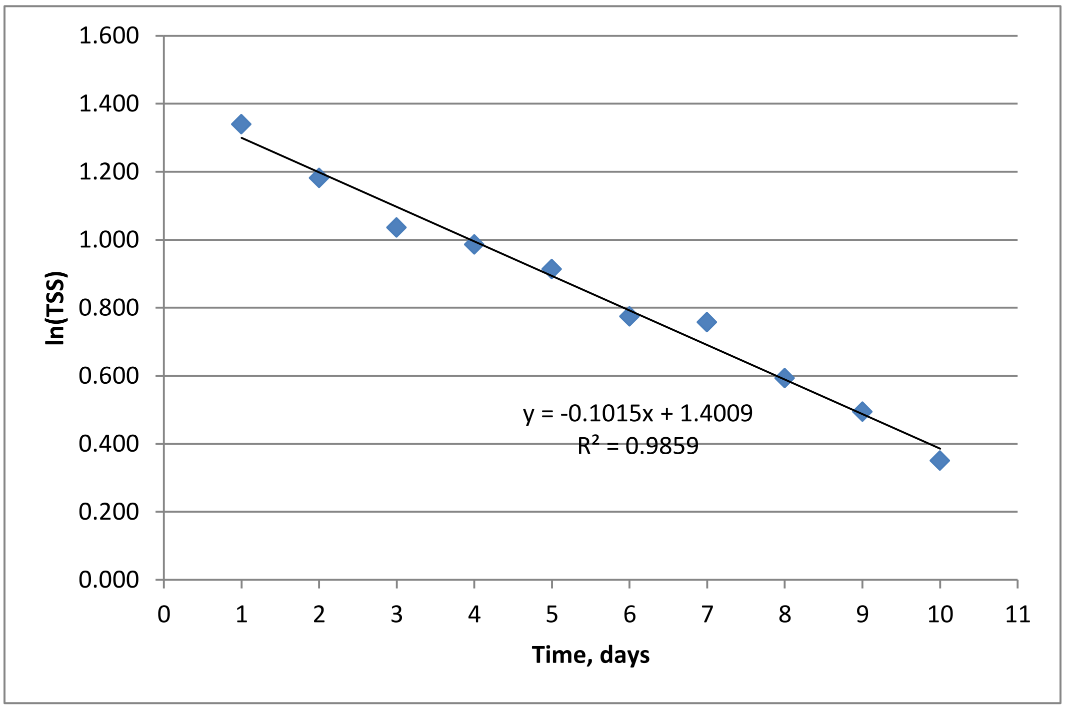
Appendix B7: Removal of solids from the pulping effluent after treatment with lime at different rates.



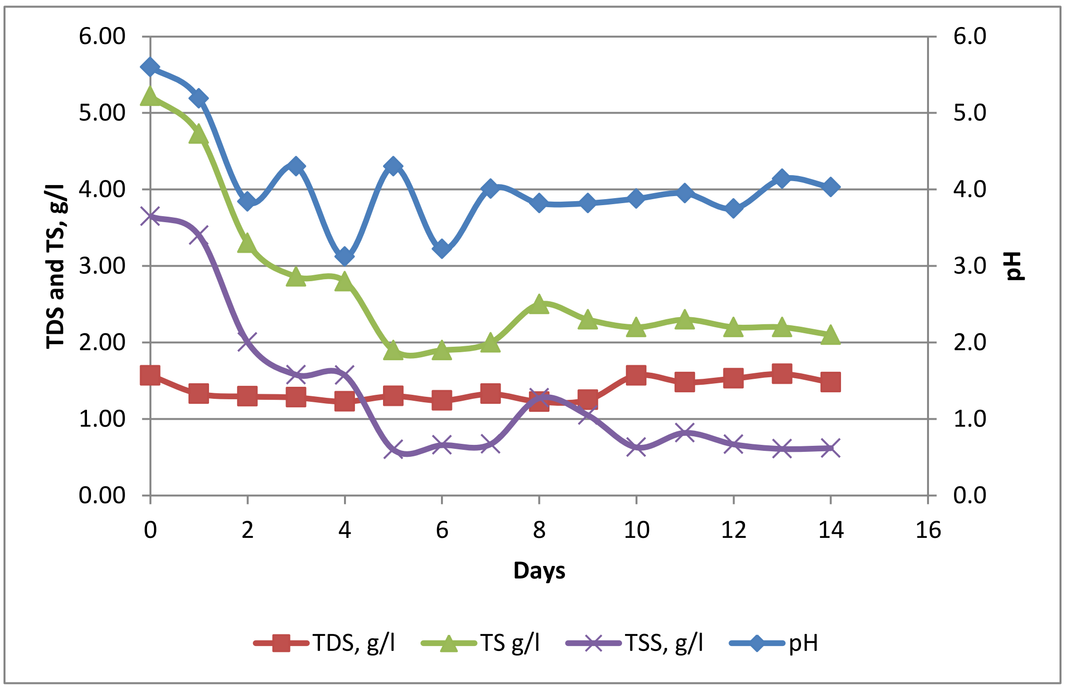
Appendix B8: Residual levels of solids in the pulping effluent after treatment with Lime



