ENVIRONMENTAL TECHNOLOGY & MANAGEMENT,
AVANS UNIVERSITY OF APPLIED SCIENCE, BREDA

Utilisation of the effluent of a plug flow digester

Bachelor Environmental Technology & Management
Final year project with FACT Foundation

Kevin CHAPON
August 2011

Report of the final year project of Kevin CHAPON,
Bachelor Environmental Technology & Management,
2010/2011
Avans Hogeschool, Breda.
Contact: kevin.chapon@live.fr

This report presents the development of the final year project of Kevin CHAPON, student in the bachelor program Environmental Technology & Management, proposed by Avans University of Applied Science in Breda, Netherlands. This project is the finalisation of the Bachelor program and is part of the final grade allowing to access to the degree. This placement took place within the Dutch NGO, FACT Foundation and was realised partly in Eindhoven, Netherlands and partly in Koulikoro, Mali.

The aims of this project were to design and evaluate of the effectiveness of solid/liquid separation from the digester effluent and to assess the potential value for (partially dried) organic fertilizer in Mali.

Two different systems, a straw filter and a solar dryer, have been designed and tested. The solid content removal of the systems and the composition of the different end products have been studied and are described in this report. The nitrogen and phosphorus content of the different phases were evaluated as well to get an idea of the fertilising effect of these products. Additional works realised during this project are presented in this report as well.

The defined solution to deal with the digester effluent is to use the straw filter to make a first decrease in the volume of the effluent and remove the bigger parts. The filtrate would then be treated by the solar dryer for further volume reduction.

Concerning the fertilising effect of the different products obtained during processing, the nutrient content (N and P) has been defined and would have a positive effect on the crops cultivation. However, further investigation concerning the experimental assessment of the fertilising effect could provide more information about the increase in the crops yield.

Table of contents

Table of figures

Table of tables

Abbreviations

ACA: Agiratec cleaning agent
ETM: Environmental Technology & Management department
FACT: FACT Foundation
HRT: Hydraulic retention time
KOH: potassium hydroxide
MBSA: Mali Biocarburant SA
MFP: Multi-functional platform
NGO: Non-governmental organisation

1. Introduction

This section is focused on presenting a general introduction to the project, followed by a formulation of the problem and concluded by a presentation of the goals of this project.

1.1. General introduction

Nowadays, the world population is facing common issues. Some environmental problems are defined as global and are linked to the human activity. This anthropogenic degradation of the environment is visible through different examples. Some specialists are convinced that the global warming is due to human activity. On a smaller scale, deforestation and landscape degradation are the proofs of the current consumption society effect. Famous industrial catastrophes could also be used as degradation examples (Bhopal: 1984; Chernobyl: 1986). These are the effects of the highly consumptive society. The intensive use of resources will lead to the end of the abundance. Resource depletion is already noticeable in many different places, for different materials. The most expected one is the end of fossil fuel. Current Western societies are mainly based on fossil fuel as energy source. This leads to pollution exposition for the people, due to the contaminants contained in the exhaust gases and produced during the combustion of fossil fuels.

Generally speaking if the worldwide population was living as the average American citizen in 2006, the need for this population would have been 5 planets. As the Earth is a limited area, it is obvious that if the developing countries are following the same growth way as the western countries, pollutions and environmental degradations will be much higher than now, especially if the predictions from the United Nations are true. This organisation is expecting 10 billion people on Earth in 2100. But another problem is that richness repartition is not equally distributed. Indeed, some large disparities appear and the economic system tends to increase these disparities.

A solution to these different problems could be an economic and cultural development respectful of the environment, called sustainable development. Lots of different processes or solutions have already been studied and are accessible. The main sustainable energy production developments are the solar energy, wind energy, hydroelectricity, geothermal energy and bio-energy treatment. This report is focused especially on the development and the use of biogas and the exploitation of the different products that are coming from the biogas production in developing countries. Indeed, energy generation through the use of biogas as been proved as economically viable and efficient.

FACT Foundation manages projects around the world for sharing the expertise and the knowledge acquired since the beginning of the foundation. Indeed, renewable energies could be effective and could offer real solutions to the current existing problems. The aim of FACT Foundation is to provide an affordable and efficient energy production for rural communities. The main goal of that kind of project for the local populations is to reach autonomy in term of energy production and use for the rural communities in the developing countries.

1.2. Problem statement

As seen during the introduction, FACT Foundation is a team of biogas specialists, and one of the technologies developed by the NGO concerns the anaerobic digestion of wet biomass. This kind of system is designed to provide affordable and reliable energy source. One of the latest developments that FACT works on in Mali, is the preparation and the implementation of a small digester that can produce biogas used in small diesel engines (Multifunctional Platforms: MFP's). The system studied during this project is mainly composed of a digester ($10m^3$), used as a test unit. This system is already implemented and working at the Mali Biocarburant SA factory located in Koulikoro. The input product is a mixture of cattle manure, water and Jatropha press cake, press residue from a plant, with nuts containing oil, used for the production of biodiesel.

The main issue of this project is to define a suitable way to deal with the effluent of the digester. Indeed, the mixture (cattle slurry, water and eventually Jatropha press cake), from the digester, has a high nutrient content value and could be used by local farmers to improve their cultures and harvests quality. Nevertheless, the mixture's water content is very high, which makes the transport and the storage impractical or complicated, and decreases the market value of the fertilizer. The problem that has to be solved in this project is to design, implement and test a water/liquid separation process facilitating the management of the effluent and its use as fertiliser.

1.3. Goals of the project

Following the problems describe in the previous section, the goals of this project are summarised below:

-Design and Evaluation of the effectiveness of solid/liquid separation from the digester effluent;
-Assessment of the potential value for (partially dried) organic fertilizer in Mali.

It is important to keep in mind that the proposed solutions have to be implemented in Koulikoro first and in small villages later, leading to some restrictions concerning the development of the system. Indeed, it could not be too sophisticated due to the local conditions. The materials used for the different systems have to be available in Mali in order to develop the local economy and to allow an on-site maintenance. The main points of attention are following:

1. Low initial capital costs;
2. Easy to construct and fabricate with available materials;
3. Easy-to-operate with no complicated electronic/mechanical protocol;
4. Easy to maintain all parts and components; and
5. Simple replacement of parts during breakdowns.

Figure 1 presents the process flow diagram of the proposed development.

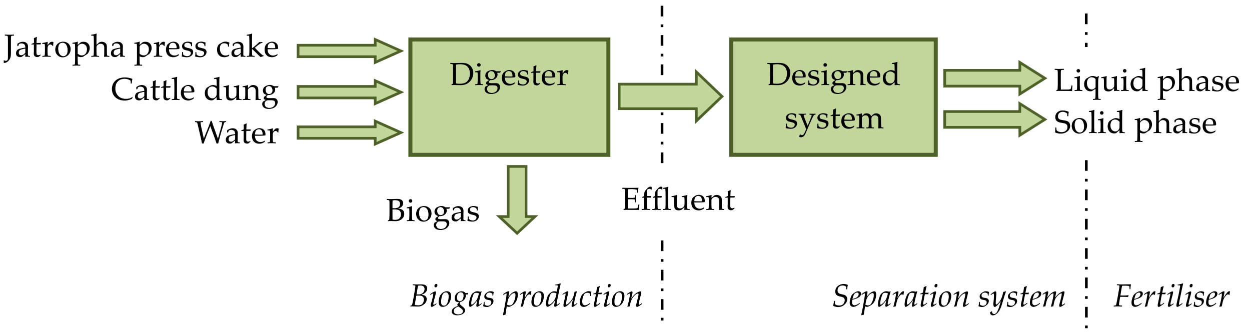

Figure 1: Process flow diagram of the system implemented in Koulikoro

2. Theoretical background information

In this section, theoretical background information of the final year project is given. Firstly, a presentation of the organisations concerned by this project is done, followed by a presentation of the locations. Finally, background information about the different topics of the project is given (Biogas production, Separation system and fertilising evaluation).

2.1. Organisations

The first part of this section presents the organisations involved in this project.

2.1.1. FACT Foundation

FACT Foundation, founded by a group of experts in biofuels in May 2005, is a Dutch NGO promoting the use of affordable and reliable biofuels and energy supply in rural area in developing countries. More especially, FACT collects, verifies and generates knowledge and experience on suitable bio energy systems and applications with the development and the implementation of small and medium project. FACT

Foundation is already presents in different continents (Lao, Panama, Mali, Honduras, Mozambique, etc) while some projects are still starting in new locations.
FACT Foundation promotes sustainable biofuels use for local and rural communities in developing countries, by providing expertise and knowledge on the implementation of biofuels cultivation and exploitation systems, by testing and monitoring innovative treatment systems, and finally, by giving a specialist advice on demand.
The three main topics of this NGO are reducing the dependence on fossil fuels of the developing countries, stimulating the local economy (on site production, harvest, use and waste treatment) and increasing the quality of life of the local people.
Structurally speaking, Fact Foundation is composed of an Office, an Executive Board and an Advisory Board.
The Office is in charge of the daily activities as well as maintaining contacts with the counterparts, projects and financiers. The office is also managing the publications, the website as well as the special events such as workshops.
FACT Foundation also used to work with a group of associates on the different projects in partner countries. Part time employees, volunteers and students are also involved in office and on-site works. FACT is focused on attracting motivated young professionals and students to deploy internships within FACT Foundation. Moreover, there are research programs set up with Eindhoven University of Technology (TU/e) and Wageningen University and Research (WUR).

2.1.2. Mali Biocarburant SA

Mali Biocarburant SA (MBSA) is a Malian company created in 2007 which is producing biodiesel based on a plant called Jatropha, in partnership with the Local Union of Jatropha producers (ULSPP), shareholders of MBSA.
This company process and transforms Jatropha nuts in oil and then, in biodiesel. Jatropha nuts provide an affordable and reliable biodiesel. With the production unit installed in Koulikoro, MBSA is the first Malian company providing biodiesel in agreement with the European quality standards.
Through its activity and its shared values, Mali Biocarburant is taking part in the agricultural, social and economic development of the country as well as the sustainable development of a growing sector in respect to the human values of the producers, actors and biodiesel consumers. The MBSA process, in each of its steps, is focused on the local benefits. The nuts are produced by local farmers then MBSA is transforming the nuts in biodiesel for a local consumption.

