

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ENVIRONMENTAL SCIENCE PROGRAM



**Linking Waste Management to Urban Agriculture: Evaluating the
performance of toilet-linked biogas digesters at two teaching
institutes in Addis Ababa**

**A Thesis Submitted in Partial Fulfillment of the Requirement for
the Degree of Masters of Science in Environmental Science**

By

Dereje Gebre Michael

March 2008

Addis Ababa, Ethiopia

Addis Ababa University
School of Graduate Studies
Environmental Science Programme

**Linking Waste Management to Urban Agriculture: Evaluating the
performance of toilet-linked biogas digesters at two teaching
institutes in Addis Ababa**

**A Thesis Submitted in Partial Fulfillment of the Requirement for
the Degree of Masters of Science in Environmental Science**

By
Dereje Gebre Michael

ACKNOWLEDGEMENT

First, I would like to thank, Dr. Seyoum Leta for his continuous support, advise and encouragement throughout this study.

I would also like to appreciate Addis Ababa University for the financial support without which the study could never be materialized.

I owe special thanks to all of the technicians at the AAU Applied Microbiology laboratory, especially to Tigist Mengesha and Hirut Teshome as well as to W/o Macha Chamargachew of Addis Ababa EPA laboratory for graciously helping me during sample collection and analyses. My appreciation also goes to Higher 12 Medium Technical and Vocational Training Institute and Kokebe Tsebah Senior Secondary school for allowing me to use their compound and biodigesters. Special thanks also for Ato G/ Medhin Atsbeha and the Environmental club members of Kokebe Tsebah school for helping me during sampling.

I would like to thank my colleagues Birhanu Rabo and Birhanu Genet for encouraging me throughout my study.

I must also thank the many people who helped me through this project without realizing what they were doing.

I owe a tremendous amount of thanks and my deepest appreciation to my wife and kids. I love you all. Thank you for supporting me through the years of schooling, working, and studying.

Last but for not least, I would like to give thanks to the Almighty GOD for helping me endure all the challenges I faced and complete my thesis in due time.

TABLE OF CONTENTS

| | |
|---|-----|
| ACKNOWLEDGEMENT | i |
| TABLE OF CONTENTS..... | ii |
| LIST OF TABLES..... | iv |
| LIST OF FIGURES | v |
| ACRONYMS..... | vi |
| ABSTRACT..... | vii |
| 1. Introduction..... | 1 |
| 2. Literature Review | 5 |
| 2.1 Types of Biodigesters | 7 |
| 2.2 Digestion..... | 9 |
| 2.3 Factors affecting Digestion process..... | 10 |
| 2.4 The effect of digestion on fecal pathogens and indicator microorganisms | 12 |
| 2.5 Fertilizer quality of bioslurry from biodigester | 13 |
| 3. Rationale of the Study..... | 16 |
| 4. Objectives of the study | 17 |
| 4.1. General Objective | 17 |
| 4.2. Specific Objectives | 17 |
| 5. Materials and Methods..... | 18 |
| 5.1 Description of the Study area and population..... | 18 |
| 5.2 Description of the Biogas digesters | 18 |
| 5.3 Sample collection..... | 19 |
| 5.4 Analyses..... | 19 |
| 5.4.1 Testing the slurry for Nitrate (NO ₃), Phosphorous (P) and Potassium (K)..... | 20 |
| 5.4.2 Identification and enumeration of indicator bacteria..... | 20 |
| 5.5 Statistical analyses | 23 |
| 6. Results and Discussion | 24 |
| 6.1 BOD and COD removal..... | 26 |
| 6.2 Coliform bacteria removal | 28 |
| 6.3 Nutrient content of the bio-slurry in the effluent samples | 32 |

| | |
|--|----|
| 7. Conclusions and Recommendations | 35 |
| References..... | 36 |
| Annexes | 42 |

LIST OF FIGURES

| | | |
|-------------|--|----|
| Figure 1. | Balloon plant (Source: Biogas Digest, Volume II) | 8 |
| Figure 2. | Fixed-dome plant (Source: Biogas Digest, Volume II) | 8 |
| Figure 3. | Floating-drum plant (Source: Biogas Digest, Volume II) | 9 |
| Figure 4. | Comparison of Nutrient Content in Different Sources of Organic Manure (Source: Gurung, | 14 |
| Figure 5. | Major Plant Nutrients in Different Types of Organic Fertilizers (Source: Gupta, 1991) | 15 |
| Figure 6. | Pictures showing BOD bottles with sensors and 20°C Chamber | 20 |
| Figure 7. | Picture showing dilution of samples for bacteriological test | 21 |
| Figure 8. | Pictures showing presumptive test before and after fermentation | 22 |
| Figure 9. | Percentage removal of COD and BOD of the two digesters | 27 |
| Figure 10. | Percentage removal of Total Coliforms and Fecal Coliforms | 29 |
| Figures 11. | The mean comparison of nutrients among the two digesters. | 33 |
| Figure 12. | Using biogas for cooking food | 44 |
| Figure 13. | Fixed-dome biogas digester under construction in Kokebe Tsebah School | 44 |
| Figure 14. | Sample sites in Kokebe Tsebah School | 45 |
| Figure 15. | Effluent samples and sample site in Higher 12 Institute | 45 |
| Figure 16. | Picture showing confirmative test before and after fermentation | 46 |
| Figure 17. | Picture showing bacteriological samples in water bath at 44°C | 46 |
| Figure 18. | Pictures showing vegetables grown on soil with bioslurry effluent added in Higher 12 Institute | 47 |

LIST OF TABLES

| | | |
|----------|--|----|
| Table 1. | Mean Temperature and pH of Influent and Effluent of Kokebe Tsebah School and Higher 12 Institute | 24 |
| Table 2. | Mean BOD ₅ , and COD of Influent & Effluent concentration values (mg/L) of both digesters | 26 |
| Table 3. | The Mean changes in number of Total and Fecal Coliforms (cells/100ml) | 28 |
| Table 4 | The mean concentration of nutrients (mg/l) in the effluent (phosphate, potassium and nitrate) | 32 |
| Table 5. | Results of physico-chemical parameters (T °, pH, COD and BOD) | 42 |
| Table 6. | Results of effluent samples for nutrient content | 43 |
| Table 7. | Results of Total and Fecal Coliforms from both influent and effluent in most probable number | 43 |

ACRONYMS

| | |
|-------|--|
| APHA | American Public Health Association |
| BOD | Biochemical oxygen demand |
| BSR | Bioenergy Systems Report |
| COD | Chemical oxygen demand |
| EEPA | Ethiopian Environmental Protection Authority |
| EREC | Energy Efficiency and Renewable Energy Clearinghouse |
| FAO | Food and Agriculture Organization |
| FC | Fecal Coliform |
| FYM | Farm Yard Manure |
| LEISA | Low External Input Sustainable Agriculture |
| MPN | Most probable Number |
| NGO | Non Governmental Organization |
| NPK | Nitrogen, Phosphorous and potassium |
| NSA | National Sludge Alliance |
| TC | Total Coliform |
| WHO | World Health Organization |

ABSTRACT

Two toilet-linked biogas digesters were assessed to determine the presence of pathogenic microorganisms and nutrient value of the effluent slurry. These were Kokebe Tsebah Senior Secondary School and Higher 12 Medium Technical and Vocational Training Institute (referred in the study as Kokebe Tsebah School and Higher 12 Institute) in Addis Ababa. The parameters analyzed were temperature, pH, biochemical oxygen demand, chemical oxygen demand, nitrate, phosphorous, potassium, total coliform and fecal coliform. They were all measured using standard methods.

The efficiency of both digesters was evaluated based on concentration and percentage removal of the above parameters. Within the study period, the mean removal efficiency of Kokebe Tsebah School and Higher 12 Institute digesters were 84.5% and 98.41% for COD and 94.25% and 98.43% for BOD, respectively. The mean effluent concentrations of both BOD and COD in both digesters were below the National Effluent Emission Standard Limit values of Ethiopia (EEPA, 2003)

The mean removal efficiency of total coliforms was 99.8% for Kokebe Tsebah School and 96% for Higher 12 while for fecal coliforms was 98.8% for Kokebe Tsebah and 79.5% for Higher 12. This indicates that the efficiency of removal is better in Kokebe Tsebah digester than the higher 12 digester. Especially fecal coliforms are better removed in Kokebe Tsebah digester. Though the digesters remove most of the coliforms, there are still enough number of coliforms per 100 milliliter (more than the standard set by WHO for use of waste water for agriculture) which can contaminate the receiving bodies.

The slurry was tested for the amount of Nitrate, phosphate and potassium for both digesters. The arithmetic mean of nitrate, phosphate and potassium per litre was also calculated for the effluent. The mean measurement of Phosphate, Potassium and Nitrate in Kokebe Tsebah School was 82 ± 3.78 , 498.3 ± 4.41 , and 38.7 ± 2.33 mg/l, respectively and for Higher 12 Institute is 141 ± 1.53 ,

123.7 ± 0.33, and 2.5 ± 0.1 mg/l, respectively. This assessment of nutrients showed that there are enough amounts of nutrients like nitrate, potassium and phosphate that can increase soil fertility if applied to vegetables and crops.

In general, the results showed that the Fermented slurry can be an excellent organic fertilizer which can make an important contribution to better crop yields and lasting soil fertility but there is a great risk of utilizing effluent slurry for gardening without any secondary treatment.