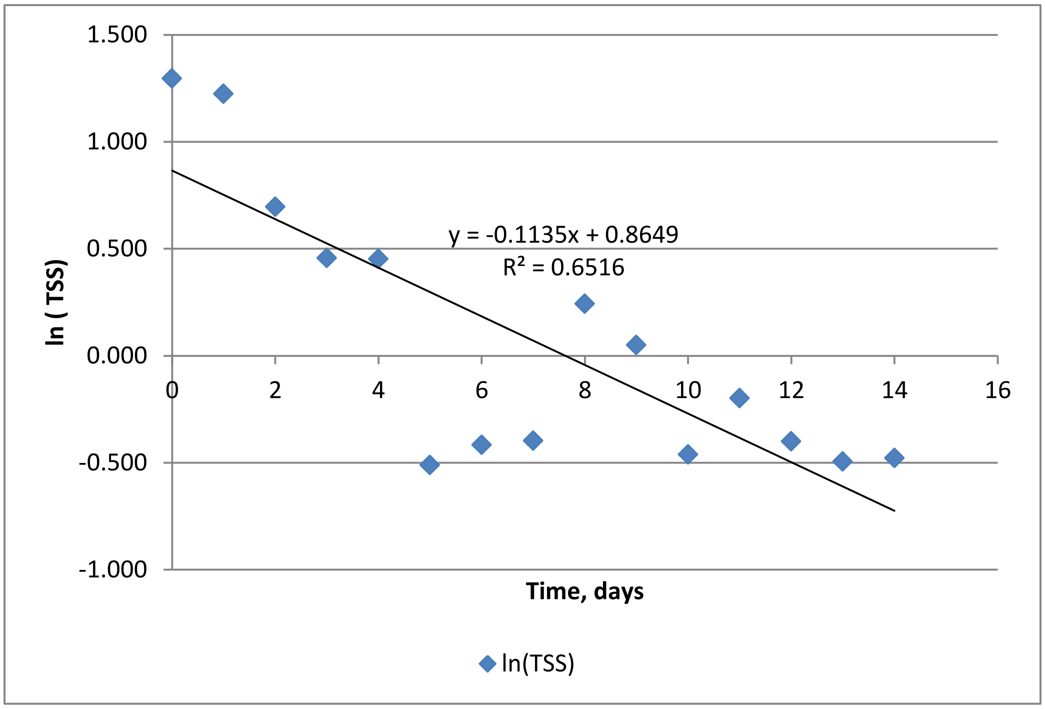
Appendix B9: Residual levels of solids in the pulping effluent after treatment with Lime.