MBSA is working with more than 4000 small Jatropha farmers in three areas of Mali and two areas in Burkina Faso. Actually, MBSA is implementing sustainable decentralized biodiesel processors in West Africa. One of the main innovative characteristic of MBSA is that the farmer union owns 20% of the shares of the company. In this case, farmers have direct benefits of the commercialisation of the product.

2.2. Locations

As explained below, this final year placement has been realised in two separated parts. The first part of the final year project took place in FACT Foundation offices, located on the campus of the Technische Universiteit of Eindhoven, Netherlands, and the second one, took place in Koulikoro, Mali, within MBSA offices.

2.2.1. Eindhoven

Figure 2 presents an overview of the FACT Foundation offices, located on the point A.

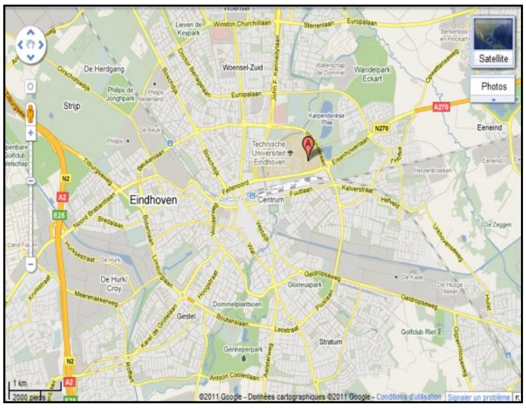

Figure 2: FACT offices location

This first part of the project was focused on the preparation of the project. Indeed, this period started by an introduction in the company and first researches and proposed solutions were evaluated in that part of the project as well. This period finished with a meeting with the Avans' supervisor, Reineke Klein Entink, the FACT supervisor for this project Bart Frederiks and the Avans student, Kevin CHAPON. This period started on the 31st of January and ended on the 18th of February.

The second part of this project was carried out in Koulikoro, Mali. Presentations of Mali and Koulikoro are given in the coming section.

2.2.2. Koulikoro, Mali

As explained before, part of the final year project took place on the African continent, in a country located in the West Africa, Mali.

2.2.2.1. Mali description

Following table (Table 1) provides general information about Mali.

Table 1: General information about Mali

Capital city	Bamako
Official language	French
Vernacular language	Bambara
Denonym	Malian
Government	Semi-presidential republic
President	Amadou Toumani Touré
Prime Minister	Cissé Mariam Kaïdama Sidibé
Area (total)	1 240 192 km2 (approx. 30 times the Netherlands)
Water (%)	1.6
Population (2009)	14 517 176 (approx. the same as Netherlands)
Density	11.7 inh/km^2

The republic of Mali is surrounded by Niger on the east, Burkina Faso and Ivory Coast on the south, Guinea on the south west, Mauritania and Senegal on the west and Algeria in the north. Mali consists of eight regions: Kayes, Koulikoro, Sikasso, Segou, Mopti, Gao, Tombouctou and Kidal.

Mali's climate ranges from sub-tropical in the south of the country to arid in the north. The country is mostly dry, with 4–5 months of rainy season (Late June to late November), often causing flooding of the Niger River. During the hot season the temperature could reach 40-45°C and the average day temperature during the rainy season is around 25 °C. During the transition between the hot and the rainy season, sandstorms and thunderstorms are common.

Figure 3 presents the location of Bamako (A) and Koulikoro (B).

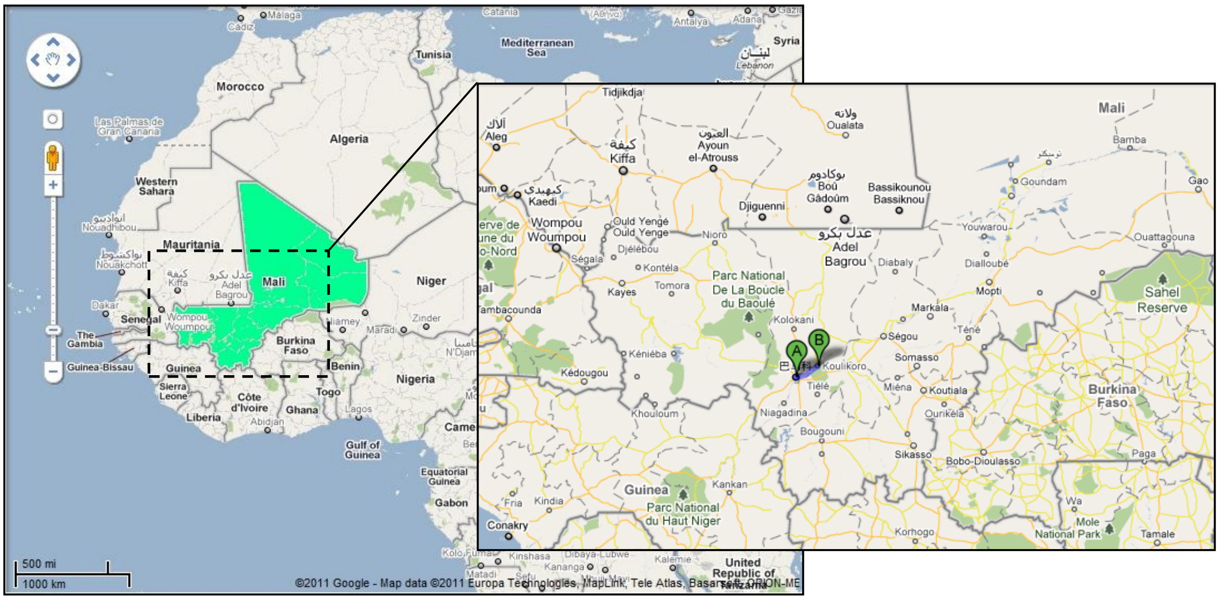

Figure 3: Location of Bamako (A) and Koulikoro (B)

2.2.2.2. Koulikoro presentation

As explain earlier, the factory of Koulikoro Biocarburant is located in the capital city of the second region of Mali, Koulikoro. The region is divided in 7 circles surrounding Bamako, these being divided in communes. The factory is located in the commune of Koulikoro in the Koulikoro circle.

This period of the project started on the 25 of February and ended on the 4th of July. This part of the project was focused on the development and on the conclusion of the project. Indeed, the different measurements and experiments have been realised during this stage of the project. The development and test of the designed separation system occurred in this stage of the project as well.

2.3. Biogas production

As explain previously, the main system of this project is digester implemented in Koulikoro. In this section, the first part concerns a presentation of anaerobic digestion, followed by a presentation of the digester installed at Mali Biocarburant Factory.

2.3.1. Anaerobic digestion [1], [2], [3]

The anaerobic digestion is a biochemical process occurring in absence of oxygen. Hydrolytic microorganisms, such as common food spoilage bacteria, break down complex organic molecules into simple sugars, amino acids, and fatty acids (Hydrolysis). Then, remaining components are broken down by acidogenic (fermentative) bacteria into short-chain fatty acids, carbon dioxide and hydrogen gases, compounds directly useable by methanogens bacteria (Acidogenesis).

The next step is undertaken by syntrophic microorganisms that convert the complex mixture of short-chain fatty acids to acetic acid releasing more carbon dioxide and hydrogen gases (Acetogenesis).
The process is concluded by the methanogenes bacteria that produce biogas from acetic acid, hydrogen and carbon dioxide (Methanogenesis).

The gas produce at the end of this process is called biogas and is a mixture of methane (approx. 60%), carbon dioxide (approx. 40%) and numerous trace elements.
Moreover, sulphate-reducing bacteria, also present in the process, are reducing sulphates and other sulphur compounds to hydrogen sulphide. This reaction leads to the production of some hydrogen sulphide in the biogas, a colourless, very poisonous, flammable gas with the characteristic foul odour of rotten eggs at a concentration up to 100 ppm.

Naturally speaking, the anaerobic digestion occurs in the psychrophilic temperature range (temperature lower than 20°C) when occurring in marsh gas and in lagoons use for livestock. Therefore, when the anaerobic occurs in a digester, it is in most of the cases, at a mesophilic temperature (35-40°C) or thermophilic temperature (55-60°C).

These two temperatures are usually preferred for two reasons. Firstly a higher loading rate of mixture can be processed because higher temperatures allowed reducing the hydraulic retention time (HRT). It means that the mixture will stay a shorter time in the digester. The hydraulic retention time is discussed with more details later. Secondly, the higher the temperature, the most efficient is the pathogens removal present in raw manure. Figure 4 presents an overview of the anaerobic digestion process.