1. Introduction

Waste is an unavoidable by product of human activities. Economic development, urbanization and improving living standards in cities, have led to increase in the quantity and complexity of generated waste. Management of Municipal Waste resulting out of rapid urbanization has become a serious concern in most of the developing countries.

According to Medina (1999) and Harsch (2001), some of the obvious outcomes of urbanization in cities of the developing world including Africa are increased incomes leading to changes in life style and consumption patterns, increase in waste generation: quantity and variety, acceleration of urban population growth and increase in spontaneous settlements leading to increased informal activities, and strain on municipal services to deal with the boom. Additional waste not followed with immediate adjustment strategies to remove it would lead to environmental deterioration and health hazards (McMicheal 2000).

Rapid growth of population and industrialization degrades urban environment and places serious stress on natural resources, which undermines equitable and sustainable development. Inefficient management and disposal of municipal waste is an obvious cause for degradation of environment in most cities of the developing world. Improper disposal of this waste leads to spread of communicable diseases, causes obnoxious conditions and spoils biosphere as a whole.

There are two major problems due to poor municipal waste management. One is the loss or under utilization of resourceful material and other is social cost due to health impact on general public suffering from improper or no collection of waste resulting in spread of diseases.

Rising problems of waste disposal and pollution management with limited land area available for disposal has led to increasing health concerns. This is of particular concern where population density continues to rise, primarily in urban and periurban areas. The contamination of surface water and groundwater resources from agricultural and municipal waste is having a significant impact of the quality of often limited supplies of fresh water.

High population density has also contributed not only to poor management of municipal waste but also to destruction of forests by land clearing for cultivation as well as by over-harvesting of forests for fuel wood. According to Long (1992), a family of 5 persons in one of Asian countries uses the equivalent of 2100 kg/year of firewood in fuel. If the economies of Southeast Asia continue to grow at the present rate, the rates of consumption of forest products and services will also increase. This will be a problem in maintaining a natural forest cover in the region. The use of non-renewable sources, like fossil fuel, is getting depleted and their prices are escalating beyond the buying ability of the people. Between 1990 and 2000 annual per capita use of diesel and gasoline increased 1.75 percent to a current level of 174 liters per person (Earth Trends, 2005).

Humans continually consume more energy resources and much of the world relies on wood energy. Only 5 percent of the Earth's total primary energy supply is provided by wood energy but it is used widely, mostly in the form of fuel wood (FAO, 2005). Elsewhere it is estimated that more than 80% of energy in the developing countries come from wood.

In developing countries such as Ethiopia, there is also a direct link between the problem of fertilizer, energy and crop production. In many rural areas, most of the inhabitants are dependent on dung and organic residue as fuel for cooking and heating. The burning of dung and plant residue is a considerable waste of plant nutrients.

Farmers in developing countries are in dire need of fertilizer for maintaining cropland productivity. Nonetheless, many small farmers continue to burn potentially valuable fertilizers, even though they cannot afford to buy chemical fertilizers.

The increasing cost of petroleum-based fuels and the problem of municipal waste management have given rise to a search for alternative sources of energy and waste treatment strategy. One such alternative is using *biodigester*, a technology that generates *biogas* (a combustible methane-based fuel) and nutrient-rich, organic effluent (Aguilar, 2000). In addition to producing fuel and fertilizer, biodigesters can increase crop yields, decrease deforestation pressure, reduce wastes and pathogens, elimination of waste odors, and improved household health (An *et al.*, 1997, 1997b; Rodriguez and Preston, 2000; Sophea and Preston, 2000).

Especially for small farmers, biogas technology is a suitable tool for making maximum use of scarce resources: After extraction of the energy content of dung and other organic waste material, the resulting sludge is still a good fertilizer, supporting general soil quality as well as higher crop yields.

Using untreated sewage sludge may be dangerous because it carries the diseases causing organisms, but anaerobic digestion not only treats municipal waste and breaks down organic wastes into biogas, it also releases plant nutrients, such as nitrogen, potassium, phosphorus and converts them into a form that can be easily absorbed by plants. However, while the value of biogas effluent slurry as a fertilizer is well known to biogas workers, most biogas programs have given it too little emphasis to know its nutrient content and the health aspect of it (Fulford, 1988).

One of the municipal wastes which should be treated in a biogas digester is human waste. Human waste can contain very large numbers of pathogenic microorganisms and these are collected and fed to the digester for treatment as well as for production of biogas (Hobson and Wheatley, 1993). Even if it is digested at a high amount of temperature in the absence of oxygen, the effluent slurry may still contain pathogenic microorganisms which will be threatening to the public health.

Biogas Technology in Ethiopia

According to Benjamin (2004), biogas technology was introduced in Ethiopia as early as 1963 E.C., when the first digester was constructed at the Ambo Agricultural College with the intent to ease the critical energy problems and to introduce new and renewable energy technologies in the rural sector. The Ethiopian Energy Authority also started construction of biogas plants in 1970 E.C., in some agricultural colleges and research centers.

Although biogas production from animal excreta is widespread in the country, currently there is a lot of interest in toilet-linked biogas generation in households, schools, monasteries, and prisons through non-governmental organizations. Communities or individuals apply the bio-slurry on their vegetable gardens or farms. It is assumed that the fermentation process and slurry can be directly used for cultivating vegetables without any further treatment. However, users are

skeptical in using the slurry for fear of contamination by resistant pathogens derived from the toilets. This necessitates the evaluation of performance of toilet-linked biodigesters so as to popularize them for further use.

Therefore, the purpose of this study is to evaluate the performance of toilet-linked biogas digesters on the basis of the presence or absence of pathogenic microorganisms and nutrient contents from the slurry.

2. Literature Review

Municipal waste management constitutes one of the most crucial health and environmental problems facing governments of developing countries. The uncollected or illegally dumped wastes constitute a disaster for human health and the environmental degradation. Even though many factors influence municipal solid waste management, population size is an important one. There is a positive correlation between city population size and both the percentage of waste generated. This suggests that increasing city size poses a greater problem to the solid waste management in developing countries or continents like Africa (Achankeng, 2003). One of the alternative ways to manage municipal waste is Biogas.

Biogas is a mixture of methane and carbon dioxide produced by bacterial degradation of organic matter and used as a fuel. Biogas results from the anaerobic liquefaction and digestion of the organic matter by micro-organisms. As a product of this process, a gas mixture of methane (2/3) and carbon dioxide (1/3) is obtained as well as an effluent with 60 % reduction of the BOD (Biological Oxygen Demand) compared with the input material. The composition of biogas varies depending on the raw materials, the organic load applied, and the time and temperature (AGAMA, 2003).

Biogas is a cheap form of energy derived from renewable resources. It is about 20 percent lighter than air and has an ignition temperature in the range of 650 to 750 °C. It is an odorless and colorless gas that burns with a blue flame similar to that of Liquefied Petroleum Gas (LPG) (Sathianathan, 1975).

Biogas is an important solution to present energy crisis, especially in rural areas. It is an environmentally clean technology. The biogas can be used as fuel for household lighting and cooking. The digested mixture or slurry can be used on the land as soil conditioner and fertilizer (LEISA, 2005, Kangmin and Ho, 2006). The Chinese estimate that one family needs 1.5 to 2.0 m³ biogas per person per day for cooking and lighting. One cubic meter of raw material produces 0.15 to 0.30 m³ of gas per day. For a family of 6 in the developing world, digester systems of liquid capacity of 4-6 m³ can meet the daily biogas requirements (about 2.9 m³) for all local residential uses.

Biodigesters are airtight containers in which waste-water and feces are fermented by bacteria. According to An *et al.*, (1997b) the principal advantages of biodigester technology are:

- Reduction in workload, especially of women;
- Reduction in pressure on natural resources, such as fuel wood;
- Cheap energy production, resulting in cash savings;
- Improving the environment or farming system by recycling manure through biodigesters to produce gas for cooking and effluent for fertilizer;
- Making use of waste which would otherwise cause pollution.

There is plenty of animal dung and human waste from which a lot of gas can be produced. Besides gas, slurry can produce a lot of organic manure that can replace nitrogen, phosphate and potash (Sharma, 2004). Using biogas not only removes polluting wastes, but also mitigates global warming by reducing one of the green house gases, methane. According to Preston and Leng (1989), the processing of the toilet waste and livestock manure by anaerobic digestion is a key component as it has many positive benefits such as reduction in emission of methane, which is a major factor in global warming.

According to Preston and Rodriguez (1996), this anaerobic digestion also contributes to decrease in pathogens, better health of people and animals, production of biogas for cooking (reduced pressure on forests for fuel wood; more comfortable working conditions in the kitchen for women) and improved nutrient recycling (reduced need for chemical fertilizer).

Most of the organic nitrogen in manure is converted to ammonia in the digester. Because inorganic is readily available and utilized by plants, it is a higher quality fertilizer. Liquid effluent can be applied to fields and the solids can still be sold as soil amendment <http://www.wifocusonenergy.com/renewable/manure.pdf>.

The effluent from biodigesters, odorless dark-colored slurry, has higher protein content, compared with the use of raw manure (Le Ha Chau, 1998). According to Marchaim and Criden (1981) and Marchaim (1983), there was no clear difference between compost and effluent treatments, but that the effluent did not increase the salinity of the soil and reduced residual

effects in the long term. The application of digested effluent over a period of years lead to continued increases in crop production according to Marchaim (1983). In long-term experiments, it was shown that the chemical and physical properties of the soil were improved markedly, after a few years of applying digester effluent, while total yields of several crops were 11 – 20% higher than controls (Marchaim, 1992).

