# EXPERIMENTAL EVALUATION OF THE USE OF BIOCHAR FROM HUMAN FECES: NEXUS APPROACH TOWARDS WASTE-ENERGY AND SOIL MANAGEMENT.

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THESIS SUBMITTED TO DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCE AND TECHNOLOGY, COLLEGE OF PUBLIC HEALTH AND MEDICAL SCIENCES, JIMMA UNIVERSITY FOR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL HEALTH.

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# Experimental evaluation of the use of biochar from Human feces: Nexus approach towards Waste-Energy and Soil management.

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## Statement of Author

I declare that this piece of work is my own and all sources of materials used for this final work have been duly acknowledged.

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## Abstract

*Nutrient and Energy trapped in household biodegradable solid waste and wastewater has to be recycled to meet the escalating energy demand and lack of urban sanitation in developing countries. Human feces in developing countries like Ethiopia area major causes of environmental pollution and community health impairment, particularly in slum areas where many people live together under low basic sanitation coverage. Hitherto, the management option involves a simply containment, treatment and disposal which is practiced in most cities of developing countries. Human waste recycling with appropriate and low cost technologies can prevent environmental contamination and protects public health. In addition, such approaches have great importance to recover energy and develop natural fertilizer from feces. However, such human waste management options are not yet explore efficiently. This article presents results of a study evaluating the feasibility of using human feces-derived char as a solid fuel for heating and cooking and a potential way to use the feces ash after energy recovered for agricultural application experimentally. The proximate analysis showed that feces have a composition of 61. 86% moisture contents, 27.28% volatile maters, 4.69% ash contents and 6.17% fixed Carbon. The pyrolyzed feces at 300 $^{0}$C had 23.7 MJ/kg of energy content which has met the FAO standard for biochar. Both the micro- and macronutrient content of feces ash were in the recommended range needed for plant growth. On the basis of the energy content, the determined combustion efficiency of feces char in this study, we found the material to have potential as a supplementary, renewable energy source in the developing world. Similarly, the nutrient content of the feces ash can substitute chemical fertilizer for agricultural application. The energy and nutrient values are comparable to those of commercial fertilizers and charcoal briquettes respectively, making feces recycling a potential substitute that also contributes to the preservation of the environment and public health.*

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## Abbreviations

- **FAO – Food and Agricultural Organization**
- **GTZ - German Technical Cooperation**
- **MDG – Millennium Development Goals**
- **PES - Portable Ecological sanitation**
- **PUDDT - Portable Urine Diversion Dry Toilet**
- **SRFA - Sanitation Research Fund for Africa**
- **UNICEF – United Nations Children's Fund**
- **WHO – World Health Organization**

# Chapter One: Introduction

## 1.1 Background

Worldwide cities are facing unprecedented demographic, environmental, economic, social and spatial challenges. One of the key 21$^{st}$ century global challenges in public health is improving the urban sanitation related problems (Sclar et al., 2005). Since 2007, more people live in urban centers than in rural areas and this tread is expected to continue. Within the next 30 years, developing countries are predicted to account for 80% of the world's urban population. Around one third of urban dwellers are living in urban slums of which more than 90% urban slums are located in developing countries (WHO, 2010). Sub-Saharan Africa is urbanizing faster than any other continent having currently 37% urbanized population (WHO and UNICEF, 2014). In 2012, 61.7 % of the Sub-Saharan Africa urban population live in slums where sanitation situation is highly deteriorated (UN-Habitat, 2014). From an urban perspective, in Sub-Saharan Africa challenges related to water and sanitation will be higher in the future due to an ever-growing city population that share already insufficient and poorly managed resources.

Sanitation is the single most cost effective public health intervention to reduce child mortality (Cairncross and Valdmanis 2006; Hutton 2013). However, lack of improved sanitation is the most important feature of slums in the African urban context. The MDG sanitation target was to reduce the proportion of the world population without access to improved sanitation from 51% in 1990 to 25% in 2015. Despite progresses, meeting the MDG sanitation target is lagging behind and becomes a challenging task in developing countries mainly in Sub-Saharan countries (WHO and UNICEF 2014). According to the report, Ethiopia is in the list of countries that are not on track to meet MDG sanitation target.

In Ethiopia, the urban population was growing at an average rate of 5.8% for the last fifty years (1961-2013), which has resulted with about 756 people adding to the urban residents daily (MoUDC, 2014). It was estimated that an adult person produces about 500 liters (550 kg) of urine and 50-180 kg of wet weight of feces per annum (Polprasert, 1995). Both human feces and urine contain enough nutrients to grow most of the plants that humans needs as food. Feces can also be used as an energy sources in the form of biochar and synthetic gas through pyrolysis and gasification processes respectively. Nevertheless, instead of utilizing the huge amount of human waste as a resource, it is usually disposed of to the nearby land and watercourses.

Even for cities with conventional sewage treatment plant, it rarely retains or destroys all bacterial and viral contaminants, it produces a large amount of sludge generally unfit for agriculture, and it causes severe pollution in freshwater and seawater ecosystems. This end of pipe solution recycles nothing. It takes valuable resources and transforms them into pollutants. As chemical fertilizer prices rise throughout the world, and as water becomes an increasingly scarce commodity, this unsustainable approach makes no sense.

Agriculture gets the nitrogen it needs from ammonia-producing plants that utilize fossil fuels such as natural gas, petroleum naphtha as a source of hydrogen. This energy-intensive process dumps carbon dioxide into the atmosphere, it consumes a finite hydrocarbon resource, and it is not sustainable. Agriculture gets the phosphorous it needs from phosphorous-bearing rocks. However, these reserves are rapidly dwindling and increasingly contaminated with pollutants such as cadmium. In as little as 25 years apatite reserves may no longer be economically exploitable and massive worldwide starvation is predicted to follow.

If we are serious about achieving sustainability in this regard, our first, and perhaps most important duty, lies in not mixing urine with feces. Within the human body these two wastes are produced and stored separately, they are excreted separately, and afterwards they should be contained and processed separately. A urine diversion toilet can be a suitable technology can be used for separation and collection.

Therefore, the main focus of this research is to explore technologies for valorization of human waste biomass with complete microbial in activation to minimize environmental contamination and public health risks using urine diversion toilets to collect urine and feces separately. This experiment is initiated with the objectives of developing biochar from human feces through pyrolysis and optimization of waste to energy sources and making one of the most important carbon sequestration methods with complete inactivation microorganisms.

## 1.2 Statement of the Problem

Waste generation is closely linked with population growth and urbanization (UNEP 2010). Poor management of human excreta is the main cause of environmental degradation such as surface and ground water contamination, air pollution, and offensive odor of the city and the source for many communicable diseases and deaths (Asian Productivity Organization 2007). From these, 80 % of all morbidity and 25 % of all mortality in developing countries are caused by polluted water by human feces (WHO, 2002). In Sub-Saharan Africa at least 1/3 of incomes spent to treat water-borne diseases (Weikersheim & Württembu 2005) and Ethiopia is grouped among the countries of lowest sanitation coverage. Even the existing latrine facility in Ethiopia is unimproved quality such as an open pit latrine or pit latrine without slabs, used by 45 percent of households in rural areas and 37 percent of households in urban areas. Overall, 38 percent of the households have no toilet facility, 16 percent in urban areas and 45 percent in rural areas (CSA 2012).

In developing countries, human feces-related diseases are very common; hence, wastes contain high concentrations of excreted pathogens such as viruses, bacteria, protozoa cysts, and helminthes eggs that may cause infections in humans due to poor waste management system. These problems arise due to untreated or inadequately-treated excreta and unsightly disposed of wastes. Treating and recovering of energy from those wastes at the source is not practiced yet (Keddy et al. 2004). The existing advances in science and technology in our country do not widely allow society to produce different alternatives source of energy by using local available materials. As a result, they rely on biomass fuel which is the main cause of deforestation. In Ethiopia, 60 to 80 million tons of biomass fuels are consumed annually this leads accelerated deforestation, soil degradation, and emission of greenhouse gases (Lakew et al. 2011). Thus, for those people that rely on solid fuels like biomass and coal for cooking, heating, and water boiling, a practical supplementary energy source should come in a solid form that works with existing cooking and heating methods.

To create a sustainable society, the nutrients and energy in solid and wastewater have to be recycled. If the nutrient and energy present in a waste from a society were recycled, the use of fossil resources would decrease and so would the undesirable effect arising from discharge of nutrient to water recipient. Waste can easily become a nuisance if not handle properly. Waste will be a resource but still they are not valued to be recycled for energy and nutrients worldwide. Human fecal waste can be safely treated and transformed into a solid fuel by thermally decomposing fecal sludge at high temperature and low oxygen conditions, a process called pyrolysis. Overall, pyrolysis reduces the fecal feedstock into useful and pathogen-free char, high-energy gas and oil. On this regard, researches are limited and no attempts have been made to use human feces for both energy and fertilizer a nexus approaches towards soil conservation, energy and sanitation (Hettiarachchi 2014).

