ANAEROBIC TREATMENT OF COFFEE WASTEWATER

A STUDY ON MONITORING AND IMPLEMENTATION OF BIOGAS AT FINCA EL SOCORRO, MATAGALPA, NICARAGUA

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COLOPHON

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PREFACE

After completing my bachelor degree in Civil Engineering, I found myself increasingly interested in the treatment of water. Thus I joined the Master of Sanitary Engineering. This master's track is part of the Water Management branch in which a student at Delft University of Technology (DUT) can take part. After completing my internship in a water purification plant in Panama, I was curious about how it would be to undertake some research in wastewater treatment. The opportunity arose for me to conduct a minor thesis in Nicaragua and was of particular interest to me because the work is done with the aim of improving the water quality for the inhabitants of Matagalpa, Nicaragua.

The research conducted in Matagalpa is part of the Aqua for All (A4A): Agua para Todos, Agua para Siempre (ApT-ApS) program. It is financially supported by Stichting Nederlandse Waterschap Bank (NWB), DGIS and the Municipality of Matagalpa. Personal support is given by Dutch Water boards such as Waterschap de Dommel and Hoogheemraadschap Stichtse Rijnlanden, Lettinga Associates Foundation (LeAF), students of different institutes of Dutch Higher Education and permanently for a period of 4 years by Nicaraguan engineers of the Environmental Office of the municipality of Matagalpa (DIMGARENA). The program has three main focus areas, which are: "Drinking Water and Sanitation", "Integrated Resource Management" and "Coffee Wastewater Treatment".

This report gives insight into the anaerobic wastewater treatment of coffee wastewater. More specifically, it gives a short description about the coffee processes which take place when converting coffee cherries into coffee beans. Furthermore, it explains the way in which the coffee wastewater is treated in order to address and improve the detrimental consequences related with the wastewater from coffee plantations in Finca El Socorro. Besides, the monitoring of this anaerobic wastewater treatment is described in this report as well as the expected biogas production and its potential benefits.

The work that has been done would not have been possible without the assistance, hospitality and encouragement of many people: among others, the engineer Roger Iván Rodriguez who was of great help during the fieldwork. Juana Maria Garcia and internship students Katia Linarte and Ana Luquez who were helping in the field and in the laboratory stationed at the DIMGARENA office. I also would like to thank the workers of the finca Constantino Rodríguez, Pedrito and José as well as the owner of the finca, Mr. Raúl Blandón. Finally, I am indebted to the Adventist Church of Matagalpa and the Nicaraguan people themselves; who with their experience, patience and motivating spirit contributed to my work.

I am also grateful to Dr. Joost Jacobi, Dr. Oscar van Zanten and Dr. Tonny Oosterhof for their willingness to help and their considerable efforts in securing a working place for me at the DIMGARENA office. Lastly, I would like to express my gratitude to Prof. Jules van Lier who provided me with enough theoretical background to complete the thesis.

SUMMARY

In order to achieve the Millennium development goals of the UN, different initiatives have been established worldwide. One of these initiatives has been developed in Matagalpa, Nicaragua. Through the program Agua para Todos – Agua para Siempre different institutions work together, the common goal being to provide safe drinking water and sanitation to a large number of the people of Matagalpa and the surrounding areas. One of the ways in which this goal is pursued is by installing wastewater treatment systems for demonstration purposes in order to reduce the contamination produced by the coffee processing industry. This industry is, at present, the major cause of pollution of open water sources in the Matagalpa province. Therefore, a new hybrid anaerobic wastewater treatment system has been developed: an improved anaerobic lagoon (LAM, because of the Spanish acronym).

One of the main objectives of this report is to throw light on the way in which such a system works and to also recommend to coffee farmers the set up size that is recommendable when installing a LAM system. In addition, the possibilities for locally integrating the use of biogas produced in the LAM system is a question that is discussed in this thesis. For this purpose, a LAM system has been installed in a medium-sized coffee farm called El Socorro.

In the period between November 2009 and January 2010, measurements were made of key parameters in El Socorro which indicate the efficiency and working of the LAM system, together with pre-treatment and post-treatment. In previous harvest seasons other students have conducted work on the characterization of coffee wastewater and this data, together with the data obtained during the last harvest season will help in providing answers to the objectives stated in the previous paragraph.

During the fieldwork unforeseen restrictions were encountered which were ultimately responsible for reducing the quantity of data below that which was anticipated. However, with the information gathered, it was obvious that in the last harvest season the lack of lime for neutralizing the coffee wastewater was a serious problem that inhibited the proper working of the biomass in the LAM system. Therefore, no biogas production took place at all. The biogas production, which should have been measured during the fieldwork, could not be measured due to prolonged delays. This is why many theoretical calculations and assumptions need to be made in order to come up answers to the questions posed by this thesis.

Measurements of wastewater revealed an average pH value of 4.9. In order to elevate this value, a base is needed which elevates the alkalinity of the wastewater. In this report two bases are studied: calcium hydroxide and calcium carbonate. From these two bases the conclusion is drawn that calcium carbonate, even when it has to be applied in larger quantities, has the preference due to the substantial difference in costs (US$ 0,49 cheaper per produced quintal oro).

The estimated biogas production, which to a large extent had been based on assumptions concerning coffee wastewater, is much lower when measured values are used to calculate methane production. Therefore, instead of the anticipated 17.5 m^3/d of CH_4, only 2.4 m^3/d could have been produced in the last harvest season. This production is not enough to run engines and can only at best be used to cook. If this application is not possible then the only option left is to flare the biogas.

At the end of the report a graph is presented in which it is shown how different coffee farmers can get an impression of how likely the successful implementation a LAM system in their coffee farms is, which not only prevents fines (by treating the wastewater), but also renders profit from biogas production in larger quantities.

ABBREVIATION LIST

A4A	Aqua for all
APT-APS	Project Agua para todos – Agua para siempre (Water for all – Water forever)
DIMGARENA	Dirección Municipal de Gestión Ambiental y Recursos Naturales (Local Government on Environmental Resources Management for the province Matagalpa in Nicaragua)
FAO	Food and Agriculture Organization (United Nations)
INE	Instituto Nicaragüense de Energía (Nicaraguan Institute of Energy)
INEC	Instituto Nacional de Estadísticas y Censos (Nicaraguan Institute of Statistics and Census)
LeAF	Lettinga Associates Foundation (NGO)
MARENA	Ministerio de Ambiente y de Recursos Naturales (Ministry of Environment and Natural Resources of Nicaragua)
MIFIC	Ministerio de Fomento, Industria y Comercio (Ministry of Promotion, Industry and Commerce of Nicaragua)
MINSA	Ministerio de Salud (Ministry of Health of Nicaragua)
WHO	World Health Organization (United Nations)

AD	Anaerobic Digestion
AWWT	Anaerobic Waste Water Treatment
BOD	Biological Oxygen Demand (mg/l)
COD	Chemical Oxygen Demand (mg/l)
COD_{rem}	Removed COD (mg/l)
CWWT	Conventional Waste Water Treatment
Finca	Farm
LAM	Laguna Anaeróbica Mejorada (Improved Anaerobic Pond)
Lata	Unit of measure (20 latas = 1 QQ_{oro})
Libra (lb)	Pound
LAR	Laguna anaeróbica rústica (Rustic Anaerobic Pond)
Manzana	≈ 0.7 hectare
masl	Metres above sea level
Mc	Muestra compuesta (Mixed Sample)
PPT	Pila de pre tratamiento (Pre Treatment reservoir)
Q	Flow [m^3/d]
QQ	Quintal (45.3 kg)
QQ_{oro}	Quintal oro
QQ_{per}	Quintal pergamino
Repela	Cutting of the last grains in harvest season which did not mature completely
V_m	Molar volume of gas
VFA	Volatile Fatty Acids (mg/l)

INDEX

1. INTRODUCTION

This chapter provides a general background of Nicaragua and introduces the problem on which this thesis is based. After this, the research objectives are presented as well as the research questions for this minor thesis. In addition, the study area is delineated together with the scope of the research. Finally the structure of the report is presented.

1.1 GENERAL INFORMATION

The research outlined in this thesis was developed in the city of Matagalpa, Nicaragua (see figure 1.1). This city is localized in the northern zone of Nicaragua in the province of Matagalpa which in turn is one of the most

Figure 1.1 Nicaragua (Source: http://maps.google.nl)

mountainous areas of the country. The official height at which the city is situated is 681 masl. The temperature in Matagalpa oscillates between the 16° and the 25° Celsius[I]. Its climate can be categorized as subtropical. The annual average rainfall is 1469 mm. However, the majority of the rainfall falls in the rainy season that stretches from May until December[II].

The province of Matagalpa is the second most productive province of the country as well as the second most populated province after the capital province. In the last census conducted in 2005 the total population in the province was 469 172, while the total population in the city reached 133 416 inhabitants[III]. The principal source of income for the province is the production of coffee. Almost 80% of all coffee production in Nicaragua stems from the provinces of Matagalpa and Jinotega. In addition, the production of corn and beans complement the region's economy. In the North-Eastern part of the city two sub catchments can be distinguished: Molino Norte and San Francisco (see figure 1.2).
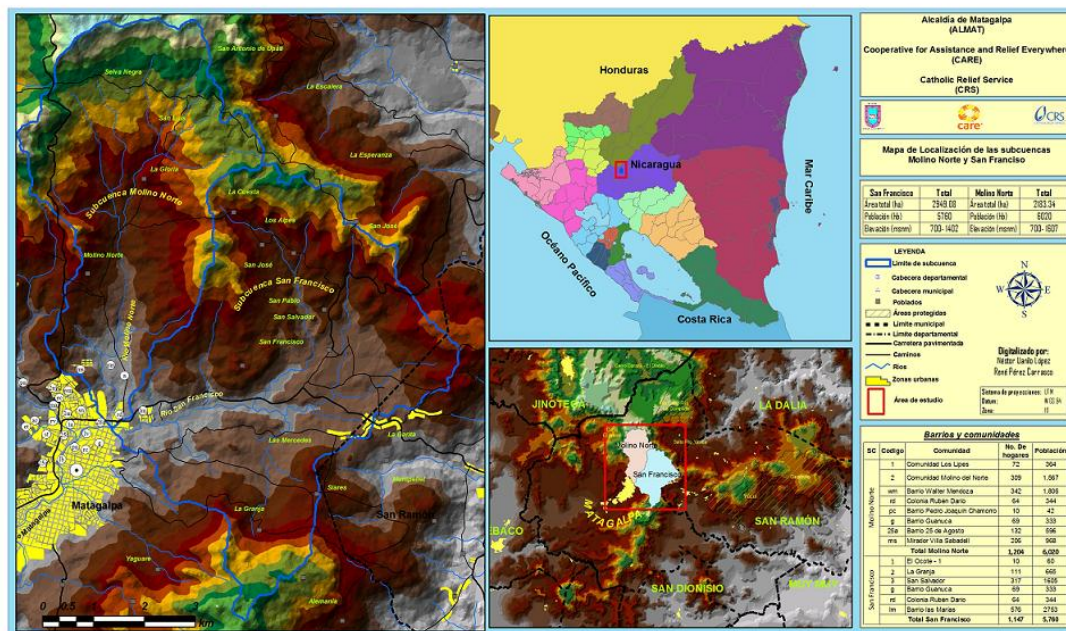
Figure 1.2, localization of sub catchments of Molino Norte and San Francisco

[I] ALCALDÍA DE MATAGALPA
[II] IRENA, 1992
[III] INEC, 2006

The water that drains these two sub catchments comes together just upstream of the city of Matagalpa and takes the name of Rio Grande de Matagalpa. The river passes through the city before turning in eastward direction heading to the Atlantic Ocean where it finally discharges its water, approximately 20 km north of the Laguna de Perlas.

1.2   PROBLEM DEFINITION

In previous times, the source water for the purification plant was extracted from the rivers of San Francisco and Molino Norte. Given the high level of contamination of the river San Francisco this source is not utilized any longer. To a large extent the contamination of the river is brought forth by the aguas mieles (coffee waste water: including the water needed for the washing of fermenting beans and for the de-pulping process). In addition, untreated domestic wastewater and cattle breeding also contribute to the contamination.

In 2003 the project, with the aim of providing potable water to the cities of Matagalpa and Jinotega was finalized (project MaJiCo). The source which is being used in this project is groundwater from the Sébaco Valley (water extraction through wells)[IV]. Currently, 58% of the water treated and distributed in Matagalpa comes from the Sébaco Valley and 42% from the river Molino Norte (see figure 1.2).

The fact that the water which requires treatment has to be transported over 23 km and that the height to which the water has to be pumped exceeds 200m results in one of the highest water tariffs in Nicaragua. In addition, it is calculated that with the actual pumping station, and the water balance in the area (natural recharge – extraction), the water will not be able to be pumped in the same quantities in 10 years from now (2020). Furthermore, agricultural activities in the region are deteriorating the water quality in the area. This poses a serious problem for the city of Matagalpa, which has a population growth rate of 4% according to Heller (2008). There is also evidence of a decrease in the water flows upstream of Matagalpa, which is a serious concern for the river of Molino Norte[V]. The reduction in water flow can be attributed to deforestation in the upstream zones, which to a large extent is motivated by expansion for cattle breeding. This in turn causes soil erosion. When this soil erosion takes place, the water can no longer be retained for much time in the subsoil and passes as run-off to the river. In the rainy season, this can eventually lead to great river floods and subsequent danger for people living on the banks of the river.

As a response to the goals set up in March 2000 by the United Nations to reduce extreme poverty in the whole world by the year 2015, the Agua para Todos – Agua para Siempre (ApT-ApS) project was initiated in Matagalpa. This program involves Water Boards, Universities and an NGO; all of which are Dutch participants. The majority of the funds come from the Netherlands while local funds contribute the outstanding amount.

Within the program APT – APS, three working lines can be distinguished which aim to increase the availability of water as well as the sanitation in the area. By doing this, the living conditions of the inhabitants of the sub catchments Molino Norte, San Francisco and the city of Matagalpa are improved. Consequently these three working lines are:
- potable water and sanitation (distribution of water in at least 6 micro systems, safe excreta deposition in latrines and rustic systems to treat household wastewater onsite),
- integrated water management at catchment level (to ensure the continuity of potable water for Matagalpa) and,
- the treatment of coffee wastewater in at least 6 demonstrative systems.

This minor thesis focuses on the last working line of the APT-APS program. In 2006 a study was conducted by Marko Sas in which he categorized the different types of coffee plantations (farms = fincas) in Matagalpa and the surrounding areas. In this study a distinction was made between big farms, middle-sized farms and small farms[VI]. After this thesis, two other theses were written by Boudewijn Zuijderhout in which an answer was sought for the questions: "Which are the most appropriate farms to install the demonstrative coffee wastewater systems?"[VII] and, "What type of ecological wastewater system could be applied on these farms?"[VIII]

[IV] EDDY KÜHL, 2000
[V] PERSONAL COMMUNICATION: ING. GARCÍA, J. M.
[VI] SAS (2) P. 17-19, 2006
[VII] ZUIJDERHOUT (2), P. 71, 2008
[VIII] ZUIJDERHOUT (1), P. 53, 2008

1.3   RESEARCH OBJECTIVES

The principal objective of this research is to get to explore if "basic technologies of anaerobic systems can be applied with good results in the so called development countries for the treatment of coffee wastewater".

Alongside the principal objective 2 sub-objectives can be highlighted:
- Provide coffee farm owners with information about the operation and maintenance of anaerobic digestion systems,
- Provide the APT-APS program with a study based on the results of the first demonstrative system in Matagalpa and to give interested persons more information about the coffee wastewater treatment in the farm El Socorro.

1.4   RESEARCH QUESTIONS

From the principal objective and as a guide for the thesis the next questions are posed:
- Which monitoring parameters are needed in order to guarantee safe operation and control of AWWT?
- What are the minimum dimensions of the anaerobic treatment to be profitable in energy production?
- Which local possibilities are present to utilize the produced biogas?
- Which efficiency should be fulfilled by the different processes in order to come to an acceptable effluent quality?
- How robust are the subsequent processes linked to each other?

1.5   STUDY AREA

After the thesis of Zuijderhout, in 2008, a start was made into building the first demonstrative system for the treatment of coffee wastewater. This took place in the farm El Socorro, property of Mr. Raúl Blandón, inhabitant of Matagalpa. Making use of the categorization proposed by Sas, the farm of Don Raúl can be placed among the middle-sized farms. The total area of the farm is 60 manzanas (approx. 42 ha.), of which 40 manzanas (28 ha) are cultivated with the species *coffea arabica.* Another part of the farm constitutes of a stone quarry from which stones were extracted to revet the road that connects the farms wet mill (beneficio húmedo) to the main road. A small part of the farm is still covered with forest. The exact localization of the farm has the coordinates 14°32'83" North and 62°18'04" East[IX]. The altitude at which the farm lies varies from the 850 to the 930 masl. Figure 1.3 shows the shape and geographical position of the farm.

Figure 1.3, Coffee farm El Socorro and wet mill in the middle, Source: http://maps.google.nl

In the north, east and south the farm borders with the property of César Calero (owner of farm Cueva del Tigre). In the west the farm borders with the farm of Mr. Salomón Carillo and at the north-west the cooperative

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[IX] *HELLER, M. P. 15, 2008*

San Jose is found. The farm is 25 minutes away from the DIMGARENA office (15 km), which is the institution where the research partly took place.

1.6   SCOPE OF RESEARCH

Some of the restrictions limiting the research were encountered in the project itself, whereas others were local restrictions. Regarding the project restrictions, it is unfortunate that the way in which the efficiency of the anaerobic treatment and the subsequent system were analyzed (through water samples) was not continuous. The lack of availability of the reagents on key moments negatively influenced the results. Also, the lack of transportation means meant that the research could not be carried out as extensively as previously had been anticipated. Local restrictions such as weather conditions affected the harvest season considerably in 2009/2010, terminating the coffee harvest much earlier than anticipated. Furthermore, on the date of leaving Nicaragua (31 March 2010), the construction of the biogas holder had not been completed. Thus due to time constraints the research focuses mainly on wastewater treatment, leaving the solid waste treatment momentarily aside.

1.7   STRUCTURE OF REPORT

This report consists of seven chapters. The first chapter presents general information about Nicaragua together with the motivations that lead to the construction of wastewater treatment systems for coffee farms, and finally a number of restrictions relevant to this thesis are mentioned. The second chapter is devoted to coffee and explains the process starting with the fruit and ending with the export of coffee. Furthermore, the different kinds of wastes that come along during the production are discussed, as well as the detrimental effects of these wastes and the norms which try to prevent these effects. Chapter 3 focuses on the different kinds of wastewater systems that have been applied for the purification of wastewaters stemming from the coffee production. Finally, it shows various advantages concerning anaerobic wastewater treatment. Chapter 4 gives the theoretical background of the application of a hybrid system designed in the last decade (LAM system, Laguna Anaeróbica Mejorada). Chapter 5 looks back at the results obtained from the fieldwork that took place during the months of November 2009 through February 2010. Furthermore, this chapter also discusses the production of biogas and calculations of biogas are performed for the Finca El Socorro. Chapter 6 summarizes the previous chapters with sound conclusions and finally chapter 7 presents recommendations to LAM system holders and to the developers of the LAM system.

2. COFFEE PROCESS

This chapter presents a small review on the coffee process: from the moment when the grain is mature in the coffee plantation until it is ready to be exported. In addition, special attention is given to the water use and the contamination caused by it. At the end of the chapter an overview is shown of the laws governing Nicaragua in regarding the discharge of wastewater into open water courses.

2.1   THE IMPORTANCE OF COFFEE

Coffee is one of the most commercialized commodities worldwide. According to FAO coffee is among the 20 commodities that generated most money compared to other commodities in 2007. In total, 5.8 million tonnes were exported worldwide generating a value of 13.7 billion USD[X]. For Central America the coffee production is of vital importance for the economy of the countries. This is illustrated in table 2.1.

Table 2.1 Dependency on coffee revenues for Central American countries[XI]

Country	Coffee as % of Country's Export	Market Share as % of Total Exports
México	2,4	5,8
Guatemala	32,4	3,6
El Salvador	59,6	3,6
Honduras	21,2	2,1
Nicaragua	30,4	0,8
Costa Rica	20,7	2,9
Total		18,8

The cultivation of coffee is the most important source of income for a large part of the rural population. During times of harvest (plucking), thousands of families go to the coffee plantations to offer their cheap labour and in this way earn some money.

The coffee production in Nicaragua is minor on a worldwide scale (see table 2.1). The coffee production itself is shown in figure 2.1. The production relies to a large extent on the weather factors. Additionally, severe fluctuations over the years in the prices of coffee can be attributed to the fact that coffee is a commodity commercialized on the stock markets.
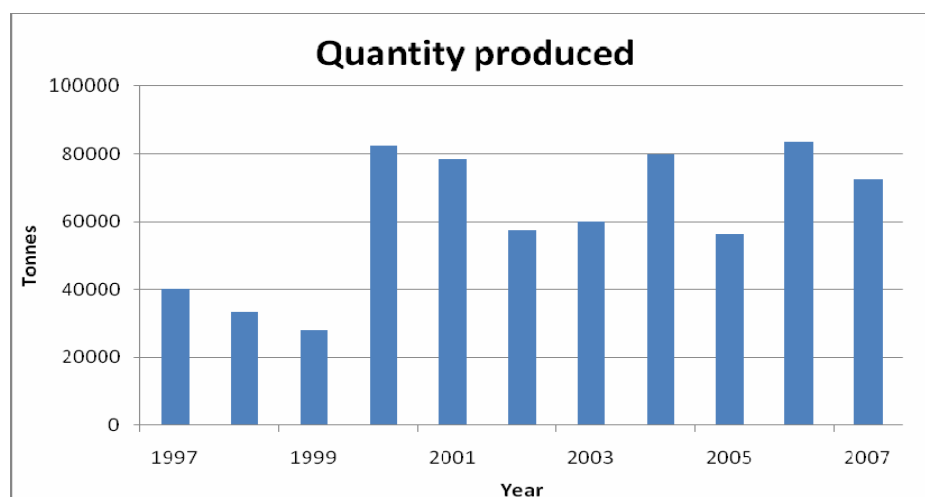
Figure 2.1, Coffee production in tones per year in Nicaragua (FAO)

In figure 2.2 the total revenues obtained during the last decade are shown (1997 to 2007). Prices are given in US$ x 1000. The major export partners of Nicaragua are shown in figure 2.3.