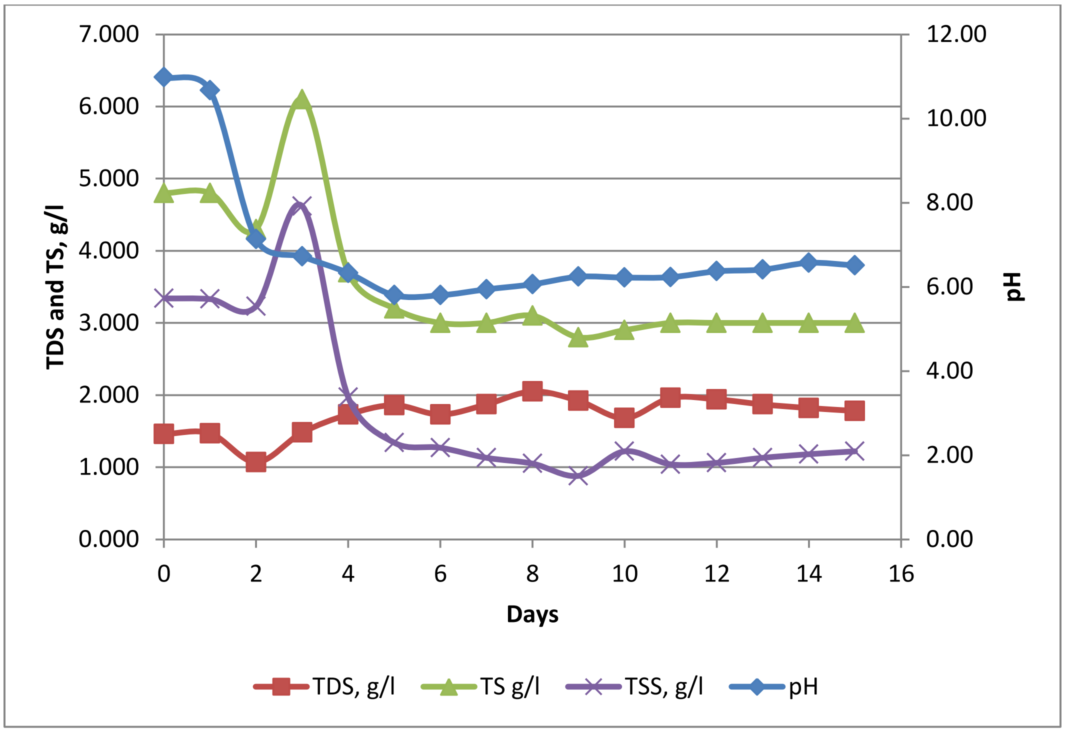
Appendix B10: The regression of ln(TSS) on time (t, days) after treatment of the pulping effluent with lime.



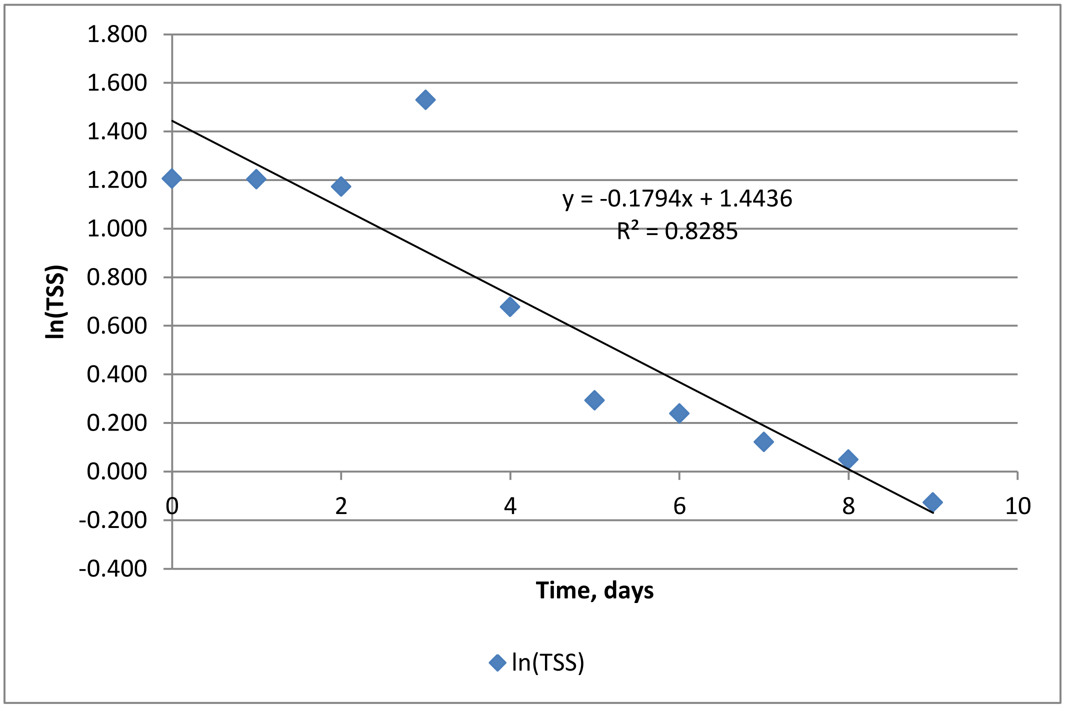
Appendix B11: Residual levels of solids in the pulping effluent after treatment with Lime.



Appendix B12: The regression of ln(TSS) on time (t, days) after treatment of the pulping effluent with lime.



Appendix B13: Residual levels of solids in the pulping effluent after treatment with Lime.