Most developing countries like Ethiopia their economy is based on agriculture; soil amendment is a key issue to boost agricultural production. Hence, a huge amount of macronutrients (N, P, and K) and micronutrients (Zn, Fe, Cu and Mn ) trapped in feces recovery will have great importance for soil amendment (Poongothai 2013). To recover nutrient from feces the first step will be separating feces from urine during collection system. Thus, in this regard developing a urine diversion dry toilet is needed. Urine diversion dry toilet can conserve 15,000 liters of pure water supply for each person per year, thus will help to replace the traditional water carriage system which is expensive. Ecological sanitation latrine, a hygienic sanitation option, prevents pollution, infections, saves water, promotes zero waste generation and encourages food production if it is equipped with waste recycling technologies that can produce energy and organic fertilizer (Werner & Bracken 2009). Therefore, this research targets to develop portable urine diversion dry toilet with waste recycling technology needed for energy and nutrient recovery.

The majority of people in Ethiopia do not have sufficient and sustainable energy to provide for their basic needs such as cooking, lighting, and they also lack energy for productive activities to improve their economic status. Women in particular are heavily burdened with solid biofuel collection and food preparation, which impacts their health and limits their opportunity for full participation in social and economic life (Doig & Adow 2011). Up to my knowledge, there is no published study done in Ethiopia on biochar production from human feces via pyrolysis for energy and plants nutrients recovery with a complete microbial stabilization. Therefore, this study aimed experimentally evaluating the feasibility of using human feces-derived char as a solid fuel for heating and cooking and a potential way to use the feces ash after energy recovered for agricultural application. Furthermore, to study the macronutrients and micronutrients content of feces ash after energy recovery to use as a crucial fertilizer for soil amendment. The research presented here was done to support the possibility of using a nexus approach towards waste, energy and soil management strategies.

## 1.3 Significance of the Study

Looking at the nexus approaches in the current scientific trade, the question arises which environmental resources have to be managed in an integrated way to achieve the sought integrated and sustainable management. Advancing a nexus approach to the sustainable management of environmental resources, focusing in particular on water, soil and waste are the current tread in a sustainable society creation processes. For example, the production of food relies on water, soil nutrient and forest conservation, with waste being an important factor for the provision of nutrients and organic material to the soil. The same is true for the production of biofuel (biochar, biogas) and energy from biomass. Thus, this study will have significance providing first hand on the possibility of application of nexus approaches towards waste, soil and energy management. Human feces being as a sources of fertilizer in soil amendment and sources of energy for household energy demand which prevents deforestation supplementing solid fuel sources. Moreover, recycling of human feces will prevent water pollution and increases safe sanitation system while breaking feco-oral disease transmission chain. Therefore, the community will be benefitted from sustainable and low cost energy production and healthy environmental condition. Moreover, this research will contribute for environmental sustainability by rapidly increasing sustainable energy production and access to basic sanitation which leads to clean water, good health care, and the protection of biodiversity.

# Chapter Two: Literature Review

## 2.1 Resource Oriented Sanitation

The flush toilet is ecologically mindless because of this it need to shift in the way people think about ecological sanitation technology that is intelligently designed and constructed to mimic nature at every step (Narain 2002). Nutrients and organic matter in human excreta are considered as a resource, food for a healthy ecology of beneficial soil organisms that eventually produce food or other benefits for people. The new approach recognizes the need and benefit of protecting environmental health and promoting human well-being, recovering and recycling nutrients, and conserving and protecting natural resources. It represents a closed-loop approach to nutrients and water problems. Its defining features it's safe, it's green and it's valuable are a major shift from conventional sanitary solutions (Harri 2004).

An important consideration in determining the logistical and financial viability of any reuse is the local market demand for that product compared to the expected supply of a given product of reuse. Waste-based businesses that rely on human waste as a primary input into the production of food and energy are a promising means of improving the function and reliability of urban sanitation value/service chains. Or a low operation cost of facilities and dual benefits for Waste-based production for safe sanitation requires safe disposal, treatment and reuse of effluent. Inadequate disposal of effluent and flooding of facilities, contaminating the water sources by neighboring settlements (Ashley 2011).

Water is one of the causes of conflict over the world communities and there is also desperate scarcity of water, which is taking an enormous human toll. There is intense competition between competing needs of water in agriculture, industry, drinking and recreation. Worse, the political economy of defecation is such that no democratic government will accept the hard fact that it cannot "afford" to invest in modern sewage systems for its citizens. The cost to build sewage treatment plants is externalized through these environmental programmers. The Sewer systems totally destroy nature's nutrient cycle in which nutrients collected from the land should be returned back to the land. With the use of sewers, this "waste" gets dumped into our aquatic systems. Therefore, while our nutrients in food come from agricultural lands, sewer systems dump into water bodies. Over time, our agricultural lands get depleted of nutrients, which then need intensive artificial fertilization. The lack of these micronutrients not only becomes a limiting factor in plant productivity but the resulting lack of these nutrients in human food becomes a threat to human health (Harri 2004).

Pyrolysis is a relatively simple, inexpensive, and robust thermo chemical technology for transforming biomass into biochar. The robust nature of the pyrolysis technology, which allows considerable flexibility in both the type and quality of the biomass raw material,(Brown et al., 2009) Environmentally sound technologies could be scaled up to accelerate the innovation and diffusion of technologies critical to the transition to a global green economy (APEC 2000). The latest trends in the field of sludge management, i.e. combustion, wet oxidation, pyrolysis, gasification and co-combustion of sewage sludge with other materials for further use as energy source, have generated significant scientific interest.

The principal goal of thermal processing of sewage sludge is the utilization of the stored energy in sludge and the minimization of environmental impacts at the same time, in order to meet the increasingly stringent standards. It is well known that sludge contains high moisture contents. Therefore the majority of energy released during thermal processes is consumed to reduce the amount of moisture. However these routes are generally considered to be self-sufficient in energy (Fytili & Zabaniotou 2008).

## 2.2 Biochar Production for soil amendment

In 2005, the world production of biochar was more than 44 million ton because current biochar production yields a mere 20% of the original biomass, it can be estimated that more than 220 million ton of biomass is processed to produce the world's supply of annual biochar developing from biomass has the capacity to amendment to the soil is an additional option. Biochar uses an boost soil carbon and enhances soil fertility sequester carbon (Garcia-Perez et al. 2010).

The incredible fertility and dark color of Midwestern US soils are often attributed to thousands of years of prairie fires building up organic carbon, and especially black carbon. (The relatively young age of the soils, the organic matter from perennial grass roots and sufficient rainfall are also factors.) Even in areas with few vegetation fires, black carbon can still be deposited in soils as small particulates in the atmosphere from far away fires fall to the ground. Black carbons in river and ocean beds are deposited through erosion of soils and burial in the sediments. Overall, the long-term existence of Black Carbon in so many of the world's soils and sediments gives credibility to the possibility of using biochar as a way to stably sequester large amounts of carbon. As important as black carbons are in the global carbon cycle, the exact amount of carbon sequestered. Char, the product of solid phase thermo chemical reactions, and soot, the gas-phase condensation products of combustion, are both considered black carbons (Brewer 2012).

Biochar restoring degraded soils and ecosystems is a strategy with multiple benefits for water quality, biomass productivity and for reducing net $Co_2$ emissions. Formation of charcoal and biochar amendment to the soil is another option. Biochar use increases soil carbon and enhances soil fertility (Laird 2010).

Biochar application helps farmers in several ways: less fertilizer is needed because biochar absorbs and slowly releases nutrients to plants; biochar improves soil moisture retention and conserves water, securing the crops against drought; farmers spend less on seeds as emergence percentages increases; biochar reduces the methane emissions from paddy fields (Esben 2011). Biochar for Sustainable agriculture is a way of raising food that is healthy for consumers and animals without causing damage to ecosystem health. The most observable form of land degradation in Ethiopia is soil erosion, which influences almost half of the agricultural land and results in soil loss of 1.5 to 2.0 billion tons per annum and low phosphorous and very low nitrogen (found in most of the southern and southwestern Ethiopia), caused by low organic content. The governments of Ethiopia, national extension package program that stressed the importance of using external inputs in order to accelerate productivities (Alemneh 2003).

However, the current fertilizer prices make it often impossible for farmers to apply fertilizers. The potential functions of biochar in soil are manifold. Provision of organic matter, sequestration of carbon, modification of soil water retention and soil physical characteristics, supply of plant available nutrients, microbial activity, and influence on GHG's emissions are all potential key functions of biochar (Esben 2011). Tests made on the fertilizing effect of the urine indicate an increased yield of 50 - 200 per cent the normal yield. In a home garden of 15 $m^2$ the production of vegetables is estimated to provide an average Ethiopian family with about 75 per cent of the vegetables and fruits needed. At the same time the system can also make use of the organic waste produced in the home and recycle it into edible products (Terrefe & Edstrom 2006).

**Table 1. Average nutrient concentrations in urine adopted from (Werner & Bracken 2009)**

| Parameter | Quantity (g/L) | Annual quantity (kg/person/yr) |
|---|---|---|
| Nitrogen | 7 | 3.5 |
| Phosphorus | 1 | 0.5 |
| Potassium | 2 | 1 |
| Sulfur | 1 | 0.5 |
| Magnesium | 0.08 | 0.04 |
| Calcium | 0.2 | 0.1 |

### 2.3 Biochar minimize greenhouse gas emission

Almost half of dry biomass weight is pure carbon. If biomass is left to decompose in air, almost all of the carbon is lost into the atmosphere within a few years. During pyrolysis, around 50% of biomass carbon is changed into biochar. It produces charcoal, which is called “biochar’’ when buried in the ground. Carbon from the waste biomass is retained in biochar and permanently sequestered in the soil, effectively removing that carbon from the atmosphere. The carbon in a ton of biochar is equivalent to 3 to 3.5 tons of $CO_2$. Biochar is not only a carbon sink, it increases soil fertility and water retention capacity in soils, while reducing nutrient leaching and providing soil microorganisms, thereby significantly increasing productivity. In Europe and America before inducing of artificial fertilizer they were used biochar but in many other parts of the world it still plays a major role in the provision of soil nutrients (Brewer, 2012).