[X] *FAO STATISTICS, 2010*
[XI] *ADAMS, M.A. P. 88. 2006*
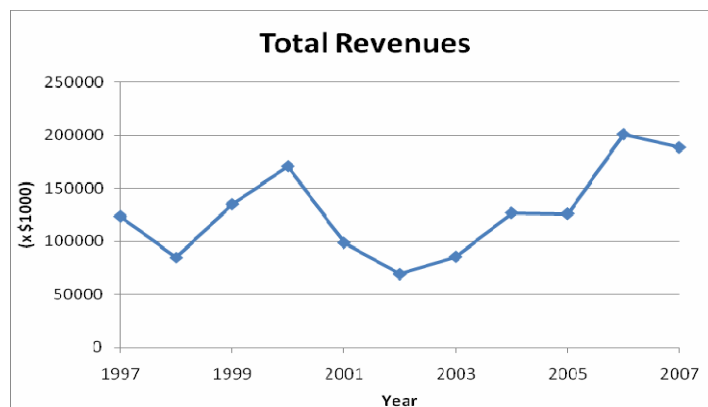
Figure 2.2 Annual revenues for Nicaragua from the export of coffee (FAO)
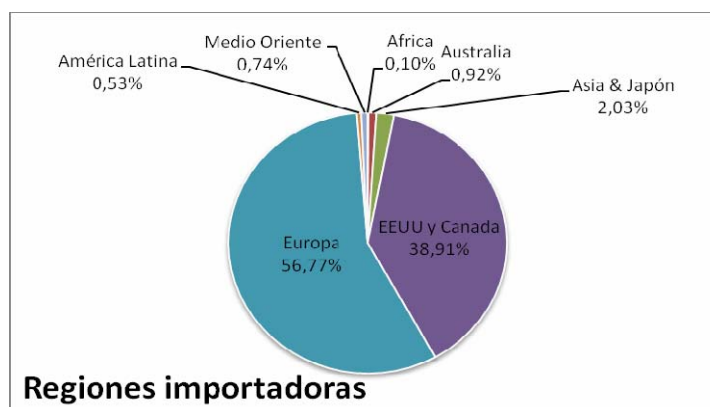
Figure 2.3 Regions of the world to which Nicaragua exports its coffee (FAO)

2.2   COFFEE PLANT

There exists a large variety of coffee plants. However, only two of them have been widely commercialized: the genus *coffea Arabica* and *coffea Canephora* (commonly known as *Robusta*). The first genus is categorized by its slow growth, delicate in growth and with less productivity rates than the *Robusta*; it is cultivated in mountainous regions between the 900 and the 2000 masl. The genus *Robusta* has higher production rates and it can be cultivated in less mountainous regions than the A*rabica*. The latter one characterizes itself for producing a fine and aromatic coffee[XII]. In Nicaragua the genus *coffea Arabica* is exported.

2.3   COFFEE FRUIT

The fruit or cherry from the coffee, as is shown in figure 2.4, consists of two grains which face each other with

their flat surfaces. Both grains are covered by the pulp (6) or mesocarp and the external skin (7) or epicarp. Each grain of coffee is covered by 3 layers, from the exterior to the interior these are: a layer of pectin (5), parchment (4) or endocarp and the silver skin (3) or spermoderm. Beneath these layers the green coffee bean is encountered. This is the way in which the coffee is traded in the market. Another name for this state in which the coffee is traded is coffee oro, expressed as QQ_{oro} (quintal oro = 45.3 kg of green coffee). In Nicaragua it is also used to sell the coffee in an earlier state as QQ_{per} (quintal pergamino), which is when the coffee bean still has the silver skin. In the coffee bean it is still possible to distinguish the central cut of the bean (1).

Figure 2.4 Coffee cherry structure

[XII] COFFEE RESEARCH (INTERNET)

2.4   BENEFICIOS (MILLS)

The harvest season lasts for approximately 90 days. During this season, the workers (cherry cutters) spend several days close to the same coffee plant cutting those grains that have matured (red). After filling one basket of grains they pour the grains in a bag which after being filled is brought to the mill where the grain is being processed. There are two different methods which can be used to process the coffee cherries: the dry mill and the wet mill.

2.4.1   DRY MILL

In the dry mill process, almost exclusively applicable to the genus *Robusta*, the grains are left in the open field to be sun-dried. After the grains have lost almost all their water content the cherries are grinded to eliminate the dehydrated mucilage, the pectin and the parchment.

In Nicaragua and Central America there is a certain ambiguity about the term "dry mill". Whereas in other countries this term is applied to the aforementioned method, in Nicaragua this term refers to the process the coffee beans undergo after having had the wet mill process.

2.4.2   WET MILL

The process in the wet mill begins by bringing the coffee cherries in the previously described bags (filled by baskets) to a reservoir. From here on the cherries are transported by gravity to the de-pulping machines. This step can be enhanced with water, or can be performed dry (more environmentally friendly) when the reservoir has been designed to this purpose[XIII]. In Nicaragua, the transport to the de-pulping machines is brought forth by water (and gravity). One major advantage of this method is that dirt, not-ripe and overripe grains will float on the water surface[XIV]. In the de-pulping machines the cherries are selected based on their size and de-pulped, which is the process in which the pulp and the outer skin are removed. There remains a slimy layer around the coffee bean with a varying thickness of 0.5 to 2 mm. The separated pulp is then used for a variety of purposes or discarded as junk (increasingly rare) after which the grains are transported to fermentation reservoirs.

In the fermentation reservoirs the grains remain between 12 and 36 hours, depending on the temperature, the thickness of the mucilage layer and the concentration of enzymes. The mucilage layer is fermented through a combination of microbial activity and the work of endogenous enzymes contained within the mucilage[XV]. Care must be taken in order to prevent that the grains are "overfermented" and acquire an undesirable sour flavor[XVI].

The process is finished after the grains are washed to eliminate the last remnants of decomposed mucilage. Afterwards the grains, in pergamino state, are put in bags (approx. 60 kg each) to be transported to the dry mill (other process as the one described in 2.4.1). The coffee is brought to this mill to be sun-dried. This process can last from 8 to 10 days depending on the region and on the weather conditions. When it is dried the parchment (pergamino) is manually or mechanically removed. Later on, the green coffee (café oro) is stored in silos and is ready to be exported. An example of the process is demonstrated on figure 2.5.

[XIII] *SEMINARIO – TALLER, EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P. 11. 2000*
[XIV] *ADAMS, M.A. P. 33. 2006*
[XV] *IBID.*
[XVI] *INTERNATIONAL COFFEE ORGANIZATION (INTERNET).*
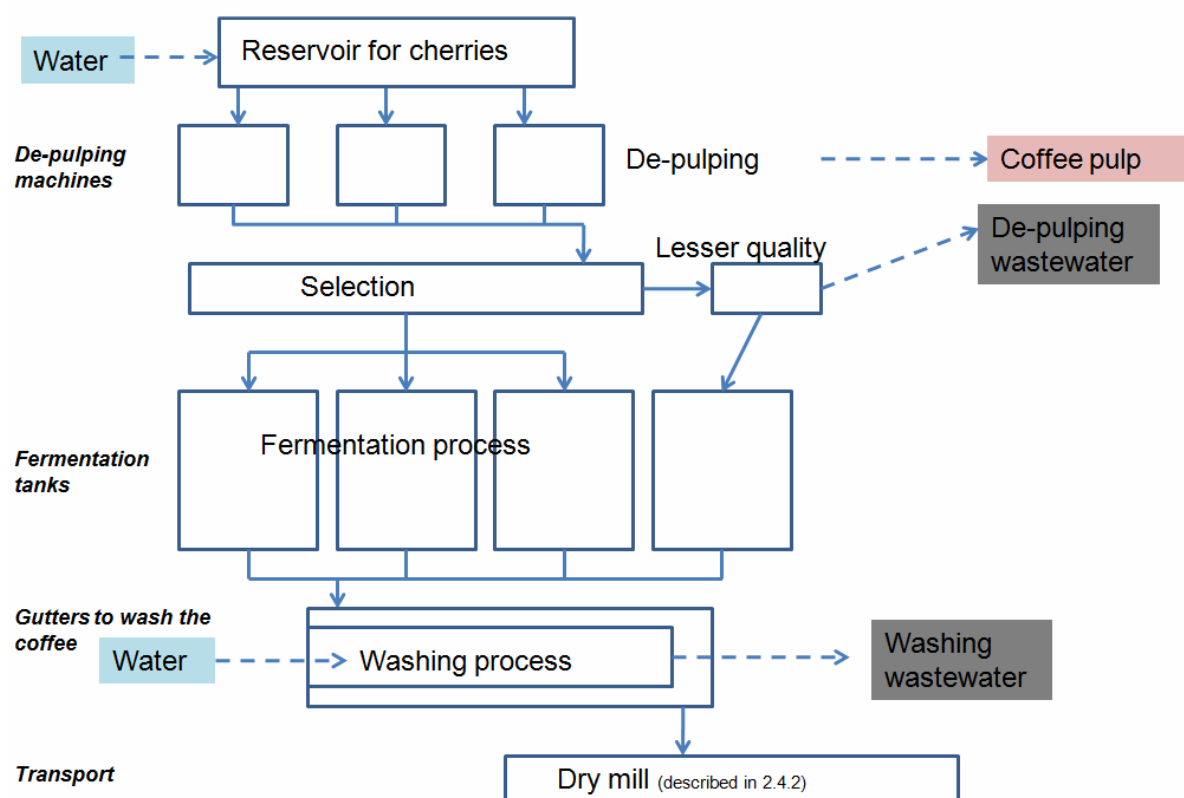
Figure 2.5 Wet mill process

2.4.3   WATER USE AT THE WET MILL

As can be seen in figure 2.5, the water use at the wet mills is diverse in both quantity and purpose. The first place where water is being used is at the reservoir for the coffee cherries, which, according to the way in which the reservoir has been designed, uses a lot of water or hardly any. The water used in this step transports the cherries to the de-pulping machines and after removing the pulp from the cherry combines itself with the pulp and part of the mucilage. This is where the first wastewater flow is generated: the de-pulping wastewater. In previous times, this wastewater flow went directly to the open water courses without any treatment. This had a great effect on the downstream farms and villages. In the 70's and 80's a large introduction of facultative lagoons took place. While this made a significant contribution to the reduction of pollution, presently these lagoons do not work adequately if at all. It must be mentioned that this water contains a large percentage of tannins and resin acids which are toxic to aquatic life, see table 2.3.

The second flow of wastewater is generated the next day when the cherries that had been harvested, after being de-pulped, have been left to ferment. During this phase the fermented grains are washed many times with abundant amounts of water to eliminate the decomposed mucilage. The aguas mieles, or coffee wastewater, generated in this process normally ends up in the same place where previously the de-pulping wastewater had flown to. From there on these wastewaters can be treated together. Nicaraguan Norms[XVII] prescribe a use $\leq$ to 2 m^3 of water per QQ_{oro}. This can be seen in table 2.2.

Table 2.2, Water use for the processing of coffee

Coment	Water (m^3/QQ$_{oro}$)	Source	Country	Recycling
Minimum	1.02	Adams, M.A. 2006	Costa Rica	Yes
Maximum	4.08	Adams, M.A. 2006	Costa Rica	No
It has to be less than	2.00	MARENA (NTON) 2006	Nicaragua	Yes
Finca San Luis	2.50	Sas, M.J. 2006	Nicaragua	Yes
Finca El Socorro	1.97	Schutgens, G. 2010	Nicaragua	Yes
Khe Sanh, Quang Tri	1.00	Mels et al. 2005	Vietnam	Yes

[XVII] *NTON 05 029-06*

According to Wasser[XVIII], who has performed research on the use of water in the coffee processing, 30% of the water is utilized for the de-pulping process and 70% for the washing of the fermented grains. From this 70%, 20% is used for eliminating the decomposed mucilage and the remaining 50% is very clean wastewater that is used to finish cleaning and selecting the grains.

2.4.4   WASTES OF THE WET MILL PROCESS

There are different waste products coming from the coffee process. They are shown graphically in figure 2.6.
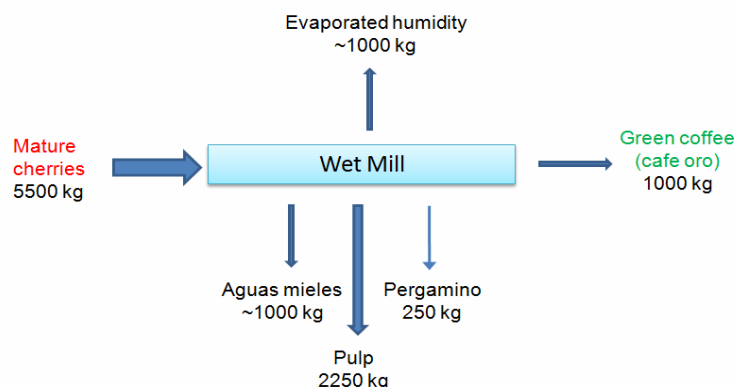
Figure 2.6, Balance of the coffee bean production (adapted from Adams. A.M. 2006)

It is obvious that the wastes, or by-products, which stem from the coffee production process are many and in no small quantities. Generally these by-products were discarded as garbage and are preferred to be thrown away in the fastest way possible. Often this meant simply discarding them into rivers and this as a result has caused a tremendous amount of pollution in open water courses. Recently, however, there has been an increase on the number of reports informing on the beneficiary uses that these by-products can provide. Figure 2.7 presents different uses which can be applied to the formerly called waste by-products.
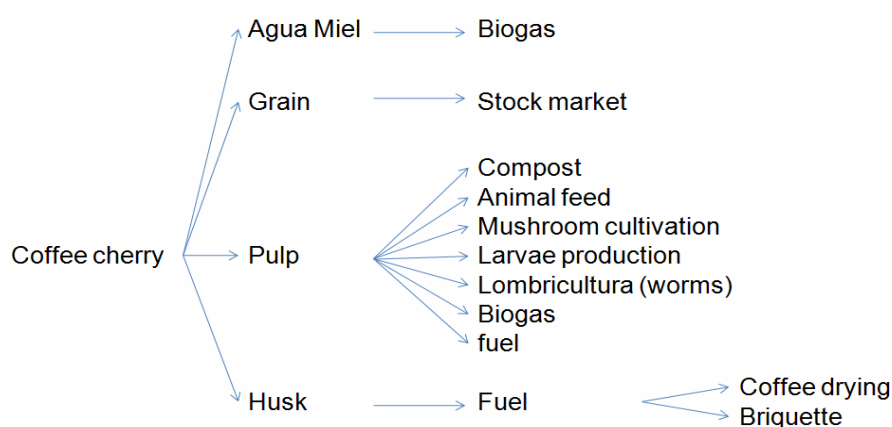
Figure 2.7, Possible uses for the by-products of coffee (adapted from Seminario-Taller. 2000)

More specifically, for the aguas mieles, pollution is generated in two phases: the de-pulping process and the washing of the fermenting grains process. In table 2.3 an impression is given of the substances contained in the wastewater of both processes.

Table 2.3, Properties of aguas mieles (Seminario-Taller. P. 10. 2000)

Water de-pulping		Water from washing	
Proteines	8.9%	Pectic substances	23.4%
Tannins	10.0%	Sugars	54.2%
Chlorogenic acid	14.5%	Cellulose	20.4%
Caffeine	22.0%		
Sugars	45.3%		

[XVIII] WASSER, R. 1986?

2.4.5   CHARACTERIZATION OF COFFEE WASTEWATER (AGUAS MIELES)

Coffee wastewater contains large concentrations of sugars, cellulose, caffeine and pectic substances as table 2.3 shows. These substances in the coffee wastewater introduce harmful characteristics into the receiving waters. Some of these characteristics, which have been monitored by the COD and BOD_5, are shown in table 2.4.

The BOD_5 represents the amount of oxygen that is necessary to decompose organic matter through bacteria present in a sample of water in 5 days at a temperature of 20° C. On the other hand, the COD represents the chemical way of oxidizing the organic matter. With the last mentioned method, the required value is obtained relatively fast (2 hours) when compared to the BOD_5. The value of COD is always larger than BOD_T, as all organic matter is biodegradable.

The detrimental effect of the lack of oxygen in the water is diverse and is reflected in the death of aquatic life, in smell and even in a few health problems provoked by the anaerobic conditions in the water[XIX]. The low pH values indicate that the water has an acid content that also harms the natural biological activity in ecosystems. Neutral water has a pH of 7. The conductivity reflects the current that can be transmitted by the water and is dependent on the amount and type of minerals in the water. Water from natural rivers has an average conductivity of 250 to 500 µS/cm, whereas industrial wastewaters can reach values of 10 mS/cm or more.

In table 2.4 a distinction is made between wastewater and recycled wastewater in which the percentage of BOD_5 and COD substantially rises. The values indicated in this table are within the range of the values found previously by Sas, M.J. (2006); Calvert and von Enden (2002); and Calvert (1997).

Table 2.4, Characterization of coffee wastewater

Parameter	Total average (mg/L)	De-pulping water (mg/L)	Water from washing (mg/L)
Total suspended solids	$7\,000 - 10\,900^{a}$	$13\,200^{b}$	$2\,900^{b}$
		$6\,200 - 11\,000^{c1}$	$1\,950 - 4\,800^{c1}$
		$3\,600 - 5\,000^{c2}$	$2\,200 - 4\,600^{c2}$
pH		$4^{d,e}$	$4^{d,e}$
Conductivity	771^{d1} (µS/cm)	728^{d1} (µS/cm)	814^{d1} (µS/cm)
Biological oxygen demand	$10\,000 - 13\,000^{a}$	$1\,800 - 2\,900^{b}$	$1\,300 - 2\,200^{b}$
(BOD_5)		$1\,800 - 9\,000^{c1}$	$1\,200 - 3\,000^{c1}$
		$900 - 2\,400^{c2}$	$1\,400 - 3\,900^{c2}$
Chemical oxygen demand	$18\,000 - 23\,000^{a}$	$13\,900 - 28\,000^{b}$	$3\,000 - 10\,000^{b}$
(COD)		$2\,950 - 14\,600^{c1}$	$1\,650 - 2\,800^{c1}$
		$1\,400 - 3\,900^{c2}$	$850 - 1\,750^{c2}$
BOD : COD ratio	$0.5 - 0.6^{a}$		
	0.9^{f}		
N : COD ratio	0.08^{a}		
P : COD ratio	0.02^{a}		

[a] – ICO (Internet, 2004)
[b] – Adams, M.A. and Dougan (1981)
[c] – Gautho and others (1991)
[d] – Sas, M.J. (2006)
[e] - Calvert and von Enden (2002)
[f] – Seghezzo, L. (2007)
1 – with recycling
2 – without recycling

2.5   NICARAGUAN NORMS FOR WASTEWATER

Nicaraguan laws state through the decree 33-95, emitted in 1995 that the Ministry of Environment and Natural Resources (MARENA) is responsible for the control and application of sanctions in relation with household discharge, industrial discharge or agricultural discharges into receiving water bodies. Additionally, article 38 of this decree specifies the norms which coffee farms have to comply with in order to be able to discharge coffee wastewater into receiving water bodies.

In the next table the values are given which appear in article 38:

[XIX] CALVERT AND VON ENDEN. 2002

Table 2.5, Decree 33-95, Article 38 about coffee mills

PARAMETER	RANGES AND MAXIMAL PERMISIBLES LIMITS (DAILY AVERAGE)
ph	6.5 – 9.0
Total Suspended Solids (mg/l)	150
Sedimentable solids (ml/l)	1
BOD_5 (mg/l)	120
COD (mg/l)	200
Grease and oils (mg/l)	10

In addition to decree 33-95, technical norms exist which are emitted by the Ministry of Promotion, Industry and Commerce (MIFIC). One of these norms is the Norma Técnica Obligatoria Nicaragüense (NTON) 05 028-06 which has been elaborated in order to protect the receiving water bodies that have been affected by the discharge of liquids and solids coming from wet mills. In this norm, in paragraph 7 guidelines are given about the water usage in wet mills. Among others, a dry de-pulping process is promoted, the use of less than 2 m^3 of water for both de-pulping and washing of fermenting beans is required and finally the reuse of water is encouraged. Guidance is also given concerning having the bottom of facultative lagoons and/or anaerobic lagoons placed to at least 2 meters above the groundwater table on that place. However, they type of soil, and thus permeability, underneath is not taken into account in this guide.

2.6   IMPACTS OF COFFEE SECTOR ON THE ECOSYSTEMS

The different impacts which the coffee production has on the ecosystems can be classified into three different categories: depletion, pollution and damage or degradation.

The first of these categories comprises the extraction of sources from the environment. Among others deforestation and erosion can be mentioned here. Central American countries fall among the countries with the highest deforestation rates in the world[XX]. Traditional coffee growing takes place under the shade of trees in natural forests, preserving in this way large areas of pristine forests. However, from the 90's onwards there has been a stimulus for coffee farmers to grow sun-coffee or tecnified coffee, by entities such as USAID[XXI], among others. The incentive for this trend is an increase in revenues. Since the 1990's, approximately 1.2 million hectares have been cultivated applying the so called sun-coffee in Central America alone, eliminating in this way large areas that were previously covered by natural forests. The intensive cultivations that are generated in this way entail a reduction in flora and fauna biodiversity in the region. This also poses problems for migrating species of birds. One of these is the shrinkage of the birds' natural habitat areas, and another a decreases in number in both Central America and North America (Canada and USA)[XXII].

In the second category, deforestation has an influence on the erosion process. This leads to an increased use of fertilizers. In turn run-off washes away the nutrients (degrading it) and at the same time contaminates other areas by spreading the pesticides.

Within the third category; deforestation and subsequent erosion result in soil degradation. In addition, it is appropriate to speculate on aquatic life degradation due to the high organic content of coffee wastewater poured into open water courses, preventing in this way to the fauna and flora of their necessary dissolved oxygen.

Apart from the categories listed here, the use of pesticides and fertilizers harms the health of many farm workers. Very often a large number of them are analphabet individuals who do not know how to correctly apply the needed quantity and who also do not understand the precautions that have to be taken when dealing with chemicals. It has also been mentioned that the increase in fertilizer use has polluted aquifers in Costa Rica with values of nitrate much higher than those permissible by the WHO. High concentrations of nitrate can lead to metahemoglobinemia in small children, also known as the blue-baby syndrome, which can be fatal to babies if the supply of oxygen is inhibited[XXIII].

[XX] MONGOBAY ➜ RAINFORESTS (INTERNET)
[XXI] ADAMS, M.A. P. 43. 2006
[XXII] IBID. P. 43
[XXIII] IBID. P. 48-50

3. Wastewater treatment systems

In this chapter a brief review is provided on the different kinds of wastewater treatment systems with special emphasis on the anaerobic treatment of coffee wastewater.