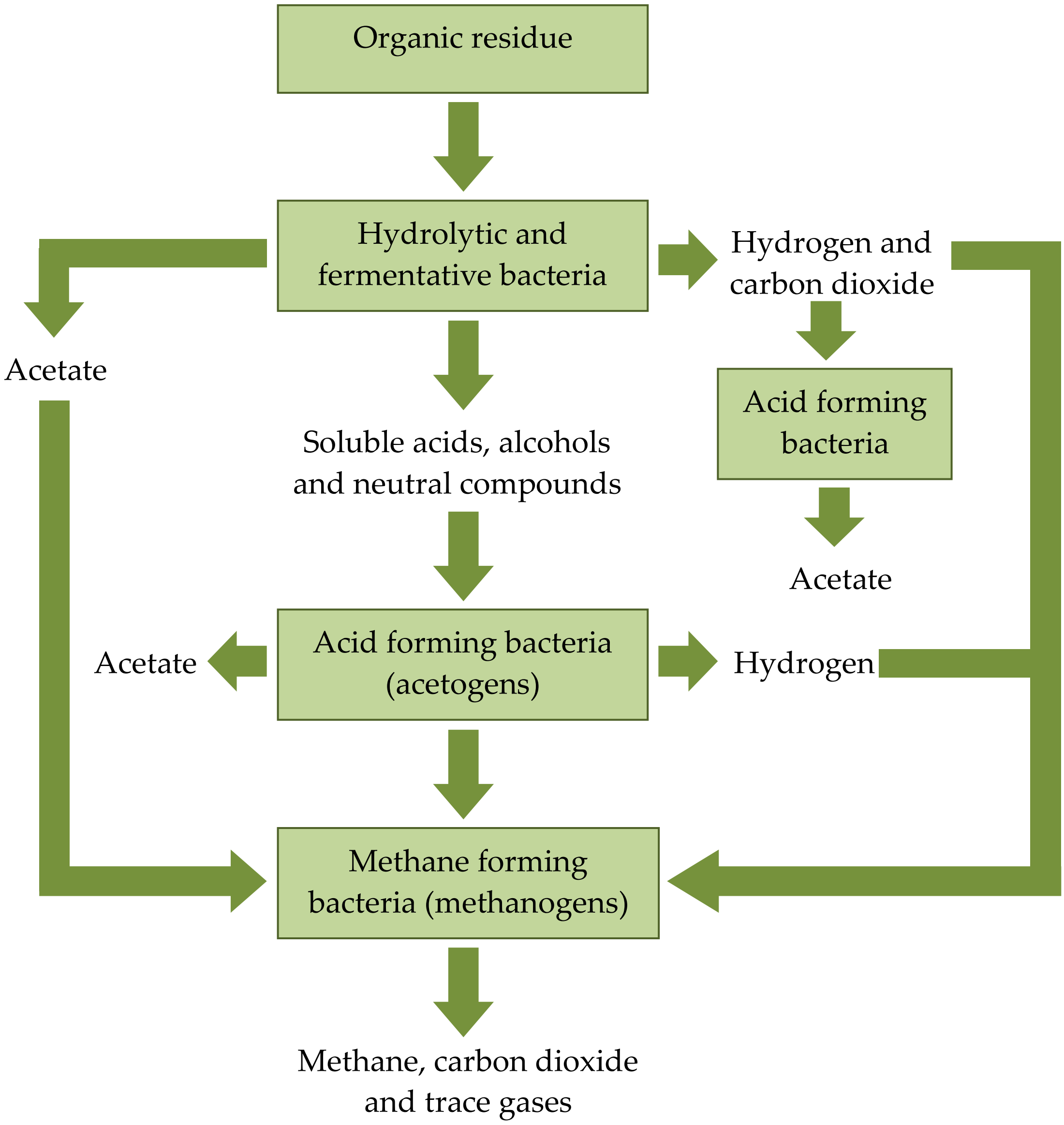

Figure 4: Overview of the anaerobic digestion process

Using anaerobic digestion in a digester, a biogas production system, leads to some benefits for the owner of the system and for the environment. The most important benefits are listed below:

- Energy production
- Odour reduction
- Reduction of pathogens
- Reduction of weed seeds

2.3.2. Biogas production system description

This section is focused on describing the digester implemented in Koulikoro, and studied during this project.

2.3.2.1. Digester [4]

The biogas system developed for this project is a plug flow type digester. The main part is a fibre re-enforced PVC bag of 10 m^3 for anaerobic digestion. The flat dimensions of the system are 7 x 2.6 meters. Following Figure 5 presents an overview of the implemented system.

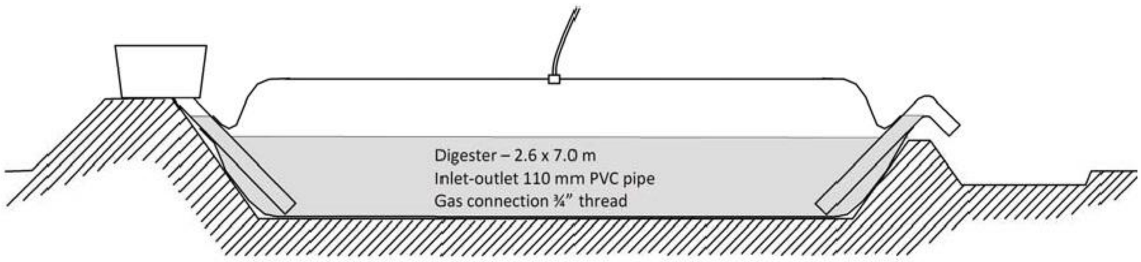

Figure 5: Representation of the digester implemented in Koulikoro

The feedstock is introduced in the digester by the inlet bucket (on the left of the picture); digested while going through the digester and the digested material ("digestate") is going out on the other side. The anaerobic digestion of the sludge is producing biogas, stored in the top part of the bag. The gas is then extracted from the bag through a network of tubes and pipes all the way to the place it supposed to be used. Different digester types are using mixing or heating system, but as this system should be usable by farmers in the countryside of developing countries, this digester is limited to a form as simple as possible. In addition, small scale systems with such systems are not cost competitive in the use defined for his project. Figure 6 is a picture of the system installed in Koulikoro.

Figure 6: Picture of the digester installed in Koulikoro

However, additional systems are needed to prevent problems and get more information about the system. Figure 7 presents an overview of all the system implemented in Koulikoro.

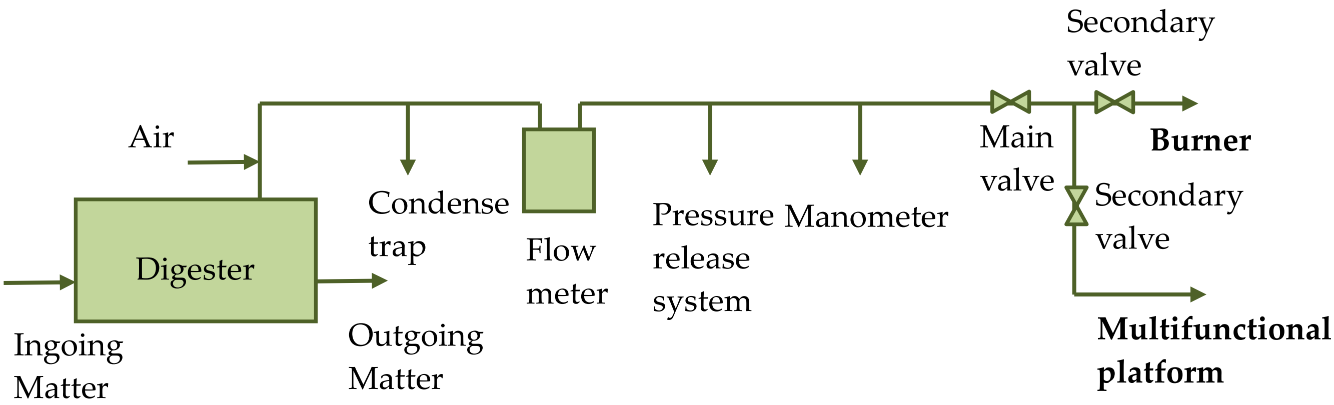

Figure 7: Overview of the biogas production system

2.3.2.2. Additional components

As explain above, others systems are needed to be implemented on the system, for security purpose or in order to get information on the current situation of the system.

Condense trap

Raw biogas is saturated with water vapour which could condensate in the gas net and measures have to be undertaken in order to prevent the water from blocking the pipe. Indeed, at the lowest point of the system, the condensate could accumulate and fill in the tube. At this place (the lowest point of the gas net), a condensate trap has to be installed.

Flow meter

In this case, a gas meter was installed in the system, measuring the biogas produced all along the project. The biogas production described in the section 3.1.2 comes from the day-to-day reading of the value.

Pressure release system

In order to prevent the bag from being submitted to too high pressures, a pressure release system has been installed. This system is composed of a plastic hose, immerged for about 10cm in water contained in a plastic water bottle. When the pressure inside the bag will be too high, the biogas will start escaping through the hose.

Pressure meter

In addition of the pressure release system, a pressure meter can be installed in the biogas network. This system is really simple and provides a good estimation of the value of the pressure inside the system. It is composed of a plastic hose, with a U shape and fills in with a small amount of water.

Air addition

As seen in the section 2.3.1 during the digestion, some hydrogen sulphide (H_2S) is produced. The hydrogen sulphide is corrosive, and when used in engine, it can damage part of the system. When using the biogas in an engine, there are different existing measures to prevent the formation of hydrogen sulphide, but the one used in this project consists of adding a small amount of air in the digester bag. Thus, H_2S is not produced. The air input is done by using an aquarium pump injecting air in the bag through a small plastic hose. A small plastic valve allows controlling the air flow in the system. The electricity supply of the pump is realised by a small PV system of 20W and a battery to store the electricity.

Valves

3 valves are added to the gas network to control the direction of the gas. As it could be used in a burner or in the multifunctional platform (see section 4.1), the valves are directing the gas in function of the needs.

Burner

A burner have been realised by Mr Gaoussou COULIBALY, teacher at the engineering school ENI in Bamako and installed on the biogas production site. This burner is used by the Koulikoro Biocarburant workers to make some tea or prepare the breakfast.

Connection to the Multifunctional Platform (see section4.1)

In order to use the biogas in the Multifunctional platform, a connection has been realised between the air intakes of the engine. In fact, a valve has been welded to the air intake pipe and the biogas is introduced in the engine through the air supply. Instead of having only air going into the combustion chamber, a mixture of air and methane are supplied to the engine.

2.3.2.3. Feeding organisation

This system is typically fed with a mixture of animal manure, providing nutrients for the micro-organisms needed for the digestion, and possibly other additional organic matter. In order to flow through the digester, the mixture should have a solid content less than 15 %. That's why, in some case, water should be added to the mixture. The mixture occupies between 60 and 70 % of the bag volume, the remaining space is used for as biogas storage, approximately one day of production. The hydraulic retention time of the system is set at 50 days so the daily input of feedstock is 1/50 of the digester volume. In this digester, the wet mixture represents 6 m^3 so the daily input should be 120l. In practice, the supply of the digester started with 35 kg of cattle dung associated to 55 litres of water during the first month. Then the amount of manure has been decreased of 5 kg every two weeks while some Jatropha press cake was added to the mixture. Indeed, after one month of supply exclusively with manure, 2 kg of press cake were added, increasing the quantity of 2 kg every two weeks. So after two month and a half, the digester was supplied by 15 kg of manure and 8 kg of Jatropha press cake, thus for the all exploitation period. As the press cake is a really dry material the amount of water has to be increased when the press cake was added. Table 2 presents the organisation of the digester's supply.