Anaerobic digestion converts much of the organic N into ammonia (Prior and Hashimoto, 1981). Ammonia availability is a predictable fertilizer, whereas organic N availability is unpredictable. The higher the percentage of N in the ammonia form, the less uncontrolled release of N from organic compounds to the soil. To maximize the benefit of manure fertilization and minimize leaching losses, ammonia is preferred.

The utilization of the anaerobic process for toilet waste management has generated major benefits in the sense of improved sanitation and safe manure is recovered and acts as a viable alternative to mineral fertilizers (Butare and Kimaro, 2002).

2.1 Types of Biodigesters

There are three main types of simple biogas plants namely: Balloon plants, Fixed-dome plants and Floating-drum plants (An *et al.*, 1997b).

Balloon plants

The balloon plant consists of a digester bag (e.g. PVC) in the upper part of which the gas is stored. The inlet and outlet are attached directly to the plastic skin of the balloon. The gas pressure is achieved through the elasticity of the balloon and by added weights placed on the balloon. The balloons materials must be UV-resistant. The balloon plant has advantages of being low cost, ease of transportation, high digester temperatures and uncomplicated cleaning, emptying and maintenance. It has disadvantage of being short lived (about five years).

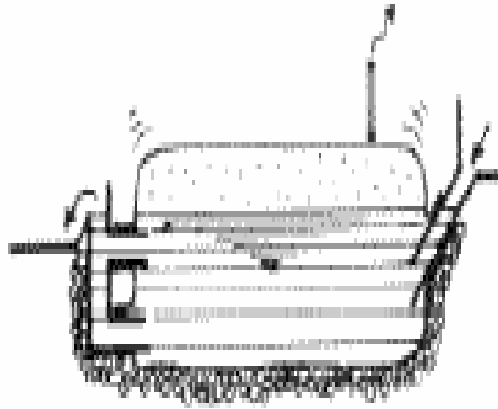


Figure 1. Balloon plant (Source: Biogas Digest, Volume II)

Fixed-dome plant

The fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. It has advantages of having relatively low construction cost, no moving parts and no rusting steel parts, hence, long life (20 years or more). Its disadvantages are being not gas tight often (porosity and cracks), gas temperature fluctuates substantially and is often very high and low digester temperature.

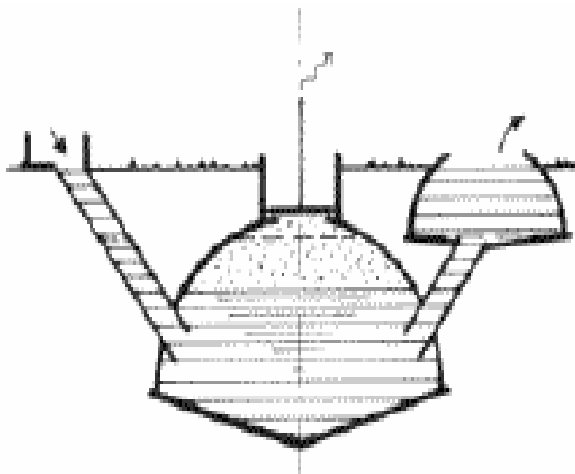


Figure 2. Fixed-dome plant (Source: Biogas Digest, Volume II)

Floating-drum plant

Floating-drum plants consist of an underground digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content. Its advantages are being simple, easy to operate, constant gas pressure and visibility of stored gas volume. Its disadvantages are having high construction cost, many steel parts liable to corrosion, resulting to short life and regular maintenance costs for painting the drum.

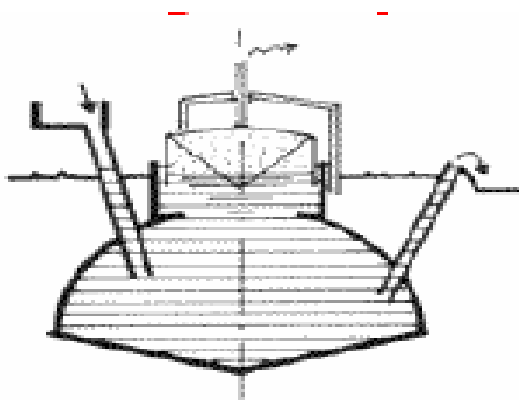


Figure 3. Floating-drum plant (Source: Biogas Digest, Volume II)

2.2 Digestion

Digestion refers to various reactions and interactions that take place among the methanogens, non-methanogens and substrates fed into the digester as input (FAO, 1996a).

According to Preston and Leng (1989) digestion increases the availability of nitrogen in organic wastes to above its usual range of 30 to 60 %, while phosphate and potash contents are not affected. Anaerobic digestion technology, or the methane-generating bioconversion, yields both

fuel (biogas) and organic fertilizer (slurry or effluent), products that are the final result of microbial action on organic residues.

These substrates are attacked through a series of breaking down steps that involve a variety of bacteria. According to Polprasert (1989), the digestion process involves the following steps: The first is hydrolysis, where complex organic molecules are broken down into simple sugars, amino acids and fatty acids with the addition of hydroxyl groups, then comes acidogenesis where a further breakdown into simpler molecules occurs, producing ammonia, carbon dioxide, which is followed by acetogenesis where the simple molecules from acidogenesis are further digested to produce carbon dioxide, hydrogen and mainly acetic acid. The methanogens then metabolize the volatile fatty acids, mainly acetic acid into methane. The final products are methane, carbon dioxide and hydrogen sulfide. The later is produced by sulfur producing bacteria under anaerobic conditions.

Generally, the major constituents of biogas are methane (CH₄, 60 percent or more by volume) and carbon dioxide (CO₂, about 35 percent); but traces of water vapor, hydrogen sulfide (H₂S), carbon monoxide (CO), and nitrogen (N₂). The composition of biogas varies according to the biological material. The methane content of biogas produced from night soil (human excreta), chicken manure and wastewater from slaughterhouse sometimes could reach 70 percent or more, while that from stalk and straw of crops is about 55 percent (Kangmin and Ho, 2006).

2.3 Factors affecting Digestion process

Carbon/Nitrogen (C/N) ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion (FAO, 1996b). If the C/N ratio is very high the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH₄).

According to TERI (1994), solid concentration in the feed material is also crucial to ensure sufficient gas production, as well as easy mixing and handling; 8-10% of total solids is the normal value required. The concentration of total solids in the input suspension can be varied within the range of 20 to 100g/litre. In practice it is recommended to limit the total solids concentration to the range of 20 to 30 g/litre (Bui Xuan An and Preston, 1999). In Nepal, 6 kg of cow dung per m³ of digester liquid volume is used (FAO, 1996b). Cow-dung has a solid concentration of about 20% and therefore, it is recommended that dung and water are mixed in a 1:1 ratio to attain the desired level of solids. One kilogram of dung produces about 40 liters of biogas. A family size biogas plant (two cubic meters) requires 50 kg of dung and equal amount of water to produce 2000 liter of gas per day. This amount of gas suffices the daily cooking requirement of a family consist of four to five members (TERI, 1994).

pH

The optimum biogas production is achieved when the pH value of the input mixture in the digester is between 6 and 7. The pH in a biodigester is also a function of the retention time. In the initial period of fermentation as large amount of organic acids are produced by acid-forming bacteria, the pH inside the digester can decrease to below 5 (Marchaim, 1991). Low pH inhibits the growth of the methanogenic bacteria and hence gas generation (Da Silva, 1979). Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, the concentration of NH₄ increases which in turn increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 and 8.2 (FAO, 1996b). A pH higher than 8.5 will start showing toxic effect on methanogens population.

Temperature

The methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35 °C. When the ambient temperature goes down to 10 °C, gas production virtually stops. Satisfactory gas production takes place in the mesophilic range between 25 and 30 °C (BSR, 1984). Temperature variations can have adverse affects on mesophilic (35 °C) digestion, or

thermophilic (55 °C) digestion. Organic material degrades more rapidly at higher temperatures because the full ranges of bacteria are at work <http://idh.vita.org/pubs/docs/ubg.html>.

The temperature effect also depends significantly on the solid concentrations of the fermentation. When high concentrations of organic loading are used (over 10% solids), bacterial activity increases with temperature (Marchaim, 1983). Proper insulation of the digester helps to increase gas production in the cold season. When the ambient temperature is 30 °C or less, the average temperature within the digester usually remains about 4 °C above the ambient temperature (Lund *et al.*, 1996).

Retention time (or hydraulic retention time)

Retention time is the average period that a given quantity of the substrate takes to move from the inlet to the outlet pipes (the average time the substrate remains in the biodigester). The retention time is calculated by dividing the total volume of the digester by the volume of input added daily. In general, the faster the rate of digestion, the shorter can be the retention time. Thus, when the temperature in the digester increases, the retention time can be shorter (Lagrange, 1979). A normal period for the digestion of dung would be 2 to 4 weeks (Da Silva, 1979).

2.4 The effect of digestion on fecal pathogens and indicator microorganisms

The digestion process results in the killing of pathogenic bacteria especially those found in animal and human feces (salmonella bacteria can be reduced by over 90% in a digester (Mapako, 1984). The more fully the sludge is digested, the more pathogens are killed. During the course of typical waste water treatment, the microorganisms in sewage are reduced in number, becoming concentrated in the sewage sludge. However, some pathogens are still present in the effluent (Rose *et al.*, 1996). The following are the principal organisms inactivated in biogas plants: Typhoid, paratyphoid, cholera and dysentery bacteria (in one or two weeks), hookworm and bilharzias (in three weeks) (<http://media.payson.tulane.edu:8083/cgi-bin/gw?e=t1c10home-hdl-1-B.131.5-11-100-20-00>).