3.1   Types of wastewater treatment

For the treatment of coffee wastewater several systems can be applied. The diagram presented below (figure 3.1) gives an indication of the classification of methods applied; these will be dealt with later on.
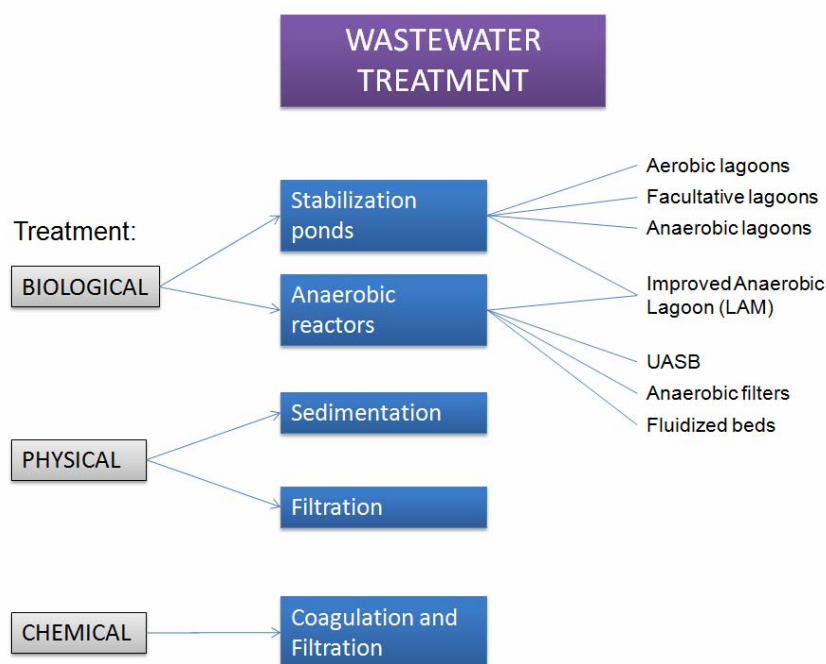
Figure 3.1 Diagrams of Wastewater Treatment Systems

3.2   Physical-chemical treatment

The physical-chemical treatment for coffee wastewater has been applied only moderately. The principle is based on availing certain products (such as lime, and aluminium sulphate) which after reacting with substances present in the pulp and the mucilage of the coffee, such as pectin, form flocks that can precipitate easily in areas where the water velocity is low, i.e. in a sedimentation basin.

The physical treatment is principally based on letting the wastewater pass through zones where the velocity of the water is so low that the heaviest particles will precipitate. After this, a filter of grind and sand can be found in which another part of the contaminants is trapped.

In México and Costa Rica, physical-chemical types of systems have been evaluated obtaining a maximum reduction of 70% to 80% of organic matter in BOD values. A disadvantage of such a system is the large supply of mineral content needed, which in turn increases the pH of the treated water to values of 11 or even 12. This entails less favorable consequences for the receiving water bodies, because the biological activity is endangered and biological post treatment systems are inhibited. Furthermore, if these waters end up in a river that is used as a source of potable water, the hardness of the water will be elevated significantly and the disinfection with chlorine from the drinking water treatment plant will be less effective. Another disadvantage is the high sludge production (around the 10 kg/QQ$_{oro}$), with a large mineral content. It is also important to mention that if the removal of organic matter is not so high, this will limit the applicability of the system for more strict norms in the future[XXIV]. The next paragraph will deal with the biological treatment (3.3) along with stabilization ponds as well as anaerobic reactors.

3.3   BIOLOGICAL TREATMENT

The biological treatment is based on the use of various types of microorganisms which play a major role in the purification of wastewater. The biological treatment can be separated based upon the form of contact between the coffee wastewater and the oxygen in the air:
- Aerobic treatment:
  o Ponds with natural aeration or maturation ponds
  o Ponds with mechanical aeration
- Anaerobic treatment (3.4, 3.5 and 3.6)

The aerobic ponds or the stabilization ponds have been applied for a number of decades already in Central America. These ponds are widely accepted due to their simplicity and cheap construction, their simple maintenance and good treatment efficiency in warmer temperatures.

The principle processes which take place in stabilization ponds are of biological nature. The purification is driven by bacteria, algae and other microorganisms which feed themselves on the organic load found in the coffee wastewater. The organic load is decomposed to the extent that the detrimental effect on the receiving water bodies is diminished.

In Nicaragua, in the coffee region, many wet mills are found in which stabilization ponds have been applied. However, many of these ponds are not functioning anymore as they should, often due to too high organic loadings applied. Nowadays these ponds function more as reservoirs.

Some of the detrimental effects which are attributed to these ponds are the bad smell and the creation of ideal conditions for the proliferation and growth of flies, mosquitoes and other insects. In addition, depending on the location they can also threaten nearby aquifers[xxv].

The following type of lagoons will be briefly described:
- Aerobic lagoons: natural aeration and mechanical aeration (3.3.1)
- Facultative lagoons (3.3.2)
- Anaerobic lagoons (3.3.3)

3.3.1   AEROBIC LAGOONS

Due to high concentrations of organic matter, the concentration of dissolved oxygen is reduced drastically unless forced or mechanical aeration is introduced. Consequently, natural aeration cannot be applied when dealing with coffee wastewater. The purification of water in aerobic lagoons depends on the activity of bacteria which need oxygen for their subsistence. With the aim of providing this oxygen, mechanical equipment can be used in order to let the water masses be well mixed with the oxygen: bacteria – oxygen – contamination (bacteria food), so an optimal contact is achieved. One clear disadvantage of this system is the energy consumption brought forth by the mechanical addition of oxygen. Comparing this system with facultative lagoons, this type of system needs a smaller surface due to the larger depth that can be applied[xxvi].

3.3.2   FACULTATIVE LAGOONS

In the facultative lagoons the work of aerobic as well as anaerobic bacteria is combined, simulating in this manner natural processes such as marshes and lakes. In the deeper part of the lagoon an anaerobic zone can be found with methanogenic activity (in the sediments) and in the upper layer of the lagoon the oxygen of the air permits the oxygenation of the water surface. Therefore, the depth of such lagoons cannot be very large. The surface of these lagoons tends to be large in order to let the sun sufficient place to enhance photosynthesis. In the same way the diffusion of the air with the wind is increased. Generally these lagoons are preceded by anaerobically pre-treated water or are used for raw household wastewater. Given the high organic loadings of coffee wastewater, a very large surface would be needed in order to be able to apply a facultative lagoon[xxvii].

[xxv] *SEMINARIO – TALLER. EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P.34. 2000*
[xxvi] *IBID. P. 35*
[xxvii] *IBID. P. 36 AND 37*

3.3.3   ANAEROBIC LAGOONS

In this case the bacteria that work to purify the water can only live in habitats without oxygen. To this end a large number of bacteria are needed. Among them, as will be explained later on, are the fermentative bacteria, the acetogenic bacteria and the methanogenic bacteria. These bacteria can be normally found at the bottom of the lagoon, given their larger density than that of water, and the grouping of these is called 'biomass'. In these lagoons the contact between biomass and wastewater is of vital importance. The applied depths vary between 4 and 5 meter, in this way the surface needed for the lagoon can be reduced as well as the contact with the air.

As a consequence of the anaerobic digestion biogas and organic acids are produced. These last ones, when using lagoons, can freely escape to the atmosphere together with odorous reduced gases like H_2S causing bad smells. This is perceived as a disadvantage as are the production of scum and the proliferation of insects, which could affect the human health. The biogas, if it is left to escape to the atmosphere, contributes even more than carbon dioxide to the greenhouse effect. By letting this detrimental process take place, what can be considered as a source of renewable energy is thrown away[XXVIII].

In the next paragraph an explanation will be given of the importance of anaerobic systems and then general principles of anaerobic digestion will be given.

3.4   IMPORTANCE OF ANAEROBIC SYSTEMS

The term Anaerobic Digestion (AD) refers to the fermentation and subsequent mineralization of organic matter. During this process organic matter is degraded and biogas is produced[XXIX]. In comparison with the conventional treatment of wastewater (CTWW) in which aeration is often applied, the anaerobic treatment (AWWT) has several advantages. The treatment can be considered to be very effective on degrading biodegradable matter. In a conventional treatment 30% to 50% of excess biological sludge is produced, whereas in AWWT the excess biological sludge production is limited to 5%. In addition this new biomass can have a market value when other AWWT are being developed and are in need of activated sludge to initiate their digestion process. Furthermore, instead of wasting energy in aeration systems, energy is produced in the form of biogas[XXX]. Besides to these positive characteristics the fact that AWWT does not require a lot of surface area can be also very attractive for those industries or farmers who have little space available.

Not surprisingly anaerobic digestion has evolved into a competitive and desired technology. At the same time, following the idea of Van Lier[XXXI], developing countries can greatly benefit by providing a renewable source for energy, which reduces the fossil fuel consumption. At the end, a reduction in emissions of carbon dioxide is achieved. With the reduction of CO_2, the owner of the farm could sell carbon credits (foreseen value € 20/ton CO_2), which can work as an incentive to apply anaerobic systems.

3.5   GENERAL PRINCIPLES OF ANAEROBIC DIGESTION

Anaerobic digestion (AD) happens in many places where large organic content is present and where a lack of oxygen is experienced. In natural ecosystems this process can be seen on marshlands, in sediments at the bottom of lakes as well as at the bottom of the sea, and also in the digestive tract of ruminants (i.e. cows, goats)[XXXII]. In anthropomorphic systems this process can be observed in municipal sewage and in municipal landfills. The process of anaerobic digestion converts complex organic compounds into CH_4, CO_2, H_2O, H_2S, NH_3 and biomass. The digestion process can be shown in the following 4 stages (figure 3.2).

1. Hydrolysis.
   Decomposition of complex (undissolved) material into less complex (dissolved) compounds (sugars, amino acids). This takes place thanks to excreted enzymes of fermentative bacteria.
2. Acidogenesis.
   Soluble compounds are converted into simple compounds by fermentative bacteria. The products: volatile fatty acids, alcohols, lactic acids, methanol, CO_2, H_2, NH_3 and H_2S. In this phase biomass is formed.
3. Acetogenesis.

[XXVIII] *SEMINARIO – TALLER. EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P. 34. 2000*
[XXIX] *VAN LIER, J ET AL. P. 415. 2008*
[XXX] *IBID.*
[XXXI] *IBID. P. 417*
[XXXII] *MES, T.Z.D. P. 11. 1998*

The products of the fermentative process become acetate, H_2, CO_2 and new cell material.

4. Methanogenesis.
Where acetate, hydrogen plus, carbonate, formate or methanol are finally converted to carbon dioxide, methane and biomass. The bacteria in charge of this process have a very slow growth rate. This means that the start of an anaerobic treatment system, without acclimatized bacteria can take a long time, and from there the importance of large quantities of bacteria at the initial phase becomes apparent.
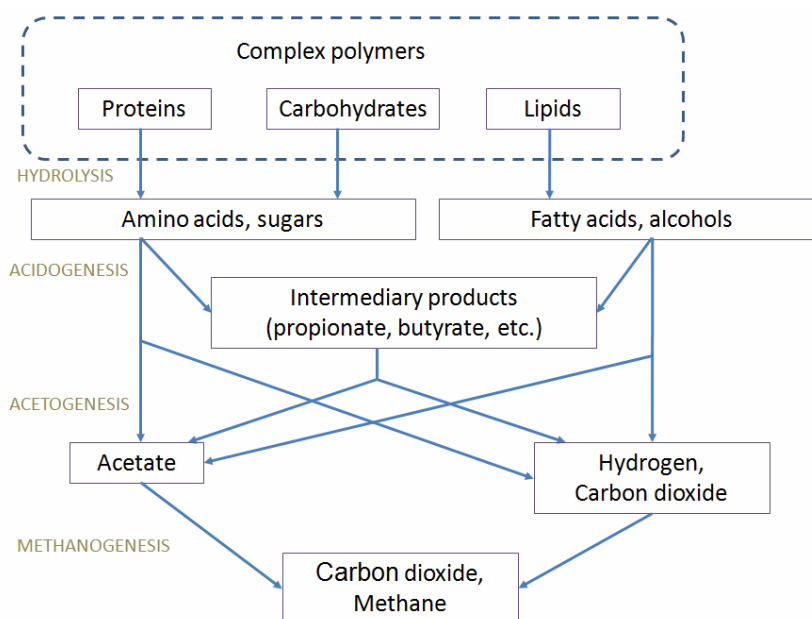
Figure 3.2, Anaerobic Digestion. Source: Van Lier, J. Biological Wastewater Treatment. 2008

3.6 APPLICATION OF ANAEROBIC SYSTEMS

3.6.1 GENERAL APPLICATIONS

Anaerobic treatment systems are applied in different sectors, among them: Agro-food industry (sugar, potatoes, starch, yeast, pectin, citric acid, cannery, confectionary, fruit, vegetables, dairy, bakery); the beverage industry (beer, malting, soft drinks, wine, fruit juices and coffee); alcohol distillery (can juice, cane molasses, beet molasses, grape wine, grain, fruit); pulp and paper industry (recycled paper, mechanical pulp, straw, bagasse); and miscellaneous (chemical, pharmaceutical, sludge liquor, landfill leachate, acid mine water, municipal sewage)[XXXIII].

In Latin America the most frequent use of anaerobic digesters is found in the rural area, or agricultural area. These digesters use animal and agricultural wastes as fermentative substrates, and sometimes mixed with human excreta. The number of digesters functioning regularly is approximately 60% of those installed. The utilization of the biogas generated in this way is in cooking, obviating the use of propane gas; in lightning and in other uses (especially, amidst small farmers where no conventional electricity grid exists)[XXXIV]. Due to the favorable geographical position of Latin America, a large production of sugar, fruits, coffee and other agro-food products are produced. There are also other industries where anaerobic digestion has been applied, such as paper industry and even in the petrochemical industry. At least 25 types of industrial wastes have been investigated with respect to their fermentation and the biogas production. Among them the most common are those reporting on the wastewater of vinasse (sugar) and coffee[XXXV].

In Central America the use of anaerobic digesters was not so prominent until 1993. Guatemala and Costa Rica have the greatest number of digesters, while Honduras and Nicaragua have a smaller quantity. The countries with the least digesters were El Salvador and Panama (see figure 3.3).

In the following paragraphs a small review will be given about anaerobic systems and their use in the coffee production sector.

[XXXIII] VAN LIER, J ET AL. P. 434. 2008
[XXXIV] NI, J.Q., NAVEAU, H., NYNS, E.J. P.765. 1993
[XXXV] IBID. P.766
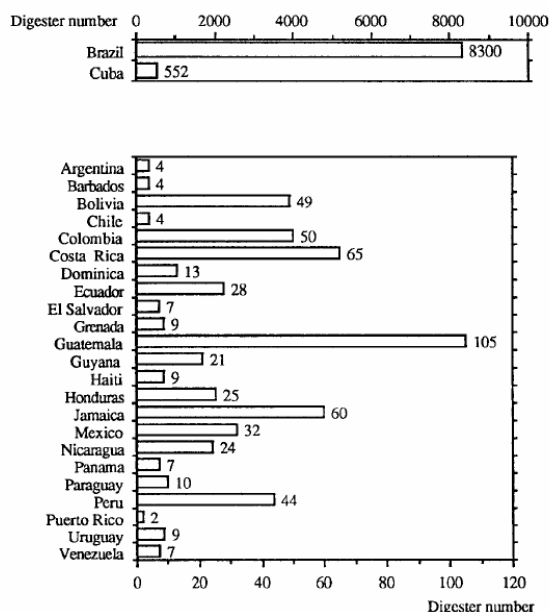
Figure 3.3 Rural digesters in Latin America. Source: Ni, J.Q., Naveau, H., Nyns, E.J. 1993

3.6.2   UPFLOW ANAEROBIC SLUDGE BED (UASB)

The UASB is started with the introduction of (activated) sludge (inoculum) into the reactor, see figure 3.4. This sludge is made of bacteria which are responsible for the purifying as well as for the biogas production. The

characteristics of the sludge play a very important role. The sludge has to settle easily, and is required to be active and stable. Due to the density of the sludge it will generally remain at the bottom part (depending on the velocities applied to the wastewater) and with the passing of time it will begin to form flocks or granules. The water, which is highly organic loaded, crosses the activated sludge in an up flow direction. Through this way the water is purified by bacteria and is ready to be guided to a post treatment (depending on the use it will receive afterwards)[XXXVI].

The capacity of the reactor will, to a great extent, depend on the amount of sludge aimed at in the reactor and also to the special characteristics of the wastewater. The best is when sludge is used that comes directly from a similar AWWT, in this case, a coffee wastewater treatment plant. If this is not the case then at the beginning the loads to be applied should be small and these must be increased slowly while the sludge gets adapted to the new kind of food (other wastewater type).

Figure 3.4, Upflow anaerobic sludge blanket

In the upflow reactor the biogas produced is captured in the upper zone. From this place it can be brought to a reservoir or to a place where it will be burnt in order to avoid contributing to the greenhouse effect. In this zone a separator is introduced in order to skim off the suspended sludge (so it goes back to the bottom), the water that has been purified and the gas (0.35 m^3 CH$_4$ are produced per kg COD$_{rem}$).

3.6.3   UPFLOW ANAEROBIC FILTER (UAF)

The principal difference between the UAF and the UASB is the way in which the sludge is retained. In the anaerobic filters inert material is used to let the bacteria attach to it and let them multiply. In addition, the inert material is used to entrap activated sludge particles between the interstices of the packing material and thus enhancing the formation of very well settling sludge aggregates. Within the most common or readily available materials found in Central American region is pumice, volcanic rocks (lava), bamboo, polyethylene,

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[XXXVI] *SEMINARIO – TALLER. EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P.42. 2000*

etc. Research conducted in Colombia concluded that the way in which the bamboo is sorted can have a positive influence; however, being bamboo an organic material itself it has a maximum lifecycle of 3 harvest seasons. After this time span the rotting bamboo will negatively affect the bacterial mass[XXXVII]. The major drawback of this system is the difficulty of fulfilling the required contact between sludge and wastewater, because clogging of the bed easily occurs[XXXVIII].

3.6.4 ANAEROBIC FLUIDIZED BED SYSTEMS (FB)

FB is in its functioning very similar to the both systems described previously; the only difference is found in the carrier material. This is formed by very small particles (between 250 and 625 µm) on which the biomass grows. Through the recirculation between the treated water and the raw wastewater these particles are fluidized in the reactor. When the biomass is expanded it is expected that a major contact time between the organic matter in the wastewater and the purifying biomass takes place. One disadvantage that is observed in this system is that when the biogas production increases it can fractionate the bed causing a considerable reduction of the expansion aimed at[XXXIX]. Furthermore, long term stable operation appears to be problematic due to an uneven biofilm development on the particles, in order to overcome this problem a high degree of pre-acidification is needed and dispersed matter should be absent[XL].

In the next chapter the improved anaerobic lagoon is dealt with. This is a hybrid system between the fermentation lagoons and the anaerobic digesters.

[XXXVII] SEMINARIO – TALLER. EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P.44. 2000
[XXXVIII] VAN LIER, J ET AL. P. 435, 436. 2008
[XXXIX] SEMINARIO – TALLER. EL TRATAMIENTO ANAERÓBICO DE LOS RESIDUOS DEL CAFÉ. P.45. 2000
[XL] VAN LIER, J ET AL. P. 439. 2008

4. IMPROVED ANAEROBIC LAGOON (LAGUNA ANAERÓBICA MEJORADA (LAM))

This chapter provides an introduction to the LAM system, together with an explanation of the whole wastewater treatment at finca El Socorro. A theoretical calculation is presented with the aim to show what the production of biogas could be in a LAM system theoretically. Next, biogas characteristics are discussed as well as the application possibilities of biogas. In conclusion, the implementation of the overall system at El Socorro is discussed.

4.1   DEVELOPMENT OF THE LAM SYSTEM

The goal of introducing a new wastewater treatment system was to provide coffee farmers with alternatives from which they could choose from in order to comply with the norms established by Nicaragua, see paragraph 2.5. In 2007 a group of the APT-APS program made a trip to Costa Rica and Nicaragua with the aim of working on a design for a cost-effective treatment of coffee wastewater in the catchment of San Francisco (Matagalpa, Nicaragua). Based on information received by the wastewater expert Daniel Paudriet of SOLAMSA, an NGO in Costa Rica, a conceptual design was finalised[XLI].

As has been mentioned previously, the LAM system is a hybrid system that tries to combine the advantages of anaerobic lagoons with the advantages of anaerobic digesters. In this way a relatively cheap treatment system is created with a small footprint, an easy operating methodology and with higher efficiencies than the normal anaerobic ponds.