Table 2: Feeding organisation for the digester

Months	Dec	Dec	Jan	Jan	Jan	Jan	Feb	Feb	Feb	Feb	Mar	Mar
Weeks	51	52	1	2	3	4	5	6	7	8	9	10
Cow manure (kg)	35	35	35	35	30	30	25	25	20	20	15	15
Press cake (kg)	0	0	0	0	2	2	4	4	6	6	8	8
Total water (l)	55	55	55	55	60	60	70	70	75	75	80	80

2.4. Separation systems

As explained before, the amount of water contained in the digester effluent is too high thus complicating the transport and storage of the product. As it could be used as fertiliser, reducing the water content of the effluent without removing the fertiliser compounds (nutrients) initially present in the mixture would facilitate the management of the product as fertiliser.

2.4.1. Aim of the separation

With this aim in sight, a separation system was designed in this project and has been tested in order to define the efficiency of the chosen technology. As the system has to be implemented on-site, in Koulikoro, Mali, and useable by farmers or small communities, the designed system has to be as simple as possible. The energy input for the operation of the system has to be as low as possible as well, because energy may not be available everywhere. The materials needed for the implementation have to be available on site and the operational cost of the system should be low. The systems designed in this project are presented in the coming section.

2.4.2. Chosen technologies

Regarding the aim of the separation, two systems have been designed and tested during this project. Coming sections are presented these systems.

2.4.2.1. Straw filtration

The document Evaluation of four farm-scale systems for the treatment of liquid pig manure [5] provides a comparison between four different systems concerning the separation of the liquid manure. This document estimates the costs of the different studied systems and the most interesting in this case is using the straw filtration principle.

As seen in the previous part, the chosen system, regarding to its simplicity and costs, is using the straw filtration principle. Based on this idea, a separation system has been designed and tested.

The filter is composed of a wood structure on which a layer of straw is placed. By gravity, the mixture is leaking through the straw layer. During this part, the liquid part of the mixture is going through the filter while the solid part is sticking to the straw filter. The aim of this system is, then to use the solid part, mixed with the straw, as a fertilizer used in land fields. The liquid out product could be used for recirculation in the digester in order to decrease the water needed in the input mixture.
The system designed during this project has a surface of $2m^2$,with a length of 2 m and a width of 1m. The wood structure is composed of two pallets linked together with a plywood piece of 5 mm on it, in order to obtain a flat surface. Then, a plastic foil is added on the plywood to insure the water-tightness of the bottom of the filter. Some wood planks are nailed on the plastic foil to do the channels of the straw filter. Then the sides of the filter are done with the extra-plywood form the bottom part. The basic structure of the filter is done. Figure 8 presents the pattern of the system and Figure 9 is a picture of the real system.

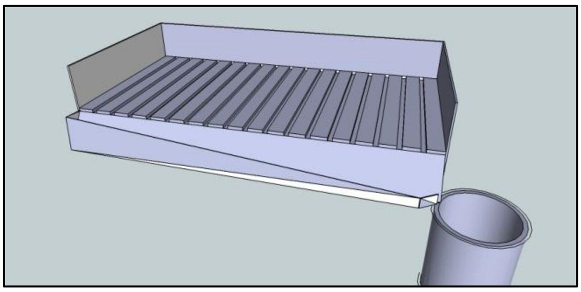

Figure 8: Representation of the straw filter

Figure 9: Picture of the straw filter

2.4.2.2. Solar dryer
The second separation system tested in this project is a solar dryer. Composed of a plastic tube structure, the system is covered by a transparent plastic foil in order to increase the temperature in the system, using greenhouse effect. The system has a height of 40 cm and a length of 3m. The dryer laid on the soil, isolated from the sand by a black plastic foil preventing mixture leakage in the soil. The system is installed with a slope of approximately 1.2° and a basin is created on the lower part of the system using wood board and concrete block. The aim of this system is to improve the evaporation speed of the water present in the digester effluent. Figure 10 is a

representation of the solar dryer tested during this project and Figure 11 is a picture of the constructed system.

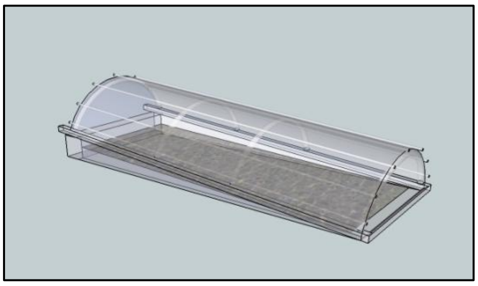

Figure 10: Representation of the straw filter

Figure 11: Solar dryer processing in Koulikoro

2.5. Fertilising effect

As explained is section 1.3, a part of the assignment was to assess the potential of using the digester's effluent as fertiliser for crops. In this section, background information about fertilising effect is given followed by an explanation of the different experiments done in order to assess the potential of the different products available on-site and the results.

2.5.1. General information [6]

Agriculture is one of the bases of the human development as it produces food for population. This sector is even more crucial in developing countries, which are highly depending on the food supply, especially coming from the agriculture. Lots of factors are influencing the food production and each area has its special food production system and type. In order to increase the crops quality, some farmers are using different type fertilisers, with the aim to meet the needs of the plants. Lots of different parameters are influencing the plant growth such as soil structure and composition, sun irradiation, growing site or previous cultivations done on the parcel. These parameters should to be taken in account, especially in the practical part of this experiment. However, the aim of this study is to assess the potential of the different products available on the site of Koulikoro Biocarburant, so they will not be studied in this report.

2.5.2. Nutrients role

In order to success in development, all the plants have some needs: sunlight, water, nutrients, traces elements and so on. In this case, the nutrients needs are more carefully described.

2.5.2.1. Nutrients

Generally speaking, sixteen elements are essential concerning the growth of the great majority of plants and they are supplied by the surrounding air, soil and water.

- Carbon (C) is supplied by the surrounding air as carbon dioxide (CO_2);
- Hydrogen (H) and oxygen (O) are supplied by water (H_2O);
- The soil is providing the other nutrients needed, Nitrogen (N) (Note: Nitrogen is also taken from the air through the activity of bacteria living in the roots module), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), sulphur (S), iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo) and Chlorine (Cl).

Other chemical elements may be used by the plants with a beneficial effect but they are not essential to the plant growth.

Excepting Carbon, supplied by the surrounding air, the entire nutrient's need of the plant is provided by the soil. These elements are divided in two categories:

- macronutrients
- micronutrients or trace elements

2.5.2.2. Macronutrients

These elements are needed in large amount and the availability of them in the soil has to be high in order to obtain an efficient plant growth. Within this group, two different types of macro nutrients are classified: *primary nutrients* (nitrogen, phosphorus and potassium) and *secondary nutrients* (magnesium, sulphur and calcium).

Function of the primary nutrients

Nitrogen (N): This element is the motor of plant growth. It comes from the soil in form of nitrate (NO_3^-) or ammonium (NH_4^+) and is a constituent of proteins, chlorophyll and nucleic acids. It composed 1-5% of the dry plant tissue.

Phosphorus (P): This element plays a key role in the transfer of energy, thus it is of primary importance for photosynthesis and other chemico-physiological processes in the plant. It is the constituent of many proteins, coenzymes, nucleic acids and metabolic substrate. It is essential for cell differentiation and for the development of the tissues, forming the growing points of the plant. It composed 0.1-0.5% of the dry plant tissue.

Potassium (K): This element has many functions, such as activating enzymes (more than 60 different), thus it plays an essential part in carbohydrate and protein synthesis. The potassium increases the water regime of the plant and increases its tolerance to drought, frost and salinity. It increases the efficiency of the defence of the plant against diseases as well and it is involved in photosynthesis. The potassium represents 0.5-0.8% of the dry plant tissue.

Function of the secondary nutrients

Magnesium (Mg): It is the principal constituent of chlorophyll, the green pigment on the leaves which functions as an acceptor of the energy supplied by the sun. Indeed, 15 to 20 percent of the magnesium contained in the plant is found in the green parts. Mg is also involved in enzyme reactions related to the energy transfer of the plant. This element is taken up from the soil in form of Mg^{2+} and represent 0.1-0.4% of the dry tissue of the plants.

Sulphur (S): This chemical element is the principal constituent of protein and also involved in the formation of chlorophyll. It is as important in plant growth as phosphorus and magnesium, but its role is often underestimated. It is absorbed in the form of SO_4^{2-} and represent 0.1-0.4% of the dry plant tissue.

Calcium (Ca): is essential for roots growth and as a constituent of cell wall materials. Thus, it plays an important role in the structure and the permeability of the membranes. It is taken up by the plant in form of Ca^{2+} and composed 0.2-1.0%of the dry plant tissue. However, the aim of Ca application is usually to reduce soil acidity.

2.5.2.3. Function of micronutrients or trace element

These elements are part of the key substances in plant growth and are comparable with the vitamins in the human body. Being taken up in small amounts, their range of optimal supply is very small.

3. Realisations and experimentations

This section describes the realisations and experimentations undertaken during this project. The biogas production is presented first, followed by the separation systems implemented in this project. Finally, explanations about the fertilising evaluation are done to conclude this section.

3.1. Biogas production

This part of the report describes the modifications of the feeding mixture organisation that happened during the project, completed by a presentation of the biogas production occurring during the project.

3.1.1. Modification of the feeding mixture

During this project, a modification of the feeding mixture occurs. Indeed, after a time the composition of the mixture has been changed. Table 3 shows the modifications that occurred during the project.