Appendix B14: The regression of ln(TSS) on time (t, days) after treatment of the pulping effluent with lime.

Appendix B15: Treatment of pulping effluent

Treatment	Days	T ^{o}C	pH	TS g/l	TDS, g/l	TSS, g/l	Days	T, ^{o}C	pH	TS, g/l	TDS, g/l	TSS, g/l
None	2	20.5	4.29	3.730	1.125	2.605	8	21.9	3.50	1.200	1.124	0.076
None	1	20.3	4.25	1.500	0.474	1.026	5	18.4	3.92	0.500	0.150	0.346
None	1	11.4	5.80	4.340	1.520	2.820	6	22.1	4.00	1.300	1.145	0.155
None	1	25.4	4.93	6.200	1.179	5.021	10	23.0	3.15	2.400	1.184	1.216
None	1	22.3	2.72	3.700	0.484	3.216	4	22.5	3.36	2.600	0.171	2.429
None	1	22.2	3.57	3.300	0.272	3.028	10	21.2	4.35	1.600	0.250	1.350
None	0	26.4	6.44	5.850	1.094	4.756	3		3.39	2.030	1.049	2.545
None	1	19.8	4.55	4.630	1.106	3.524	5	24.4	3.12	2.770	1.143	1.627
Cement	1	10.4	5.80	4.500	1.500	3.000	8	21.5	4.74	1.600	1.400	0.200
Cement	1	10.4	5.80	4.500	0.563	3.937	8	21.5	4.74	1.600	0.463	1.137
Cement	1	24.4	8.17	7.900	1.226	6.674	10	21.3	3.49	3.600	1.530	2.070
$Ca(OH)_2$	1	23.4	12.96	7.800	2.260	5.540	15	23.4	12.44	2.600	1.760	0.840
$Ca(OH)_2$	1	25.2	12.96	8.100	2.170	5.930	13	22.8	12.61	3.200	1.780	1.420
$Ca(OH)_2$	1	9.4	5.70	5.050	1.550	3.500	11	20.4	12.74	3.700	2.490	1.210
Lime	1	9.8	5.60	5.220	1.570	3.650	6	22.1	4.30	1.900	1.300	0.600
Lime A	1	23.0	6.88	6.900	1.107	5.793	11	23.1	4.07	2.800	1.380	1.420
Lime B	1	24.6	6.34	7.100	1.160	5.940	10	22.4	3.98	2.900	1.500	1.400
Magmax	1	24.6	6.14	7.300	1.164	6.136	12	23.2	4.01	3.000	1.620	1.380
Lime	1	9.8	5.60	5.220	1.570	3.650	15	21.9	4.03	2.100	1.480	0.620
$Ca(OH)_2$	1	9.4	5.70	5.050	1.550	3.500	11	20.4	12.74	3.700	2.490	1.210