4.2   THE LAM SYSTEM

4.2.1   MEASURES OF LAM SYSTEM

The LAM system has the form of a truncated pyramid upside down. It is designed to be covered in order to capture the biogas. The influent to the LAM travels to the bottom of the LAM and is distributed evenly on the bottom surface to enhance the mixing. At the upper side of the LAM the effluent is collected through four outlet points (one in each side) from where the water flows to the next treatment step, see figure 4.1. The enlarging of the surface area with the depth causes low velocities in the upper part and slightly higher velocities in the bottom. This enhances the formation of aggregates in the bottom and the settling of solids at the top.
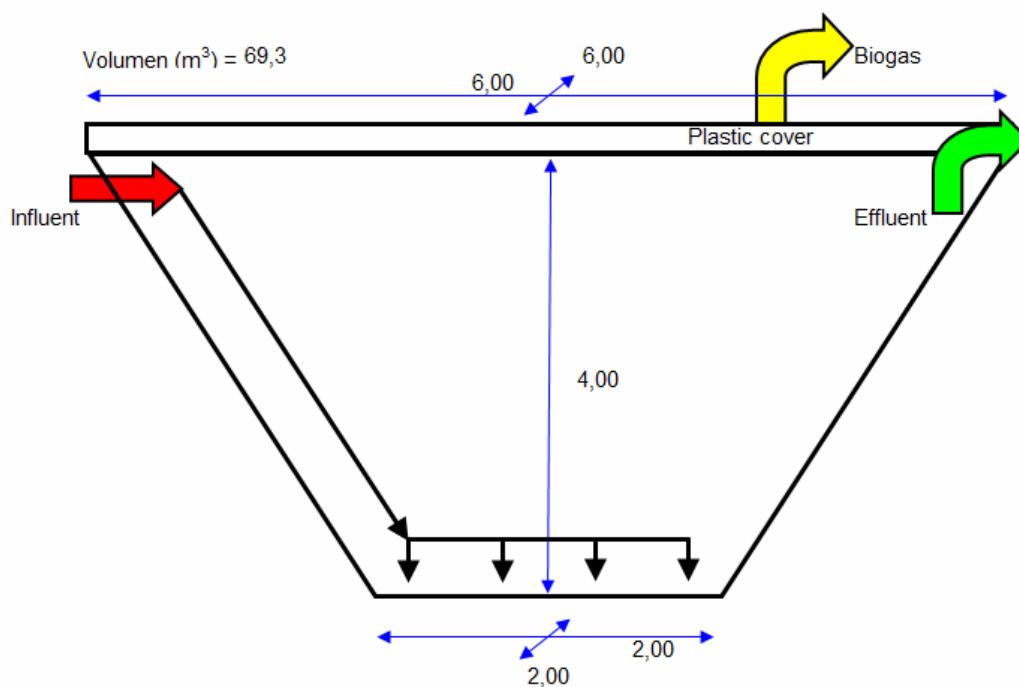
Figure 4.1 Conceptual design of LAM system

[XLI] ZUIJDERHOUT [2]. P. 58,59

4.2.2   TREATMENT SYSTEM IN FINCA EL SOCORRO

The treatment of wastewater in the coffee farm El Socorro is based on a multiple steps treatment. It begins with stabilization of the pH of the wastewater in a pre-treatment reservoir (see figure 4.2). Once the pH is corrected the wastewater continues to the LAM system. Here the anaerobic digestion takes place. After a hydraulic retention time of 7 to 8 days, the water is expected to be purified to 50% or 70% of the initial COD concentration[XLII]. The next step is a facultative lagoon that was previously the only treatment, in which a 30% to 50% COD removal is expected. Finally the water flows to a biofilter before infiltrating into the ground.
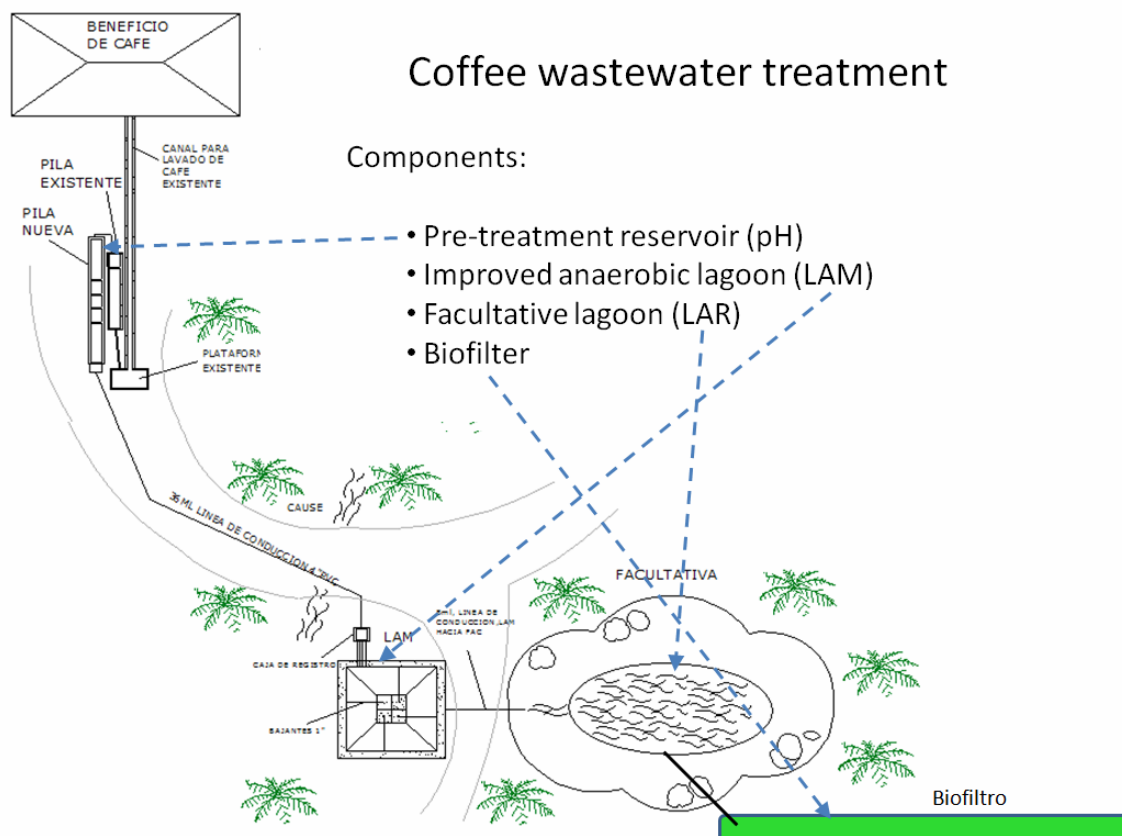
Figure 4.2 Coffee wastewater treatment at finca El Socorro

4.3   THEORETICAL WORKING OF LAM

Theoretically the LAM system should be able to digest large quantities of wastewater. Due to the fact that coffee wastewater is very acidic, a pre-treatment is needed in order to avoid the pH in the system dropping too low. Low pH values inhibit the proper working of the biomass.

4.3.1   PARAMETERS NEEDED TO MONITOR AD-SYSTEMS

Adequate measurement techniques and measurement devices are needed in order to characterize the water composition and concentration of substances. For this purpose on-line, semi continuous or in-line measurements are preferred as they present the user with the possibility to react when needed. However, on a level of a coffee farm, this may be more difficult to achieve.

This sub-paragraph is mainly based on the review report of LeAF: "Agro-industry wastewater characteristics affecting anaerobic treatment". Knowledge of the normal variation pattern is valuable in detecting abnormal events and taking the right control action to prevent treatment upsets[XLIII]. Taking this report as a basis, the needed parameters for an optimal operation of an AD-system will be discussed. It must be noted, however, that the coffee farm in which the LAM system has been installed does not have the size of an industry for which this report has been written. Nevertheless, it provides an indication of the measurements that are important when running an AD system. Within brackets it will be addressed if the possibility exists to utilize these measurements for the project APT-APS in Matagalpa.

[XLII] SEGHEZZO, L. TDR. P. 5. 2007
[XLIII] LEAF.AGROIWATECH. DELIVERABLE D1. PART 2. P. 3,4. 2005

Alkalinity [not presently available]

Alkalinity is the capacity of the wastewater to take up protons. It could also be defined as the excess of positive charges over the anions of strong acids[XLIV]. A high alkalinity means a high buffering capacity of the water. Waters with low alkalinity are at risk of causing a sudden decrease in the reactor pH, due to processes such as nitrification or acidification. In the latter case an accumulation of VFA takes place and the acid forming bacteria will dominate over the methane forming bacteria. Alkalinity can be calculated based on the different elements contained in the water (i.e. calcium and manganese). Therefore lab measurements would be required. In most cases in anaerobic digestion processes, the VFA is the most important variable factor affecting the bicarbonate alkalinity.

BOD [no measurements]

As defined previously, BOD is the biochemical oxygen demand. Or alternatively, it is the amount of oxygen per volume of unit of water consumed by the available micro-organisms in a specific period at a temperature of 20°C. It was developed to provide an indication of the pollution in river water. Generally a fixed period of five days is taken. With a few measurements of BOD an estimation of the biodegradability of the organic substances can be performed as every wastewater type has a more or less constant BOD/COD fraction.

COD [available data and possibilities to continue measuring]

The Chemical Oxygen Demand is measured by oxidizing reduced compounds, mostly organic matter in water with a chemical oxidant (generally dichromate) and determining the amount of used oxidant. The only disadvantage with this method is that it does not make a distinction between biodegradable and non-biodegradable organic substances. It is a relatively fast and secure method to determine the organic pollution in water.

Conductivity [available with on-line probe]

The electrical conductivity is a measure of the ability of water to conduct an electrical current, and it depends on the concentration of ions present in the solution. It can also be used as a measure of total dissolved solids (TDS).

Dissolved Oxygen [available with on-line probe]

Dissolved oxygen is specially applied in the operation and research of aerobic wastewater treatment. However, for AD-Systems it also helps to characterize the influent water and the types of bacteria (aerobic or anaerobic) which are present in a system (including the post-treatment systems).

Flow [only with the bucket method and with a hydrometric whirling (molinete hidrométrico)]

Measurements can be performed manually but on-line measurements can be achieved with instruments based on water level changes and based on electromagnetic or ultrasonic principles. These are of great importance in order to calculate the load of contamination produce by agro-industrial wastewaters.

Nitrogen [total Nitrogen, with reagents]

Nitrogen is present in different forms: organically bound N, nitrate, nitrite and ammonium. During biological wastewater treatment most organic N will be converted into inorganic N, and a small part will end up in the waste biomass.

pH [available with on-line probe]

pH is a measure of the proton concentration, pointing to either an acid solution or a basic solution. In on-line monitoring the pH is very effective in predicting the behavior of biological processes.

Redox potential [no measurements performed and no information available]

The redox potential can be considered as an indication of the oxidative status of a liquid. It is the potential of an inert electrode when present in a solution.

[XLIV] LEAF. AGROIWATECH. DELIVERABLE D2. P. 16. 2005

Suspended Solids (SS) [no equipment available]
For the determination of the suspended solids filters are normally used to retain all the particles that are greater in size than the used filter pore-size. The retained sample is dried and weighed.

Temperature [available with on-line probe]
It is important to measure temperature to have an indication of the range in which biological processes take place. Different devices exist to measure temperature on-line.

Total Organic Carbon (TOC) [device to use reagents available, reagents not available]
Total organic carbon is a measure to physically or physically/chemically convert all the present carbon into CO_2.

Toxicity [no equipment available]
Toxicity is not an absolute variable, but it is always related to certain biological processes. Measurements are therefore, always based on the effect of wastewater or a compound to be investigated on a process. Especially in the startup period, the reactor is sensitive to toxic substances that may inhibit the development of a proper biomass[XLV].

Turbidity [no equipment available]
Turbidity is a measure of the optical properties of water that cause light to be scattered, absorbed and reflected depending on the colloidal matter and suspended solids. It can also be used as a measure of the suspended solids concentration (SS).

Volatile fatty acids (VFA) [no data available]
Volatile fatty acids are formed from organic compounds. Acidifying bacteria can still be active in environments were the pH is 4.8. This means, that while the acidification process continues, the methanogenic process becomes inhibited by the low pH values. When the buffer capacity is low, these VFA may lead to a drop in pH, which subsequently will stop the methanogenic bacteria and eventually can lead to an overall failure of the reactor[XLVI]. This problem can be circumvented by adding an appropriate amount of lime or chalk to the influent to increase the buffer capacity.

4.3.2 WASTEWATER CHARACTERISTICS AFFECTING AD-SYSTEMS
Anaerobic treatment is particularly of interest for BOD values exceeding 1000 mg/l. If BOD values are consistently lower or fluctuate a lot then biomass may not be retained in the anaerobic reactor, if biomass is not well aggregated.

Possible problems in AD-systems might be attributed to the following factors:
- Pollution loads fluctuate substantially. Prevented by a buffer tank ahead of LAM system (exists),
- High concentration of solids. Prevented by screens removal devices (exists),
- Specific compounds, for example pectic substances can interfere with the settling of SS.
- Imbalanced C:N:P ratio, can be prevented by conditioning of the wastewater characteristics,
- Rapid start of hydrolysis and acidification may cause high volatile fatty acids.

In table 2.4 an overview was given of the main coffee wastewater characteristics. However, in order to compare the results of the theoretical and the encountered COD values, average values drawn from table 2.4 will be used, see table 4.1. When values have not been measured an assumption will be made and its justification will be discussed. As has been specified previously there are two streams of wastewater generated in the coffee process at different times. In this exercise we assume a constant loading rate and a complete mixing, because both streams come together in a reservoir and mix over there. From there the water is dosed with a constant flow during 24 hours to the LAM.

[XLV] LEAF. AGROIWATECH. DELIVERABLE D1. PART 1. P.29. 2005
[XLVI] LEAF. AGROIWATECH. DELIVERABLE D2. P. 19. 2005

Table 4.1, Average values of coffee wastewater characteristics

Parameter	Average[XLVII]	Design average[XLVIII]	Average[XLIX]
TSS (mg/l)	9000	1000	
pH	4	7	4.90[L]
Conductivity (µS/cm)	771		3956[LI]
BOD (mg/l)	11500	9000	
COD (mg/l)	20500	10000	3056
BOD:COD ratio	0.6	0.9	
N : COD ratio	0.08		0.11
P : COD ratio	0.02		0.01
Production (QQ$_{oro}$/year)		800	266
Water (m^3/QQ$_{oro}$)	2.00	0.35	1.97
Harvest season (days)	90	90	60
Hydraulic Retention Time (days)		7	8.1

4.3.3 pH CORRECTION

The need for a pH correction can be visualized in figure 4.3. In this figure the pH at which the different processes work best is given. In the horizontal axis the pH value is given while in the vertical axis the different processes that take place during AD are presented.
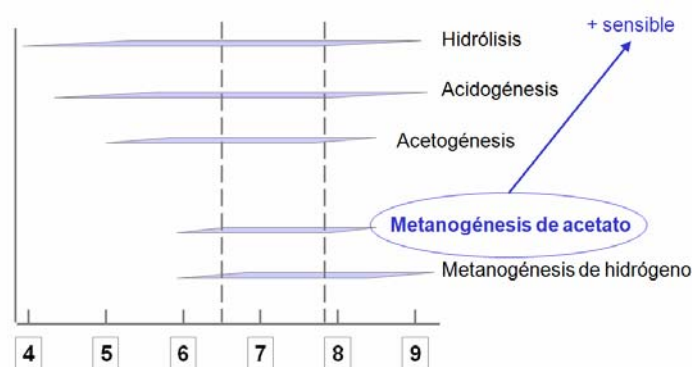
Figure 4.3, Optimal pH for different AD processes (source: Seghezzo, L.)

The place in which the pH correction happens is the pre-treatment reservoir. Before this reservoir there is another reservoir (R1), of approximately 4 m^3, which is mainly used for recirculation of wastewater at the moment of washing the fermented coffee beans (approximately the first 15 minutes), see figure 4.4. The next reservoir (R2) functions as a balancing chamber to cope with COD and flow fluctuations. Figure 4.5 shows the design characteristics of this reservoir. The reservoir has a total volume of 14 m^3. This volume can be divided into two separate reservoirs. The first part comprises then the first 6 m, from left to right with a volume of 9,5 m^3 (one internal weir). The second part after the 2nd weir has a volume of 4,5 m^3. The addition of lime to increase the pH level should be done in the first part of reservoir (R2). The average pH value of the influent to the reservoir R2 is 4.9. In order to calculate how much bicarbonate is needed to bring the pH of the water in R2 to a pH value of 7.2 the next formulas[LII] are used:
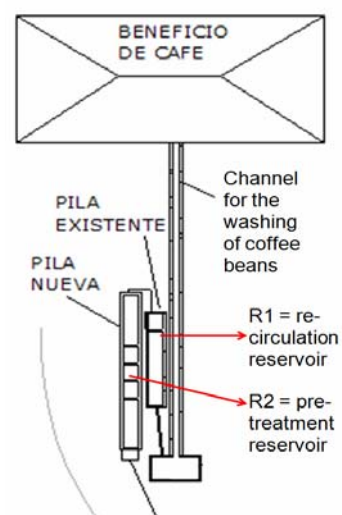
Figure 4.4, Reservoir R1 and R2

[XLVII] *AVERAGE VALUES ACCORDING TO LITERATURE*
[XLVIII] *DESIGN BASED ON THESE AVERAGE VALUES AFTER PH CORRECTION. VALUES OF COD, BOD AND WATER CONSUMPTION WERE ASSUMED (2007)*
[XLIX] *AVERAGE VALUES FOR COFFEE SEASON 2009/2010 IN EL SOCORRO GOING INTO THE LAM SYSTEM*
[L] *SEE APPENDIX A*
[LI] *IBID. COMBINATION OF WASHING AND DE-PULPING WATER*
[LII] *LEAF.AGROIWATERCH. DELIVERABLE D1. P. 17,18. 2005*
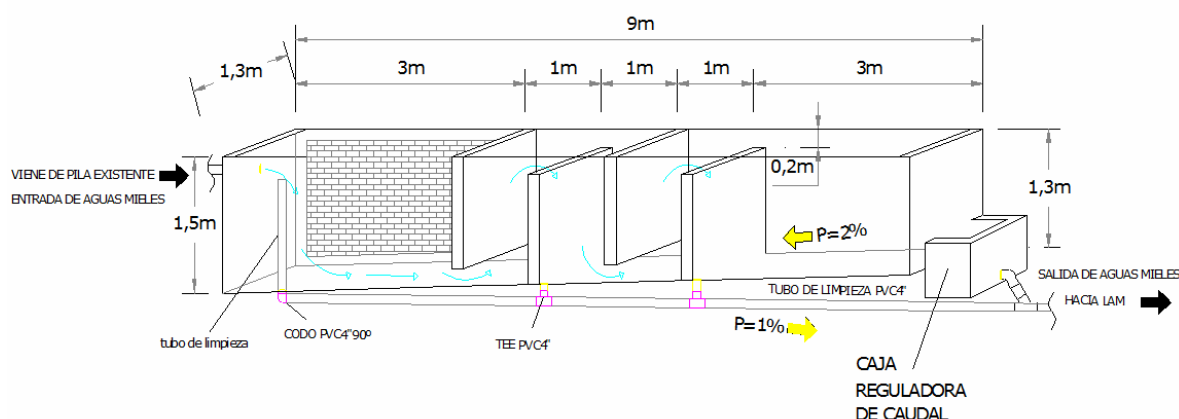
Figure 4.5 Pre-treatment reservoir (R2)

$$pH = pK_1 + \log [HCO_3]/[H_2CO_3] \qquad [4.1]$$

$$[H_2CO_3] = K_H * pCO_2 \qquad [4.2]$$
$$pCO_2 = P_{atm} * CO_2 \text{ percentage} \qquad [4.3]$$
$$K_H = 1 / (H*R*K_T) \qquad [4.4]$$

$$[HCO_3] = \alpha_0 * K_H * pCO_2 / \alpha_1 \qquad [4.5]$$
$$\alpha_0 = 1 / \{10 * (pH - pK_1) + 1\} \qquad [4.6]$$
$$\alpha_1 = 1 - \alpha_0 \qquad [4.7]$$

In which,   El Socorro

pK_1	= carbonic acid	[-]	6.3
$[HCO_3]$	= bicarbonate	[mol/L]	0.00037[LIII]
$[H_2CO_3]$	= carbonic acid	[mol/L]	0.00929
K_H	= Henry's law constant	[mol/atm]	0.0344
pCO_2	= partial pressure of CO_2 in biogas	[atm]	0.27
P_{atm}	= Pressure in atmosphere	[atm]	0.9
H	= ratio gas/liquid concentration (for CO_2)	[-]	1.2
R	= gas constant	[L*atm/(°K*mol)]	0.082057
K_T	= temperature in Kelvin degrees	[°K]	295
α_0	= dimensionless parameter	[-]	-0.0769
α_1	= dimensionless parameter	[-]	1.0769

With an initial pH of 4.9 and using formula [4.1] to [4.7] it follows that the bicarbonate concentration [molarity] of the water is only 0.37 mmol/L. In order to increase the pH of the water to 7.2 a total concentration of 73.88 mmol/L is needed in the water. This means that still 73.51 mmol/L of HCO_3 should be added to the water. The dosing of $Ca(OH)_2$ will increase the alkalinity, this is calculated with formula [4.8].

$$2 CO_2 + Ca(OH)_2 \rightarrow 2 HCO_3^- + Ca^{2+} \qquad [4.8]^{[LIV]}$$
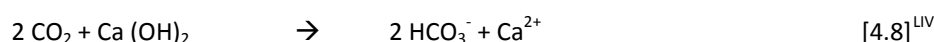
From here it follows that 1 mmol/L of $Ca(OH)_2$ will lead to 2 mmol/L of HCO_3^-. This means that in order to increase the pH to a value of 7.2, an amount of 36.76 mmol/L of $Ca(OH)_2$ should be added. When this value is multiplied with the molar mass of $Ca(OH)_2$ - 74 g/mol - it gives an amount of 2720 mg/L of $Ca(OH)_2$ to be dosed. That means that when the first part of the reservoir is full (9.5 m^3) an amount of 9500 L * 2720 mg/L = 25.84 kg of $Ca(OH)_2$ should be dosed. With an average water use of 2 m^3/QQ$_{oro}$, this means approximately 5.44 kg of $Ca(OH)_2$ per QQ$_{oro}$. Therefore with an expected coffee production of 800 QQ$_{oro}$ at least 4352 kg of $Ca(OH)_2$ should be available at the beginning of the next season. The price at which this quantity is sold is 60 lb (1 lb = 0.453 kg) for C$ 172.00^{LV} (US$ 1 = C$ 21.40^{LVI}). This is equal to US$295.50 per ton of calcium hydroxide. So the

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[LIII] *INITIAL CONCENTRATION OF BICARBONATE IN COFFEE WASTEWATER IN EL SOCORRO (AT A pH VALUE OF 4.9)*

[LIV] *VAN DIJK, H. LECTURE NOTES CT2011. COLLEGE 8, SLIDE 40. 2010*

[LV] *ING. RODRÍGUES, R. PERSONAL COMMUNICATION*

[LVI] *BANCO CENTRAL DE NICARAGUA, 20TH OF JULY 2010: US$ 1 = C$ 21.40. THIS CHANGE RATE IS APPLIED IN THIS MINOR THESIS*

total inversion costs only for pH neutralization involve approximately US$ 1286, without taking into account transportation costs. Nevertheless, it has to be mentioned here that to go from a pH value of 7 to 7.2 a lot of extra alkalinity is needed; this is shown in table 4.2. Even more $CaCO_3$ could be used instead of $Ca(OH)_2$ (almost half the costs). This is much cheaper and easier to acquire. The calculations performed in order to calculate the alkalinity needed by adding calcium carbonate ($CaCO_3$) are given in appendix B.

Table 4.2 Costs of raising alkalinity per QQ$_{oro}$ for either calcium carbonate or calcium hydroxide

pH correction	Kg CaCO$_3$/QQ$_{oro}$	266 QQ$_{oro}$	800 QQ$_{oro}$	Kg Ca(OH)$_2$/QQ$_{oro}$	266 QQ$_{oro}$	800 QQ$_{oro}$
4.9 → 7.0	4.136	US$ 147	US$ 443	3.424	US$ 269	US$ 809
4.9 → 7.2	6.600	US$ 232	US$ 707	5.440	US$ 428	US$ 1286

4.3.4   THEORETICAL BIOGAS PRODUCTION

The values used to design the anaerobic treatment plant are given in table 4.3. Values used in this table are based on data provided by the farm owner. Design measures have been indicated already in figure 4.1.