Table 3: Composition of the input mixture

Date	From March to 24/05/2011	From 25/05/2011 to 28/06/2011	From 29/06/2011 to now
Amount of cow dung (kg)	15	10	5
Amount of Jatropha press cake (kg)	8	10	10
Amount of water (l)	80	85	60

3.1.2. Daily biogas production

One of the important points in this project was to gather data. Concerning the biogas production, a counter was installed on the gas network, recording the instantaneous biogas production. Figure 12 presents the biogas production during the whole period of the final year project. The average daily production for the whole period (excepting unrecorded data) is 2.71 m^3/day.

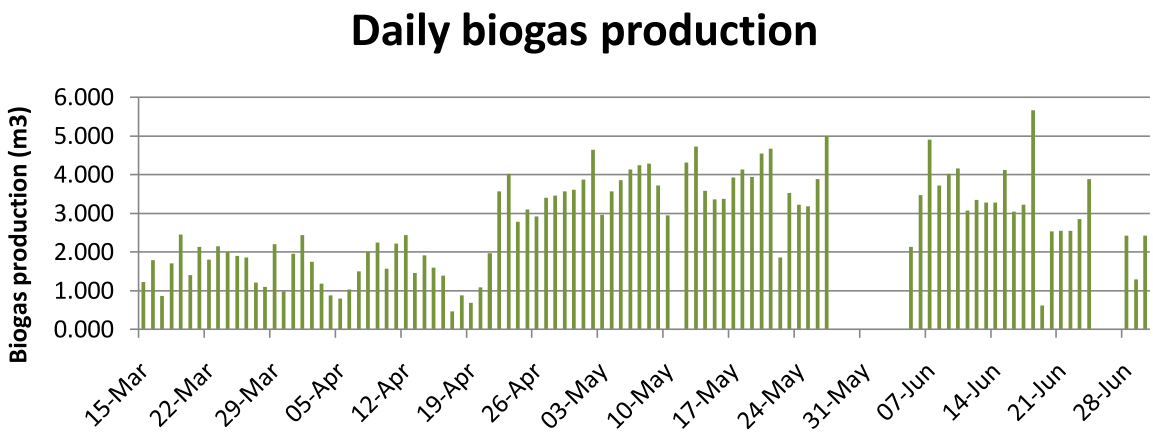

Figure 12: Daily biogas production during the project

Note: Some values are represented as zero but, in fact, it means that the data were not available these days. (Modification on the counter, trip in small villages, etc.)

3.2. Separation systems

Measurements and experiments realised on the separation systems are presented in the coming section.

3.2.1. Straw filtration

In order to define the efficiency of the system concerning the solid accumulation in the straw, the solid content of the liquid filtrate and the amount of water evaporated have been measured as followed.

3.2.1.1. Measurements

This section of the report describes the measurements realised on the straw filtration, concerning different parameters.

Solid contents of the effluent and the liquid filtrate

For this experiment a sample of mixture is used. Firstly, the container where the mixture is put is weighted. This value will be use later. After this step, the manure is put in the container and dried in the sun. In order to have a product as dry as possible, the container will be placed in front of the sun for a period of 3 to 5 days.. After the drying time, the container is weighted a second time. The following formula presents the way of definition concerning the water content, used in this protocol:

$$W_C = ((M_{eff} - M_c) - (M_{dp} - M_c))/ (M_{eff} - M_c)$$

W_C: Water content (%)
M_{eff}: Mass of the effluent and the container (g)
M_c: Mass of the container (g)
M_{dp}: Mass of the dried product and the container (g)

Using this method, the solid content of the effluent has been determined. In average, on the whole period, the solid content of the effluent was around 8%. It means that 92% of the effluent was composed of liquid.

Amount of water evaporated

Concerning the amount of water evaporated, it has been calculated as followed:

$$W_e = M_{im} - M_{of} - (M_{fs} - M_{is})$$

W_e: Amount of water evaporated (kg)
M_{im}: Mass of the input mixture (kg)
M_{of}: Mass of the outgoing filtrate (kg)
M_{is}: Initial mass of straw layer (kg)
M_{fs}: Final mass of the straw layer (kg)

The system has been tested in different configurations. Firstly, 7 kg of straw was used on the filter, but after a short period of use (2-3 days), the mixture was staying on the filter without going through it, creating liquid layers on the top of the filter. Regarding to the results, another batch of tests have been realised with 3.5 kg of straw on the filter.

With this configuration, two different tests have been realised: a first one, feeding the straw filter with approximately 30 kg of mixture per day and a second one feeding the filter with 45 kg of mixture per day. Results are presented in the coming section.

3.2.1.2. Results

Table 4 describes the results of the experiments realised on the straw filter, following the description of the previous section.

Table 4: Straw filtration parameters

Parameters	30 kg/day	45 kg/day
Total amount of mixture used on the filter (kg)	206.5	195.5
Number of working days (day)	7	4
Average amount of mixture going out of the filter (% of the input)	46 %	37 %
Average solid content of the liquid filtrate (%)	2.1%	2.6%
Average reduction of the solid content of the effluent (%)	74%	67%
Amount of solid trapped in the straw (kg)	2	1.5
Total amount of water evaporated (kg)	110	99

During the experiments, after a certain time, a cake was formed on the top of the filter. Once the mixture was not going through the filter anymore, the straw with the cake was installed in the sun for further drying and weighted after couple of days (5-6).

This table underline the fact that the filter has been blocked earlier with the 45 kg/day. One of the possible causes is that the filter did not have enough time to dry between the last feeding of one day and the feeding of the day after. The cake was still full of liquid and permeable.

In both case, the amount of evaporated water is higher than the amount of water treated by the filter.

3.2.1.3. Conclusion

The straw filter could partly decrease the volume of the effluent as most of the water is evaporating during processing but in order to treat the total amount of effluent going out of the digester, the surface of the filter should be increase. As seen in the description, the test with a feeding of 30 l/day was more efficient in solid accumulation, so, normally, a system three times bigger could treat the whole effluent with approximately the same results. However, it is important to notice that this type of system is highly sensitive to weather conditions and different results could be obtain regarding the temperature, the solar irradiation, the wind speed and other weather parameters.

3.2.2. Solar drying system

Concerning the solar drying system, only little experiments have been realised on the system. Indeed, this system has been implemented at the end of the period of the project and because of bad weather conditions; the system has been restarted several times without getting some results. However, some leads about further developments could be sort out of these tests.

3.2.2.1. Measurements

The first test realised on the system has been done with a feeding of approximately 60 l. unfortunately, after 5 days of processing, a storm during the night put the system upside down and the rain went into the mixture basin, compromising the results. Concerning the second batch of tests, the system has been reinforced in order to support stormy weather, but people working on the site, removed the top part of the system (transparent plastic foil) during a storm to prevent it from collapsing, compromising once again the total drying of the mixture. However measurements realised before the storm are presented in the following Table 5.

Table 5: Solar drying results

Date	Amount of effluent (kg)	Solid content of the effluent (%)	Solid content of the partially dried product (%)
June 16th	62	13.1	6.6 (after 4 days)
June 21th	97	8.7	4.3 (after 1 day)

The samples were taken on the side of the digester with the less dried mixture, after mixing. Figure 13 presents a picture of the solar dryer after 4 days, in the first case of experimentation. The tape meter on the right side of the dryer represents 1m.

Figure 13: Solar dryer after 4 days of processing

As explained above, the results were not complete but conclusions and leads for further development could still be made.

3.2.2.2. Conclusion

The aim of this system is to treat approximately 100l of mixture per day. In order to obtain a reasonable drying of the mixture, other tests on bigger systems should be done. Another system based on the same principle but 4 times bigger could be tested. However, it is important to notice that this type of system is highly sensitive to weather condition and different results could be obtain regarding the temperature, the solar irradiation, the wind speed and other weather parameters.

3.3. Fertilising effect

This section presents the experiments done in order to assess the fertilising potential of the different products.

3.3.1. Nutrients cycle

In order to get an idea of the fertilising potential of the different solid products, analysis concerning nitrogen and phosphorus content are presented in the following Table 6.

Note: Analysis concerning the potassium, the last macro-nutrient, is not presented in this study because products and materials needed to realise this test were not available or too expensive.

Table 6: Nitrogen and phosphorus content of the different solid products

Product	Total nitrogen content (%)	Total phosphorus content (%)
Solid part of the straw filter	2.4	3.11
Jatropha press cake	1.2	4.79
Decomposed Jatropha press cake	3.9	5.17
Cattle dung	0.9	1.53

In addition, evaluation of the nitrogen and phosphorus content have been realised on the liquid part of the filtrate. Results are presented in Table 7.

Table 7: Nitrogen and Phopshorus content of the liquid filtrate

Parameters	Concentration (mg/l)	Content (%)
Nitrates (NO_3^-)	0,000	0
Nitrites (NO_2^-)	0,000	0
Ammoniums (NH_4^+)	3880	0.388
Phosphates (PO_4^{3-})	16257	1.6257

Note: In order to get the content in percentage, a value of 1 kg/l for the filtrate has been defined, coming from a measurement realised in the laboratory with a hydrometer. The total nitrogen in this case is defined as (NO_3^- + NO_2^- + NH_4^+).

Table 8 presents the nitrogen and phosphorus content of the different products of the process.

Table 8: Nitrogen and phosphorus content of the different products

Product	Quantity (kg/d)	Nitrogen content		Phosphorus content	
		(%)	(g/day)	(%)	(g/day)
Cattle dung	15	0.9	135	1.53	229.5
Jatropha press cake	8	1.2	96	4.79	383.2
Solid part of the filtrate	0.285	2.4	6.84	3.11	8.86
Liquid part of the filtrate	47.38	0.388	183	1.63	770.3

3.3.1.1. *Nitrogen cycle*

Figure 14 presents the nitrogen cycle of the system.