Environmentally sound technologies could be scaled up to accelerate the innovation and diffusion of technologies critical to the transition to a global green economy (Satishkumar et al. 2010). There is a net annual increase in atmospheric carbon on the order of 5gigatons (1015grams) of carbon per year (Gt C/yr). Many of today’s bio energy systems and environmentally conscience consumer products strive to be carbon neutral, where the rate of carbon dioxide production throughout the process is equal to the rate of carbon removal from the atmosphere (Brewer 2012).

## 2.4 Resource Recovery from Waste Stream

The amount of human wastes produced by a person depends on the composition of the food consumed. Foods low in fibers, such as meat, result in smaller amounts (mass and volume) of feces than foods high in fiber (Vinneras 2001). Waste recycling is promoted for both economic and environmental reasons, but the use of fresh excreta carries considerable health hazards. On other hand it rich source of nitrogen and other nutrients necessary for plant growth. The Chinese rely over 90 per cent of excreta for agriculture (WHO/UNEP 1997). The heating value of mixed municipal waste ranges from < 6 to >14 MJ/kg (Bogner et al. 2007).

**Table 2 The energy value of the different feed stocks adopted from (Özçimen 2011).**

| **Raw material of biochar** | **HHVMJ/kg)** |
|---|---|
| Olive oil residue | 15.5 |
| Laurel extraction residue | 20.7 |
| Corn stover | 21 |
| Hardwood bedding | 23.4 |

All over the world wastes generation rate is highly fisted to population, wealth and urbanization, is still a key challenge for municipalities to collect, recycle, treat and dispose of waste. Recycling of wastes in safe environment and many public heaths in affordable way is the cornerstone of sustainable development and successful waste management carry out which parallel decrease GHG emissions and improve the quality of life, promote public health, prevent water and soil contamination, conserve natural resources and provide renewable energy benefits (Bogner et al. 2007).

**Table 3. Effect of pyrolysis temperature on elemental composition and heating value of human feces adopted. From** (Jeanne 2013)

| Feedstock | Pyrolysis temp(ºC) | % ASH | C | H | N | O | HHV(MJ/kg) |
|---|---|---|---|---|---|---|---|
| Human Feces | 300 | 20.0 | 58.23 | 6.10 | 5.19 | 10.47 | 25.57 ± 0.08 |
| Human Feces | 450 | 37.1 | 50.67 | 1.90 | 4.76 | 5,56 | 17.91 ± 0.40 |

Human excreta are the raw material which is the waste products of body metabolism. The appearance, physical and chemical characteristics of urine and feces depend largely on the health of the person excreting the material, as well as on the amount and type of food and liquid consumed. Human wastes consist mainly of non-matabolised material combined with some matabolised material undigested nutrients are excreted with the faeces The lower the digestibility of the diet, the higher the mass of feces excreted per day (e.g. Sweden 51 kg/cap/yr (wet mass), China 115 kg/cap/yr, Kenya 190 kg/cap/yr) extremely high number of many different pathogens concentrations of contaminating substance in feces are usually lower than in chemical ferilisers (e.g. cadmium) and farmyard manure (Niwagaba 2009).

Every day, 2 million tons of sewage and industrial and agricultural waste are discharged into the world's water the equivalent of the weight of the entire human population of 6.8 billion people. Human Waste require of adequate sanitation contaminates water courses worldwide and is one of the most significant forms of water pollution which are the number one killer of children under five years old and more people die from unsafe water annually than from all forms of violence, including war. Unsafe water causes 4 billion cases of diarrhea each year, and results in 2.2 million deaths, mostly of children under five. This means that 15% of child deaths each year are attributable to diarrhea – a child dying every 15 seconds (Ross 2008). Ethiopia is expected to achieve the MDG target if current trends continue. It observed the reductions of at least 60 per cent of child mortalities(UNEPA 2013). Access to adequate sanitation is a key mechanism for improving the health and well-being of the most vulnerable individuals and the poorest countries in the world. Exposure to human fecal waste increases the likelihood of contracting certain diseases. The transition to improved sanitation is accompanied by more than a 30% reduction in child mortality (UNU-INWEH 2010).

## 2.4 Sanitation coverage

"Sanitation is more importance than independence", said Mahatma Gandhi. It is clearly a critical issue, linked as it to human health and dignity. The government and other independent bodies WHO/UNICEF Joint Monitoring Program data report of Sanitation coverage data have great discrepancy. The government data show an increase to 39 % coverage by 2009 (30 % rural, 88 % urban) from a baseline of close to zero in 1990 on the other hand, show a 12 % improved sanitation coverage in 2008 with the MDG sanitation target of 52 % by 2015 in order to meet the MDG sanitation target, 5.8 million Ethiopians need to get access to improved sanitation facilities annually. There is also a huge disparity between urban and rural areas, with only 8 % of the rural population and 29 % of the urban population using improved sanitation facilities .still 60 %, of population is practices open defecation(UNICEF 2010).

Human wastes can contain large concentrations of pathogenic viruses, bacteria, cysts of protozoa and eggs of helminthes (Timmer & Visker 1998). At any one time, 1.5 billion people suffer from parasitic worm infections from human excreta in the environment one gram of faces can contain10,000,000 viruses, 1,000,000 bacteria, 1,000 parasite cysts, 100 parasite eggs (Brian & Christine 2003). Especially in Africa urban migration increases, available latrines are receiving more and more users. However, while latrine coverage may remain insufficient, the safe collection and treatment of fecal sludge from systems that do exist is arguably the weakest link in the sanitation value chain. An estimated 2.4 billion users of on-site sanitation systems generate fecal sludge that goes untreated, resulting in pervasive environmental contamination(Moe & Rheingans 2006). Environmental sustainability should be an integral part of the design, implementation, operation and maintenance of facilities and the accompanying hygiene education program(Water Aid in Nepal, 2011).

## 2.5 Waste Characterization and Key Properties

The proximate analysis determines the moisture, volatile matter, ash and fixed carbon content in the fuel. It is a quick and practical way of assessing the fuels quality and type. The moisture content of biomass has a marked effect on the conversion efficiency and heating value. Higher moisture of biomass has a more tendency to decompose resulting in energy loss during storage. Volatile matter of the biomass is higher than the coal (around 75%). Higher volatile matter of the biomass makes it more readily devolatilization than solid fuel. Liberating less fixed carbon hence makes them more useful for pyrolysis and gasification. Ash content and moisture content affect the heating value. Ash content depends upon the plant and soil conditions in which the plant grows (Shadangi

2010).Biomass residues normally have much lower ash content but their ashes have a higher percentage of alkaline minerals, especially potash (Grover & Mishra 1996).

# Chapter Three: Objectives

## 3.1 General Objective

To evaluate experimentally the feasibility of using human feces-derived char as a solid fuel for heating and cooking and a potential way to address escalating energy demand, soil amendment and lack of urban sanitation.

## 3.2 Specific Objective

1. To develop urine diversion toilet system for separate collection of feces from Urine.

2. To characterize raw human feces using key proximate and ultimate properties.

3. To manufacture feces char via slow pyrolysis and measure its energy yield experimentally.

4. To determine the micronutrient and macronutrient constituent of human feces ash for agricultural application after energy recovery.

# Chapter Four: Methods and Materials

## 4.1. Study Design and Period

Laboratory based experimental study was conducted in different laboratories to evaluate the energy and nutrient contents of human feces from December, 2013 to April, 2014. The sampled human feces was characterized using key properties (Ultimate and proximate properties) at Environmental Health and Soil Laboratories in Jimma University. Feces char manufacturing, and measurement of its heating value and nutrient content were performed at Ethiopian Geological Survey, and Jije Chemical Analytical laboratory in Addis Ababa, Ethiopia.

## 4.2 Experimental Detail

So as to achieve the study objectives, the first step was to collect feces and urine separately. Thus, a portable urine diversion dry toilet was designed and developed prior to the experimental work (see Annex the detail of the PUDDT) for collecting feces sample. The developed PUDDT aimed to prevent the health risk due to direct handling of feces and promote closed lope sanitation technology for urban set up which aimed in recycling nutrient and energy from feces. Following 24hr collection period, the collected feces with the PUDDT was characterized with key properties (ultimate and proximate analysis). Then, a second batch feces sample was collected for char manufacturing with slow pyrolysis following moisture content removal by dry oven. Fecal matter was collected from anonymous volunteers at Jimma University who willing to use the UDDT during the sampling period. Subsequently, the manufactured feces char energy content as heating value was measured experimentally to use feces as household solid fuel resources. Then, remaining feces ash after heating value measurement was analyzed for plant nutritional value including micro- and macronutrient constituents so as to recycle feces nutrients to the agriculture field. Triplicate sample was taken for the energy value determination, key properties characterization and plant nutrient value measurements in this experimental work so as to evaluate the precision of measurements.