Appendix B16: Characteristics of raw and treated effluent

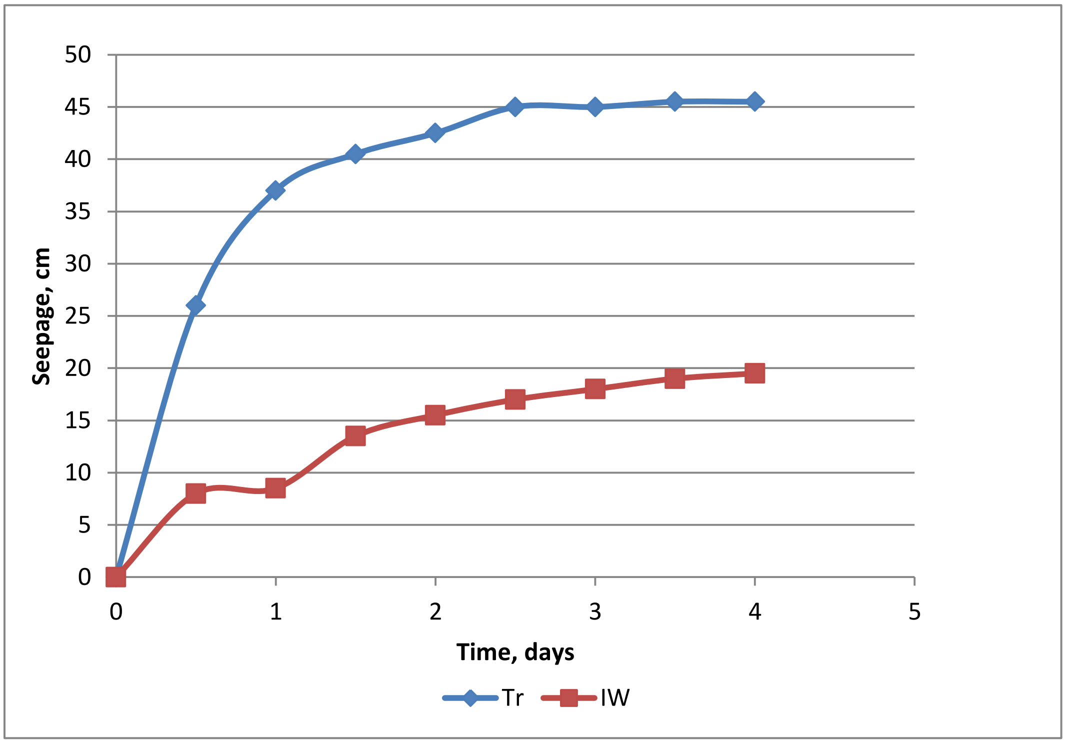
Initial status of the effluent			Treated Effluent		
pH	TDS, g/l	TS, g/l	pH	TDS, g/l	TS, g/l
5.70	1.230	5.040	3.64	1.500	3.150
4.64	1.460	8.160	3.78	1.400	1.590
5.23	1.420	7.460	3.81	1.430	3.970
3.87	1.560	9.110	3.65	1.460	3.760
4.26	1.440	9.560	3.74	1.360	2.860
4.89	1.400	6.750	3.69	1.271	1.910
5.80	1.420	2.840	4.00	0.944	1.560
3.90	1.540	4.050	3.85	1.121	1.595
5.36	1.370	8.920	3.43	1.500	3.200

Appendix B17 The TSS and pH of the raw and the lime treated pulping effluent, solids removal (%) and the resident time.

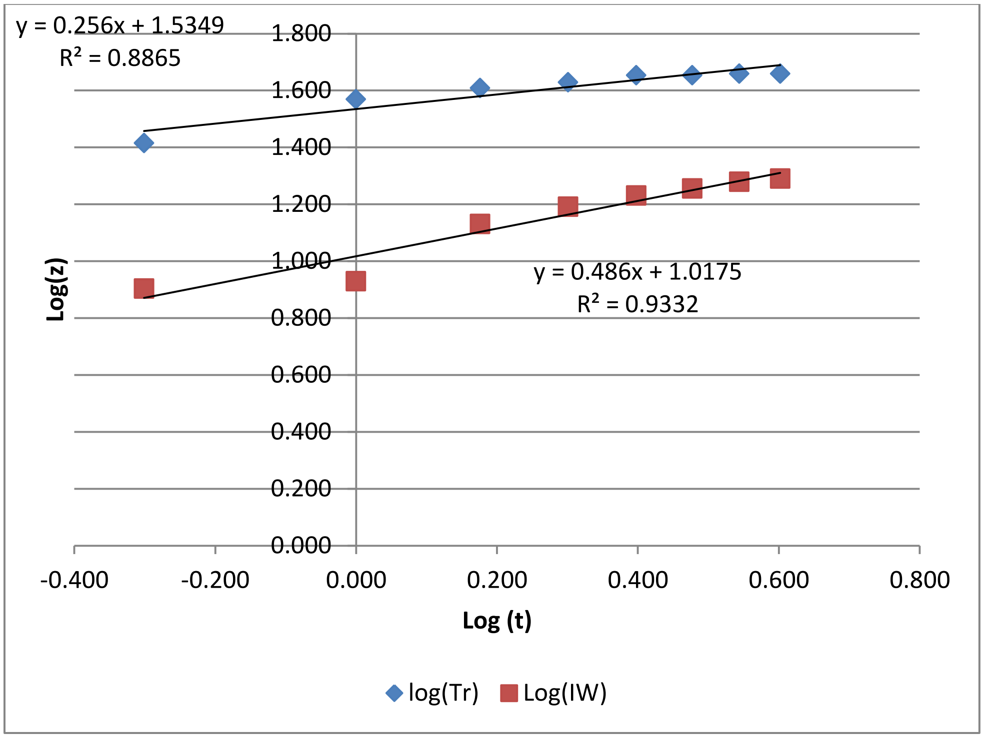
pH	TSS, g/l	Days	pH	TSS, g/l	%TSS
5.70	3.500	11	12.74	1.21	65.429
5.60	3.650	15	4.03	0.62	83.014
12.96	5.540	15	12.44	0.84	84.838
6.88	5.793	11	4.07	1.42	75.488
12.96	5.930	13	12.61	1.42	76.054
6.34	5.940	10	3.98	1.40	76.431
6.14	6.136	12	4.01	1.38	77.510
5.60	3.650	6	4.30	0.60	83.562