In all countries, one objective of waste-water treatment should be the reduction, and if possible the removal, of parasites, bacteria and pathogenic viruses that cause endemic diseases. According to Chará *et al.*, (1999), ponds with water plants and for fish culture are technological options through which such objectives can be fully realized.

Generally, the excellent bacteriological quality of stabilized pond effluent is taken as beneficial in the integrated management for agriculture, livestock, horticulture, aquaculture and forestation. The design of these systems should be adjusted according to the effluent quality required for the intended usage. The use of wastewater facilitates the efficient use of water, the provision of natural fertilizers and food, the creation of employment sources and economic income, and the expansion of agricultural frontiers in desert areas (Moscoso and Leon, 2000).

According to National Sludge Alliance (NSA) fact sheet (NSA, 1998), sewage residue from the treatment process (sludge) is used as an uncontrolled fertilizer on food crop production. Researchers found that not only had food poisoning incidents soared to 81 million annually since sludge has been considered to be a fertilizer, over ten percent of the dairy herds in the US are now infected by Salmonella and *E. coli*, which contaminate the milk and the meat. The study also outlined the public health risk from pathogens. "The relative public health risk associated with the beneficial use of sludge is directly related to the extent of public exposure and risks increase if the sludge is used on food crops or public access areas. The routes of exposure may take various forms, including handwork in gardens and eating uncooked vegetables, grown in sludge amended soils (NSA Public Fact Sheet 123, 1998).

2.5 Fertilizer quality of bioslurry from biodigester

The main products from the biodigester are biogas and effluent, which is a potential fertilizer because the anaerobic digestion process results in conversion of organic nitrogen from manure to ionized ammonia (NH_4^+) which can be used directly by plant roots (Forchhammer, 1994).

Thus, it has been found in Vietnam that the effluent was a better fertilizer compared with raw manure for application to cassava and duckweed (Chau, 1998a and b), although there are few reports of trials to compare the two sources of plant nutrients. It is also important to note that

biodigester effluent, as well as behaving as inorganic fertilizer, also contains the organic materials from the digestion of bacteria that fish can use as food to grow (Rakocy and Ginty, 1989).

The studies of Sanmaneechai et al (1992) at the Chiang Mai University Farm showed that application of fermented slurry could increase the organic matter and phosphorus contents in the soil. It also showed that the fermented slurry plot gave higher yield than no fertilizer plot.

According to Mikled et. al (1994), a study showed that use of fermented slurry as liquid fertilizer for baby corn (field crops) and Napier grass (forage crops) at different rates as compared to chemical fertilizer, towards the end of the first year and throughout the second year, all fermented slurry treatments produced the same yield or even higher at the higher levels of fermented slurry.

According to Gurung (1997), the biogas effluent when compared with farm yard manure (FYM) and improved compost, gives high content of fertilizer in terms of NPK (see the figure below).

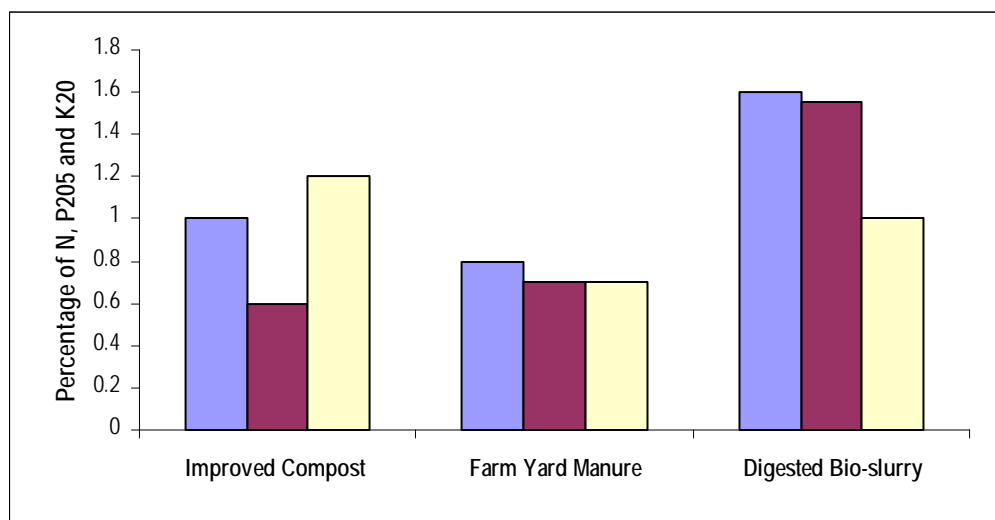


Figure 4. Comparison of Nutrient Content in Different Sources of Organic Manure (Source: Gurung, 1997)

Similarly, Gupta (1991) analyzed the major plant nutrients -NPK- in composted manure, farm yard manure (FYM) and digested bio-slurry (which is indicated in the figure below) and it shows that digested slurry has better percentage of NPK than composted manure and farm yard manure.

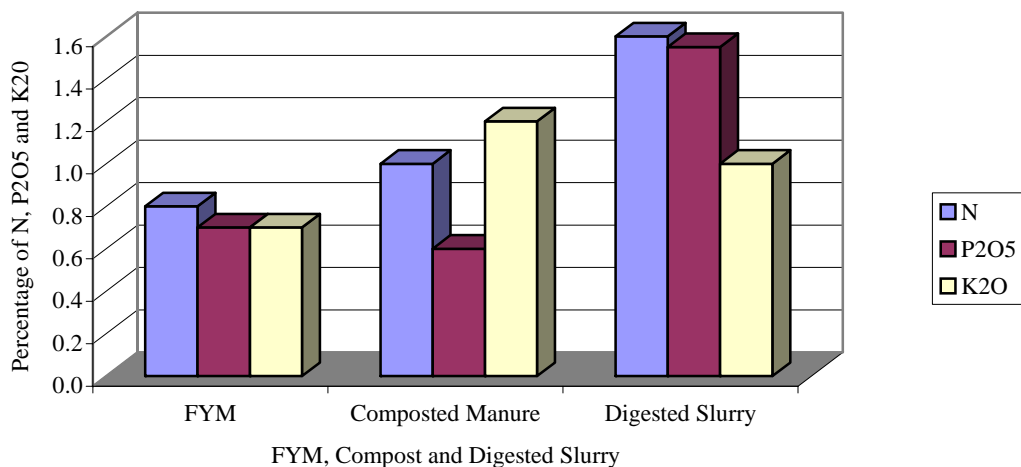


Figure 5. Major Plant Nutrients in Different Types of Organic Fertilizers (Source: Gupta, 1991)

The above statements indicate that, though the slurry is important fertilizer, it may still have pathogens which are dangerous to the health of the public. Therefore, the effluent has to be studied and a recommendation has to come out on the use of slurry as a fertilizer.

3. Rationale of the Study

In view of the ever increasing accumulation of domestic waste in urban centers, as a result of population increase, it becomes very costly to dispose them with conventional management systems such as land fill, incineration, and the expensive modern pond systems. This necessitates alternative raw waste management systems that involve the dual purpose of protection (from pollution) and production of biomass, bio-fertilizer and biofuel.

The use of farm yard manure for the purpose of generating biogas as a fuel and bioslurry as fertilizer is well known. Recently biogas production from toilet attached biogas digester is being promoted by farmers or individuals in urban centers. The application of effluent slurry for cultivating vegetables is being popularized. However the public is skeptical about using the slurry for fear of contamination by pathogens passing from the toilets. Since there is scarce information about the effectiveness of biogas digesters to eliminate pathogens in the effluent slurry in the country.

The primary purpose of this study was to evaluate the effectiveness of biogas digesters in Kokebe Tsebah School and Higher 12 Institute regarding reduction of pathogenic microorganisms and concentration of nutrients for the application of slurry as fertilizer.

4. Objectives of the study

4.1. General Objective

The general objective of this study was to evaluate the slurry of toilet-linked digesters for the nutrient value and the removal efficiency of pathogenic microorganisms.

4.2. Specific Objectives

1. Evaluation of nutrient value of sludge from biogas digester for potential use as fertilizer.
2. Evaluation of sludge from biogas digester for pathogenic microorganisms.

5. Materials and Methods

5.1 Description of the Study area and population

This study was conducted in Kokebe Tsebah Senior Secondary School and Higher 12 Technical and Vocational Training Institute in Addis Ababa, Ethiopia.

The Kokebe Tsebah Senior Secondary School is located in Yeka Kifle Ketema, Addis Ababa at altitude of 2427 meters above sea level. The school toilet is giving service for 4700 students and before the biogas digester was built by the support of a local NGO, Institute for Sustainable Development, the sewage from the toilet flowed directly to the Kebena River. The school saves birr 240/month of kerosene for cooking in the staff lounge, and birr 360/year for buying butane gas for laboratories use.

The Higher 12 Technical and Vocational Training Institute is located in Yeka Kifle Ketema, Addis Ababa at altitude of 2459 meters above sea level. The school toilet is giving service to 3000 students and staff. Before the biogas digester was built in collaboration with two local NGOs, Lem Ethiopia and Institute for Sustainable Development, the school had used an average of 8 trucks per year to dump the toilet. The Institute saves birr 340/month of kerosene for cooking in the staff lounge and home economics class as well as birr 2400/year for pumping out the toilettes.