The survey done during the sample collection period showed that there was no odor and fly problem with the technology. Moreover, it has fulfilled the objective of on-site sanitation technology and made it easy collection and separation of feces from urine. The interview with users showed that the technology was comfortable for both male and female. However, there was a special complain on its comforts from disabled people.

The additional design of the urine collection system has protected users from urine back flash, especially for females. During the data collection period, a total of 37 female users were interviewed and most of them have confirmed that urination bed is very comfortable, and no back flashed to the users. Routine cleaning is needed to guarantee of good hygiene and proper use of this portable toilet. Care should be taken to prevent chemicals entering into the fecal drum as this will damage the pyrolysis process. Introducing of cover material of top and drum should implement to each user and educating first-time users on the basic steps of using a portable ecological sanitation toilet management systems.

## 4.3 Collection, Preparation and Storage of Sample

Feces sample was collected by putting the portable UDDT at Jimma university main campus. Approximately 130 anonymous volunteers, including students and employee of the university have used the UDDT during one day of feces sample collection period. Jimma University Research Ethical Committee approval was obtained prior to the study to collect feces sample and conduct the study. Information about the participants, including their diet was not assessed. However, the diet was likely a mixture of vegetable and non-vegetable just looking at the students menu provided by the university canteen. Some studies have shown that diets high in vegetable fiber produce feces with higher energy and fat levels than those from low fiber diets. Also, people eating high-fiber diets and living in rural areas produce more feces than those living in urban areas eating diets with less fiber. The collected material was quickly deposited in a metal container after mixing with stick in the UDDT storage tank and the proximity analyzing was conducted over night of collection days approximately within 24hr. At the same time, for the pyrolysis experimental work the collected feces matter moisture content was removed it at 105ºC for 24 h in a dry oven. Then the dry feces matter was stored at -20 °C for a maximum of two weeks until the laboratory analysis was initiated.

## 4.4 Proximate and Ultimate Analysis

The proximate analysis provides the weight percent of moisture, combustibles (composed entirely of volatile matter and fixed carbon), and ash in the biomass sample. Herein, the fixed carbon is the portion of combustible residue after removal of moisture, ash, and volatile materials from feces. Thus, one gram of the sampled feces was prepared in three replicate after homogenizing. Then determination of percentage of moisture, volatile, ash and fixed carbon content of the feces was carried out based on ASTM standard methods for chemical analysis of wood charcoal proc designation: D1762 – 84 (2007). Each of the triplicate sample was repeatedly carried out to evaluate the precision of measurement. The ultimate analyses of feces matter provide the weight fractions of non-mineral major elements (i.e., carbon, hydrogen, nitrogen, oxygen, and sulfur), which can be used to examine the extent of heating value and the organic constituents in the samples. It was conducted by using an elemental analyzer (Model: vario EL III Element Analyzer; Elementary Co., Germany). However, in this study the ultimate analysis was limited to the determination of Carbon, Nitrogen and Sulfur content of the feces. Similarly, in order to evaluate the precision of measurement, each sample was carried out in triplicate.

## 4.5 Pyrolysis and Energy Value of Feces Char

Half kilogram of oven dried feces prepared in a triplicate sample after carefully homogenizing was transported to Ethiopian geological survey laboratory for the pyrolysis experiment. The replicate samples were transported via a cold chain system after a careful packing in a metal container to prevent fecal matter degradation. The samples were placed in a pyrolysis chamber (Thermo Scientific Lindberg Blue M heavy duty box furnace). Internal temperature of the feces was monitored with a thermocouple and temperature data logger. Pyrolysis was conducted at $300^{O}C$ which is known as slow pyrolysis. The slow pyrolysis was chosen for this specific experimental work as it provides good char and energy yield compared to high temperature pyrolysis of human feces based on literature review (Preto 2008). The samples were held at the target temperature for 2hr, and the resulted chars were pulverized and homogenized before measuring the energy value as a heating value. The feces char yield was calculated using the following formula

$$\text{Feces char Yield} = \frac{\text{Mass of feces char}}{\text{Mass of raw feces}} \times 100\%$$

When energy is derived from biomass fuels by combustion in air, the calorific value (or termed the heating value) equates to the heat energy released. The higher heating value (HHV), measured with an adiabatic oxygen bomb calorimeter represent the higher value of the biomass in energy content. In this experiment, the energy content of the manufactured feces char was determined with bomb calorimeter after a homogenous triplicate sample was derived from the faces char. In order to evaluate the precision of measurement, each sample was repeatedly carried out in triplicate.

### 4.6 Feces Char Yield Per Capita Per Year and Energy Value Cost Estimation

Feces char yield per capita per year was calculated after subtracting percent of moisture content from the average value of human feces production per capita per year estimated for developing countries (Niwagaba 2009) multiplied by hundred divided by percent of feces char yield determined experimentally in this study. For the energy cost estimation, the value of the current oil price and currency value of ETB was considered.

### 4.7 Nutrient Content of Feces Ash

The use of feces matter as a soil amendment for agriculture, forestry, or urban landscape is subject to meeting pathogen standards. Applying feces to land is an effective way of utilizing the resource value of nutrients in it. However, there has to be a technology to inactivate pathogens percent in feces. Thus, this was the main driver to test the nutrient content of feces ash for agricultural application. Using Element Analyzer (Elementar Co., Germany) both micro- and macronutrient constituents of feces ash was determined. The determination of micronutrients was limited to Mn/Fe/Cu/Zn analysis, whereas Na/K/Ca/Mg/P for macronutrient. Due to financial limitation, a triplicate sample was not analyzed.

### 4.8 Data Quality Control

For the experimental work the standard laboratory procedures were followed and well qualified laboratories in the country was chosen to perform the analysis. To minimize variability within the test a triplicate sample was used for each tests. The human excreta were collected by educated and oriented person. Temperature and time relationship was closely monitored during production of feces char.

## 4.9 Ethical Consideration

Before the start of data collection, ethical clearance was obtained from Ethical clearance board of Jimma University. A formal letter was written to all concerned bodies and permission was secured at all levels. Informed verbal consent was obtained from each participant.

# Chapter Five: Result

## 5.1 Design of Urine Diversion Dry Toilet (UDDT) and User Convenience

For sustainable human waste management, our first, and perhaps the most important duty, lies in not mixing urine with feces. Most energy and nutrient recovery technology from human waste requires, feces and urine should be contained and processed separately. Thus, for this experimental study, on-site portable urine diversion toilet was designed and adopted so as to collect urine and feces separately. This newly adopted urine diversion toilet was designed to be comfortable for both male and female considering the socio-cultural, economic conditions, free from odor and fly nuisance, and installed with eco-friendly waste recycling technology. The collected feces with this technology were used for the experimental work in this study.

## 5.2 Proximate and Ultimate Composition of Human Feces

For the experimental works, raw human feces were collected using properly designed urine diversion toilet for urban setups. The collated raw feces and the manufactured biochar have been analyzed and the key properties (proximate and ultimate composition) have been examined. Table 1 shows the proximate composition of raw human feces in percent weight/ weight (% w/w) with the standard error. The moisture (61.86±0.57 %) and ash content (4.69±0.57%) were the highest and lowest value, respectively.

Table 4. Proximate analysis of raw human feces

| **Properties** | **Unit** | **Mean ± SE** |
|---|---|---|
| Moisture contents | % w/w | 61.8 ± 0.577 |
| Volatile Maters | % w/w | 27.3 ± 0.577 |
| Ash contents | % w/w | 4.7 ± 0.577 |
| Fixed carbon | % w/w | 6.1 ± 0.577 |

Correspondingly, the ultimate analysis which was limited to the determination of total nitrogen (mg/kg), total sulfur (mg/kg) and total organic matter (mg/kg) are showed in table 2. The ratio of C: N is higher than the ratio of N: S analyzed for the raw human feces. The total organic carbons constitute the highest percentage (46.08%), followed by total nitrogen (4.57%) and total sulfur (0.2488%) in raw human feces.

**Table 5 . Ultimate analysis of the raw feces on as received basis**

| Parameters | mg/kg (%) |
|---|---|
| Total Nitrogen | 45,700 (4.57) |
| Total Sulfur | 2,488(0.25) |
| Total Organic carbon | 460,800(46.10) |
| | Ratio |
| Nitrogen to Sulfur (N/S) | 18.37 |
| Carbon to Sulfur (C/S) | 185.20 |

## 5.3 Energy Content Human Feces Char

Figure 2 shows the measured heating value of raw human feces and the manufactured biochar compared with other commonly used solid fuels in developing countries from literatures. The manufacture biochar energy content (23.7MJ/kg) in this study was higher compared to non-carbonized raw human feces (17.92MJ/Kg). Comparing with literature values, on the basis of calorific values in MJ/kg, human feces briquettes with starch binder were determined to have higher energy contents than the human feces char from this study. However, human feces char, without briquetting, have high in energy content compared to commonly use solid fuels in developing countries.

## 5.4. Elemental Composition of Human Feces Ash

Table 7 provides the nutrient content of human feces ash after the energy is recovered. Fecal sludge is very rich in nutrients and organic matter and is thus attractive to farmers as a supplement or replacement for commercial fertilizers. Thus, the ash content of the human feces char was further analyzed to determine its plant nutritional constituents for agricultural purpose after a complete microbial inactivation. Comparing with the recommended "sufficient value" for plant growth, the analyzed nutrients were in the recommended range. The percentage of phosphors and potassium were very high reversely the percentage of calcium and sodium were very low.