Table 4.3 Some parameters needed in order to calculate the biogas production

	Parameter =	Value for design
Basic information	Flow (m^3/d) =	9,11
	Concentration (kgCOD/m^3) =	10,00
	HRT (d) =	7,61
Improved Anaerobic Lagoon (LAM)	Depth (m) =	4,00
	Volume (m^3) =	69
	Sides (above) (m) =	6,00
	Sides (bottom) (m) =	2,00
	Area (above) (m^2) =	36,00
	Area (bottom) (m^2) =	4,00
	Up flow velocity (above) (m/h) =	0,01
	Up flow velocity (bottom) (m/h) =	0,09
	Organic Volumetric Loading (kgCOD/m^3.d) =	10,12
	Influent injection points =	4
	Distance between outlet of injection points and bottom (m) =	0,20

In order to calculate the biogas production some values are given in table 4.4 and several equations are presented[LVII].

Table 4.4 Values used to design the LAM system

Parameters	Value	Unit	Comment
LAM efficiency (LAM$_{ef}$)	50	%	Assumed
Methane in biogas (C$_{CH4}$)	70	%	Literature
COD$_{acetate}$	64	gCOD/mole	
Molar volume of gas (V$_m$)	22.4	L/mole	At 0 °C
Temperature (K$_{abs}$)	273	°K	At 0 °C
COD/BOD ratio (r$_{C/D}$)	0.9	-	Assumed
Theoretical CH$_4$ production	0.35	m^3/kgCOD	Section 3.6.2 and eq. [4.9] – [4.13]

$$\text{TP CH}_4 \quad = V_m / COD_{acetate} \quad\quad\quad [4.9]$$
$$\text{OLR} \quad = Q * C \quad\quad\quad [4.10]$$
$$COD_{rem} \quad = OLR * LAM_{ef} \quad\quad\quad [4.11]$$
$$\text{NTP CH}_4 \quad = COD_{rem} * \text{TP CH}_4 * r_{C/D} \quad\quad\quad [4.12]$$
$$\text{W CH}_4 \quad = \text{NTP CH}_4 * (K_{T0} + T(°C)) / (K_{T0} * P_{atm}) \quad\quad\quad [4.13]$$
$$\text{Biogas} \quad = \text{W CH}_4 / C_{CH4} \quad\quad\quad [4.14]$$

In which,

TP CH$_4$	= Theoretical production of CH$_4$	[m^3/kgCOD]
V$_m$	= Molecular volume of gas in ideal condition	[L/mole]
COD$_{acetate}$	= COD weight in Acetate	[gCOD/mole]

[LVII] CALCULATION SHEETS, SEGHEZZO, L. 2007

OLR	= Organic loading rate of COD in wastewater	[kgCOD/d]
C	= Concentration of COD in wastewater	[kgCOD/m^3]
COD$_{rem}$	= COD removed	[kgCOD/d]
NTP CH$_4$	= Theoretical production of CH$_4$ in ideal situation	[m^3/d]
W CH$_4$	= CH$_4$ production in variable weather conditions	[m^3/d]
K$_{T0}$	= 273 degrees Kelvin at 0 °C	[°K]
T(°C)	= Mean air temperature	[°C]
Biogas	= Biogas production	[m^3/d]
C$_{CH4}$	= Methane content in biogas	[%]

Other parameters are previously defined.

Using equations [4.9] to [4.14] the total production of biogas is 24.9 m^3/d. With a methane content of 70%, this means that an average of 17.5 cubic meters of methane is produced daily. So 17.5 m^3 of CH$_4$ * 90 days of harvest = 1575 m^3 CH$_4$. And the yield per QQ$_{oro}$ would entail (supposed 800 QQ$_{oro}$) = 1.97 CH$_4$ m^3/QQ$_{oro}$.

4.4 BIOGAS

4.4.1 GENERAL

Biogas is one of the major by-products of anaerobic digestion. It consists mainly of methane and carbon dioxide while smaller quantities of hydrogen sulfide, nitrogen and water vapor are present as well[LVIII]. Due to the high content of CH$_4$ (≈ 70%) it is considered a valuable by-product. The calorific value of methane (33 - 40 MJ/m^3) in biogas is higher than coal gas (17 - 18 MJ/m^3) and smaller than natural gas (39 - 80 MJ/m^3)[LIX].

4.4.2 BIOGAS HOLDER AND TRANSPORTATION SYSTEM

When biogas storage systems are built care must be taken with the material choice, as hydrogen sulfide (H$_2$S) is a highly corrosive and toxic gas. Metal construction components should be avoided or given special attention at their design. There also exists the possibility to purify the biogas. This can be done on a small scale by dry desulphurization using ferrous substances. Locally available soils with iron content can be used to achieve this goal[LX].

For the transportation of biogas, pipelines can be used as well as hoses. The most vulnerable parts of the system are the connections; therefore the installations of these parts should be closely supervised. When pipelines are used, they can be of galvanized steel or PVC. In case high amounts of H$_2$S are present, this will lead to corrosion of the steel pipes and especially non-ferrous metals are damaged more rapidly. UV-resistance pipes can be installed aboveground; whereas PVC pipes should be underground. In the latter case special attention should be paid to their design to prevent damage to the lines by voles or rats[LXI].

The biogas can also have a large content of steam. Most of the steam will condensate on the biogas holder and return as water to the LAM system. In some cases, however, the biogas which goes into the piping system will still have some steam: this cools along the pipeline and water condenses out in the line. It is of great importance, in this case, to have the pipelines slightly tilted and that provisions are made to drain the condensate[LXII]. In many cases a small diameter for the pipe will suffice. In China, diameters of 12 mm and 20 mm have been successfully applied[LXIII].

4.4.3 BIOGAS UTILIZATION

Generally, biogas is utilized in industries where AD is applied for effluent heating. The energy is used for the production process or to heat the influent to the digesters. By doing so, the efficiency of COD removal is enhanced. Alternatively, the biogas can be utilized for cooking to offset the need of firewood or natural gas. More specifically, for coffee farms, the biogas could be used for drying of coffee beans. Furthermore, another use that has been applied in Costa Rica[LXIV], for example, is the use of biogas as fuel for the generation of electricity. In addition, biogas can also be used for radiant heaters (for the raising of young livestock: e.g. piglets

[LVIII] BOMBARDIERE, Y.E. P. 19. 2000
[LIX] BARNETT, A. P. 47. 1978
[LX] MUCHE, H. ZIMMERMAN, H. P 2. 1985
[LXI] DEUBLEIN, D. STEINHAUSER, A. P. 187. 2008
[LXII] BARNETT, A. P. 47. 1978
[LXIII] DEUBLEIN, D. STEINHAUSER, A. P. 187. 2008
[LXIV] FEIL, F.S., P. 2. 2001

and chickens), biogas lamps, incubators, refrigerators and engines[LXV]. When all of the above mentioned possibilities are not applicable or cost effective the best option is to flare the biogas instead of venting it, which increases the greenhouse gas emissions with an impact 21 times the impact of carbon dioxide.

In the event the biogas is used only for cooking, lightning, the running of a radiant heater or a refrigerator no conditioning is necessary. In case engines want to be used, either for recirculation of water or for heating the influent wastewater to the LAM system a study on the content of H_2S should be performed to see if there is need for a desulphurization device.

Table 4.5 presents some values concerning the amount of biogas needed to use some of the aforementioned appliances.

Table 4.5 Possible applications for finca el Socorro[LXVI]

Application	Demand (l)	Comment
Cooking	300	per person per meal
Lightning	150	per day
Radiant heater	300	per hour
Refrigerator	1200 - 1800	Per day for 100 l volume, depending on outside temperature
Engine	10000	At least

4.4.4   DETRIMENTAL EFFECT OF H_2S

Hydrogen sulphide forms an acid which corrodes engine parts in the combustion chamber, exhaust system and various bearings. This effect is increased by the frequent start/stops, short running times and the changes in temperature after starting up the engine and after stopping. The sulphur content further decreases the time in between essential oil changes, because water vapor and SO_2 from combustion both dissolve in the lubricating oil changing the oil properties and making the oil acidic. Furthermore, it is also important in case of use of cooking stoves to properly ventilate well the rooms for the health of the inhabitants of the dwelling, because they could be burned by SO_2 in the air. Some indicators are irritation of mucous membranes, coughing and watery eyes[LXVII].

Moreover, sulphur dioxide (SO_2) formed during the combustion of biogas with contents of H_2S pollutes the environment by generating ´acid rain´. This acid rain in turn damages plants and makes soils, which have a low concentration of lime, acidic and this as a consequence affects the fertility of the soils. However, the concentration released by biogas plants of small farmers is not that high, in contrast to large urban areas.

4.4.5   DESULPHURIZATION

Before desulphurization of the biogas, the sulphur content in the biogas should first be measured. This can be done in several ways: with the laboratory method, the lead-acetate method, detection with iodine and the test-tube method[LXVIII]. Unfortunately none of these methods are simple or cheap.

There have been many methods applied in order to desulphurizate biogas, but for small scale plants there are a few methods that work, one of which is the so called 'dry process' method. Although the degree of purification is not the highest quality, the main advantage is that maintenance and technical complexity are relatively simple. In this process the desulphurization is based on the chemical reaction between H_2S and a suitable substance. The principle is that ferrous absorbent material in a closed, gas tight, container purifies the gas when it flows through it in an upflow direction. In this way the gas is freed from H_2S[LXIX].

Chemically, the absorbing material should have some iron content in the form of oxides: hydrated oxides or hydroxides. These will react as follows:

$$2\ Fe(OH)_3 + 3\ H_2S \rightarrow Fe_2S_3 + 6\ H_2O$$
$$Fe(OH)_2\ +\ \ H_2S \rightarrow FeS\ \ + 2\ H_2O$$
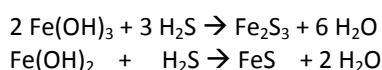
[LXV] GTZ. P. 19. UNDATED, AFTER 1997
[LXVI] IBID. P. 19-23
[LXVII] MUCHE, H. ZIMMERMAN, H. P. 8,9. 1985
[LXVIII] IBID. P. 10
[LXIX] IBID. P. 11

This process has a limit and finishes after some time. A large part of iron is then present as a sulphide.

Regeneration occurs when treating the sulphidized absorbent with atmospheric oxygen. The iron can be returned to the active oxide form required for the purification of the gas:

$$2 \text{ Fe}_2\text{S}_3 + 3 \text{ O}_2 + 6 \text{ H}_2\text{O} \rightarrow 3 \text{ Fe (OH)}_3 + 3 \text{ S}_2$$
$$2 \text{ FeS} \quad + \quad \text{O}_2 + 2 \text{ H}_2\text{O} \rightarrow 2 \text{ Fe (OH)}_2 + \quad \text{S}_2$$

This regeneration cannot be repeated indefinitely. After a certain amount of time the absorbent becomes coated with elementary sulphur and its pores become clogged[LXX]. More information about how to design a desulphurization system can be found on the booklet: Purification of Biogas, written by the GTZ.

Another option that would be easily implemented in small scale coffee farms would be the addition of a small quantity of oxygen into the biogas holder[LXXI]. Then the next process would take place:

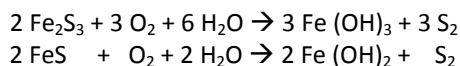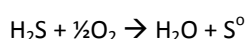$$\text{H}_2\text{S} + \tfrac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{S}^\text{o}$$

This will create water on one hand while the sulphur will just precipitate on the other hand. It is important not to overdose oxygen into the gas holder, because methane can be explosive when it is mixed with oxygen. At concentrations of 5% to 10% of methane and 90% to 95% of air a very explosive mixture is created[LXXII].

4.4.6 IMPACTS ON CULTURE, HEALTH AND EDUCATION

In some areas of the world the use of biogas has led to changes in culture and has provided educational opportunities. Where previously only day light could be use to do homework and other activities, the use of biogas lamps now increases the amount of time for students to study and for other essential household activities. Another advantage of the use of biogas relates to time which was previously spent gathering fuel wood can now be used for other activities. From experience in other countries it has been seen that women, who are largely in charge of collecting fuel wood, cooking meals and working in the fields, will now have more time to spend with their children[LXXIII]. However, in cases where the production of biogas is only seasonal, these advantages are also only experienced seasonally. A possible drawback is that the positive effects of the biogas production are often only used for the benefit of the landlord of the farm, while the farm attendants and their families are neglected. In addition, the possibility of having more free time for some individuals may lead to a misuse of time and money, which not only affects the individuals themselves but also the community.

Concerning health issues, it can be noted that the use of biogas in India and China, instead of firewood, has led to a decrease in eye infections, lungs problems and respiratory problems[LXXIV]. This is mainly attributed to smoke-free and ash-free kitchens[LXXV].

4.5 POST-TREATMENT OF WASTEWATER

As has been explained in sub-paragraph 4.2.2 the post-treatment in the finca El Socorro consists of a facultative lagoon followed by a bio-filter. The working of a facultative lagoon has been explained in sub-paragraph 3.3.2. The bio-filter is a wetland system, or water harmonica, in which the wastewater is infiltrated after a large portion of the COD has been removed. In this wetland, elephant grass has been planted (see figure 4.6) which grows as a result of the wastewater; benefitting from its high nutrient content and consequently produces biomass which is used for compost in the coffee plantations.

The water that infiltrates into the ground will have a residence time of some days before reaching the water stream El Ocote. This will depend on the permeability of the ground and on the energy gradient between the river and the groundwater flow.

[LXX] IBID. P. 12
[LXXI] VAN LIER, J. PERSONAL COMMUNICATION
[LXXII] VROM ➔ INTERNET
[LXXIII] DEUBLEIN, D. STEINHAUSER, A. P. 245. 2008
[LXXIV] GREENPOWER IN INDIA ➔ INTERNET
[LXXV] INSTITUTE FOR SCIENCE IN SOCIETY ➔ INTERNET
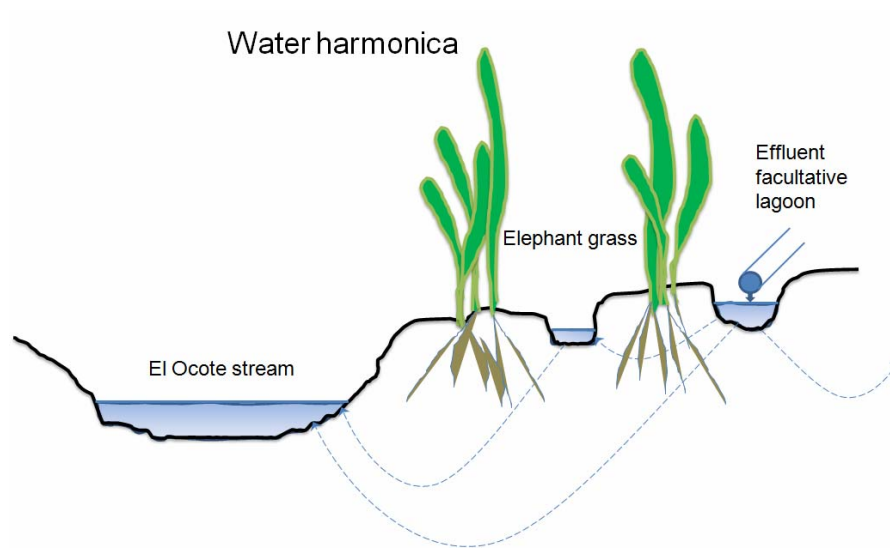
Figure 4.6, Wetland system in El Socorro

5. RESULTS OF MONITORING AT FINCA EL SOCORRO

In this paragraph the results obtained during the harvest season 2009/2010 are presented. The results are presented in chronological order as well as in the order at which the wastewater flows through the system.

5.1   HARVEST SEASON 2009/2010

The harvest season 2009/2010 was characterized by low quantities of rain during the maturation of the grains and prolonged dry periods. The amount of QQ_{oro} produced in the last 6 seasons is shown in figure 5.1.
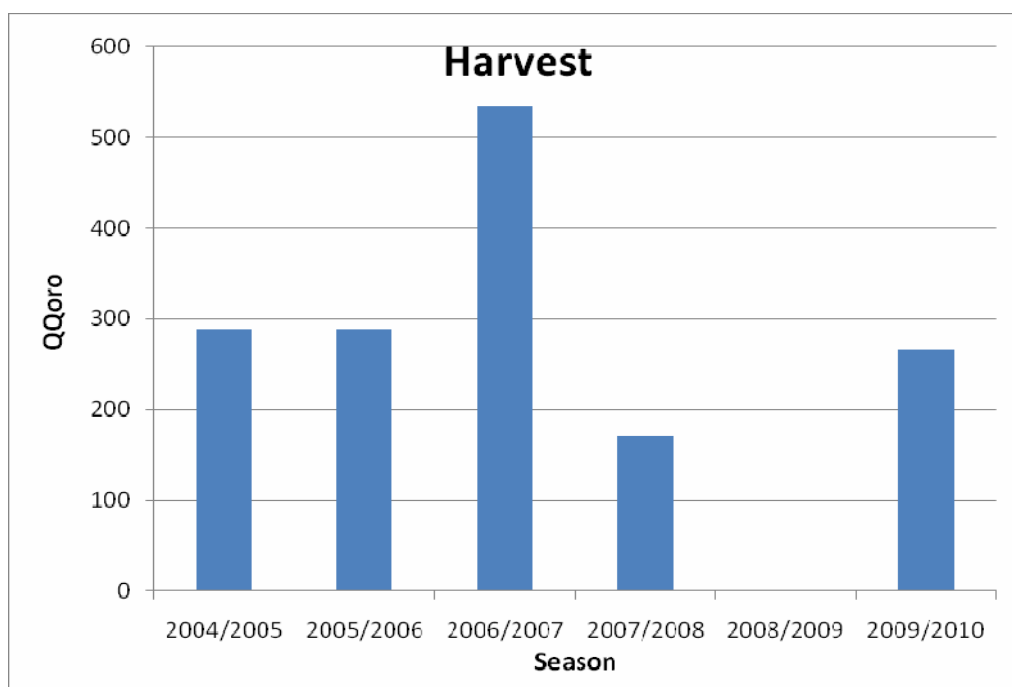
Figure 5.1 Harvested quantities in the last 6 seasons

In other seasons, the harvest is spread over almost 90 days, however, due to the abnormal weather conditions this season the harvest ended after just 60 days. In table 5.1, the days and amount of coffee cherries harvested is given. It is clear that in October, workers only cut cherries for a duration of one week after which the normal harvest season began 3 weeks later. The numbers shown in this table represent the number of latas per day which were cut. 20 latas is equal to one QQ_{oro}.

Sunday is normally observed as day-off. This means that the farm workers work 6 days per week and 8 hours per day (from 6:00 to 14:00). Many of them, however, have to walk between one and two hours to get from their homes to the finca and the same amount of time to return home at the end of the day.

The total amount of QQ_{oro} produced in this season was 266. Looking at normal production rates, this figure is rather low. From Procafé[LXXVI] it is known that a well managed finca will produce a quantity of 25 QQ_{oro}/mz whereas a less cultivated area produces roughly 10 QQ_{oro}/mz. In the case of Finca el Socorro the production yield was only 6,5 QQ_{oro}/mz. In the first and second case the inversion costs are subsequently 48.02 US$/$QQ_{oro}$ and 57.11 US$/$QQ_{oro}$, this means that in El Socorro the inversion cost may be around the 60 US$/$QQ_{oro}$. Adopting this value, the total inversion cost for the season 2009/2010 was around the 16 000 US$.

The mean price for $QQ_{pergamino}$ fluctuated between the C$ 1100 and the C$ 1250[LXXVII]. This represents a value of C$ 2200 to C$ 2500 for each QQ_{oro}. Assuming a value of C$ 2400, the total revenues for this season were: 266 [QQ_{oro}] * 2400 [C$/$QQ_{oro}$] / 20.9 [US$/C$] = 30 500 US$.

[LXXVI] PROCAFÉ, COST-PRODUCTION. SLIDE 8-13. 2009
[LXXVII] TORRES, J.P. PERSONAL COMMUNICATION

Table 5.1 Harvest season 2009/2010

		Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total/week
			Number of latas cherries during the coffee season 2009/2010 at El Socorro						
2009	October	41	87	88	108,8	51			334,8
		42							0
		43							0
	November	44							0
		45				64	72	96,5	232,5
		46	157	130	121,5	198,5	108	145	860
		47	128	139	119,5	112	95	81	674,5
	December	48	74,5	90	97	103	96	98	558,5
		49	98	85	148	142	71,5	42	586,5
		50	45,5	68	82	53	69	73	390,5
		51	73	95	87	51,5	CHRISTMAS	46	352,5
		52	141,5	73	80,5	87	NEW YEAR	107,5	489,5
2010	January	1	68,5	87	70,5	36			262
		2				45	54	58,5	157,5
		3	62	87	75,5	75	66	55,5	421
		4							0
Total per season									5319,8

In table 5.1 it can be also seen that after the 1st week of January the production suddenly stopped. This was the case because almost all cherries had already been cut, and the ones that had not been cut were still too green. Thus the cherries were left to ripen for 1 week and were then cut but as expected these were of lower quality. At the end the cherries that are not ripe are cut and let to dry in the sun (applying the dry mill method) and are sold local consumption. The different colors indicate when samples were taken; a legend is given in table 5.2.

Table 5.2 Legend for table 5.1

	Not in Matagalpa
	Jacco's mission
	Samples washing
	Samples depulping
	Samples both washing and depulping
	No samples due to lack of car
	Holidays
	Error in sample taking
	Repela: only depulping

5.2   WATER SAMPLING

In order to calculate the efficiency of the LAM system and the post-treatment system, water samples were taken during the de-pulping process and of the wastewater flow after it had washed the fermented grains (12 to 18 hours after de-pulping). These samples are denoted as Mc (mixed sample). Besides, these samples were also taken of the influent to the LAM system (PPT), the effluent of the LAM System (which is also the influent of the facultative lagoon) and of the effluent of the facultative lagoon (LAR). In this chapter the facultative lagoon is denoted as LAR (Laguna Anaeróbica Rústica).

5.2.1   RESULTS OF WATER SAMPLING
The different parameters that were monitored are presented below in table 5.3.

Table 5.3 Parameters monitored in Finca el Socorro per location

Monitor Location	COD	P-Tot.	N-Tot.	Cond.	Elect. Charge	O$_2$	pH	T [°C]
Mc	Constant	Constant	Constant	Constant	Some	Constant	Constant	Constant
PPT	Constant	Constant	Constant	Constant	Some	Constant	Constant	Constant
LAM	Constant	Constant	Constant	Constant	Some	Constant	Constant	Constant
LAR	Constant	Constant	Constant	Constant	Some	Constant	Constant	Constant
El Ocote	Some	NO	NO	Some	Some	Some	Some	Some

The results of the different processes are given in tables 5.4 and 5.5.