5.2 Description of the Biogas digesters

The biogas digesters used for this study were fixed-dome shaped digesters in Kokebe Tsebah Senior Secondary School and Higher 12 Technical and Vocational Training Institute with capacities of 32 m³ and 20 m³, respectively.

5.3 Sample collection

Seven samples were collected every 15 days from both the influent and the effluent for three consecutive sampling periods (from 20 May to 5 July 2007) from both digesters. Samples were taken from the inlet and outlet chambers of the digester early in the morning. Each sample (50-200ml) glass bottles was transported to the laboratory for bacteriological, COD, BOD, Nitrate, Potassium and Phosphorous, using icebox and immediately analyzed.

5.4 Analyses

Temperature was measured on-site using portable thermometer and pH was read on calibrated Beckman's 050pH meter. COD of both the influent and the effluent were measured calorimetrically by spectrophotometer (DR/ 2010, USA) according to HACH instructions. BOD of both the influent and the effluent were measured (in Addis Ababa Environmental Protection Laboratory) for each sampling using a BOD sensor (Lovibond BSB/BOD Sensor).

From the effluent 157 ml and from the influent 21.7ml were taken (since it is raw and may contain BOD value more than the sensor counts) and two drops of potassium hydroxide solution were added to a BOD bottle which contains a magnetic stirrer and the bottle was closed with a BOD sensor which can count the daily BOD level up to five days. The bottle then was put in a thermostat of 20°C for five days.



Figure 6. Pictures showing BOD bottles with sensors and 20°C Chamber

5.4.1 Testing the slurry for Nitrate (NO₃), Phosphorous (P) and Potassium (K)

Nitrate, phosphate and potassium quantity of effluent samples from the two schools were measured by spectrophotometer (JENWAY 6305, Germany) for each sampling.

In line with this, the prepared effluent samples were diluted with distilled water until they became within the range to be read by the spectrophotometer and were placed into the cell holder and the amount of Nitrate, Phosphate and potassium in milligram per liter was read. This value was converted into actual value with respect to the dilution process.

5.4.2 Identification and enumeration of indicator bacteria

All the samples were analyzed bacteriologically for fecal coliforms and total coliforms using standard methods of Multiple-Tube Method as described in (APHA, 1998).

5.4.2.1 Presumptive Test

The samples were diluted and inoculated to a series of tubes containing DEV lactose broth medium (NERCKKGAA, Germany). The reagent (28g) was suspended in 1litre of distilled water an, and 10ml of the media was dispensed into test tubes fitted with fermentation (Durham) tubes and then autoclaved for 15 minutes at 121°C and left for 24hrs in 37 °C incubator. Tubes showing gas formation was regarded as “presumptive positive” since they indicate possible presence of coliforms.



Figure 7. Picture showing dilution of samples for bacteriological test



Figure 8. Pictures showing presumptive test before and after fermentation

5.4.2.2 Confirmative Test

For the confirmative test, a more selective medium called Brila broth or Brilliant-green bile lactose broth for microbiology (NERCKKGAA, Germany) was prepared. The reagent (40g) was suspended in 1litre of distilled water and, 10ml of the medium was dispensed into test tubes fitted with fermentation (Durham) tubes and then autoclaved for 15 minutes at 121°C. Samples from positive tubes of the presumptive test were inoculated into each tube using inoculating needles. Half of the tubes were incubated at 37 °C for 48hrs and the rest were incubated at 44 °C water bath for 24hrs to confirm the presence of Total coliforms and Fecal coliforms, respectively. The tubes then were examined for gas formation like the presumptive test and the concentration of bacteria was estimated from the number of positive tubes inoculated by the most probable number (MPN) of bacteria using specially devised statistical tables (APHA, 1998).

5.5 Statistical analyses

Data were analyzed using Microsoft Excel and SPSS version 15.0. The Mean and Standard Error was done using SPSS package. Comparing proportions (percentages) was useful to compare the removal of BOD, COD and coliforms.

6. Results and Discussion

Characteristics of influent slurries and factors that affect the digestion process as well as the survival of indicator microorganisms such as pH and temperature were assessed during monitoring. Other parameters such as COD and BOD were also assessed. The nutrients values of the effluent as well as the bacterial concentration of both the influent and the effluent were also studied.

Table 1 presents the mean pH and temperature for both digesters namely Kokebe Tsebah School and Higher 12 Institute.

Table 1. Mean Temperature and pH of Influent and Effluent of Kokebe Tsebah School and Higher 12 Institute

| Digester site | Temperature, °C | pH, pH unit |
|----------------------------------|------------------------|--------------------|
| Kokebe Tsebah school Influent | 17.20±0.49 | 7.21±0.03 |
| Kokebe Tsebah School Effluent | 17.90±0.43 | 8.07±0.24 |
| Higher 12 Institute Influent | 17.40±0.32 | 7.20±0.05 |
| Higher 12 Institute Effluent | 17.40±0.41 | 7.68±0.35 |

The significant parameters for Kokebe Tsebah school and Higher 12 Institute influent includes pH value of 7.21 ± 0.03 and 7.20 ± 0.05 , respectively.

The significant parameters for Kokebe Tsebah school and Higher 12 Institute influent includes temperature value of 17.2 ± 0.49 °C and 17.4 ± 0.32 °C, respectively.

The significant parameters for Kokebe Tsebah school and Higher 12 Institute effluent includes pH value of 8.07 ± 0.25 and 7.68 ± 0.035 , respectively.

The significant parameters for Kokebe Tsebah school and Higher 12 Institute effluent includes temperature value of 17.9 ± 0.44 °C and 17.4 ± 0.42 °C, respectively.

Temperature

The ambient temperature was within the range of 17.6 to 22.2 for Kokebe Tsebah and 14.5 to 22.0 for higher 12. According to Lund *et al* (1996), when the ambient temperature is 30 °C or less, the average temperature within the digester remains about 4 °C above the ambient temperature. Increasing the digester temperature, in turn increases the performance of the digester and that would kill most of the pathogenic organisms. The methanogens are inactive in extreme high and low temperatures.

pH

According to Da Silva (1979), the optimum biogas production is achieved when the pH value of the input mixture in the digester is between 6 and 7. The pH value range of the two digesters, for Kokebe Tsebah and Higher 12 Schools were: 7.16-7.28 (for influents) and 7.66 – 8.52 and 7.02 – 8.23 for effluents of both Kokebe Tsebah School and Higher 12 Institute, respectively. According to FAO/CMS (1996b), when the pH range remains buffered between 7.2 and 8.2 the methane production level is stabilized, a pH higher than 8.5 will start showing toxic effect on methanogens population, hence, brings reduction in production of biogas.

6.1 BOD and COD removal

The significant parameters for Kokebe Tsebah School and Higher 12 Institute influent includes the mean values of COD (7416.67 ± 2018.53 mg/l) and BOD₅ (2200 ± 152.75 mg/l) and COD ($6876.67 \pm 1762,92$ mg/l) and BOD₅ (2116.67 ± 142.40 mg/l) respectively and the Kokebe Tsebah School and Higher 12 Institute effluent includes mean values of COD (1150 ± 476.97 mg/l) and BOD₅ (126.67 ± 3.33 mg/l) and COD (1100 ± 485.63 mg/l) and BOD₅ (33.3 ± 3.33 mg/l), respectively.

Table 2. Mean BOD₅, and COD of Influent & Effluent concentration values (mg/L) of both digesters

| Digester site | | BOD, mg/l | % Removal | COD, mg/l | % Removal |
|----------------------|----------|----------------|-----------|-----------------|-----------|
| Kokebe Tsebah School | Influent | 2200.00±152.75 | 94.25 | 7416.67±2018.52 | 84.5 |
| | Effluent | 126.67±3.33 | | 1150.00±476.96 | |
| Higher 12 Institute | Influent | 2116.67±142.40 | 98.43 | 6876.67±1762,92 | 98.41 |
| | Effluent | 33.33±3.33 | | 1100.00±458.62 | |

The two digesters vary in size and this affects the retention time. The bigger the digester volume the longer is the retention day/time. The efficiency of COD and BOD destruction is greatest at lower retention time with greater total methane production. The volume of the Higher 12 Institute digester is smaller than that of Kokebe Tsebah Senior Secondary School digester. Even though, the organic load of the two digesters seems similar, the destruction of COD and BOD is high in Higher 12 Institute's digester.