**Table6. Micronutrient and macronutrient contents of human feces ash per person per year yields**

| **Nutrient Type** | **mg/kg of ash** | **Kg/Ca/year/dry wt./** | **% by weight** | **Sufficient range value (PPM)** (Habtegebrial 2009) |
|---|---|---|---|---|
| **Micronutrient** | | | | |
| Mn | 1332.05 | 0.0119 | 4.69 | 30 - 250* |
| Fe | 15260.62 | 0.1354 | 1.52 | 100* |
| Cu | 189.19 | 0.0012 | 0.01 | 189.19* |
| Zn | 1254.83 | 0.0112 | 0.13 | 33 - 49* |
| **Macronutrient** | | | | |
| Na | 15444.02 | 0.1372 | 1.54 | 4.56* |
| K | 110038.6 | 0.9802 | 11.00 | 3.50 – 5.10* |
| Ca | 3783.78 | 0.0337 | 0.38 | 2.10 -3.00* |
| Mg | 50193.05 | 0.4545 | 5.10 | 0.15 - 0.62* |

| | | | | |
|---|---|---|---|---|
| P | 121679.50 | 1.0845 | 12.17 | 0.42 - 0.69* |

## 5.5. Human Feces Char Yield and Estimation

The result for % char yield and % ash content compared with literature values at different pyrolys temperature are shown in table 4. In this study the slow pyrolysis of human feces has result the highest value of char yield (88.9%) and the lowest ash content percent (4.7%) compared with values from literature(Jeanne 2013). The char yield decreases as the pyrolysis temperature increased, which was a base for this study to choose slow pyrolysis. Correspondingly, the ash content increased substantially for chars with higher pyrolysis temperature.

**Table 7. Human waste biochar yield and ash content in percentage**

| Pyrolysis Temp in $^0$C | % Char yield | % Ash |
|---|---|---|
| **300** | 88.9 | 4.7 |

Considering the result from literature (Hill 2013) on average a person in developing country produces 190 kg/cap/yr wet weight feces. If the 61.86% of moisture removed the dry weight will became 72.47 kg/cap/yr. The result from slow pyrolysis showed that 88.9%of this can be converted to char yeiled which will yeild 64.41 kg/cap/yr char. Thus, this can estimeted to be have heating value of 1, 526.44 mega joule cap/yr or 424.kilowatt hour cap/yr.

# Chapter 6: Discussions

## 6.1 Portable Urine Diversion Dry Toilet (UDDT)

Shifting from wasteful, expensive, contaminating, water-based toilets to decentralized, environmentally friendly, dry toilets should be more a matter of paradigm shift than capital investment. This is especially true for those who have little money, are potentially living on the street, or are in the upheaval of an emergency (Narain 2002). Our excretion systems are made in such a way that the liquids and solids are stored separately and leave the body separately. Similarly, the designed portable urine diversion toilets make use of this natural separation, keeping the urine and feces separate for separate treatment. The key things that a urine dry toilet needs to do are: (1) jail up the potentially dangerous feces that may transmit many terrible diseases (including diarrhea, cholera, typhoid, and intestinal worm eggs) long enough for these to die and (2) set the urine free on the soil, where it is excellent fertilizer for the plants and transmits no disease (Pradhan 2006).

In this regard the designed portable urine diversion dry toilet in this study has fulfilled these two requirements. The separation of urine from toilet also greatly reduces the potential for stench and keeps the volume of dangerous material small and manageable(Hill 2013).

Also the designed portable urine diversion dry toilet is a modern, urine-separating, environmentally friendly toilet with the capacity to cope with both temporary and permanent urban needs. Using the toilet is as natural as using a pit latrine toilet. It has the same stability and a seat that is both comfortable to sit on and easy to keep clean. The vent pipe rapidly ventilates and helps dry the contents in the collection tank. As the liquid and solid wastes are never mixed, there is no foul smell.

However, the toilet is slightly more difficult to keep clean compared to other toilets because of both the lack of water and the need to separate the solid feces and liquid urine. No design will work for everyone and, therefore, some users may have difficulty separating both streams perfectly, which may result in extra cleaning and maintenance. Feces can be accidentally deposited in the urine section, causing blockages and cleaning problems which is also observed in many urine diversion toilet (Pranger et al. 2013). All of the surfaces should be cleaned regularly to prevent odors and to minimize the formation of stains. Water should not be poured in the toilet for cleaning. Instead, a damp cloth may be used to wipe down the seat and the inner bowls. Some toilets are easily removable and can be cleaned more thoroughly. It is important that the feces remain separate and dry. When the toilet is cleaned with water, care should be taken to ensure that the feces are not mixed with water.

Because urine is collected separately, calcium- and magnesium-based minerals and salts can precipitate and build up in pipes and on surfaces where urine is constantly present. Thus, washing the bowl with a mild acid (e.g., vinegar) and/or hot water can prevent the build-up of mineral deposits and scaling. Stronger (> 24% acetic) acid or a caustic soda solution (2 parts water to 1 part soda) can be used for removing blockages. However, in some cases manual removal may be required (Kvarnstrom et al., 2006).

The venting pipe also requires occasional maintenance. It is critical to regularly check its functioning. The designed toilet in this study amide to, recycle feces considering human health and environment health, while minimizing resource. Rain water harvesting system was installed on the toilet to collect water for hand washing.

The United Nations Millennium Declaration, signed in September 2000 commits the states "*to reduce by half the proportion of people without sustainable access to safe drinking water and sanitation by 2015*", which is formally referred to as goal 7, target 10(Nation 2005). These mean that huge amounts of investment are required, in case the conventional sanitation is considered. Over a year for each person some 400-500 liters of urine and 50 liters of feces are flushed away with 15,000 liters of pure water (Drewko 2007).

Ecological sanitation latrine, a hygienic sanitation option, prevents pollution, infections, saves water, promotes zero waste management and encourages food production. In addition, it helps: Promotion of recycling conservation of resources and contribution to the preservation of soil fertility improvement of agricultural productivity and hence contributes to food security via reusing nutrient trapped in the urine and feces, it increasing user comfort/security, in particular for women and girls promotion of a holistic, interdisciplinary approach (WaterAid in Nepal 2011).

Over the past ten years, a number of traditional pit latrines have been constructed in Ethiopia (FMH 2005). However, evidence indicates that many of these latrines were either not completed; are not used; or give problems with emptying especially in urban set up. They are also thought to have contributed to the loss of groundwater resources through pollution (Sanitation 2002).Thus, portable urine diversion dry toilet are the future focus from the point view of protecting environmental pollution and for effective recycling human feces. Basically research into the development, acceptability of this type of technology under Ethiopia conditions is far from complete, in particular, the handling and re-use of the dried product by householders. Although research into on-site sanitation has been carried out in the past, there has not been any coherent attempt to carry out research across a wide range of available technologies and their environmental and social suitability, as well as their economic sustainability under Ethiopia conditions. Hence, this designed toilet will rise up and it could improve the sanitation coverage of Ethiopia in urban areas.

## 6.2 Energy Content of Feces Char

The manufactured feces biochar in this study has met the FAO standards for biochar energy which is 22 MJ/kg.

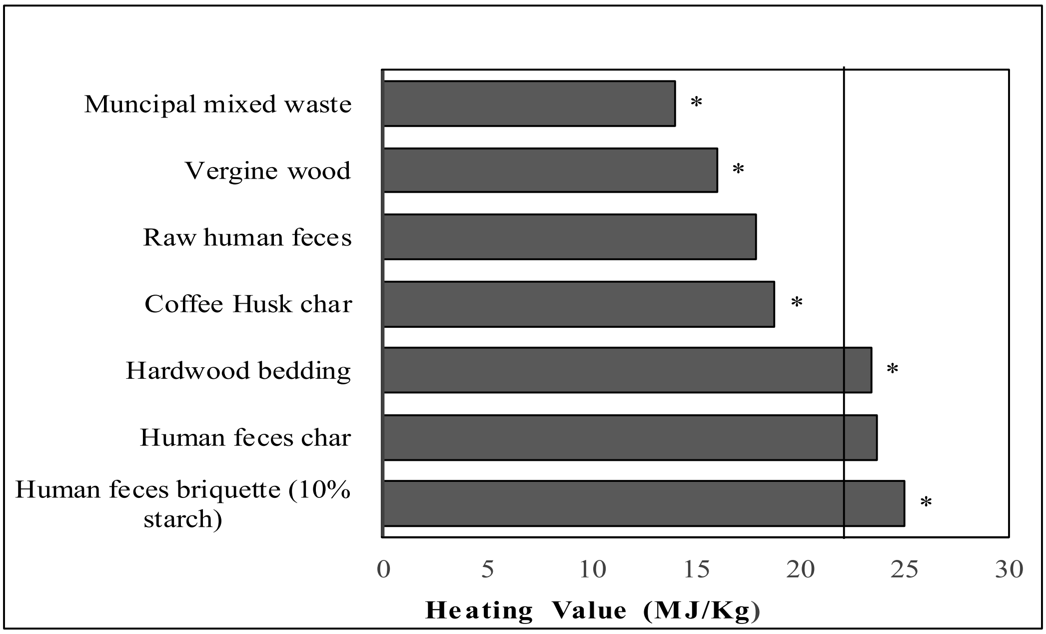


Figure 1. Heating value of human feces and solid fuels compared from literatures

Heating value of raw human feces, manufacture human feces char in this study and common selected solid fuels.* indicate a range of reported values from literatures. The vertical line indicates the minimum FAO briquette heating value standard (22 MJ/kg)

The proximate analysis result from the raw feces analysis was used for a predictive model to correlate to its heating value. The predictive models used (Eq1 and Eq2) as shown in table 5 has predictive a comparable energy content measured experimentally though Bomb calorimeter of raw human feces (17.9±0.15 MJ/Kg). However, the model Eq3 prediction was far more less than the experimentally measured.