Table 5.4, pH and COD values of the treatment system together with P-total values

Date	Latas	QQ oro	Water usage (m3) Depulping	Washing	Total	pH LAM in	LAM out	LAR out	COD (mg/l) LAM in	LAM out	LAR out	kgCOD/day Inf. LAM	Efl. LAM	Efl. LAR	P-Total (mg/l) LAM in	LAM out	LAR out	kg P-total/day LAM in	LAM out	LAR out
Total	5319,3	266,0	153,92	370,78	524,70				91684	74432	30039	512,6	360,5	153,2	273,8	203,75	122,1	1,539	1,11	0,779
Mean	88,7	4,43	2,57	6,18	8,60	5,35	5,63	6,18	3056	2481	1001	25,6	18,0	7,7	16,1	12,0	7,2	0,128	0,092	0,065
Minimum	36,0	1,80	1,04	2,51	2,52	4,91	4,56	4,55	1015	1200	155	6,2	7,0	1,1	4,4	5,5	0,8	0,029	0,036	0,006
Maximum	198,5	9,93	5,74	13,84	16,96	6,17	6,49	7,68	11890	4210	2325	156,3	54,5	18,9	36,2	17,5	14,8	0,476	0,230	0,185
Percentage removed (using mean values)													30%	58%					28%	30%
Percentage removed (using total values)													30%	58%					28%	30%
Percentage removed (using mean values) System														70%						49%
Percentage removed (using total values) System														70%						49%

Table 5.5, N-total and TOC concentrations in wastewater system

Date	Latas	QQ oro	Water usage (m3) Depulping	Washing	Total	N-Total (mg/l) LAM in	LAM out	LAR out	kg N-total/day LAM in	LAM out	LAR out	TOC (mg/l) LAM in	LAM out	LAR out	kg TOC/day LAM in	LAM out	LAR out
Total	5319,3	266,0	153,92	370,78	524,70	4505	3870	2430	19,60	15,60	10,04						
Mean	88,7	4,43	2,57	6,18	8,60	347	298	187	2,45	1,95	1,25	665	487	127	4,13	2,80	0,77
Minimum	36,0	1,80	1,04	2,51	2,52	180	135	110	1,17	0,66	0,69	100	50	50	0,89	0,27	0,29
Maximum	198,5	9,93	5,74	13,84	16,96	855	635	315	6,36	3,61	2,34	2680	735	267	15,96	4,26	1,59
Percentage removed (using mean values)										20%	36%					32%	72%
Percentage removed (using total values)										20%	36%						72%
Percentage removed (using mean values) System											49%						81%
Percentage removed (using total values) System											49%						

Water samples were taken in the morning and when possible also in the afternoon. In the morning the washing of the fermented grains of the previous day took place and during the afternoons, samples were taken of the wastewater of the de-pulping process of the cherries which had been cut during the day.

5.3 EFFICIENCY OF LAM SYSTEM

5.3.1 COD REMOVAL

The efficiency of the LAM system is judged according to its COD removal. According to table 5.4 the purification in the LAM system is very low. The LAM system had been designed to reduce the COD load in 50% to 70%, however, only a reduction of 30% was observed (kgCOD/day). In figure 5.2 the efficiency of the LAM and LAR system are expressed in organic load (kgCOD/d). In figure 5.2 it can be observed that especially after the repela (15-1-2010) the COD load entering the LAM system is lower than the COD load leaving the LAM system. There are 2 possible reasons for this, firstly the fact that during the repela the last grains of the harvest season are cut, often these are not mature at all and thus contain low quantities of organic matter while secondly the fact that the average hydraulic retention time approximated to 8 days.
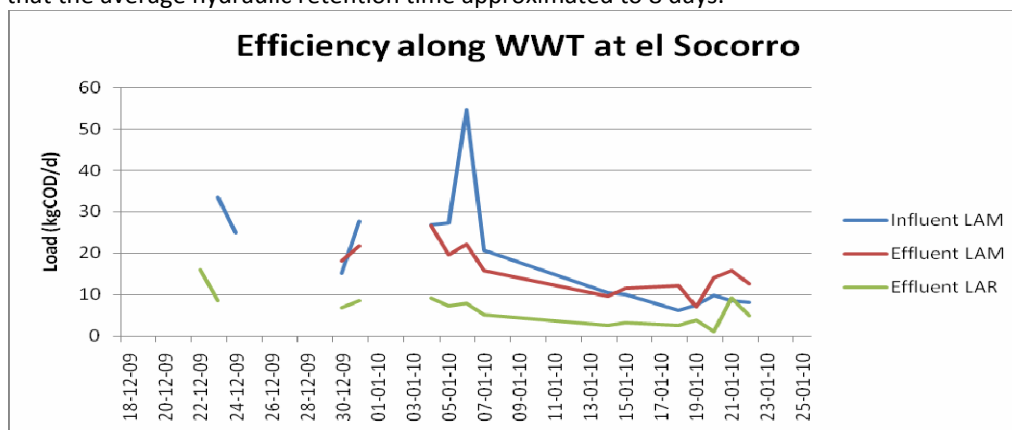
Figure 5.2, Efficiency of LAM system

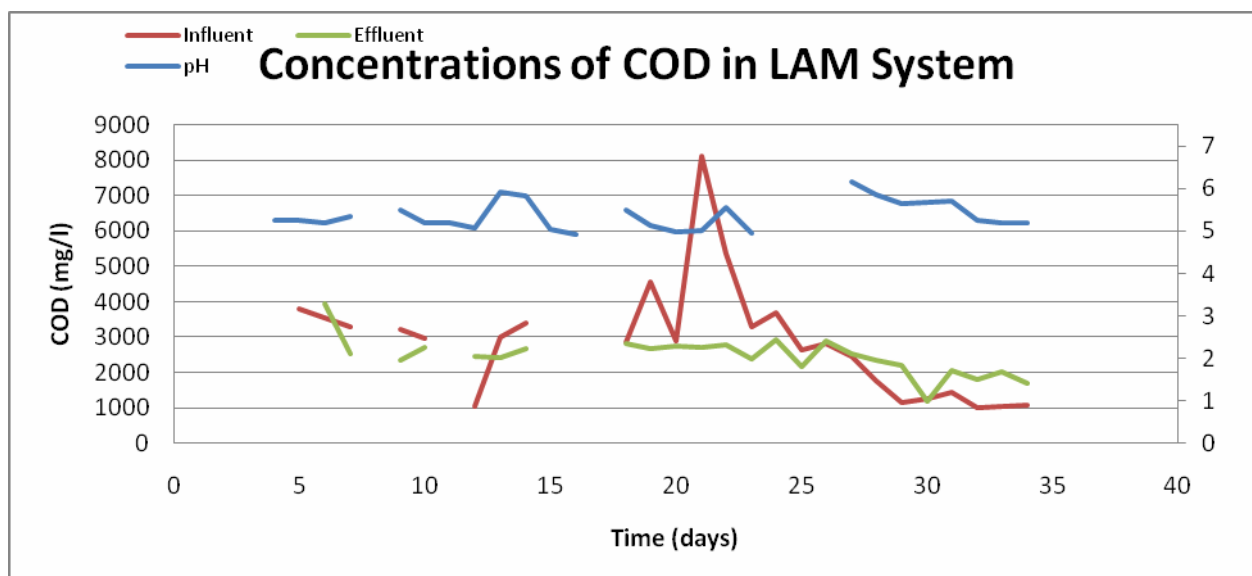When looking at the mean concentrations of COD entering and leaving the LAM system the next figure (5.3) is obtained.

Figure 5.3 Concentrations of COD entering and leaving the LAM system

5.3.2   PH VALUES

As has been mentioned previously in section 4.3.3 (pH correction), the values encountered in the LAM system are too low to permit methanogenic processes.

5.3.3   NITROGEN

The elements Nitrogen (N) and Phosphorus (P) are essential for the growth of microorganisms. They are often denoted as nutrients or biostimulants. Other elements in minor quantities, such as iron, are also needed for the growth of microorganisms but in most cases N and P are the most important. Insufficient nitrogen could lead to reduced treatability of the wastewater[LXXVIII].

Table 5.6 Composition of coffee pulp, parchment and mucilage[LXXIX]

Parameter (%)	Pulp (400-432 g)†		Parchment (35 − 61 g)†	Mucilage (33 - 51 g)†
	Fresh (%)	Dry Basis (%)	(%)	(%) @ Dry Basis
Moisture	76.7	0	7.6	-
Dry matter	23.3	100	92.4	-
Ether extract (fat content)	0.5	2.1	0.6 - 1.5	-
Crude fibre	3.0 - 3.4	12.9 − 14.6	70.0	17.8 − 18.0
Crude protein (% N x 6.25)	2.1	9.0	1.0 - 2.4	-
Ash	1.5 - 1.9	6.4 − 8.3	0.5-1.0	0.4 − 0.6
Nitrogen-Free Extract	15.8	67.8	18.9	45.8
Total Pectin Substances	1.5	6.5	-	35.8
Total Sugars	3.4	14.4	-	45.8
Reducing sugars	2.9	12.4	-	27.8
Non-reducing sugars	0.5	2.0	-	18.0
Tannins	0.4 − 2.0	1.8 − 8.6	-	-
Other Carbohydrates	8.9 − 10.5	38.3 − 45.1	-	-

†   per Kg of coffee cherries
(-)   data not available or not applicable

Concerning coffee wastewater, Nitrogen is found in the pulp, in the parchment and in the mucilage. See table 5.6. From these three sources the coffee wastewater is supplied by nitrogen. During the monitoring in the harvest season 2009/2010 the Total Nitrogen was monitored. Total Nitrogen comprises organic nitrogen,

[LXXVIII] TCHOBANOGLOUS, G. ET AL. P.60. 2003
[LXXIX] ADAMS, M.A. P. 131. 2006

ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). The organic fraction consists of a complex mixture of compounds including amino acids, amino sugars, and proteins (all of which are present in one or more of the AD processes).

The total nitrogen content of the wastewater was determined during the monitoring with the Method 10072 of the Hach Procedures Manual for the DR/890 Colorimeter (available on request, at www.hach.com). At pH values below 7 the ammonia Nitrogen in water can only be present in the form of NH_4^+. The reduction obtained in the LAM system can be attributed to two different kinds of processes. One is that the nitrogen has been used by the biomass to produce new cell material and the other is that part of the ammonium has been anaerobically oxidized as in the annamox process in which nitrite is used to oxidize ammonium. The LAM showed a reduction in Total Nitrogen of 20%.

5.3.4   PHOSPHORUS

Phosphorus can be also considered as an important element contributing to the growth of algae and other biological organisms. It is because of this property that there is presently much interest in controlling the amount of phosphorus compounds that enter surface waters[LXXX]. It is however, to a certain extent unfortunate, that the Nicaraguan norms do not enforce any limits values on the discharge of either phosphorus or nitrogen.

The phosphorus content measured in the coffee wastewater accounts for the orthophosphate PO_4^{3-}. It has been determined using the Method 8048. The phosphorus reduction in the LAM systems was 28% from a mean value of 128 g/day to 92 g/day of PO_4^{3-}.

5.3.5   NUTRIENTS REQUIREMENT

Based on the expected growth yield and the empirical cell formula for anaerobic cells ($C_5H_7O_2NP_{0.06}S_{0.1}$) the following requirements can be calculated:

Acidified substrate: COD:N:P = 1000:5:1
Non-acidified substrate: COD:N:P =   350:5:1

From table 5.4 and 5.5 it is evident that the nutrient ratio is 3053:347:16 so it easily fulfills the acidified part of the substrate. For the, more exigent, non-acidified part of the substrate the ratio in El Socorro is: 350:40:1.8. This ratio fulfills both requirements and therefore there is no need of nutrient addition.

5.3.6   TOTAL ORGANIC CARBON (TOC)

In addition to these nutrients, also the Total Organic Carbon (TOC) was monitored for a few samples. The total organic carbon is found in the polysaccharides and amino sugars among others. The BOD/TOC ratios for untreated municipal wastewater vary between 1.2 and 2. Assuming, in the best case scenario, a ratio of 2 for coffee wastewater the corresponding BOD concentration going into the LAM system would be 1330 mg/l. This is around 44% of the mean COD value of 3053 mg/l. Looking at the TOC removal in the LAM system, this corresponds very well with the COD removal subsequently these values are 32% and 30% respectively. It should be noted that the number of TOC samples analyzed did not exceed 25, whereas for COD it was 91.

5.3.7   FACTORS CONTRIBUTING TO POOR PERFORMANCE OF LAM SYSTEM

One of the factors that inhibited the reduction of COD is the constant low pH values that were dealt with during the whole harvest season 2009/2010. Despite many efforts of the local team, the purchased chalk did not arrive in time to apply the right quantities to the system. In those cases when there was chalk available it was not correctly applied. As can be seen in figure 5.3, the pH values are all in the range of 5 to 6 with a mean value of 5.35 (See table 5.4). From section 4.3.3 and especially from figure 4.3 it is clear that in this phase only hydrolysis and acidification could have taken place, this means that it is highly unlikely that some Methanogenesis took place and that the bubbles that were observed during the field trips were that of H_2S in small quantities as well as CO_2 in larger quantities.

Another detrimental factor for the performance of the LAM system was that between the 26th and 27th of November the LAM was emptied in order to improve the pipelines that were distributing the water at the bottom of LAM system. There was a suspicion that the flow was not evenly distributed but that only one or two pipelines were transporting all the water to the bottom of the LAM, see figure 5.4. This suspicion proved to be

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[LXXX]TCHOBANOGLOUS, G. ET AL. P. 63. 2003

correct and the reparation of this problem required several days, not to mention the filling of the LAM system. Due to this delay, almost 1 month's worth of data regarding the working of the biomass at the LAM system was lost (the 22nd of December the LAM system was working again).
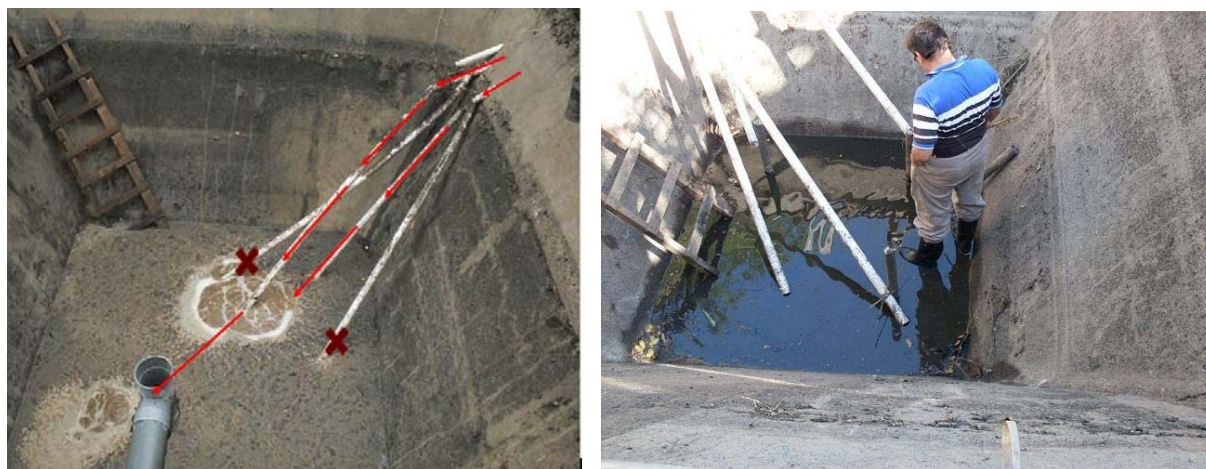
Figure 5.4 and Figure 5.5, Reparation of LAM distribution system

Furthermore, during the emptying of the LAM system, a large amount of the biomass present in the LAM system was accidentally removed (see figure 5.5). Data about the biomass content before and after this event are lacking.

5.4   EFFICIENCY OF LAR SYSTEM

5.4.1   COD REMOVAL

The LAR system, which is in fact a facultative lagoon, performed remarkably well during the harvest season of 2009/2010. Initially it hoped that it would achieve a purification capacity of 30%, but the actual purification that took was approximately 60%, bringing the combined efficiency of the LAM and the LAR system to 70% as can be seen in table 5.4. The average COD load produced at the coffee finca was 25,6 kgCOD/day, while the load leaving the system was around the 7,7 kgCOD/day. Figure 5.6 shows the COD concentrations in three different places in the finca el Socorro.
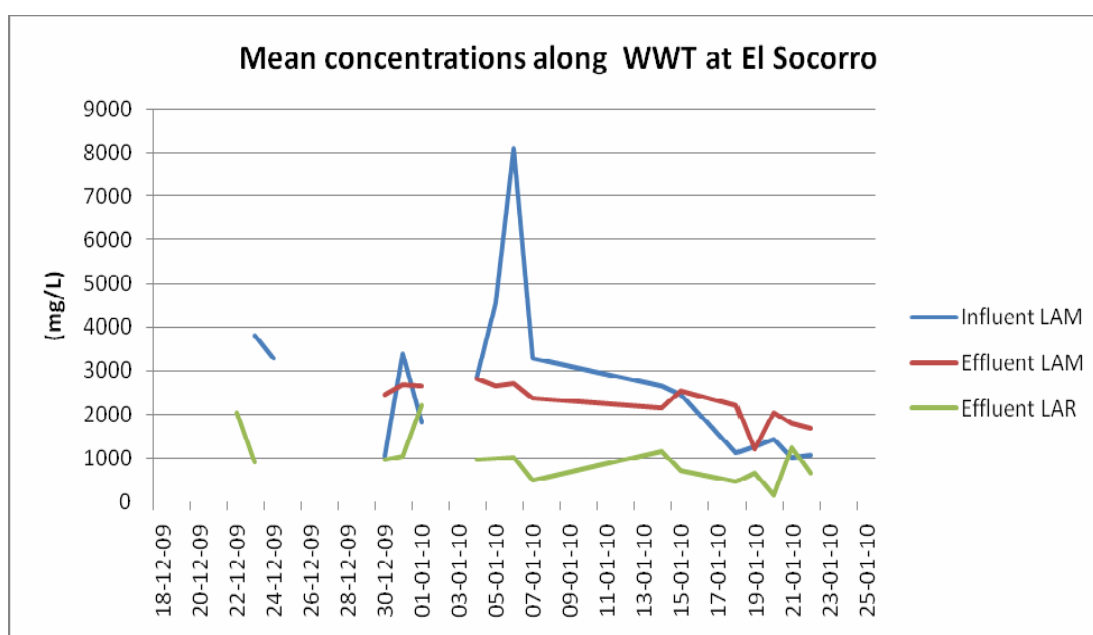
Figure 5.6 COD concentrations in the LAM and LAR systems

The different monitoring places are shown in figure 5.7.

5.4.2 NITROGEN REMOVAL

Nitrogen experiences a larger removal in the facultative pond as compared to the LAM system, 36% against 20%. The reason for this may be that due to the facultative character of the pond some aerobic denitrification may have taken place over there, although the dissolved oxygen concentration in this place was 1.49 mg O_2/L, see table 5.7.

5.4.3 PHOSPHORUS REMOVAL

Phosphorus was removed in the same amount in both the LAR system (30%) as well as the LAM system (28%). This may indicate that the processes taking place in the LAM system may apply for the LAR system. Over the two treatment steps a total removal of 49% was achieved.

5.4.4 TOC REMOVAL

The total organic carbon concentration appears to be removed more efficiently in the LAR system (72%) as compared to the TOC removal in the LAM system (32%). The TOC removal accomplished by the LAM and LAR systems together equates to 81%.
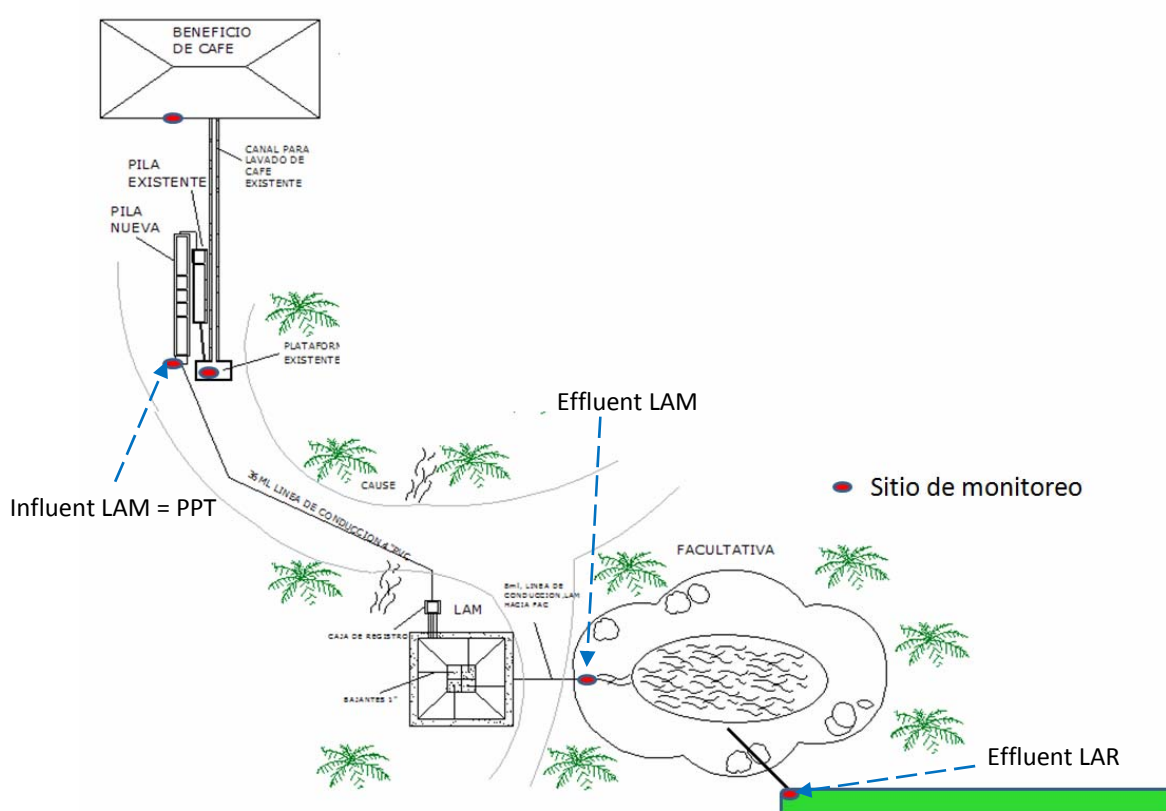
Figure 5.7 Monitoring places at finca El Socorro (red ovals)

Table 5.7, Dissolved oxygen concentrations after each treatment step at el Socorro

		LAVADO			DESPULPADO	
Oxígeno Disuelto (mg/Lt)						
Fecha	PPT	LAM	LAR	PPT	LAM	LAR
24-12-2009	0,64	0,60	0,37			
28-12-2009	0,07	0,34	1,08	0,20	0,33	1,11
29-12-2009				0,51	0,64	0,64
30-12-2009	0,23	1,12	1,76	0,53	1,32	1,63
31-12-2009	0,79	0,84	0,85	0,48	0,71	1,14
1-1-2010	0,16	1,19	0,97			

4-1-2010	1,68	1,63	2,13			
5-1-2010	0,32	2,34	2,27	0,11	1,04	1,90
6-1-2010	1,54	1,26	0,02	0,17	1,58	1,27
7-1-2010	0,19	2,14	1,69			
15-1-2010	1,19	2,74	1,94	0,77	1,12	0,48
18-1-2010						
19-1-2010				1,69	1,05	0,67
20-1-2010						
21-1-2010	0,24	1,52	3,36	1,63	2,11	1,93
22-1-2010				2,59	3,55	3,03
Promedio	0,64	1,43	1,49	0,87	1,35	1,38

5.5   BIOFILTER

The reduction of nutrients and COD load on the biofilter is very difficult to assess. Only a few samples were taken of the river water (El Ocote), upstream and downstream of the biofilter, the last treatment step in the wastewater system of finca El Socorro. These few samples showed values below the 200 mg/L COD, which is the Nicaraguan Norm. The effect of the wastewater treatment on El Ocote water was difficult to assess, as the last step in the treatment infiltrated the treated wastewater in the underground and through sub-surface flow the water reached the river system. No data is available about the soil characteristics and the varying flow of stream El Ocote is not known in sufficient detail.