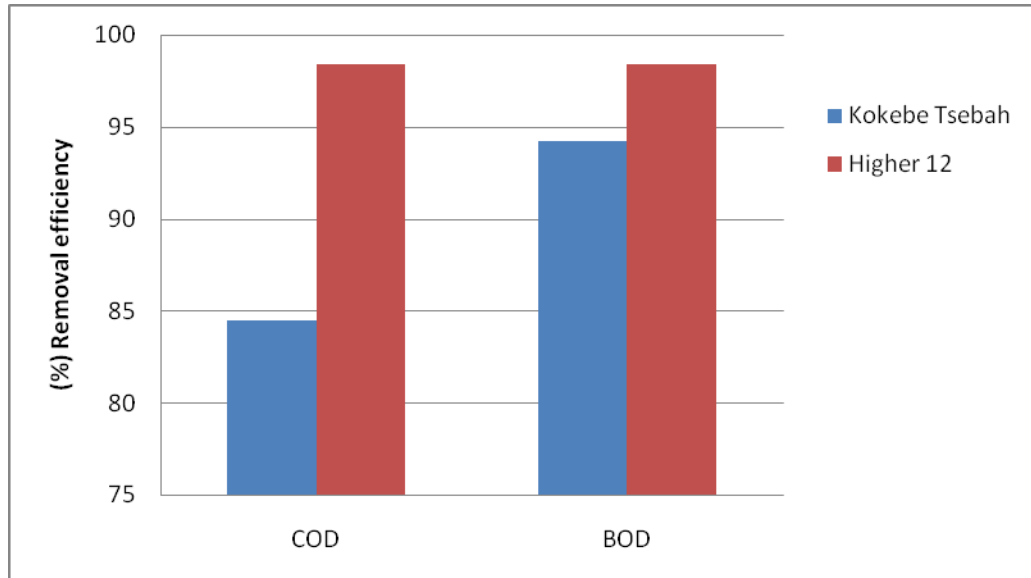


Figure 9. *Percentage removal of COD and BOD of the two digesters*

The percentage removal of COD was 84.5% for Kokebe Tsebah School and 98.41% for Higher 12 Institute as well as the percentage removal of BOD was 94.25 for Kokebe Tsebah School and 98.43% for Higher 12 institute (Figure 9) shows slight variation. The COD and BOD removal is slightly better in Higher 12 Institute than that of Kokebe Tsebah School. In all the cases, the mean effluent concentrations of BOD in both digesters was below the National Effluent Emission Standard Limit values of Ethiopia (EEPA, 2003), which is 80 mg/l for BOD₅, where as the concentration of COD for both digesters were above the National Emission Efficiency Limit value of Ethiopia, which is 250 mg/l for COD.

According to An *et al.* (1997b) preliminary field data suggests that biodigesters are very effective in reducing slurry BOD, especially in pig manure-based systems. Reductions in effluent BOD can lead to a better local water quality than untreated excreta when they are discharged in to the receiving water bodies. The result also confirms that the BOD is reduced effectively by the two biodigesters.

6.2 Coliform bacteria removal

Detailed evaluations of the two biodigesters (Kokebe Tsebah School and Higher 12 Institute) have been carried out to determine the composition of the effluent slurry for indicator microorganisms. The mean result of the Total coliforms and Fecal Coliforms from both the influent and effluent of the two schools are presented in the table below.

Table 3. The Mean changes in number of Total and Fecal Coliforms (cells/100ml)

| Digester site | Total Coliforms | % Removal | Fecal Coliforms | % Removal |
|-------------------------------|------------------|-----------|-----------------|-----------|
| Kokebe Tsebah School Influent | 18500000±8836477 | 99.79 | 2683333±1053697 | 98.89 |
| Kokebe Tsebah School Effluent | 40666±24774 | | 30000±10000 | |
| Higher 12 Institute Influent | 17986000±8162229 | 96.33 | 2843333±1124964 | 80.09 |
| Higher 12 Institute Effluent | 679666±470237 | | 566333±521533 | |

Coliforms were found both in the influent slurry as well as effluent of both digesters of Kokebe Tsebah School and Higher 12 Institute.

The mean values for Kokebe Tsebah School influent includes Total Coliform ($1.85 \times 10^7 \pm 8.84 \times 10^6$ cells/100ml) and Fecal Coliform ($2.68 \times 10^6 \pm 1 \times 10^6$ cells/100ml). The mean values for Higher 12 Institute influent includes Total Coliform ($1.79 \times 10^7 \pm 8.16 \times 10^6$ cells/100ml) and Fecal Coliform ($2.84 \times 10^6 \pm 1 \times 10^6$ cells/100ml).

The mean values for Kokebe Tsebah Senior Secondary school effluent includes Total Coliforms ($4.07 \times 10^4 \pm 2.47 \times 10^4$ cells/100ml) and Fecal Coliforms ($3 \times 10^4 \pm 1 \times 10^4$ cells/100ml). The mean

values for Higher 12 Technical and Vocational Training Institute effluent includes Total Coliform ($6.79 \times 10^5 \pm 4.7 \times 10^5$ cells/100ml) and Fecal coliforms ($5.66 \times 10^5 \pm 5.21 \times 10^5$ cells/100ml).

The Percentage removal of total coliforms is 99.79% for Kokebe Tsebah School and 96.33% for Higher 12. Percentage removal of fecal coliforms is 98.89% for Kokebe Tsebah and 80.09% for Higher 12. This indicates that the efficiency of removal is better in Kokebe Tsebah digester than the higher 12 digester. Especially fecal coliforms are better removed in Kokebe Tsebah digester (Figure 10).

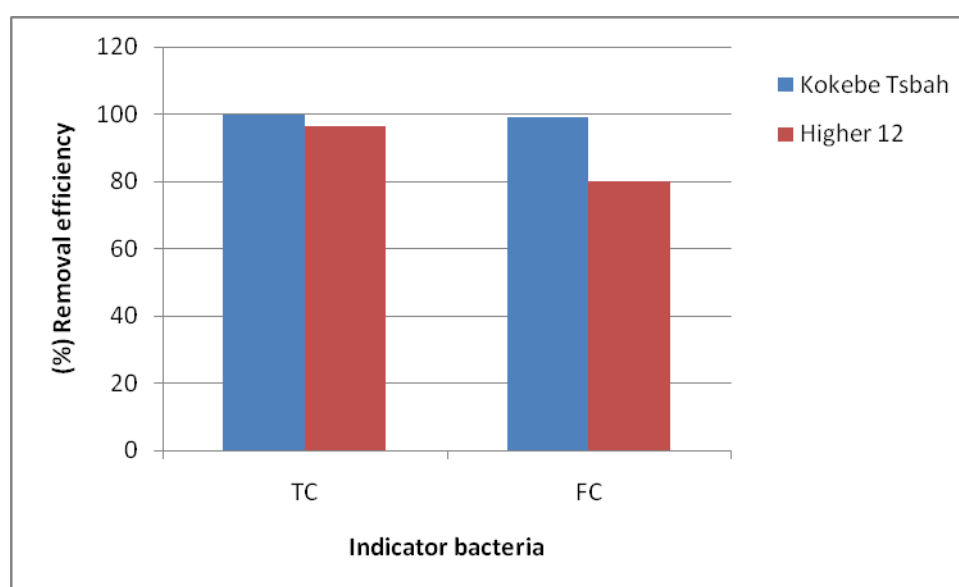


Figure 10. Percentage removal of Total Coliforms and Fecal Coliforms

Temperature plays a crucial role in decreasing coliforms and other microorganisms. According to Winblad and Simpson-Hebert (2004), most microorganisms survive well at low temperature (below 5°C) and die off rapidly at high temperatures (above 40°C). The ambient temperature range of Kokebe Tsebah School and Higher 12 Institute was 17.6 – 22.2 and 14.5 – 22.0, respectively. The ambient temperature is directly related to digester temperature and it could be the case for better removal of coliforms in Kokebe Tsebah School.

The performance efficiency results of both digesters indicated that biogas digester has higher bacterial removal capability, but the mean final effluent concentration of FC was above the Effluent Emission Standard limit values (1000 fecal coliforms/100ml) set by World Health Organization (1989). Even though there is a decrease in the number of coliforms in the effluent as compared to the influent, the concentration is still higher than the WHO standard and can contaminate the environment (soil, plants, and people handling the effluent).

If such slurry is used as fertilizer, especially for vegetables, which get minimal cooking before consumption, it leads to infection (Pawlowski, 1989). Irrigation of crops and vegetables with this water also leads to contamination of soil, food and water (Adams *et al*, 1999). Pathogens can survive for extended periods inside leafy vegetables or in protected cracks or stem areas (Faecham *et al*, 1978).

Therefore, the presence of several coliforms in the effluent slurry (which in turn indicates the presence of pathogenic microorganisms) has its own environmental implication. In line with this, all components of the environment, that is, soil, water, plants and people can be affected when effluent slurries are utilized for gardening and/or discharged into the water bodies.

In order to make it safe and suitable for gardening, the effluent slurry can undergo further treatment. According to Winblad and Simpson-Hebert (2004), the slurry can pass through high temperature composting (50-60°C) either in an open compost pit or mechanical composting bin or other methods like increasing pH by addition of lime or urea and if necessary by carbonization.

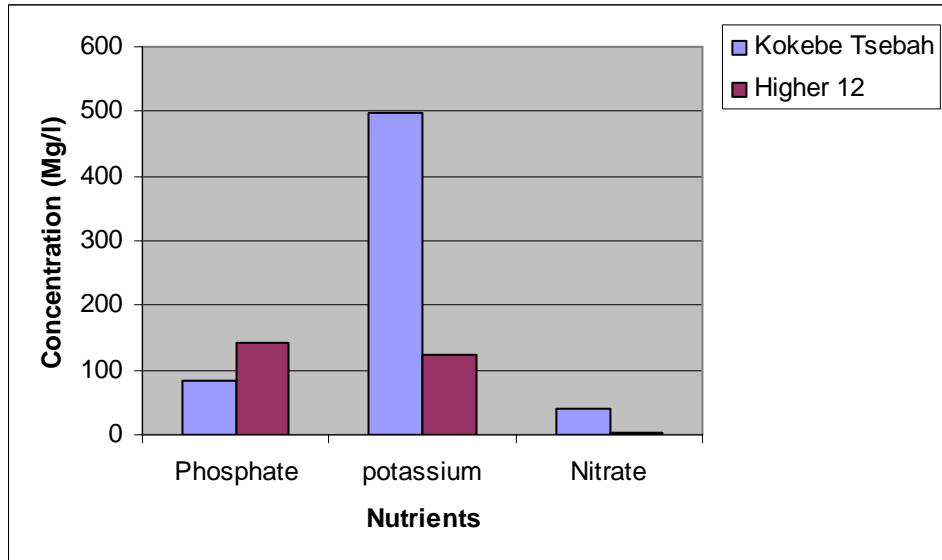
6.3 Nutrient content of the bio-slurry in the effluent samples

Evaluation of the two biodigesters (Kokebe Tsebah School and Higher 12 Institute) have been carried out to determine the composition of the effluent slurry for nutrient value. The mean result of the influent and effluent from both digesters are presented in Table 2.