APPENDIX C

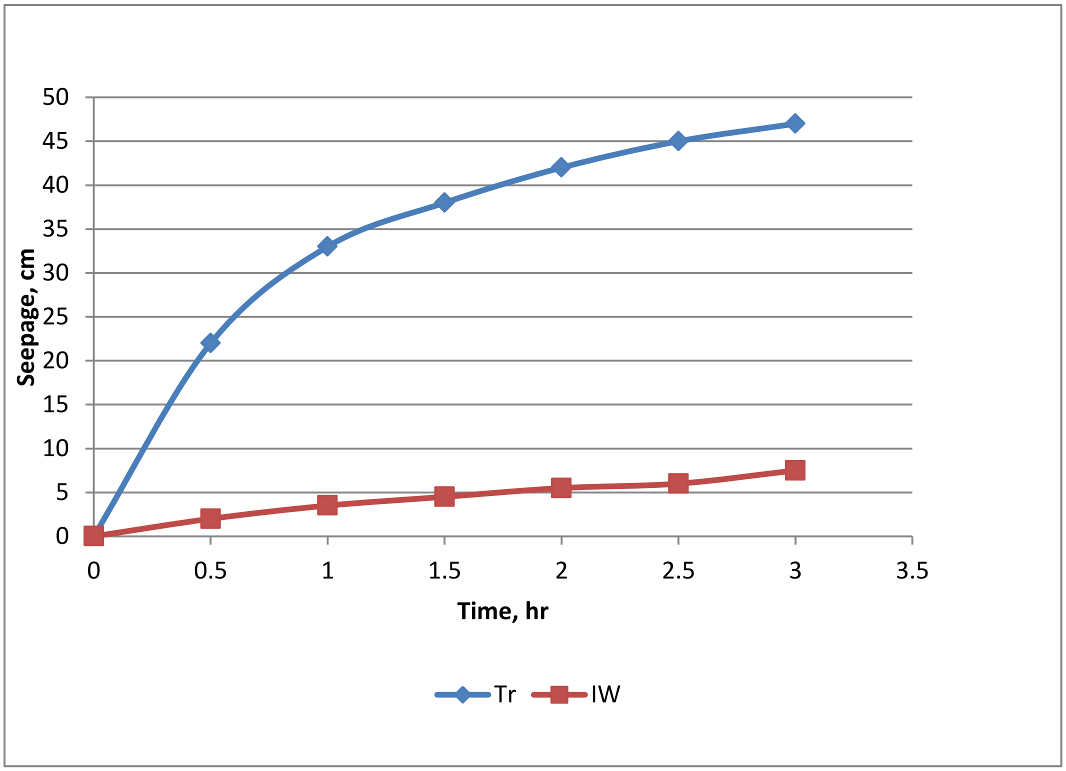
SEEPAGE OF RAW AND TREATED COFFEE PROCESSING EFFLUENT



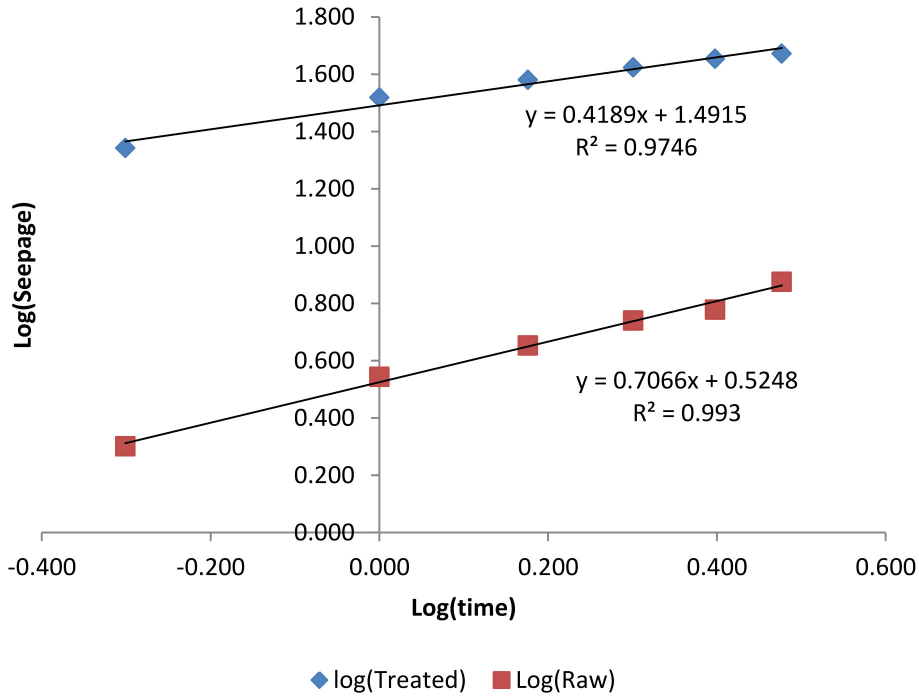
Appendix C1: Seepage of raw (IW) and treated (Tr) coffee effluent