**Table 8. Empirical model for predicting the energy content of raw human feces**

| Model based on proximate analysis: | | |
|---|---|---|
| **Name** | **HV in MJ/ kg** | **Equation** |
| Eq1 | 18.46 | 356.248VM - 6998.497 |
| Eq2 | 17.96 | 356.047VM - 118.035FC - 5600.613 |
| Eq3 Benton | 12.00 | 44.75VM - 5.85W + 21.2 |

VM = %Volatile Matter, FC = Fixed Carbon, W = Total Moisture, HV heating value

In many developing countries it is common for feces sludge to be applied to agricultural land after little or no treatment. For example, farmers in Tamale (northern Ghana) receive sludge on their land directly from cesspit trucks (Cofie & Adamtey 2009). Feces sludge is very rich in nutrients and organic matter and is thus attractive to farmers as a supplement or replacement for commercial fertilizers. However, there is great health risk using feces without complete activation for agricultural purpose(Shaw 2010). The significance of this study lies in determining the energy content of feces chars for energy and nutrient recovery option and for successful implementation of nexus approaches towards waste, energy and soil management. In this study the char yield via slow pyrolysis at 300 $^{O}$C in this study has resulted high char yield which was 88.8%. According to (Jeanne 2013) high value of char was obtained at low pyrolysis process of human feces than at higher temperature pyrolysis which was 46%. The increased char yield in this study might be due to low volatile matter presence in the tested feces linked with dietary system. High volatile matter constituent in biomass will result high emission and decreases char yield during pyrolysis process (Vigouroux 2001). Moreover, (UNC 2012). Studied the effect of pyrolysis temperature on artificially generated feces than real human feces. This all may account for huge difference observed in char yield in this study.

From the standpoint of conversion of biomass to energy and bio fuels, the heating value of biomass is a very important property. In this regard, the energy value of human feces in this study has met the minimum requirement set by FAO for biochar which is 22 MJ/kg. Raw feces have lower energy value than the manufactured char. The difference between them is probably associated with density (Moka 2012). Conclude that the higher the bulk density the lower the heating value of biomass. Even though in this study the bulk density of the raw and the manufactured feces char was not measured, the raw feces will have higher value. The Empirical model Eq2 was found to accurately predict experimentally determined heating values for raw produced in this set of experiments within the average standard error of the experimental measurements. Its use might save time and cost in future raw feces research.

Comparing the study result with literature values, briquetting human fecal char with 20% molasses and 7% lime using the pressure of a typical hand press created a briquetting with heating value slightly lower than that of commercial charcoal briquettes and the manufactured char in this study. However, briquettes made with 10% molasses and 3.5% lime binder as well as those with 10% starch binder had higher heating value (Barbara *et al.* 2012).Thus, this shows that a variety of locally available binders could be tested so as to improve the energy yield of feces char via briquetting for domestic use. Correspondingly, comparing with the energy content obtained from coffee husk char (Desta et al., 2011), virgin wood (Morris 1996), hard wood bedding (Pourhashem et al. 2013). Municipal mixed waste(ISWA 2008). The manufactured feces char in this study has high heating value. (Hertel 2013) observed that a higher percentage of carbon in feces derived char is in the form of aliphatic hydrocarbons compared to wood char. Moreover, the alkenes present in fecal char are more energy-rich (Fabbri et al. 2012).Thus, this might be the reason for the observed high heating value of feces char compared with literature value of other biomass.

Calculating the energy value and comparing it with commercially available oil value. A total of 36.46 litter/year equivalent oil can be obtained from a single individual. Also converting this value to the electricity energy value it will be 425 kwh/year. Currently average Ethiopian consumes 36kwh/year (Electric & Corporation 2010). Therefore, energy recovery from feces will be an important energy sources at least for household purpose such as cooking. Considering the total population of Ethiopian people especially those inhabiting in urban setup, it will have huge impact on income where majority of people in urban area inhabit slum area where there is no sufficient energy supply (UN 2000).

### 6.3 Feces Char and Its plant nutritional Contents

Human excreta are a good source of organic matter and plant nutrients (Malkki 1997). The use of human excreta as fertilizer in agriculture has been a common practice in some parts of the world. Of late, especially in rural areas of developing countries, on adopting sanitation systems that use negligible quantities of water, promote cycling of nutrients, and envisage utilization of human excreta to produce fertilizers for supporting agricultural needs (Were 2008). However, since feces may contain pathogens, processing of feces is necessary before this can be utilized as a fertilizer (Phuc et al. 2006). Conversion of human excreta to good quality manure without any foul odor flies and pathogen transmission is a challenging task. Thus, complete inactivation of microorganism and recovery of nutrient and energy from feces was the main concern of this paper to promote nexus approach towards soil, energy and waste management.

Rather than direct application of raw feces for agriculture purpose which has high health risk and energy content, the ash from the byproduct of feces char after energy is recovered was tested for plant nutritional value. The nutritional value of the ash as tested was in the recommended range for plant growth. The micronutrients (Mn, Fe, Cu, and Zn) constituents were higher than the values in chemical fertilizer (Mohammad et al. 2012). Similarly, the macronutrients (Na, K, Ca, Mg and P) have exceeded the recommended value for chemical fertilizer constituents (Simha 2013). Concluded that if the nutrients in the feces of one person were used for grain cultivation, it would enable the production of the annual amount of grain consumed by one person (250 kg). Thus, the result the plant nutritional analysis tested on feces ash after energy covered showed that still it can be used for soil amendment for agricultural purpose. Studies in both tropical and temperate climates have demonstrated biochar ability to increase plant growth, reduce leaching of nutrients, increase water retention, and increase microbial activity (Hunt et al. 2010). However, the application a study has to be done on field study id the feces ash will have the same effect as other biomass biochar.

To limit the risk of helminthes infestation, the developing country governments have recently introduced a set of guidelines for the proper composting of human excreta before its use in agriculture field (Malkki 1997).The guidelines have been established taking as a starting point for the use of traditional composting latrines. However, such measure will be successful in urban setup because of following reasons (1) in urban area space to build traditional pit latrine is scarce (Nordberg & Winblad 1994). (2) composting will not completely deactivate pathogenic organism in feces (Illmer, 2002), (3) based on this study result directly applying feces to agricultural field is wasting huge energy trapped in it. Therefore, using the feces ash after energy recovered for agricultural purpose will minimizes the health risk and prevents wasting energy. Moreover, the designed urine diversion dry toilet in this study can be installed and used in urban areas with no space requirement to excavate which makes to recover energy and nutrient from feces zero risk. Normally, such options will simplify, succeeding the principles of the sustainable development recirculation of nutrients of human beings from urban areas to agricultural land which is one of the big challenges of our time (Malkki 1997).

Sodium (Na) and potassium (K) were characterized from feces ash showed in table 7 were 15444.02 mg/kg (1.54%) and 110038.61mg/kg (11%), respectively. The result was comparable with sufficient range recommended for sodium (4.56ppm) and potassium (3.5ppm) for plant growth. However, it may needs optimization and testing soil contents of sodium for agricultural application for not causing a problem when applied as it will disturb Catani balance in the soil (Randon 2002). Phosphorus, calcium, and magnesium contents in feces ash were higher. Phosphorus was12.17 %, calciumwas0.378 % and magnesiumwas5 %.These elements were higher proportion of ash that may supply important macro-and micronutrients beneficial for the plant and soil microbial community if applied to the agricultural field.

However, as nitrogen evaporates in the feces ash during the energy recovery process there might be a need to supplement the feces ash with other sources. One person produces annually approximately 500l urine. The urine fraction contains 98% of the nitrogen, 65% of the phosphorus, and 80% of the potassium excreted by a human. Most of the nitrogen in human urine is in a form suitable for plants, for example ammonia nitrogen (Elmsquist et al. 2003). Thus, addition of urine for nitrogen supplement might be good if feces ash is planned to be used for agricultural purpose.

The study done by (Silva 2000) organic soil amendments for sustainable agriculture showed that different biomass of macronutrient from poultry (broiler) manure, the contents of Coliseum (Ca), phosphorus and Magnesium (Mg) 2.3% weight, 2.1% weight, 1.0 % weight, respectively. Comparing this value with the current study on feces ash phosphorus (12.17%)

and magnesium (5%) were much higher and controversially the content of calcium was too low. The observed difference in calcium content might be due to physiological makeup and diet intake difference in animal and human (Institute of Medicine serves of the National Academes 2010). Observed that ash process don not change the calcium content of biomass. Therefore, human waste ash has inadequate amount of calcium contents for plant nutrients mean than it needs other supply of calcium for soil amendments. The result of micronutrients contents analysis of feces ash for Fe (15260.62mg/kg) , Zn(1254.83mg/kg), Mn (1332.05mg/kg), Cu (189.19mg/kg) were above the limitation of plants nutrients need for growth in soil. Thus, this shows that feces ash after energy recover could be used to optimize soil micronutrient constituents.