5.6   EFFICIENCY OF DIFFERENT TREATMENT STEPS

An acceptable effluent quality is essential but this can only be assessed by monitoring the efficiency of the different treatment steps that are involved and this is problematic. According to MARENA (see section 2.5), the decree 33-95 shows that the major parameter of concern is the COD concentration discharged in the open waters. This concentration should be lower than 200 mg/L.

In the last harvest season the average COD concentration was 3053 mg/L and the efficiency of the LAM system in terms of load was 30%. In the subsequent step the efficiency in terms of load was 58%. Combining these two efficiencies the final efficiency was 70%. However, as has been explained in previous paragraph a third treatment step is being utilized. This treatment step is more difficult to assess, see section 5.5. With the present first two steps a reduction in COD concentrations was seen of almost 70% bringing the COD concentration to values around the 1000 mg/L. This value is still too high to discharge in the open water courses. Assuming a reduction efficiency of 50%[LXXXI] in the biofilter a final concentration of 500 mg/L could be expected. However, due to mixing and dilution with ground water flow the real value is difficult to measure. The LAM system has been designed to be operated at efficiencies ranging from 50% to 75%. Assuming an efficiency of 70% in the LAM and 60% in the LAR the COD concentration would be drastically reduced to 366 mg/L and after the biofilter the COD concentration would easily meet the MARENA norms.

5.7   BIOGAS PRODUCTION

As has been calculated previously and based on an assumed production of 800 QQ_{oro} in a harvest season of 90 days the average production of biogas is almost 25 m^3 per day. From this, 17.5 m^3 represent methane (1.97 m^3 of CH_4 per QQ_{oro}). It has to be noted, however, that biogas production could also be taken out of the pulp by-product. In this minor thesis, however, this has not been explored.

According to figure 4.3 and the pH values shown in table 5.4 no biogas production took place at all. According to the equilibrium situation between HCO_3^- and CO_2, and the pH values in the LAM system, almost no alkalinity at all was present in the LAM system. Figure 5.8 shows that with an average pH value of 5.35 almost 95% of the equilibrium of bicarbonate and carbon dioxide consisted of CO_2.
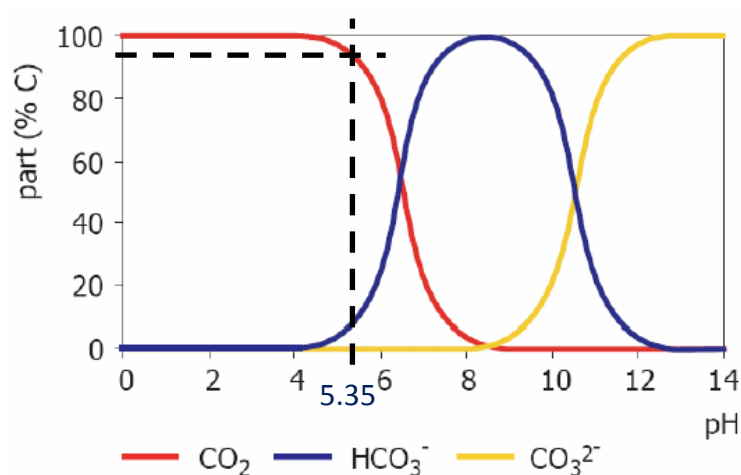
[LXXXI] HELLER, M. P.49. 2008

Figure 5.8 Equilibrium situations at different pH values

However, in order to be able to make a prediction about biogas production that could have taken place if the reactor had been working properly it is assumed that the 4 different stages as described in section 3.5 took place. Therefore instead of using the assumed production of 800 QQ_{oro}, the present production of 266 QQ_{oro} is used. Data corresponding with the water use during season 2009/2010 has been measured at three independent occasions for both de-pulping and washing (see table 5.8 and 5.9). The total consumption was 1.97 m^3/QQ_{oro}.

Table 5.8 Water usage during de-pulping

Water usage during de-pulping				
Date	18-jan	20-jan	21-jan	Mean
Latas	62	75,5	71,5	
QQ_{oro}	3,1	3,775	3,575	
m^3/QQ_{oro}	0,556	0,728	0,452	0,579

Table 5.9 Water usage during washing of fermented beans

Water usage during washing				
Date	17-dec	6-jan	15-jan	Mean
Latas	82	87	45	
QQ_{oro}	4,1	4,35	2,25	
m^3/QQ_{oro}	1,029	1,068	2,085	1,394

By changing some of the assumed values in the original calculation with values found in the research conducted during harvest season 2009/2010 table 5.10 can be produced. The values that were changed are: COD (from 10000 mg/L to 3053 mg/L), BOD (from 9000 mg/L to 1330 mg/L → assumed after TOC concentrations measured, see section 5.3.6). When using values found in literature the BOD/COD ratio for Coffee wastewater was found to be on average 0.58 in Xalapa, Mexcio[LXXXII], however during the period of the test this ratio varied between the 0.33 and 0.83; temperature (assumed 25 °C, measured 22 °C); water consumption (from 9.11 m^3/day to 8.60 m^3/day, see tables 5.4 and 5.5 in combination with tables 5.8 and 5.9) and the efficiency of COD removal which is assumed to be 50%.

Table 5.10 Values used for the calculation of Biogas production 2009/2010

	Parameter =	Values for 09/10
Basic information	Flow (m^3/d) =	8,60
	Concentration ($kgCOD/m^3$) =	3,05
	HRT (d) =	8,06
Improved Anaerobic Lagoon (LAM)	Depth (m) =	4,00
	Volume (m^3) =	69
	Sides (above) (m) =	6,00

[LXXXII] BELLO-MENDOZA, R. AND CASTILLO-RIVERA, P. 219-225. 1998

Sides (bottom) (m) =	2,00
Area (above) (m^2) =	36,00
Area (bottom) (m^2) =	4,00
Up flow velocity (above) (m/h) =	0,01
Up flow velocity (bottom) (m/h) =	0,09
Organic Volumetric Loading (kgCOD/m^3.d) =	2,92
Influent injection points =	4
Distance between outlet of injection points and bottom (m) =	0,20

Applying the formulae in section 4.3.4 the foreseen biogas production drastically decreases to only 3.43 m^3/day, which entails about 2.40 m^3/day of methane. This is equal to 0.53 m^3 of CH_4/QQ_{oro}. Using the BOD/COD ratio found in literature for the coffee wastewater in Xalapa, Mexico the biogas production would become 4.57 m^3/day. And applying the varying BOD/COD ratios found over there the biogas production would vary between the 2.60 m^3/day and 6.54 m^3/day. The large difference between the yield obtained for the coffee wastewater and the yield that could be achieved theoretically is to a large extent a consequence of the supposed high level of BOD concentration in the coffee wastewater at the design phase. The supposed higher temperatures of the water have a minor influence on the production of biogas as well as the altitude which has an influence on the atmospheric pressure. Furthermore the assumption of 800 QQ_{oro} production was only met by one third.

5.7.1 POSSIBILITIES OF BIOGAS UTILIZATION AT FINCA EL SOCORRO

Biogas utilization in a wet mill can have various uses as has been mentioned in section 4.4.3. In Mexico, for example, a study has been conducted about the number of anaerobic digesters applied to agro-industrial wastewaters. From this study only the wet mills have been selected to show which amount of biogas is produced and for which purpose the biogas is used there, see table 5.11.

Table 5.11 Biogas production and utilization from coffee farms in Veracruz, México[LXXXIII]

Name	Place	Flow [m^3/d]	COD [g/l]	T [°C]	OLR [kgCOD/m^3d]	HRT [d]	COD Rem.	Biogas [m^3]	Use of biogas
Bola de Oro	Coatepec	22.5	5	35	0.45	11	97%[+]	-	Vented
	Tlapexcatl	3 - 4	$3-6$	18-20	3	2.5-3.3	70%	7.7	Cooking
Solidaridad	Huatusco	60	$3-6$	18-20	3	1.5	75%	96	Flared up
Pr. M. Sodas	Huatusco	375	2.25	17-19	1.875	1.2	73%	204	Flared up
V. Guerrero	Misantla	50	1.5-2.5	18-20	1.83	2	60%	47	Flared up
Cerro Cintepe	Catemaco	29-43	8 - 12	20	4	2.5-3.8	83%*	120	Coffee dryers
Roma	Emiliano Zapata	57	$4-7$[+]	20	1.5 - 2	7 - 10	90%*		Vented

[+] BOD
* Expected, wastewater treatment plants were being installed in 1998

Due to the relatively small size of Finca El Socorro the drying of coffee does not happen in the farm itself. Small to medium size farm holders usually bring their coffee to a central place where it is dried. Don Raul brings his coffee to the city of Matagalpa for drying. Therefore, this option is not taken into consideration for the possible uses of biogas at el Socorro and as it has been calculated the present biogas production is also too small.

In the Finca El Socorro three dwellings are located. The attendant, Constantino Rodriguez, who is presently in charge of the wastewater treatment system, lives in the house which lies the closest to the AWWT (15 m). During the harvest time, his family is often with him at the Finca. This household is comprised of 6 individuals: Constantino, his wife and 3 children and his brother. This little house is located behind the office of the owner: Raúl Blandón. In the second house, located approximately 170 m from the AWWT, 3 people live while in the last house 7 people live (230 m from the AWWT). The houses are connected to the energy supply from the national electricity grid regulated by INE and run by Union Fenosa[LXXXIV]. The source of the energy is hydroelectric power developed in the Apanás Lake by the Hydrogesa plant.

The house of the attendant does not have a gas stove; instead they cook with fuel wood. In the house itself the devices which are used that consume energy are: a light bulb, radio and mobile phone chargers. In the office of Don Raul, a gas cooker can be found. This cooker uses a propane gas cylinder.

[LXXXIII] MONROY, O. P. 2-5. 2000
[LXXXIV] ING. RODRÍGUEZ, R. PERSONAL COMMUNICATION

The revenues that could be achieved by the use of the biogas (the methane content) can be expressed in terms of electricity consumed or in terms of the propane gas that otherwise would need to be bought.

FOR PROPANE GAS:

The price of a cylinder of 25 lb[LXXXVI] (or 11.3 kg), the most widely used, is US$ 11.45. The different cylinders in which propane gas is sold have capacities of 10 lb, 25 lb, 50 lb and 100 lb. The density of methane is 0.717 g/L. This is equal to 0.717 kg/m^3. In order to achieve the same quantity of pounds per cylinder: 11.3475/0.717 = 15.82 m^3 of CH_4 are needed. In this case the price of 1 m^3 of CH_4 is US$ 0.723. It has to be noted that the price of propane gas in Nicaragua has fluctuated considerably over the last few years. Currently the prices are similar in Central American countries except for El Salvador where the propane gas is subsidized. See table 5.12.

Table 5.12 Prices of propane gas in Central American Countries[LXXXV]

DESCRIPCION	NICARAGUA	*COSTA RICA	**GUATEMALA	***SAN SALVADOR	**HONDURAS
COMBUSTIBLES(GLS)					
Gasolina Extra o Super	$3.88	$4.37	$3.43	$3.40	$3.71
Gasolina Extra o Super con desc. Pr	$3.53				
Gasolina Regular	$3.78	$4.15	$3.31	$3.21	$3.44
Gasolina Regular con desc. Proy.	$3.43				
Diesel	$3.37	$3.67	$2.83	$2.99	$3.12
Diesel con desc. Proy.	$2.97				
GAS PROPANO (GLP)					
10 LBS	$4.58	$6.42	$5.22	$2.04	$4.56
25 Lbs	$11.45	$16.05	$13.04	$5.10	$11.40
100 Lbs	$52.68	$64.86	$52.16	$20.41	$46.49

* Los precios de los combustibles en Costa Rica son conforme a la Gaceta No. 115, última actualización realizada al 16 de Junio del 2010. (www.recope.gob.cr)

** Los Precios de los combustibles en Guatemala y Honduras son conforme a la ultima actualizacion realizada por el Ministerio de Energia y Minas de Guatemala al 21 de Junio del 2010. (www.mem.gt)

*** Los precios de los combustibles en El Salvador son conforme a la ultima actualizacion realizada por el Ministerio de Economia al 25 de Junio del 2010. (www.minec.gob.sv)

EN LOS PRECIOS DEL GLP DEL SALVADOR SE INCLUYE SUBSIDIO DE 1.6 DOLARES/GALON

DÓLAR OFICIAL NICARAGUA   C$ 21.3452

FOR ELECTRICITY:

The electricity price that has been paid in the region in which the finca is situated has had an average price in the last 10 months of C$ 5.63 per kWh[LXXXVII], this equals US$ 0,263 per kWh. 1 m^3 of CH_4 has an energy content of 35 846 kJ/m^3 (at 0° C, and 1 atm), so 1 m^3 of $CH_4 \approx$ 10 kWh. However, in order to convert 1 m^3 of CH_4 into electricity 20% is lost and 50% becomes heat, leaving only 30% as electricity[LXXXVIII]. Therefore 1 m^3 of CH_4 is equal to approximately 3 kWh. This means that a price of US$ 0.79 can be paid for 1 m^3 of CH_4. The savings made by transforming biogas into electricity or by using biogas instead of propane gas for cooking are very similar and will largely depend on the possibilities to use this renewable source in the location itself.

Due to the low quantity of biogas that has been produced in finca el Socorro the opportunities to use biogas are few. These opportunities have been listed in table 5.13, which is a slightly elaborated copy of table 4.5.

Table 5.13 Possible applications for finca el Socorro[LXXXIX]

Application	Biogas demand (l)	Comment
Cooking	150 - 300	per person per meal
	40 - 165[XC]	1 liter of water, resp. 5 liters of water
Lightning	120 - 150	per day
Radiant heater	200 - 300	per hour
Refrigerator	30 - 75[XCI]	per hour for 100 l volume, depending on outside temperature
Engine	10000	At least

[LXXXV] MINISTERIO DE TRANSPORTE E INFRAESTRUCTURA DE NICARAGUA (MTI). P.2. 2010

[LXXXVI] SPANISH ABBREVIATION FOR LIBRA = POUND

[LXXXVII] ING. RODRÍGUEZ, R. PERSONAL COMMUNICATION

[LXXXVIII] HENZE, M. ET AL. P. 318. 2002

[LXXXIX] GTZ. P. 19-23. UNDATED, AFTER 1997

[XC] NIJAGUNA, B.T. P. 235. 2002

[XCI] IBID.

The biogas utilization can be a direct or an indirect benefit to the finca owner.

In the first case the biogas could be utilized for cooling of the refrigerator. When this is the case, assuming a biogas demand of 75 L/hr, a total amount of 1.8 m^3 of biogas would be needed per day. The produced biogas, with a LAM efficiency of 50%, is of 3.43 m^3 a day. The other 1.63 m^3 of biogas could be used for cooking with the gas cooker at the fincas' office and for lighting of the houses.

In the second case, the benefits are directly experienced by the attendant of the finca and by the people living in the finca. These benefits could be indirectly beneficial to the fincas' owner by building trustfulness and good will. This in turn may lead to a synergy of better care of the AWWT, leading to an enhanced efficiency of the LAM system and thus higher production rates of methane. In order to achieve this, first the families within the finca should see the benefits of cooking with biogas instead of cooking with firewood, see paragraph 4.4.6. In addition, the contribution in the reduction of greenhouse gases should be made clear in the minds of biogas consumers. Then the next step should be to make (a) gas cooker(s) available. Once the gas cooker is implemented it can be used to prepare around 20 meals.

With this minor production of biogas only a few possibilities are presented to use the biogas. The use of radiant heaters or incubators, as well as the use of engines cannot be sustained. Increasing the efficiency of the LAM system to 75%, which is possible (see table 5.11), and having a larger biodegradability (BOD:COD ratio) of the wastewater (which further test will determine) will lead to higher biogas production rates of around 10 m^3/d of biogas with a produced quantity of 400 - 450 QQ_{oro}. This is just enough to work with engines, which could be helpful for the recirculation of the water with the water pump located in the finca.

5.8   ECONOMY OF SCALES

Or in other words, from which set-up size is the application of a LAM system profitable? In order to answer this question a comparison should be made between different LAM systems, their inversion costs and the profits they make with the byproduct of biogas.

In this section the possible penalties for the violation of norms of MARENA (paragraph 2.5), are not taken into account for two reasons. First there are no data regarding the financial penalties which are given when the norms are violated. Secondly, the entity responsible for the application of the penalties does not function in a standardized way because it must control both large fincas as well as small fincas. One of the objectives of the norms is to regain the natural 'pristine' water composition of the rivers in these zones and the large fincas are the ones that contribute more in either achieving this goal or losing sight of it.

5.8.1   INVERSION COSTS

The inversion costs account for the building of the LAM system in terms of excavation, material, construction, logistics, the distribution system and the gas holder. Until now two LAM systems have been built in Matagalpa. The LAM system for El Socorro and another LAM system for Cueva del Tigre (2 to 3 kilometers further afield). The inversion costs for the first LAM in El Socorro were in total US$ 12 486, whereas the inversion costs for the LAM at Cueva del Tigre were of US$ 18 000. For the first LAM the design was based upon a production of 800 QQ_{oro}, whereas in the second case the design was based on a production of 4000 QQ_{oro}. In order to make an easy estimation of the cost involved it is assumed that the LAM is built with the revenues of the QQ_{oro} sold in the first year, therefore the first variable IC (inversion costs) is the inversion divided by the design value of QQ_{oro}. This means that for El Socorro IC is US$ 15.60 /QQ_{oro}, and for Cueva del Tigre US$ 4.50 /QQ_{oro}. When illustrated on a graph the US$/$QQ_{oro}$ is given on the vertical axis and at the horizontal axis the estimated yearly production amount of QQ_{oro}. This graph gives us two points from which a relation can be drawn for the inversion costs per unit of QQ_{oro}. The range has been chosen in line with the range of coffee farms that are present in Matagalpa (< 10 000 QQ_{oro}).

From only two points it is very tricky to assume a trend line, but in this case, in the absence of additional data we are left with no other option. Applying a linear line between both points reveals that for fincas with a production of more than 2780 QQ_{oro} no inversion should be made at all. This is of course incorrect and a linear trend is obviously not a realistic approach. The other two trend lines which approach a more realistic value are the power function and the exponential function[XCII]. From these two the exponential function shows a decline

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[XCII] THIS TWO FUNCTIONS RECEIVE THIS NAME BY THE MICROSOFT PROGRAM EXCEL

in total inversion costs for coffee farms producing more than 2500 QQ_{oro}, however, this is contradictory and therefore this function is not accepted. Thus the choice falls upon the power function, which suggests more conservative and realistic values for large fincas. Figure 5.9 shows this graph. On the vertical axis the price is given while on the horizontal axis the amount of QQ_{oro}.
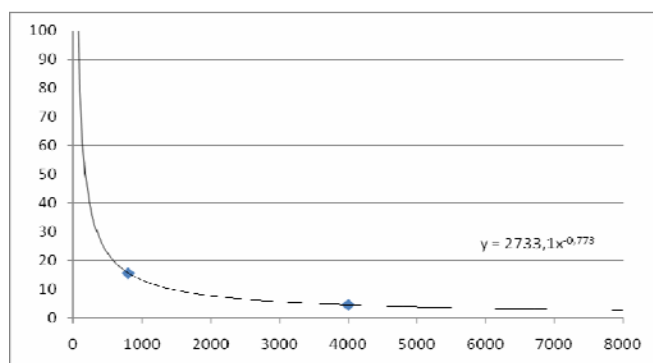

Figure 5.9 Power function of economy of scales for inversion costs

With formula [5.1] a table can be made in which inversion costs are given for the different sizes of fincas.

$$IC = 2733.1 \, QQ_{oro}^{-0.773} \tag{5.1}$$

In which the paremeters are as previously defined.

5.8.2 OPERATIONAL COSTS

The largest item in the operational costs is the buying of the base to increase the pH of the water. The two kinds of base that have been bought in El Socorro are: calcium hydroxide and calcium carbonate. Of these two calcium carbonate has a value of approximately US$ 0.55 per QQ_{oro} in order to increase the pH from 4.9 to 7.0 (with the values as assumed in Appendix B, table C), and calcium hydroxide has a value of US$ 1.01 per QQ_{oro} to achieve the same alkalinity. In order to achieve a pH value of 7.2, much more alkalinity would be needed[XCIII] and an increase of 60% would be seen in the costs. Take note that other operational costs such as transportation costs to buy the base or the salary of the attendant are not involved in this thesis.

5.8.3 REVENUES

The revenues of the LAM in terms of biogas production depend on different factors such as: biodegradability of the coffee wastewater, temperature, atmospheric pressure (altitude), strength of wastewater, methane content in biogas and efficiency of the LAM system. In order to calculate the revenues per QQ_{oro} two different efficiencies were calculated: 50% and 75%. For the other values refer to table 5.14.

Table 5.14 Values used to determine the revenues from biogas production

	Unit	Value	Comment
BOD:COD	[-]	0.44	Assumed/measured, see paragraph 5.3.6
Temperature	[°C]	22.0	Measured in fieldwork
Atm. pressure	[atm]	0.90	Measured in fieldwork
Strength WW	[kgCOD/m^3]	3.05	Measured in fieldwork
Methane content	[-]	0.70	Assumed from literature

Variation is also present in the biodegradability of wastewater flow and the revenues are shown in table 5.15.