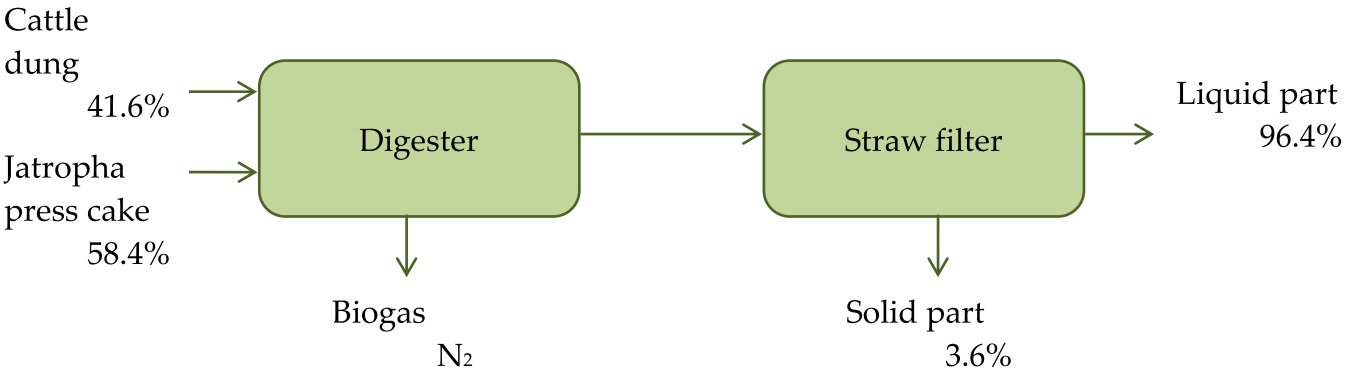

Figure 14 : Nitrogen cycle

The percentages defined above are based on the measurement realised on the products. These values represent only the solid or dissolved nitrogen and do not take in account the nitrogen transformed during biogas production. Percentages on the right side (cattle dung and Jatropha press cake) represent the percentage of the total nitrogen input and the percentages on the left side (Solid and liquid part of the filtrate) represent the percentage of the total solid and dissolved nitrogen in the effluent.

3.3.1.2. *Phosphorus cycle*

Figure 15 presents the phosphorus cycle of the system.

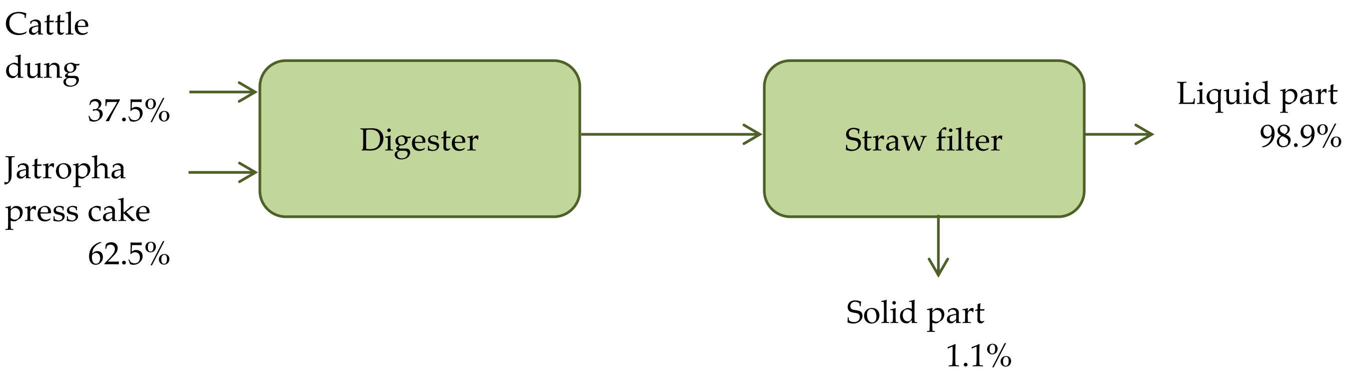

Figure 15: Phosphorus cycle

It is important to keep in mind that the measurements have not been realised on exactly the same sample but must be seen more as informative. Indeed, it is impossible, in the current case implementation, to obtain exactly the sample tested in the input as the mixture is mixed while going through the digester. However, considering the total nitrogen on the input side and the total nitrogen on the output side, in addition of the nitrogen transformed during biogas production and the uncertainties of the measurements, the values presented in this diagram appear to be acceptable.

3.3.2. Experimental tests of the fertilising value

This section is focused on describing the experimental tests done in order to estimate the fertilising effect of the different products of the digester. To do so, the experiments describe below have been done.

The comparison test will be done between 5 different types of fertilizers and a control parcel without any treatment. These tests are implemented on cucumbers and gumbo. The coming part describes the different fertilisers used in this test.

3.3.2.1. Fertilisers used in the experiment [7], [8], [9]

In order to have an overview of the fertilising effect of different products of the process, a comparison will be done between different products. The products used in the experiments are a chemical fertiliser, raw cattle manure, untreated digester effluent, solid fraction present after the straw filtration: filter cake and decomposed Jatropha press cake. A control parcel is used in this experiment as well, without any fertilising treatment. Figure 16 presents the process flow diagram of some of the elements used in this experiment.

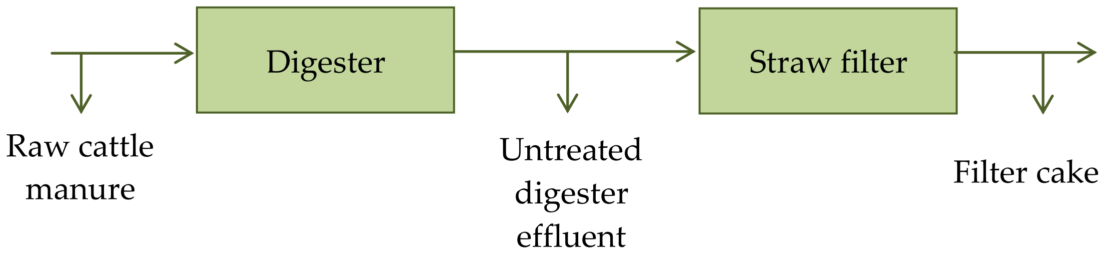

Figure 16: Elements used for the experimental test

Chemical fertiliser

In this test the chemical fertiliser used is commercialised by the Yara West Africa, Yara Mali Partner. This one is a complex fertiliser with trace elements ("Engrais complexe NPK+oligo-elements"). The composition of this fertiliser is 12% of nitrogen (N), 11% of phosphate (P_2O_5), 18% of potassium (K_2O), 2.7% of magnesium (MgO), 20% of sulphur (SO_2), 0.015% of boron and 0.02% of zinc (Zn). The recommendation for the use of this fertiliser is 400 to 800 kg/ha/cycle. In this case, the tested parcel has a surface of 1 m^2, so the amount of fertiliser used for this parcel is defined as 80g.

Raw cattle manure

The second product use as fertiliser in this comparison is raw cattle manure. In this parcel of 1 m^2, 2 kg of raw cattle manure is used (20 ton/ha).

Untreated digester effluent

Assuming a solid content of 10% for the digested effluent, 20 kg of digested mixture is used as fertiliser for this parcel, in order to get approximately 2 kg of solid content. Keep in mind that the daily input is composed of 77.7% of water (80l/d), 14.6% of raw cattle manure (15 kg/d) and 7.7% of Jatropha press cake (8kg/d).

Filter cake

In order to get approximately the same amount as the raw manure used in this test, 2 kg of filter cake is used to fertilise the parcel of $1m^2$.

Decomposed Jatropha press cake

As some decomposed Jatropha press cakes were available on the site of the experiments, it has been included in the fertilising effect estimation. In order to allow a comparison, the same amount (2kg) of decomposed press cake as raw cattle manure and filter cake is used for this test.

Control parcel

In this experiment, a control parcel is settled. This parcel is not supplied with fertiliser and aimed to have a comparison between the effects of the different fertilisers with a ground without any fertiliser. However, a side effect of the fertilisers used in the past years on the board could have an effect on the actual harvest.

3.3.2.2. Parcels organisation

During this test, two different types of cultures were tested. Half of the space was filled with cucumbers seeds and the other half was used for gumbo. The total size of the board was 10 m^2 (10m x 1m) but only 6m of this board was used for the experiments. This parcel ($6m^2$) was divided in six area of 1 m^2, themselves divided in two, to carry out experiments on both types of seeds. Figure 17 presents the organisation of the experimental parcels.

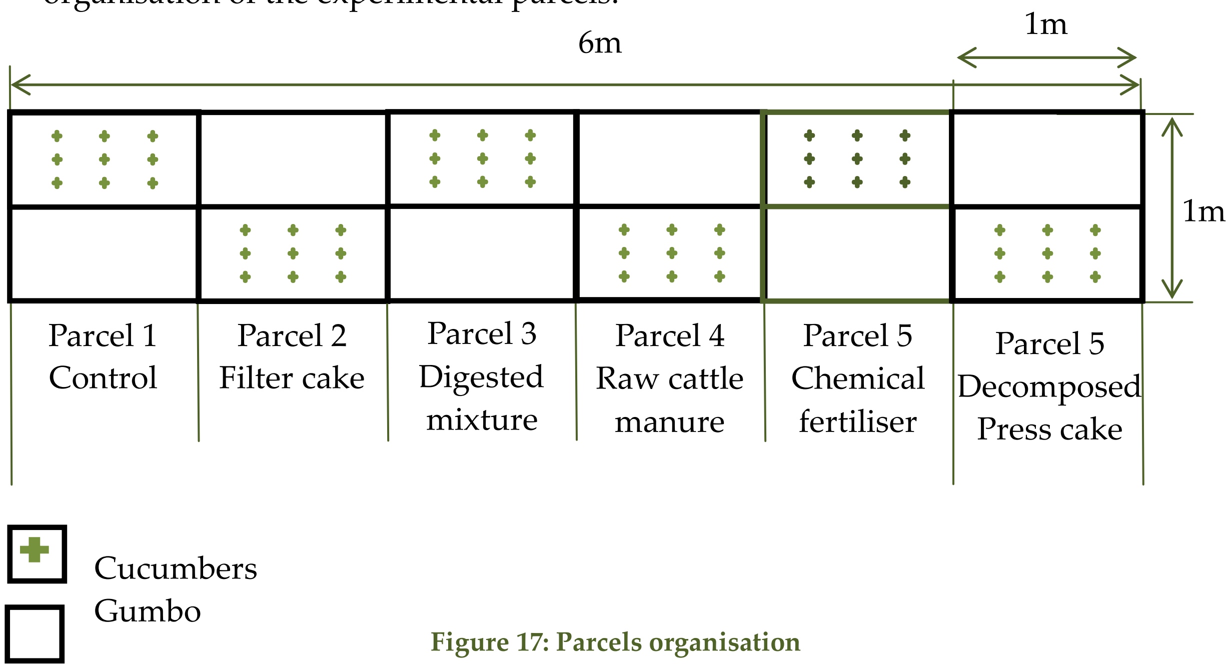

Figure 17: Parcels organisation

The cultivation was organised as followed. Eighteen seeds of each type were first planted in each parcel, spread in nine holes. Each hole was first filled with two seeds at a depth of approximately two centimetres, and then recovered by some soil. However, for the gumbo used in the decomposed press cake parcel, 30 seeds were planted, distributed between 15 holes, using the whole area of the parcel.
All the plantations were done manually.