Table 4. The mean concentration of nutrients (mg/l) in the effluent (phosphate, potassium and nitrate)

| Digester site | Phosphate | Potassium | Nitrate |
|-----------------------------|------------------|------------------|----------------|
| Kokebe Tsebah School | 82±3.78 | 498.3±4.41 | 38.7±2.33 |
| Higher 12 Institute | 141±1.53 | 123.7±0.33 | 2.5±0.1 |

The effluent was tested for the amount of Nitrate, phosphate and potassium for both digesters. The arithmetic mean of nitrate, phosphate and potassium per litre was also calculated for the effluent. The mean measurement of Phosphate, Potassium and Nitrate in Kokebe Tsebah School was 82 ± 3.78 , 498.3 ± 4.41 , and 38.7 ± 2.33 mg/l, respectively and for Higher 12 Institute is 141 ± 1.53 , 123.7 ± 0.33 , and 2.5 ± 0.1 mg/l, respectively (Figure 15).



Figures 11. The mean comparison of nutrients among the two digesters.

The result shows that there is a good amount of basic mineral elements (N P K) in the effluent slurries of both digesters. The concentration of nitrate was less in the effluent of Higher 12 digester. This could be because of the low retention time of the Higher 12 digester among some other factors. According to Tesfaye (2006), as the retention time decreases the concentration of ammonia in the effluent increases which in turn decreases the concentration of other forms of nitrogen.

Biodigester effluent has been shown to have a positive effect on the yield of many crop species (An *et al*, 1997, Sophea and Preston, 2000, Venning, 2001). In addition, effluent may provide an inexpensive alternative to chemical fertilizer and help retain site nutrients. According to Sanmaneechai *et al.*, (1992) the study using fermented slurry gave about 4.7 times more yield than the no fertilizer plot and even more than the only chemical fertilizer plot when tried for kale.

According to Gurung (1997) and Gupta (1991), the nutrient value of the effluent is rich in major plant nutrients compared to traditional FYM and compost. Both studies showed that digested slurry was appreciably high as compared to that for FYM and composted manure.

Therefore, biogas slurry has proved to be high quality organic manure when compared to Farm Yard Manure, because in Farm Yard Manure, the nutrients are lost by volatilization (especially nitrogen) due to exposure to sun (heat) as well as by leaching. According to Moulik (1990), only approximately 10 percent of the total nitrogen content in fresh dung is readily available for plant growth. A major portion of it has first to be biologically transformed in the soil and is only then gradually released for plant use. When fresh cow dung dries, approximately 30 to 50 percent of the nitrogen escapes within 10 days. While nitrogen escaping from digested slurry within the same period amounts to only 10 to 15 percent. Therefore, the value of slurry as fertilizer, if used directly in the field as it comes out of the plant, is higher than when it is used after being stored and dried.

Though interactions between fertilizer effluent and soil chemistry have not been examined in sufficient detail, the FAO (1992) reports that up to 90 percent of slurry Nitrogen, Phosphorus, and Potassium are retained in the effluent.

Finally, according to Amrit B. (2006) the use of bio-slurry for various purposes in agriculture system can save expenditure on imported agro-chemicals to significant amount both at farmers' level and national level. Varied uses of bio-slurry as plant nutrient, soil conditioner/vitalizer and fish feed have tremendous beneficial impact on agriculture system. However, there is a need of exploring its potential to maximum extent thorough researches so that farmers can be convinced for its proper utilization and safety for both economic and environmental benefits.

7. Conclusion and Recommendations

Fermented slurry, sometimes called bio-slurry, is an excellent organic fertilizer which can make an important contribution to better crop yields and lasting soil fertility. Although the nutrient content of the slurry is high and it is important for use as a fertilizer, the high number of total coliforms and fecal coliforms found can contaminate the environment in which the effluent is being released. As a conclusion, effluent slurry of digesters could be a potential source of environmental pollution in general and human infection in particular. Therefore, in order to avoid pollution and utilize the slurry as a source of fertilizer, the following recommendations are forwarded:

1. The effluents should undergo a secondary treatment to reduce the amount of coliforms and pathogenic microorganisms.
2. The effluent can be used as a substrate for making compost. This process is effective in eliminating pathogens because of the high temperature and long retention time of more than a month.
3. Awareness creation should be done by concerned institutions in the country on the impact of direct release of bioslurry on crops and vegetables.

References

1. Achankeng , E. (2003). Globalization, Urbanization and Municipal Solid Waste Management in Africa
2. Adams, A. M., Ortega, Y.R. and Jinneman, K. C. (1999). *Cyclospora*. Academic Press, London.
3. AGAMA (2003). Biogas Technology: Delivering Ecological Sanitation and Renewable Energy.
4. Aguilar, F. X. (2000). “How to Install a Polyethylene Biogas Plant.” Sri Lanka.
5. Amrit B. (2006). Physico-chemical Analysis of Bio-slurry and Farm Yard Manure for Comparison of Nutrient Contents and other Benefits so as to Better Promote Bio-slurry. Yashoda Sustainable Development (P) Ltd., Kathmandu, Nepal
6. An, B.X., Preston, T.R. and Dolberg, F. (1997). The introduction of low-cost polyethylene tube biodigesters on small scale farms in Vietnam. *Livestock Research for Rural Development*. Volume 9. Number 2.
7. An, B.X., Rodriguez, L. and Preston, Sarwatt, S.V., Preston, T.R. and Dolberg, F. (1997b). Installation and performance of low-cost polyethylene tube biodigesters on small-scale farms. *United Nations Food and Agriculture Organization, World Animal Review* 88-1997.
8. APHA, (1998). *Standard Methods for the Examination of Water and Waste water*, 19th ed. American Public Health association, Washington DC.
9. Benjamin J. (2004). *Renewable energy and development Brochure to accompany the mobile exhibition on renewable energy in Ethiopia*, Addis Ababa.
10. *Bioenergy Systems Report (BSR 1984): “Innovations in Biogas Systems and Technology”*1984. Bio-energy Systems and Technology Project of the USAID.

11. Bui X. A. and Preston, T. R. (1999). Gas production from pig manure fed at different loading rates to polyethylene tubular biodigesters, Livestock Research for Rural Development, Volume 11, Number 1, 1999
12. Butare, A. and Kimaro A., (2002). Anaerobic technology for toilet wastes management: the case study of the Cyangugu pilot project, Kigali institute of Science, Technology and management, Kigali, Rwanda.
13. Chará J, Pedraza G. and Conde N. (1999). The productive water decontamination system: A tool for protecting water resources in the tropics. Livestock Research for Rural Development: <http://www.cipav.org.co/lrrd/lrrd11/1/cha111.htm>
14. Chau, L. H. (1998a). Biodigester effluent versus manure from pig or cattle as fertilizer for production of cassava foliage (*Manihot esculenta*). Livestock Research for Rural Development: <http://www.cipav.org.co/lrrd/lrrd10/3/chau1.htm>
15. Chau, L. H. (1998b). Biodigester effluent versus manure, from pigs or cattle, as fertilizer for duckweed (*Lemna* spp.). Livestock Research for Rural Development: <http://www.cipav.org.co/lrrd/lrrd10/3/chau2.htm>
16. Da Silva E. J. (1979). Biogas generation: developments. Problems, and tasks - an overview in: Bioconversion of Organic Residues for Rural Communities The United Nations University. (<http://www.unu.edu/unupress/unupbooks/80434e/80434E0k.htm>)
17. EarthTrends (2005). "Energy Consumption by Source." EarthTrends Data Tables. World Resources Institute. http://earthtrends.wri.org/pdf_library/data_tables/ene2_2005.pdf
18. EEPA / UNIDO (2003). Standards for Industrial Pollution Control in Ethiopia. Part Three, Standards for Industrial Effluents (General). FEPE of Ethiopia. Vol. 1. pp45-48
19. FAO (1992). Biogas Processes for Sustainable Development. Rome.
20. FAO (2005). State of the World's Forests: 2005. Rome, Italy.
21. FAO/CMS (1996a). A system approach to biogas technology from "Biogas technology: a training manual for extension"
<http://www.fao.org/waicent/faoinfo/sustdev/EGdirect/EGre0021.htm>

22. FAO/CMS (1996b) Components of a biogas system from "Biogas technology: a training manual for extension"
<http://www.fao.org/waicent/faoinfo/sustdev/EGdirect/EGre0022htm>
23. Feachem, R., McGarry, M. and Mara, D. (1978). Waters, Wastes and Health in Hot Climates. John Wiley and Sons, Chichester.
24. Forchhammer N.C. (1994). Ecological Plant Physiology. Institute of Biological Science University of Aarhus.
25. Fulford, D. (1988). Running A Biogas Programme. A hand book. J and L composition, North Yorkshire.
26. Gupta (1991). Bio-fertilizer from Biogas Plants. Changing Villages, Vol 10, No.1, Jan-Mar, 1991.
27. Gurung, J. B. (1997). Review of Literature on Effect of Slurry Use on Crop Production. Biogas Support Programme.
28. Harsch, E. (2001). "African cities under strain: Initiatives to improve housing, services, security and governance." Africa Recovery 15(1-2): 30.
29. Hobson, P. N. and Wheatley, A. D. (1993). Anaerobic Digestion. Modern theory and practice. Elsevier Applied Science, New York.
30. Kangmin, L. and Mae-Wan, H. (2006). Biogas China, ISIS Press Release.
31. Lagrange, B. (1979). Biomethane 2: Principles – Techniques Utilization, EDISUD, La Calade, 13100 Aix-en-Provence, France.
32. LEISA (2005). Magazine on Low External Input and Sustainable Agriculture, Volume 21 No. 1, March 2005.
33. Long, C (1992). Review and Prospects for Biogas Development in Guangxi Zhuang Autonomous Region (Chinese) China Biogas 10 (3), pp. 1-4.
34. Lund, M. S., Andersen, S. S. and Torry-Smith, M. (1996). Building of a Flexibility Bag Biogas Digester in Tanzania, Student Report. Technical University of Denmark, Copenhagen.