Table 5.15 CH$_4$ production for each QQ_{oro} in function of LAM eff. and biodegradability

		Eff. m^3 CH$_4$/QQ$_{oro}$		US$ / QQ$_{oro}$[XCIV]	
	BOD:COD	**50%**	**75%**	**50%**	**75%**
Low	0.44	0.54	0.81	0.43	0.64
Medium	0.66	0.81	1.22	0.64	0.96
High	0.82	1.02	1.53	0.81	1.21

[XCIII] SEE TABLE C, APPENDIX B

[XCIV] THE VALUE OF 0.79 US$/CH$_4$ HAS BEEN USED HERE IN LINE WITH SUBPARAGRAPH 5.7.1

Table 5.15 gives an indication of the possible revenues according to the production potential (QQ$_{oro}$ per harvest season) of each coffee farm.

5.8.4   BREAK-EVEN POINT

The break-even point indicates the moment on a chart when expenses equal the returns. From this point onwards only revenues are booked[XCV]. As has been mentioned earlier, the revenues of applying a wastewater treatment system in order to avoid the penalties are not taken into account in this calculation. Looking at table 5.15, it can be seen that there are in principle 4 values that can be computed when calcium carbonate is applied (US$ 0.55/QQ$_{oro}$). The one with the Low BOD/COD ratio and 50% efficiency is not profitable as the operational costs are higher than the profits, and the medium for 50% efficiency is the same as the low for 75% efficiency. In the case when calcium hydroxide (US$ 1.01/QQ$_{oro}$) is to be used it only makes sense to study one option (high biodegradability and 75% efficiency in LAM system).

In order to calculate the break-even point a balance equation needs to be applied, this is equation [5.2]:

$$IC/T + C*T = R*T \qquad \text{[5.2]}$$

In which,

IC = Inversion costs   [US$/QQ$_{oro}$]
C = costs   [US$/(QQ$_{oro}$*year)]
T = time   [year]
R = revenues   [US$/(QQ$_{oro}$*year)]

Transforming formula [5.2], formula [5.3] is achieved.

$$T = (IC / (R - C))^{\frac{1}{2}} \qquad \text{[year]} \qquad \text{[5.3]}$$

This formula results in figure 5.10. In this figure the production potential of each coffee farm is put on the horizontal axis and the time until the break-even point is reached is shown in the vertical axis. Figure 5.10, indicates with which type of base, and with what kind of efficiency the break-even point is reached after a certain amount of years. The first index in the legend stands for the biodegradability (see table 5.15) the percentage indicates the efficiency of the LAM system and the last index denotes the type of base applied. Note that the horizontal axis is not evenly distributed.

Looking at the finca of Don Raúl, which has a supposed biodegradability of 0.44 (LOW) and supposing an efficiency of 75% that could be reached in the LAM system, the break-even point can only be reached if CaCO$_3$ is used as base. Calcium hydroxide is too expensive to apply there. With the production rate of around the 250 QQ$_{oro}$ the break-even point is reached after 20 years. If the actual design criterion is met, 800 QQ$_{oro}$, this point would be reached after 13 years. It is obvious then that the economy of scales plays an important role in the application of LAM systems.

From figure 5.10 it is clear that, considering costs, CaCO$_3$ has a clear advantage over Ca(OH)$_2$. However, due to the lower solubility of CaCO$_3$ in water, larger amounts have to be bought and the process of increasing the pH of the water takes longer.

Considering the number of years needed before the break-even point is reached, reliable materials should be used in the construction of LAM systems in order to prevent premature expenses for unforeseen repairs. This figure also shows the importance of a good characterization of the coffee wastewater to be treated. With small BOD:COD ratios (LOW), the farms that could make use of LAM systems should at least have a production potential of 3000 QQ$_{oro}$ or more.

[XCV] IN THIS CALCULATION INTEREST RATES AND INFLATION FACTORS ARE NOT INCLUDED
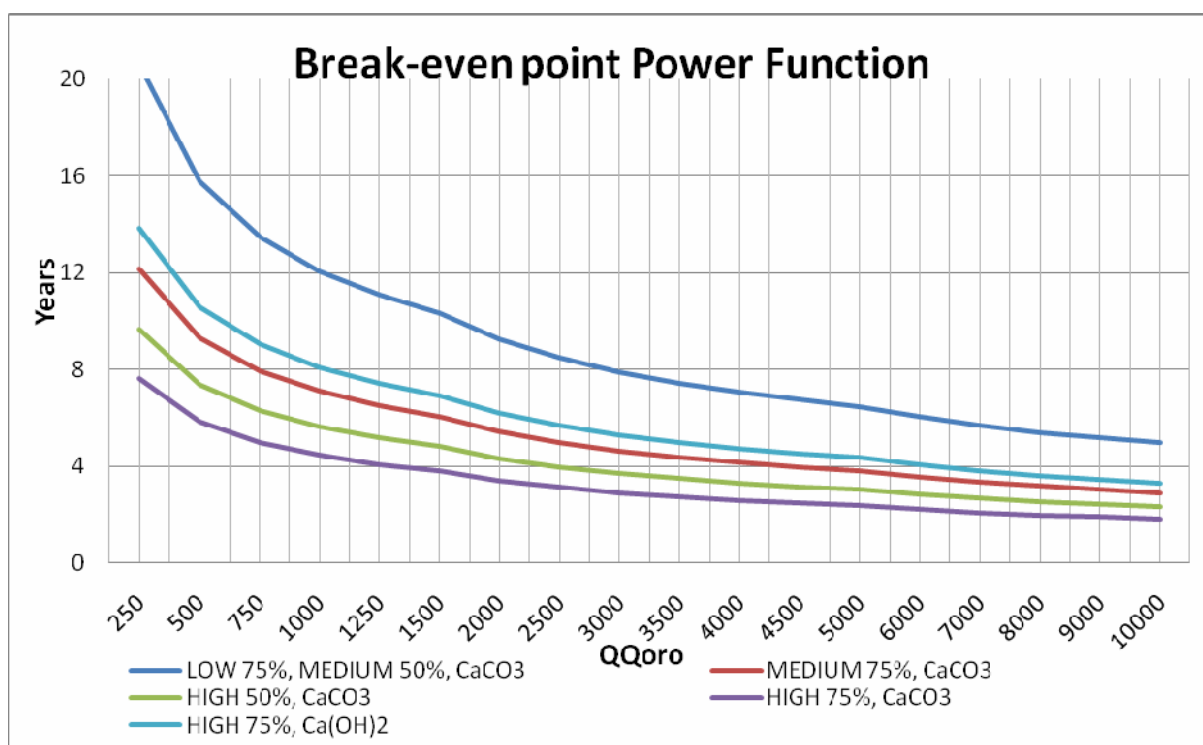
Figure 5.10 Break-even point for different sizes of coffee plantations

Figure 5.10 should be carefully assessed before drawing any conclusions, considering the amount of values which have been assumed and the suppositions made in order to achieve the inversion costs (just from two LAM's which have been built). In addition, the fluctuations on energy prices will sometimes favor the construction of LAM systems, whereas in other cases they will discourage their application. However, this figure gives a general impression of the application possibilities of LAM systems for coffee wastewater treatment in Nicaragua and Central American countries.

A possible way to reduce costs in AD in a LAM system can be drawn from the process itself. The final stage of methane production from organic matter is the conversion of acetate into CH_4 and HCO_3^- (CO_2/OH^-), this is, a conversion of a relatively strong acid into a weak carbonic acid. Because both end-products are gaseous, they will automatically escape from the liquid phase. This shows that there seems to be a removal of acidity while at the same time a production of alkalinity. Both processes will tend to raise the pH in the LAM system. Due to the relation between the carbonic system (CO_2-HCO_3^--$CO_3^=$) and the pH in the anaerobic digester (LAM system), there will be an interrelationship between the alkalinity, the acidity and the pH. Therefore the pH could be adjusted by adding alkalinity as has been shown in the previous paragraphs or by substracting acidity from the digester[xcvi]. This is possible by stripping CO_2 from the effluent of the LAM system and re-circulating the effluent into the feeding of the LAM. Nevertheless, in order to do this in El Socorro an installation of a carbon dioxide stripping mechanism is required. There are different ways in which such a stripping machine could be installed. A cascade, for example, would fit the purpose as well as spray devices. Due to the graph shown in figure 5.10, this application is more relevant to larger coffee farms in which the production of methane will also be enough to run their own engines in order to re-circulate a part of the wastewater and in this way make a valuable use of the alkalinity that has been already dosed at the start up of the system. At the same time the lines that are drawn in figure 5.10 will drop; leading to faster revenues after the installation of a LAM system.

[xcvi] *VAN HAANDEL, A., VAN LIER, J.B. P. 5. 2006*

6. CONCLUSIONS

Basic technology of anaerobic digestion for coffee wastewater has been widely applied and in a number of cases it has successfully been implemented. More specifically for coffee wastewater, the application of a LAM system (a hybrid system between an anaerobic lagoon and a UASB) which was developed in the last 5 years can be applied under certain circumstances.

Prior to the installation of a LAM system on a coffee farm it is crucial that sufficient knowledge and know how about the working of a LAM system has been imparted to those responsible for it. A reliable attendant should be assigned to be in charge of operating and maintaining the system in order to achieve high efficiency levels of treatment. High COD removal will improve the biogas production at the coffee farm.

Because of the strong acidic character of the wastewaters originating from the de-pulping process and the washing of fermented coffee beans pH correction is needed. This will prevent the efficiency of the LAM to decrease because of an alteration in the habitat of the micro-organisms working in the LAM system. The pH can be corrected with different bases. The selection of the type of base to be used should be carefully researched in accordance with its availability, costs and ease of use on a coffee farm. Bearing in mind that the base is one of the main components that makes up the operational costs, the choice of the base will in most cases fall upon calcium carbonate.

Presently, the applications of biogas in El Socorro are few and are mainly to be found in the area of electricity production for small devices such as: lighting, mobile phone chargers and radios. As a renewable source of energy biogas can be used as fuel for cooking, instead of burning firewood. This will promote a healthier environment by reducing respiratory illnesses and might give more opportunities of development to local children.

For small coffee farms a LAM system will reduce the COD load, especially if a post treatment is applied, in a way that it complies with the MARENA norms, however, no monetary revenues will be seen (as it is the case for El Socorro). Therefore another wastewater treatment system is more suitable. In order to build self sustainable LAM systems (systems in which the break-even point is reached within 5 years) the coffee farms in which the LAM systems are installed should have a production potential of 3000 QQ_{oro} or more of coffee. In the event that operational costs are reduced by re-circulating the effluent of the LAM after stripping the carbon dioxide the production potential for self sustainable LAM systems become lower.

With the introduction of these LAM systems in different coffee plantations understanding will increase and maximum efficiency can be achieved. The size of these LAM's will be based on the production capacity per coffee farm and on the achievable hydraulic retention time aimed at (around the 7 days).

As a closing thought the LAM system poses opportunities for middle-large to large coffee farms to improve their coffee wastewater treatment while at the same time it offers the possibility to make profit of the by-product biogas produced in the purification of the wastewater through anaerobic systems.

7. RECOMMENDATIONS

Based on the fieldwork performed during the months of November 2009 and February 2010 and the investigation performed afterwards several recommendations can be proposed. First, recommendations are given concerning the proper management of a LAM system and those points which are accessible to improvement are presented. Subsequently, recommendations on where and how to implement LAM systems are presented.

For places where LAM systems are being built or have already been built the following points are highlighted:

- Sufficient inoculum should be available in the bottom of the LAM system by September (before the harvest season starts). This inoculum can be gathered from anaerobic or facultative lagoons in other coffee plantations where the biomass sludge has settled in the previous years.
- The distribution system at the bottom of the LAM should be installed correct. It is crucial to avoid any changes during the harvest season.
- From the formulas presented in this minor thesis calculations can be made regarding the quantity of base material that should be available for the next harvest season. If it is calcium hydroxide 3.424 kg/QQ_{oro} should be available whereas if it is calcium carbonate 4.136 kg/QQ_{oro} should be available.
- Wastewater with a corrected pH value of 7 should be added to the LAM continuously. This means a constant flow of wastewater should be introduced to the LAM system. In El Socorro, in order to empty reservoir R2 (pre-acidification pond, figure 4.5) in about 22 hours a flow of 7 L per minute should be aimed for.
- The grid separators that prevent other coffee wastes going into the LAM system need to be cleaned rigorously every day in order to prevent blockages and other wastes entering the LAM system.
- According to Heller[XCVII] the wastewater production per QQ_{oro} in the harvest season 2007/2008 was 2.646m^3/QQ_{oro}. This has been reduced to 1.97m^3/QQ_{oro} in harvest season 2009/2010 due to recycling and is considered good progress. However, less water can be used without harming the quality of the beans. Therefore it has been proposed to use recycled water for the de-pulping as well as for the washing of fermented beans (which has been applied in El Socorro last harvest season).
- During the last phase of the washing of the fermented beans, the wastewater is relatively clean. Therefore it is recommended to direct this water to the facultative lagoon instead of bringing this water to the pre-acidification reservoir and then to the LAM as it only dilutes the COD concentration and diminishes the load. This is the case for the last 10 to 15 minutes during the washing phase in El Socorro.
- The water going from the LAR to the biofilter needs to be dosed constantly during approximately 12 hours, from sunrise to sunset, in order to take advantage of the photosynthesis process of the plants.
- Coffee wastewater stemming from the washing of fermented beans in the LAM system should be treated and coffee beans should be de-pulped using dry methods (see section 2.4.2) once these new improvements are implemented.

For coffee farms planning to construct a LAM system the following recommendations apply:

- Characterize the coffee wastewater in order to investigate the biodegradability of it.
- A LAM system is a system that is constructed to last 10 to 15 years. In order to maximize the profitable returns from the system the potential coffee production that a coffee farm will produce over the next decade should be projected.
- Coffee farms producing 3000 QQ_{oro} or more per season will benefits in a time lapse of a lustrum.

[XCVII] HELLER, M. P. 45. TABLE 4.6. 2008

- In situ experiments to calculate the amount of base needed for the coffee wastewater in Nicaragua and every specific region where coffee is grown should be developed and implemented.
- The graph shown in figure 5.10 should be further validated with more research in order to be able to make appropriate decisions concerning the implementation of LAM systems in coffee plantations.
- Investigate the electricity demand of a de-pulping machine, to see if the biogas could serve as an alternative source of fuel for the de-pulping process.
- Investigate the need for desulphurization in case of biogas use for engines.
- Evaluate the possibilities to use cheaper construction materials as has been proposed by R.I. Rodriguez in order to minimize inversion costs and let smaller farms also benefit from the system.
- Investigate the possibilities to trade in carbon credits in Central American countries.
- Investigate if the LAM system can successfully be implemented for other types of wastewaters.

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APPENDICES

APPENDIX A – MEASUREMENTS AT FINCA EL SOCORRO

Table A, pH concentration at finca el Socorro

pH								
		LAVADO				DESPULPADO		
Fecha	Mc	PPT	LAM	LAR	Mc	PPT	LAM	LAR
11-12-2009	4,53		4,53	4,8				
14-12-2009		5,19		5,24				
17-12-2009	4,94	5,20		5,81				
18-12-2009		5,29	5,33	6,37				
22-12-2009		5,25	5,39	6,27				
23-12-2009	4,73	5,25	5,31	5,79	4,81	5,19	5,40	5,50
24-12-2009		5,35	5,42	5,12				
28-12-2009		5,49	5,43	5,59		5,20	5,47	6,65
29-12-2009						5,20	6,29	6,24
30-12-2009		5,07	5,48	5,29	5,04	5,92	5,54	5,48
31-12-2009	4,81	5,83	5,52	5,60	4,91	5,03	5,48	5,50
1-1-2010	5,24	4,91	5,52	5,52				
4-1-2010		5,49	5,58	5,76				
5-1-2010	5,12	5,13	5,60	5,99		4,97	5,54	5,66
6-1-2010	4,69	5,55	6,49	4,55	4,87	5,00	5,57	6,12
7-1-2010	4,80	4,94	5,55	6,51				
15-1-2010		5,85	5,71	7,37				
18-1-2010						5,66	7,29	5,89
19-1-2010					5,14	5,67	6,04	7,32
20-1-2010					5,71	5,72	5,92	7,68
21-1-2010	5,24	5,24	5,93	7,27	6,76	5,20	5,92	7,27
22-1-2010								
Promedio[XCVIII]	4,95	5,34	5,63	5,86	5,32	5,34	5,86	6,30
Promedio[XCIX]	4,90	5,31	5,52	5,81	5,32	5,34	5,86	6,30

Table B, Conductivity measurements at Finca el Socorro

Conductividad					
	LAVADO			DESPULPADO	
Fecha	PPT	LAM	LAR	PPT	LAM	LAR
11-12-2009		2710	2720			
14-12-2009	3020		2640			
17-12-2009	3420		2590			
18-12-2009	3930	3490	2710			
22-12-2009	4550	4050	2460			
23-12-2009	5150	4120	2370	4140	4320	1806
24-12-2009	3290	2520	2030			
28-12-2009	3210	2360	2325			
29-12-2009	5030	4510	1976	1300	2250	467

[XCVIII] *AVERAGE FROM 23RD OF DECEMBER TO 22ND OF JANUARY, APPLIES ALSO TO TABLE B*
[XCIX] *AVERAGE FROM 11TH OF DECEMBER TO 22ND OF JANUARY, APPLIES ALSO TO TABLE B*

30-12-2009	2870	4620	2046	7350	4680	1997
31-12-2009	6810	4600	1908	3620	4570	4590
1-1-2010	2026	4610	3810			
4-1-2010	4970	4890	1984			
5-1-2010	3390	4980	2185	3040	4990	2171
6-1-2010	4930	3170	2090	3760	4920	2250
7-1-2010	3860	4920	2097			
15-1-2010	5180	5140	2700	6490	5130	2880
18-1-2010						
19-1-2010				2980	3250	3130
20-1-2010						
21-1-2010	2980	3250	3130	1979	4820	4040
22-1-2010				3150	4490	3550
Promedio		4130	4130	2358	3781	4342	2688
Promedio		4036	3996	2432	3781	4342	2688

APPENDIX B

METHOD METCALF & EDDY

In order to increase the alkalinity of the wastewater to a pH value of 7 or 7.2 first some values which were derived from the fieldwork are presented. These are: T = 22 °C; Q = 8.6 m^3/d. Assumed values from literature on coffee wastewater: alkalinity 39 mg/L as $CaCO_3$; CO_2 content in biogas is equal to 30%. For the carbonate equilibrium constant (k_{a1}) at a temperature of 22 °C a value of 4.288 x 10^{-7} can be interpolated in the book of Metcalf & Eddy. The formula required to calculate the correct Henry's law coefficient is calculated with the following formula:

$$Log_{10} H = (-A / T) + B$$

In which T is the temperature and A and B constants specific for carbon dioxide. So,

$$Log_{10} H = (-1012.4 / (273.15+22)) + 6.606 ➔ H = 1503.95 \text{ atm}$$

First the concentration of HCO_3^- required to maintain the pH at or near a value of 7 or 7.2 is determined. Concentration of H_2CO_3 is determined with

$$P_g = H * x_g$$

$$x_{H2CO3} = P_g / H = (0.9 \text{ atm}) (0.30 [\% CO_2])/ (1504) = 1.795 \text{ x } 10^{-4}$$

Because one liter of water contains 55.6 mole the mole fraction of H_2CO_3 is equal to

$$x_{H2CO3} = \text{mole gas } (n_g) / [\text{mole gas } (n_g) + \text{mole water } (n_w)]$$

$$1.795 \text{ x } 10^{-4} = [H_2CO_3] / \{[H_2CO_3] + [55.6 \text{ mole/L}]\}$$

Because the number of moles of dissolved gas in a liter of water is much less than the number of moles of water,

$$[H_2CO_3] \sim= 1.795 \text{ x } 10^{-4} * [55.6 \text{ mole/L}] \approx 9.982 \text{ x } 10^{-3} \text{ mole/L}$$

To determine the concentration of HCO_3^- required in order to maintain the pH at or near a value of 7 or 7.2

$$[HCO_3^-][H^+] / [H_2CO_3] = k_{a1}$$

$$[HCO_3^-] = k_{a1} [H_2CO_3] / [H^+]$$

$$[HCO_3^-] = [\ 4.288 \times 10^{-7}\ mole/L * 9.982 \times 10^{-3}\ mole/L\ ] / [\ 10^{-7\ (or\ -7.2)}\ mole/L\ ]$$

$$[HCO_3^-] = 0.0428\ (or\ 0.0678)^C\ mole/L$$

$$HCO_3^- = 0.0428\ mole/L * 61\ g/mole * 1000\ mg/g = 2611\ mg/L\ (or\ 4136\ mg/L)$$

Determination of the required amount of alkalinity per day:

Equivalents of HCO_3^- = (2.611 g/L) / (61 g/mole) = 0.0428 eq/L (or 0.0678 eq/L)

1 eq $CaCO_3$ = MW/2 = (100 g/mole)/2 = 50 g $CaCO_3$ / eq

Alkalinity as $CaCO_3$ = 0.0428 eq/L * 50 g/eq * 1000 mg/g = 2140 mg/L (or 3390 mg/L)

Alkalinity needed as $CaCO_3$ = 2140 – 40 = 2100 mg/L (or 3350 mg/L) as $CaCO_3$

Daily alkalinity addition = 2100 g/m^3 * 8.6 m^3/day * 0.001 kg/g = 18.06 kg/day (or 28.81 kg/day)

A bag of 25 lb costs C\$ 32,50[Cl]. This equals US\$ 134,00 for a ton of calcium carbonate ($CaCO_3$).

Table C, Amount of kg per QQ$_{oro}$ for different base type and different pH value

pH correction	Kg **CaCO$_3$**/QQ$_{oro}$	266 QQ$_{oro}$	800 QQ$_{oro}$	Kg **Ca(OH)$_2$**/QQ$_{oro}$	266 QQ$_{oro}$	800 QQ$_{oro}$
4.9 → 7.0	4.136	US\$ 147	US\$ 443	3.424	US\$ 269	US\$ 809
4.9 → 7.2	6.600	US\$ 232	US\$ 707	5.440	US\$ 428	US\$ 1286

The table above provides an indication of the costs that are related with either calcium carbonate or calcium hydroxide for the harvest yield of last harvest season 2009/2010 and for the expected maximum harvest yield.

[C] VALUES IN BRACKETS REPRESENT FOR A pH CORRECTION TO 7.2
[Cl] PERSONAL COMMUNICATION. ING. RODRIGUEZ, R.I.