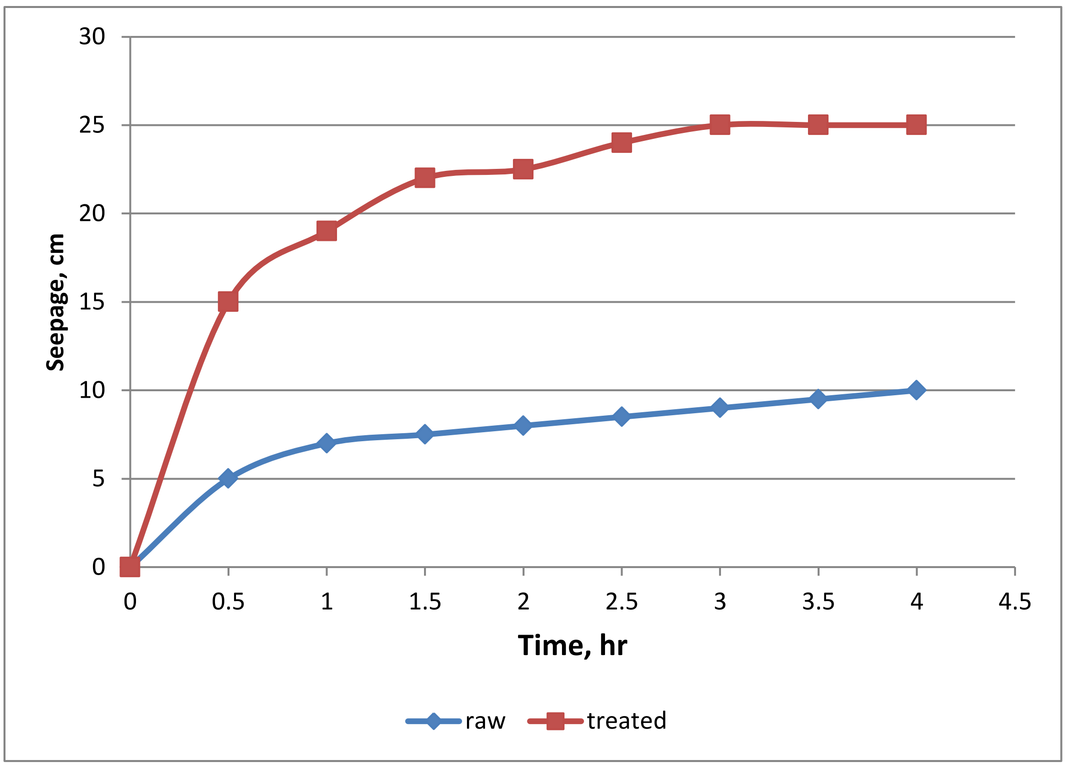
Appendix C2: Regression of log(z) on log(t) for raw and treated coffee effluent