35. Mapako, M. C. (1984). Biogas for Zimbabwe, An illustrated account of the many aspects of biogas with special regard to the Zimbabwean situation. Department of Energy Resources and development, Harare.
36. Marchaim, U and Criden, J (1981). Fuel gas production from biomass, Vol. 1, CRC press, Boca Raton, Florida, pp. 95-120.
37. Marchaim, U. (1983) 3rd International Symposium on Anaerobic Digestion, Boston, MA, pp. 343-355.
38. Marchaim, U. (1991). Biological Wastes.
39. Marchaim, U. (1992). Biogas processes for sustainable development.
40. McMichael, A. J. (2000). The urban environment and health in a world of increasing globalization: issues for developing countries. Bulletin of the World Health Organization, 200, 78. W. H. Organization, World Health Organization. 78 (9).
41. Medina, M. (1999). Globalization, Development, and Municipal Solid waste
42. Moscoso, J. and Leon, G. (2000). Treatment and sanitary use of wastewater and Wastewater use in aquaculture.
43. Moulik, T. K. (1990) Diffusion of Biogas Technology: Strategies and Policy. International Conference on Biogas Technologies and Implementation Strategy Report. GTZ/BORDA.
44. NSA Public Fact Sheet 123 (1998). The Terrible Truth, National Sludge Alliance, New York, USA.
45. Pawlowski, Z. (1989). Ascariasis. In: *Tropical and Geotropical Medicine*, pp. 369-378, McGraw Hill Information Service Company, New York.
46. Polprasert, C. (1989). Organic Waste Recycling, Asian Institute of Technology, Bangkok.
47. Preston, T. R. and Leng, R. A. (1989). The greenhouse effect and its implications for world agriculture. The need for environmentally friendly development. Livestock Research for Rural Development: <http://www.cipav.org.co/lrrd/lrrd1/1/preston.htm>

48. Preston, T. R. and Rodriguez, L. (1996). Recent developments in the recycling of livestock excreta; an essential feature of sustainable farming systems in the tropics
<http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/recycle/default.htm>
49. Prior, R. L. and Hashimoto, A. G. (1981). Fuel Gas Production from Biomass, Vol. 2. CRC Press, Florida, pp. 215-238.
50. Rakocy, J. E. and McGinty, A.S. (1989). Pond culture of tilapia, Southern regional Aquaculture Center. SRAC publication No. 280.
51. Rose, J.B., Dickson, L.J., Farrah, S.R. and Carahan, R.P. (1996). Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility, *Water Res.* 30:2785-2797.
52. Sathianathan, M. A. (1975). Biogas Achievements and Challenges. Association of Voluntary Agencies for Rural Development. New Delhi, India.
53. Sanmaneechai, M., Insomphan, S., Phuekpong, B., Knacharoenpong, A. and Kornisaranukul, P. (1992), Utilization of fermented slurry as fertilizer for crops. Proceedings of Conference on “Biogas in Thailand Present and Future Perspective, Thai-German Biogas Programme (GTZ)”, Chiang Mai, Thailand (27-28 February, 1992).
54. Sharma, P.D. (2004). *Ecology and Environment*, 7th ed. New delhi, India.
55. Sophea and Preston, K. and Preston, T.R. (2001). “Introducing biodigesters and vegetable growing in Tayeung Village, Takeo Province.” MS thesis. University of Tropical Agriculture, Royal University of Agriculture. Phnom Penh, Cambodia.
56. TERI (1994). Biogas: a source of rural employment. New Delhi: Tata Energy Research Institute <http://www.teriin.org/renew/tech/biogas/about.htm>
57. Tesfaye, H. (2006). Assessment of Intestinal Parasites in the Effluent Slurry of Toilet - Linked Biogas Digesters. MSc Thesis, Addis Ababa University.
58. Venning, K. (2001). Effects of Fertilization with Biodigester Effluent on the Growth and Composition of Selected Water Plants. Project in Agricultural Science 212-424 – Report. The Institute of Land and Food Resources.

59. WHO (World Health Organization). (1989). Health guidelines for the use of wastewater in agriculture and aquaculture. Report of a World Health Organization Scientific Group, *WHO Technical Report Series 778*, World Health Organization, Geneva, Switzerland.
60. Winblad, U. and Simpson-Hebert, M. (editors) (2004): Ecological Sanitation – revised and enlarged edition. SEI, Stockholm, Sweden.

ANNEX 1: Tables showing direct results of the study

Table 5. Results of physico-chemical parameters (T °, pH, COD and BOD)

| Digester site | Samples | Samplings | Temperature (° C) | | pH | COD | BOD |
|----------------------|----------|-----------------|-------------------|--------------------------------|--------------------------------|-------|------|
| Kokebe Tsebah School | Influent | 1 st | 18.0 | Ambient 1 st – 22.2 | 7.16 | 5250 | 2000 |
| | | 2 nd | 17.3 | | 7.21 | 11450 | 2500 |
| | | 3 rd | 16.3 | Ambient 2 nd – 20.1 | 7.28 | 5550 | 2100 |
| | Effluent | 1 st | 18.7 | | 8.52 | 600 | 120 |
| | | 2 nd | 17.8 | | Ambient 3 rd – 17.6 | 8.03 | 2100 |
| | | 3 rd | 17.2 | 7.66 | | 750 | 130 |
| Higher 12 Institute | Influent | 1 st | 17.9 | Ambient 1 st – 22.0 | 7.20 | 5000 | 1950 |
| | | 2 nd | 17.5 | | 7.11 | 10400 | 2400 |
| | | 3 rd | 16.8 | Ambient 2 nd – 19.6 | 7.30 | 5230 | 2000 |
| | Effluent | 1 st | 18.2 | | 8.23 | 2050 | 30 |
| | | 2 nd | 17.2 | | Ambient 3 rd – 14.5 | 7.80 | 800 |
| | | 3 rd | 16.8 | 7.02 | | 450 | 40 |

Table 6. Results of effluent samples for nutrient content

| Digester site | Samplings | Potassium Mg/litre | Nitrate Mg/litre | Phosphate Mg/litre |
|----------------------|-----------------|-----------------------|---------------------|-----------------------|
| Kokebe Tsebah School | 1 st | 490.00 | 35.00 | 75.00 |
| | 2 nd | 505.00 | 38.00 | 83.00 |
| | 3 rd | 500.00 | 43.00 | 88.00 |
| Higher 12 Institute | 1 st | 123.00 | 2.30 | 140.00 |
| | 2 nd | 124.00 | 2.53 | 144.00 |
| | 3 rd | 124.00 | 2.64 | 139.00 |

Table 7. Results of Total and Fecal Coliforms from both influent and effluent in most probable number

| Digester site | Samples | Samplings | Type of bacteria | |
|----------------------|----------|-----------------|---------------------|--------------------|
| | | | Total Coliform | Fecal Coliform |
| Kokebe Tsebah School | Influent | 1 st | 4×10^6 | 4×10^6 |
| | | 2 nd | 1.7×10^7 | 6×10^5 |
| | | 3 rd | 3.45×10^7 | 3.45×10^6 |
| | Effluent | 1 st | 2×10^4 | 5×10^4 |
| | | 2 nd | 1.2×10^4 | 2×10^4 |
| | | 3 rd | 9×10^4 | 2×10^4 |
| Higher 12 Institute | Influent | 1 st | 4.258×10^6 | 4.3×10^6 |
| | | 2 nd | 1.72×10^7 | 6.3×10^5 |
| | | 3 rd | 3.25×10^7 | 3.6×10^6 |
| | Effluent | 1 st | 9×10^4 | 2×10^4 |
| | | 2 nd | 34×10^4 | 7×10^4 |
| | | 3 rd | 1.6×10^6 | 1.6×10^6 |

ANNEX 2: Pictures



Figure 12. Using biogas for cooking food



Figure 13. Fixed-dome biogas digester under construction in Kokebe Tsebah School



Figure 14. Sample sites in Kokebe Tsebah School



Figure 15. Effluent samples and sample site in Higher 12 Institute



Figure 16. Picture showing confirmative test before and after fermentation



Figure 17. picture showing bacteriological samples in water bath at 44°C



Figure 18. Pictures showing vegetables grown on soil with bioslurry effluent added in Higher 12 Institute

Declaration

I, the undersigned, declare that this thesis is my original work and it has not been presented in other university, college or institutions, seeking for similar degree or other purposes. All sources of the materials used in the thesis have been duly acknowledged.

Dereje Gebre Michael Hussein

Name

Signature