## 6.4 Development of Urban sanitation towards Nexus Approach.

The Nexus Approach to environmental resources management examines the inter-relatedness and interdependencies of environmental resources and their transitions and fluxes across spatial scales and between compartments (Hoff and Holger, 2011.). This approach is based on the understanding that environmental resources are inextricably intertwined. Global change will put additional pressure on environmental resources and related ecosystem services as well as on the economic development (Huelsmann et al., 2014). Nexus concepts have been used in the individual areas of energy, soil, and waste for years (Lal, 2013.). However, the close relationships, interactions, and interdependencies between these resources are usually not taken into consideration when integrated resource management concepts are developed (Huelsmann et al., 2014). Yet fixing one challenge in managing one resource often creates challenges for other resources. A better solution can be achieved if these resources are managed collectively using a nexus approach (Hoff and Holger, 2011).

The integrated and interconnected management of energy, soil and waste can increase resource use efficiency while at the same time environmental risks and ecological degradation can be minimized. The nexus approach to the sustainable management of water, soil and waste is promoted in this study were closely related to the water, energy and food security nexus, looking at it from an environmental resources perspective (Huelsmann et al., 2014). It is instrumental to meet the current challenges of growing food demands, climate change, urbanization, and water pollution. Thus, this experimentally study showed that retaining human waste (feces and urine) via urine diversion dry toilet will help to recover energy and nutrient trapped in it. In addition, on-site contaminant of feces especially in urban area prevents contamination of water sources and soil, thus, increases the urban sanitation coverage preventing environmental degradation. MOH (2005) report of Ethiopia showed that 60% percent of the disease transmission occurring in the country was as result of poor sanitation. Thus, the designed urine diversion dry toilet will help to increase improved sanitation system in the country. Moreover, the energy recovered from feces char will have huge impact household energy demanded meeting (Victor & Victor 2002). Observed that in most developing countries people uses forest biomass as energy sources which has resulted deforestation and interfering with climate change. This study showed that the energy recovered from feces is renewable and could save forest as it have sufficient range recommended by FOA. In addition, the byproduct after energy recovered, the feces ash can be used for agriculture activity as it has sufficient range of micronutrient and macronutrient. The production of food relies on soil and soil amendment activities, with waste being an important factor for the provision of nutrients and organic material.

The demand for food is going to increase: Feeding 7 billion in 2010 will make intensive agriculture while degrading more soil (Sachs1990). Thus, application of feces ash after the energy recovered will decrease the cost of chemical fertilizer burden and increases soil nutrient requirement for cultivation of crop.

Generally, based on this experimental study, the nexus approaches towards human feces management, soil amendment and energy are a promising future for sustainable development of poor countries like Ethiopia. However, more field experiment, knowledge-based policies and reform of professional practice are important. This need derives from the understanding that there is a lack of blueprints for development based on integrated management of waste, soil and energy resources both in developing and in developed countries.

# Chapter Seven: Conclusion and Recommendations

## 7.1 Conclusion

On the basis of the energy content, the determined combustion efficiency of feces char in this study, we found the material to have potential as a supplementary, renewable energy source in the developing world. Successful use of fecal char as a renewable energy source, however, will require energy efficient ways to produce it as the pyrolysis by itself is expensive. The results obtained for this study showed that the manufactured feces char can replace the traditional available biomass fuels. It has fulfilled the minimum requirement set by FAO for biochar which is 22MJ/kg.

As increasing demand for solid fuels continues to drive deforestation and air pollution, and as inadequate urban sanitation continues to pose a major threat to water quality and public health, solutions for treating human waste and providing renewable and affordable fuel sources will be necessary. In this regard, the manufactured biochar can also be used without any health risk as a complete inactivation of pathogenic organism will be achieved at the pyrolysis temperature. It may help to reduced deforestation and pollution of soil and water, while on the hand the feces ash, as tested in this study, could be used as a good nutrient supplementary than using chemical fertilizers which has more impact on the environment. Thus, waste-fed per urban agriculture can contribute importantly to improving the livelihood of slum settler even at large scale for organic farmers.

On other hand this piece of work tried to display the Millennium development Goal based on WHO Guides line value the combination of improved sanitation and the safe use of human excreta and helps to reduce the burden of sanitation and hygiene-associated ill-health. Thus, in this regard the adopted urine diversion dry toilet will play a significant role. Improved nutrition and food security reduce susceptibility to diseases in children. Improved health and nutrition associated with waste-fed agriculture and reduce susceptibility to anemia and other conditions that affect maternal mortality. Thus, for environmental protection office working for protecting soil, water and climate change this project will fulfill these needs through the safe use of human excreta contributes to less pressure on freshwater resources, forest and public health.

When looking at the nexus approaches in the current scientific tread, the question arises which environmental resources have to be managed in an integrated way to achieve the sought integrated and sustainable management. For this study, these environmental resources are: Waste (human feces), soil and energy. The production of food relies on soil, with waste (feces ash) being an important factor for the provision of nutrients. The same is true for the production of bio-fuel and energy from biomass.

### 7.2 Recommendations

Based on the experimental work done, in this study, on the possibility of using nexus approach towards human feces, soil amendment and energy, the following recommendations are forwarded:

- ❖ The manufactured feces char has to be studied further after briquetting with locally available binders such as molasses, etc. to increase its energy yield or produce quality briquette for household use.
- ❖ Further study at agricultural field has to be conducted to evaluate the plant nutritional value of the feces ash.
- ❖ The first hand on nexus approach, in this study, suggested the possibility of integrated management of waste, soil and energy. However, further similar studies has be done considering solar panel for drying the feces before pyrolysis or designing especial toilet, which might uses concentrated sunlight to dry the feces.

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## Annex

Table of Analytical Testing methods Service Laboratory

| Parameter | Test Method |
|---|---|
| **Potassium (K)** | AOAC Official method 923.03 – Flame Photometer |
| **Sodium (Na)** | AOAC Official method 923.03 – Flame Photometer |
| **Calcium (Ca)** | AOAC Official method 923.03 – Flame Photometer |
| **Magnesium (Mg)** | AOAC Official method 923.03 – Air- Acetylene FAAS |
| **Iron(Fe)** | AOAC Official method 923.03 – Air- Acetylene FAAS |
| **Zinc (Zn)** | AOAC Official method 923.03 – Air- Acetylene FAAS |
| **Copper (Cu)** | AOAC Official method 923.03 – Air- Acetylene FAAS |
| **Manganese (Mn)** | AOAC Official method 923.03 – Air- Acetylene FAAS |

.1 Sufficient rage plants nutrients

**Sufficient rage plants macronutrients**

| S/N | Sufficient rage | Unit % | | | | |
|---|---|---|---|---|---|---|
| | | Na | K | Ca | Mg | P |
| 1 | | 4.56 | 3.50 – 5. 10 | 2.10 -3.0 | 0.15 -0.62 | 0.42- |

**Sufficient rage plants micronutrients**

| S/N | | Unit ppm | | | |
|---|---|---|---|---|---|
| | | Mn | Fe | Cu | Zn |
| 1 | Sufficient rage | 30- 250 | 100 | 189.19 | 33 49 |

Interpretation of total in soil Nitrogen adapted from Chapman, 1971 and Unger, 1972)

| Human waste | Total-N (%) | Sufficiency Level | Total-N (%) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| contents | | | |
| Total Nitrogen | 4.57 | Very low | < 0.1 |
| | | Low | 0.1-0.2 |
| | | Medium | 0.2-0.3 |
| | | High | 0.3-0.4 |
| | | Very high | > 0.4 |

The total Nitrogen of this thesis is 4.57% when campers the standard it shows very high but during pyrolysis it expected to decreased and the char will be sorbs the nutrients and realized to the plant slowly

The percent C increased with increasing pyrolysis temperature. Feedstock's lost 60-70% of their nitrogen during the pyrolysis process. The C remaining after acid hydrolysis is estimated to have a mean residence time in soils of hundreds to thousands of years, and this is the key property for biochar to be used for long-term carbon sequestration in soil

9.3 Phosphorous (P)

| Human waste biochar contents | Mg/kg | Sufficiency Level | Total (%) |
|---|---|---|---|
| Total Phosphorous (P) | 121679.5mg/kg | Very low | <5 |
| | | Low | 5-8 |
| | | Medium | 8- 12 |
| | | High | 12- 20 |
| | | Very high | >20 |

Frank 1990 (Adapted from agricultural compendium: FAO and Booker (MTS)

Source: B. Frank 1990 (Adapted from agricultural compendium: FAO and Booker (MTS)

Neither plants nor animals can grow without phosphorous (P). Next to nitrogen, P has more widespread influences on both natural and agricultural ecosystems than any other essential element and its involvement in photosynthetic carbon fixation and energy transfer processes that greatly affect the growth and yield of crops, and the atmospheric N2 fixation of legumes.