3.3.2.3. Theoretical amounts of nitrogen and phosphorus provided

Table 9 presents the theoretical amount of nitrogen and phosphorus provided by the different products.

Table 9: Theoretical amount of N and P added to the parcels

Products	Nitrogen added (g)	Phosphorus added (g)
Filter cake	48	62.2
Effluent	77.6	325.14
Cattle dung	18	30.6
Chemical fertiliser	9.6	14.4
Decomposed press cake	78	103.4

3.3.2.4. Parcels preparation

In order to obtain some good conditions, the parcels had to be prepared one week before planting. For the filter cake, and the raw cattle manure, the fertilisers have been put in the parcels, mixed with the soil and then watered with approximately 20l of water and mixed again. For the digested mixture, 10 litres have been spread the first day, with direct mixing to prevent evaporation as much as possible and 10 litres the day after, with direct mixing as well. Concerning the chemical fertiliser, 80g of it have been spread in the parcels, mixed with the soil and watered with approximately 20 litres of water. For the decomposed Jatropha press cake, it has been mixed with 7 litres of water, mixed and then spread on the parcel. Another 13 litres of water were added during the mixing of the soil. The parcels were watered three times a day with two water can of 10l.

3.3.2.5. Monitoring

Unfortunately, this experiment has been compromised because of communication problem. Indeed, after 3 weeks, due to organisation changes in the company, the parcels were not watered in the week end anymore leading to the death of the crops grown on the less efficient parcels (control and filter cake). Moreover, the person in charge of watering the parcels decides to stop watering the parcels where the crops were not in a good state during a period where the student was not on the site of the factory.
In addition, the gumbo, a plant higher than cucumber created shadow on the cucumber plants leading to the death of those. Finally, results were available only for

the gumbo on the cattle dung, chemical fertiliser and decomposed press cake parcels. Results are presented in the coming section.

3.3.2.6. Results

Following table (Table 10) presents the results of the practical experiments realised for the fertilising evaluation.

Table 10: Parameters of the experimental tests

	Chemical fertiliser			Decomposed Jatropha press cake			Cattle dung	
Date of the harvest	05/07	12/07	19/07	05/07	12/07	19/07	12/07	19/07
Number of fruits	8	18	21	5	15	35	10	10
Weight of the harvest (g)	158.3	481.4	768.6	96.65	296.65	1134.1	222.8	293.85
Average weight/fruit	19.79	26.74	36.61	19.33	19.78	32.4	22.28	29.39

The harvests have been realised in three times, according to the maturity of the fruits. Table 11 presents the results of the experimental tests undertaken on the site of the factory of Mali Biocarburant in Koulikoro.

Table 11: Results of the experimental tests

	Chemical fertiliser	Decomposed Jatropha press cake	Cattle dung
Number of plants	14	23	12
Average weight/fruit (g)	27.72	23.84	25.83
Total number of fruits	47	55	20
Total weight of the fruits harvested (g)	1408.6	1527.4	516.65
Average number of fruits/plant	3.36	2.39	1.67
Average weight of the harvest/plant (g)	100.61	66.41	43.05

Despite the fact that the 3 firsts parcels (control, filter cake and digester effluent) were not watered anymore in the middle of the experiment, the development of the plants was better on the other parcels. In fact, the plants on of parcel 1 and 2 were underdeveloped and really small compare to the other. Due to that fact, the plants were not watered anymore.

However some conclusions could still be made. In each parameter (Average weight per fruit, Average number of fruits per plant) the chemical fertiliser was more efficient than the other products used.
In order to make a comparison, the decomposed press cake is defined as basis. Indeed, this parcel was the only one with no cost for the product as it was available on site.

Table 12: Comparison of the harvest with the decomposed press cake parcel as basis

	Chemical fertiliser	Cattle dung
Average weight/fruit	+ 51.5 %	- 35.2 %
Average number of fruits/plant	+ 40.4 %	- 30.3 %

3.3.2.7. Conclusion

This experiment is a clear illustration of the fact that the development of the plants is not only depending on the nutrients supplied to the plants, but on a lot of different factors. Indeed, the chemical fertiliser was providing less nitrogen and phosphorus than the other products by the harvest was better with it.

4. Additional works

An additional work, done during this project, was concerning the use of biogas in a multifunctional platform, a system implemented in many place in Mali, offering a solution to reduce women's labour and producing electricity. The coming section is focused on describing the multifunctional platform (MFP).

4.1. Multi functional platform (MFP)

One of the additional works realised during this project was focused on using biogas in a multifunctional platform. This section describes the system and the experiments realised on the system.

4.1.1. System description [10]

Basically, the MFP is a diesel engine, fed by Jatropha oil or diesel, used in the small villages of Mali to reduce the women's labour in the villages and to produce electricity. Figure 19 presents the configuration of the MFP installed in Koulikoro and Figure 18 is a picture of the system itself.

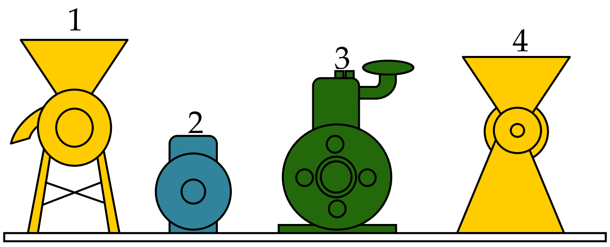

Figure 18: Configuration of the MFP

Figure 19: Picture of the MFP

1: Cereal mill
2: Generator 7.5 kW, 33.6 A, 1500 rpm
3: Engine Lister 7.35 kW, 1000 rpm
4: Cereal husking

The aim of these tests was to reduce the diesel (in this case biodiesel) consumption in order to decrease the operational cost of the system. Indeed, the biogas production, beside the cost of the system and the eventual cost of the manure, is free.
In order to use the biogas in the platform, a tap has been welded to the air intake of the engine, as shown in Figure 20.

Figure 20: Tap connection for biogas supply

4.1.2. Implementation of the experiments

To get an idea about the effect of using biogas on the MFP, different parameters were measured all along the experiments. They are presented in Table 13.

Table 13: Parameters of the MFP tests

Parameters	Unit	Way of measurement
Biodiesel consumption	g/min	Scale
Engine speed	rpm	Speed counter
Load power	W	Multimeter
Biogas consumption	m^3/min	Biogas counter
Time	min	Chronometer

The measurements of these parameters, realised on the site of Koulikoro, lead to the realisation of a graph, showing the engine consumption in function of the load. This experiment has been realised in different configurations. Different biogas flows were used to determine the biodiesel use reduction in the different cases. Different receptors were plugged and unplugged in order to change the load of the system. Tests have been realised with loads of 3.5 to 0 kW.

4.1.3. Results

Figure 21 presents the results of these experiments.

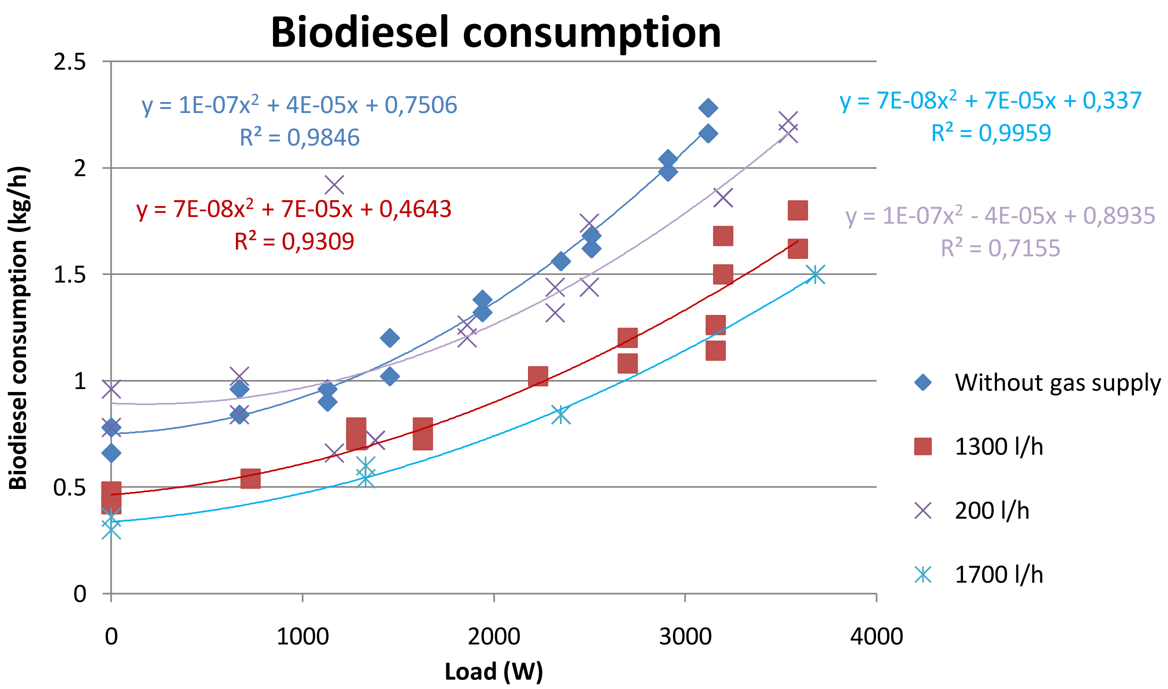

Figure 21: Biodiesel consumption regarding the load and the biogas flow.