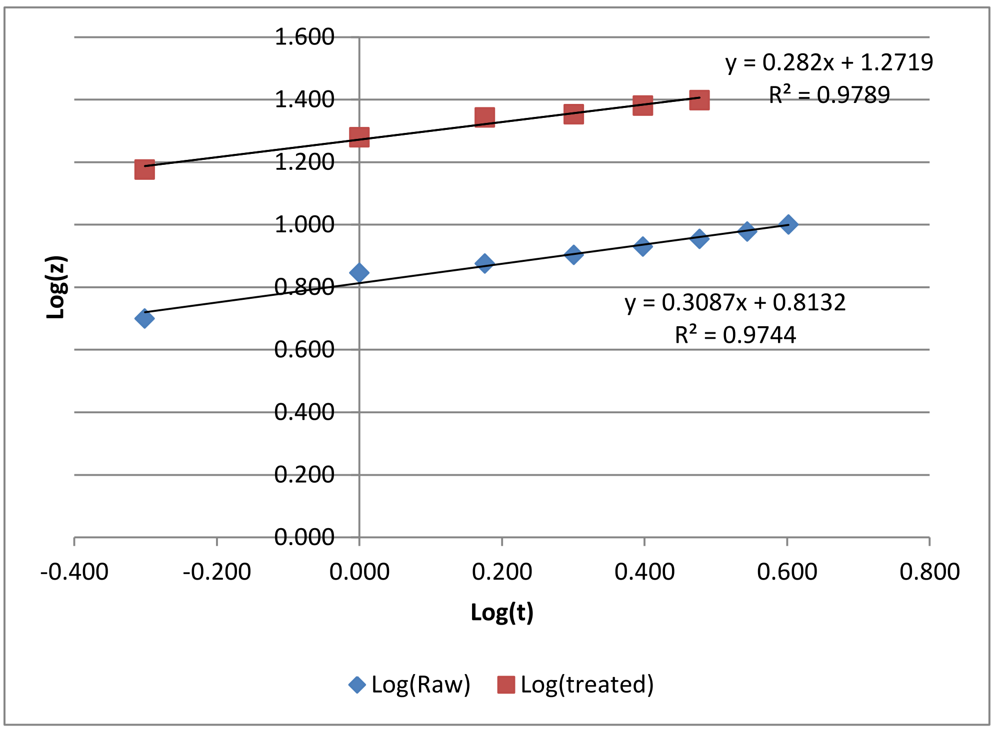
Appendix C3: Seepage of raw and treated coffee effluent



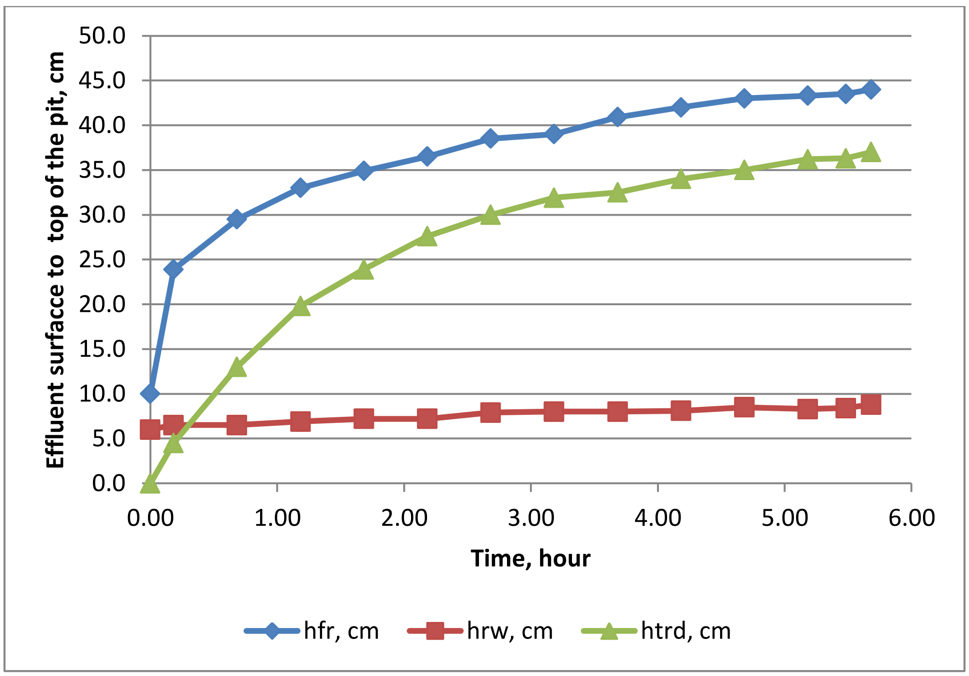
Appendix C4: Regression of log (z) on log (t) for seepage of raw and treated coffee effluent.



Appendix C5: Seepage of raw and treated coffee effluent



Appendix C6: Regression of log (z) on log (t) for seepage of raw and treated coffee effluent.



Appendix C7: Seepage of raw and treated coffee effluent

Key: hfr Depth to the surface of fresh water in the pit
Rw Raw effluent
Trd Treated effluent