As shown in Figure 21, the biodiesel consumption of the MFP decrease when the biogas flow increase. During this experiment, a reduction of approximately 40 % has been reached. Results were quite promising and research on how to increase even more the biogas use are still running in Koulikoro.

4.2. Small Scale digester

During this project, a small scale digester has been created. The aim of this system was to test the waste water coming from the factory as water supply for the digester. This water may contain glycerol, soap, and some chemical products used during the biodiesel transformation process (Potassium hydroxide (KOH), Agiratec cleaning agent (ACA)).

4.2.1. System description

As for all the systems implemented in this project, the small scale digester has been realised with material available in Koulikoro. The main component of the digester is an oil barrel with plastic tubes inside to insure the input of the daily feeding mixture and the output of the effluent. Following pictures present a representation of the system (Figure 22) and a picture of it (Figure 23).

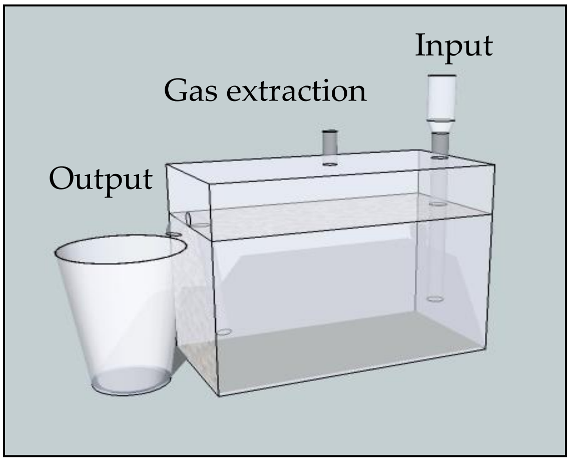

Figure 23: Representation of the small scale digester

Figure 22: Picture of the small scale digester

In order to have more information about this system some parameters have been defined. The coming section describes the defined parameters.

4.2.2. Parameters

Different parameters have to be defined in order to have more information about the system.

4.2.2.1. Volumes

Table 14 describes the parameters of the designed digester.

Table 14: Small scale digester parameters

Parameters	Value	
Total volume of the digester	19,4 l	100,00%
Volume of mixture	14,5 l	74,80%
Volume of gas	4,9l	25,20%

These volumes have been determined in an experimental way, using scale.

4.2.2.2. Hydraulic retention time & feeding organisation

In order to have an idea about how much time the mixture spends in the digester, it's important to define the hydraulic retention time. As shown before (see section 2.3.2.3) an HRT of 50 days is advised, so it gives a daily feeding value of 14.5 / 50 = 0.29 l. For practical issue, a value of 35 cl is used in this project, giving a HRT of 48.3 days.

This mixture was part of the slurry made in the inlet bucket, supplying the 10m^3 digester. The mixture was carefully mixed in order to obtain a mixture as homogenous as possible. A 35 cl plastic bottle was then filled with mixture, and this mixture was added to the small scale digester.

4.2.3. Results

Unfortunately, the small scale digester did not reach a regular biogas production allowing to compare the biogas production with water and with the wastewater. Indeed, as seen in section 3.1.2, the biogas production of the principal digester took some time to reach a "constant" value. Consequently, the use of waste water as water supply for the digester is not defined yet.

4.3. Sedimentation tests

During the processing of the digester, it has been observed that the bigger parts of the effluent were settling down at the bottom of the outlet bucket. Regarding that fact, tests about sedimentation to separate solid and liquid have been realised. The coming section describes the implementation and the results of the tests.

4.3.1. Natural sedimentation

In order to define the potential of sedimentation for the treatment of the effluent, part of the raw effluent has been collected and tested in a measuring test-tube. 375 cl of mixture were used during this experiment with a solid content of approximately 5%. Figure 24 presents the evolution of the tests.

Figure 24: Sedimentation test; *left*: after a couple a minutes; *middle*: after 1 hour; *right*: after 3 days

The picture on the left represents the system after approximately 4 minutes. It shows the first elements that are settling down, mainly big particles and pieces of undigested fibrous materials. After 1 hour (middle picture), two phases are easily identifiable. The bottom part is darker and more particles joined the first ones visible on the left picture. The solid content of the top phase at this moment was 3%. When comparing the two last pictures (middle and left), it is visible that the bottom layer did not change so much. Moreover, changes in the solid content of the top phase are really small. Other experiments realised during this project result in a sedimentation time of 30 minutes for the bigger particles. As shown on in Figure 24, most of the particles that are settling down are already at the bottom of the test-tube after 1h.
Note: During some of the experiments, a layer of solid material appears at the top of the test-tube. It was due to the formation of an impervious layer on the top of the bottom layer, brought up by some small gas bubbles appearing under this impervious layer. This could be a point of attention if implementing a sedimentation separation system for the treatment of digested mixture.

4.3.2. Chemical sedimentation

As most of the nutrients are dissolved in the water, a chemical sedimentation has been tested with two different products:

- NALCO CAT-FLOC 8799 Plus (Diallyldimethylammonium Chloride)
- Citric acid

4.3.2.1. Citric acid

The experimental chemical sedimentation has been tested with citric acid. The concentration of the solution was 0.5%. Basically, 3 ml of citric acid were added to 600ml of effluent. This test did not give good results as the particles were not settling down. Unfortunately, other tests could not have been realised due to the lack of materials present in the lab.

4.3.2.2. NALCO CAT-FLOC 8799 Plus

The second experiment of chemical sedimentation has been realised with the product NALCO CAT-FLOC 8799 Plus. This product, also called Diallyldimethylammonium Chloride gave more results than the citric acid. Indeed, after two hours the top part of the mixture was clearer than the top part obtained with the natural sedimentation. Unfortunately, more information about the composition of both phases is not available. However, it could be a lead to follow for experimenting chemical sedimentation. Figure 25 presents the state of the experiment after 2 hours.

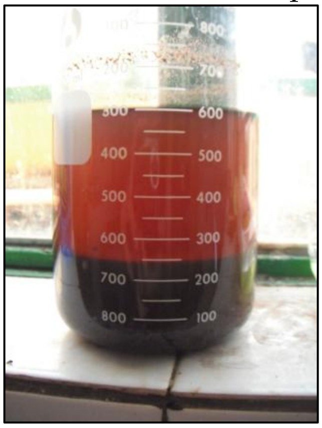

Figure 25: Sedimentation with CAT-FLOC 8799 Plus

4.3.3. Conclusion

Without getting precise results, the sedimentation could be investigated further as a mean of separation. However, regarding the goals of this project, design a system realisable by farmer in the countryside, the use of chemical enhanced sedimentation could hard to implement because of the chemical availability on site. Concerning the natural sedimentation, the results in the top phase solid content are similar to the one obtained with the straw filter.

5. Conclusions and recommendations

Regarding the aims and constraints of this project, different systems have been designed and tested with different results. The proposed solution to decrease the volume of the effluent is to use the two systems designed for this project. In order to treat 100 l of effluent (approximately the daily output of the digester) a straw filter of 6 m^2 with 10 kg of straw could used first. This system would remove the bigger parts of the effluent and partly decrease the water content of the effluent. The remaining effluent (mixture going out of the filter) could be processed by the solar drying system. Regarding the results of the tested system, two solar dryers of 3m^2 could process the remaining filtrate (2 times 25l of effluent). Combining these two systems would decrease the volume of the effluent mainly due to water evaporation. These two systems have been realised with materials available on site and are easy to implement, process and maintain. A first reduction of the volume through the straw filter would increase the evaporation speed of the effluent processed by the solar dryer system.
However, these systems are highly sensitive to local weather conditions so the location of the systems has to be defined regarding these constraints. Rain, wind and solar irradiation have an important influence on the efficiency of the systems and have to be taken in account.

Concerning the fertilising value of the products, the experiments realised in the laboratory show that all the products have important nitrogen and phosphorus content, useful for the crops. Nevertheless, the experimental tests of these products did not show clear results concerning increase in crops production. This underline the fact that crops growth and production depends on a lot of different factors and not only nutrients availability. Further investigations on the effect of these products have to be realised to define in a more detailed way, the effect of these products on the harvest. Other crops could be tested as well but regarding the nutrients content of these products the effect on the crops would be anyway positive compared to cultivation without using any additional products for ground fertilisation.

References

[1]: Methane recovery from animal manures: the current opportunities casebook, P. Lusk, Resource Development Associates, Washington, DC, National Renewable Energy Laboratory, September 1998.

[2]: U.S. Anaerobic digester, Status Report, AgSTAR, EPA, October 2010.

[3]: The implementation of animal biomass to energy project at large scale diary in Jerome, Idaho, Patrick Wootton, PE, GE Jenbacher, February 2009.

[4]: Biogas Bag Installation Manual, for small bag-type plug flow digesters, B. Frederiks, FACT Foundation, May 2011.Available at: www.fact-foundation.com

[5]: Evaluation of four farm-scale systems for the treatment of liquid pig manure, R. Melse; N. Verdoes; July 2005.

[6]: Fertilizers and their use, Fourth edition, Food and agriculture Organization of the United Nation, International Fertilizer Industry Association, 2000.

[7]: Long-term tillage and manure application on soil organic fractions and crop performance under Sudano-Sahelian conditions, A. Mando, B. Ouattara, M. Sedogo, L. Stroosnijder, K. Ouattara, L. Brussaard, B. Vanlauwe. 2004.

[8]: The use of anaerobically digested cattle slurry as a fertiliser for vegetables, J. Gomez Gomez, G. Viniegra Gonzalez, 1977.

[9]: Guide de gestion globale de la ferme maraîchère biologique et diversifié, Chapitre 14 Fertilisation, A. Weill, J. Duval, 2009.

[10]: Plates-formes Multifonctionnelles utilisant l'huile de Jatropha comme carburant. Dr. F S Rodriguez-Sanchez, 2009.