. Therefore based on the soil fertility human wastes will be the one of the natural plant nutrients.

4 Sulfur

Interpretation of $SO4^{2-}$ and organic-S soil test values

| Human waste biochar contents | Mg/kg | Soil S Status | Organic-S Ppm |
|---|---|---|---|
| Total Sulfur | 0.2488 | Deficient | 0-10 |
| | | Adequate | 10-20 |

Sulfur is required for the synthesis of S- amino acids, cysteine and methionine, which are sentential components making up 90% of total S in plants. One of the functions of the S aminoacids in proteins is the formation of disulfide (-S-S-) bonds between polypeptide chains within a protein causing to fold Sulfur is essential component of ferre\doxin and nitrogen's enzymes

**5. Potassium (K)**

General calibration of the $NH_4OAc$-K soil test

| Human waste biochar contents | Mg/kg | | |
|---|---|---|---|
| Potassium (K) | 110038.16mg/kg | Very low | < 40 |
| | | Low | 41-80 |
| | | Medium | 8 1-120 |
| | | High | 121-160 |

Potassium is an essential element for all living things. It is absorbed by plants in large amounts than any other nutrient except N. Unlike N and P, potassium causes no off-site environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic system. Indeed human waste biochar is full of potassium contents which very important for plant growth

6 Calcium (Ca)

Calcium (Ca) of human wastes and stander contents for soil amendment

| Human waste Ash contents | Mg/kg | Soil S Status | Organic-S Ppm |
|---|---|---|---|
| Calcium (Ca) | 3783.78mg/kg | Deficient | 0-10 |
| | | Adequate | 10-20 |

Calcium has many functions in plants, such as participating in structural stability and integrity of cell wall and plasma membrane, by providing intermolecular linkage; translocation of carbohydrates and nutrients; and cell elongation and cell division.

7. Magnesium (Mg)

Magnesium (Mg) content of human wastes with the stander

| Human waste ash contents | Mg/kg | Soil S Status | Organic-S Ppm |
|---|---|---|---|
| Magnesium (Mg) | 50193.0mg/kg | Deficient | 0-10 |
| | | Adequate | 10-20 |

The amount and rate of $Mg^{2+}$ from soils depend considerably on the amount of Mg bearing minerals in the soil

Magnesium ions are more easily leached from the upper soil layer than $Ca^{2+}$, because of the thicker hydration shell around $Mg^{2+}$ ($Mg^{2+}$ is smaller in size) that causes it to be less tightly adsorbed to soil colloids. Magnesium is therefore very prone to leaching and leaching rates are in the order of 2 to 30 kg Mg/ha/yr. Because of this, subsoil of sandy soils contains higher levels of Mg in the upper part of the profile..

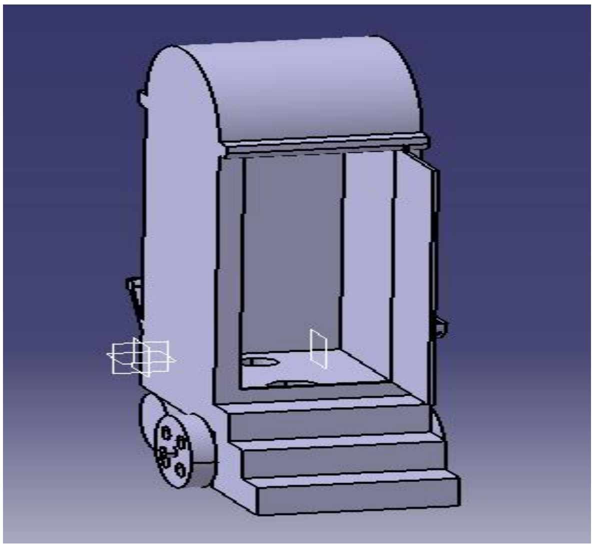
In green leaves a major function of Mg, and certainly its most familiar function, is its role as the central atom of the chlorophyll molecules (Fig. 2.12), and without chlorophyll photosynthesis would not occur. The proportion of the total Mg bound to chlorophyll depends very much on Mg supply, which ranges between 6 and 25%. Another major function of $Mg^{2+}$ is the function as bridging element that brings

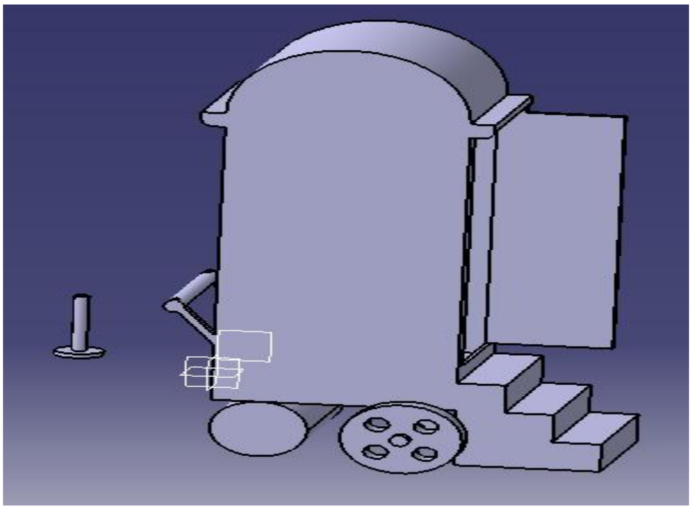
## 8. MICRONUTRIENTS

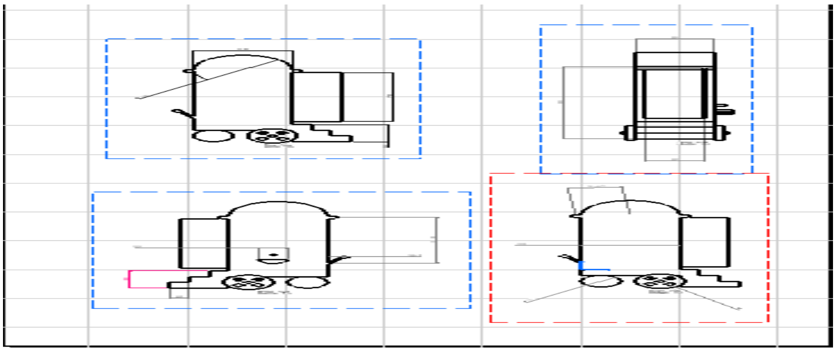
**Interpretation of DTPA-extractable Fe, Zn, Mn, and Cu in soil sand human wastes contents**

| | Fe | Zn | Mn | Cu |
|---|---|---|---|---|
| | mg/kg | | | |
| | 15260.62 | 1254.83 | 1332.05 | 189.19 |

| Sufficiency Level | Fe | Zn | Mn | Cu |
|---|---|---|---|---|
| | ppm | | | |
| Low(deficient) | 0-2.5 | 0-0.5 | $<$ 1.0 | 0-0.4 |
| Marginal | 2.6-4.5 | 0.6-1.0 | – | 0.4-0.6 |
| High (sufficient) | $>$ 4.5 | $>$ 1.0 | $>$ 1.0 | $>$ 0.6 |







9.9 Design Portable Ecological sanitation

Portable ecological sanitation toilet was newly designed technology to be Cheap; quick to make; and more conferrable; move easily.

9.10 Hand washing facilities

This portable ecological sanitation well design to be harvesting rain water during rain time and filing during dry season. This hand washing facility is collecting the water from the roof of the latrine in both sides in to 20 Liters of Jerkin which is attached to the inner part of the latrine whole hand washing facilities are extremely important to improve child development, and thereby increase a child's well-being and societal productivity(UNICEF 2010).

Environmental sustainability should be an integral part of the design, implementation, operation and maintenance of facilities and the accompanying hygiene education program(WaterAid Nepal, 2011)

Harvesting system and collector jar

1 Slab Supports

Portable ecological sanitation slab was design need squat type of seat which is ease to relieve people as wheel commune style an culture of Ethiopian seat during deifications and comforted used for both female or male and children the one meter squire and footrest 33cm and 20gaje of Irene sheet covered with thin mean two cm concrete, by 1: 1 ratio to protect rust and ease to clean the toilet which is strong enough to support the users. it could also be made of pvc. Additional manual hand set was design to be cover the hole of fecal matter which is rotated clockwise to cover after use of each visit within this hand set controversial use to open and close the dram of continuer by rotating anti clockwise. Also some additional design on urine collection is that during urination especially females to be protected from flashing of urine by making long and folded tip of urine collector dish on the slab materials used for long lasting

Manual hand set

2 Operator Responsibilities

Routine cleaning is to guarantee of good hygiene and proper use of this portable toilet. Care should be taken to prevent chemicals from entering into the poop drum as this will ruin the pyrolysis process cleaning inside and outside of the toilet structure verifying that sufficient cover material is being applied by users. Introducing of cover material of top and drum should implement to each user.

This portable ecological sanitation will be similar to other Urine diverting (UD) toilet timely removal and storage of filled drums to avoid any human-fecal contact from overfilled drums. Periodic verification of clear and functioning urine pipes to avoid blockages in the seat's drain. Provision of toilet paper and appropriate disposal of used toilet paper. Provision of water and soap for the hand washing specially during dry season and educating first-time users on the basic steps of using a portable ecological sanitation toilet management systems.

3 Collected Urine

In this portable ecological sanitation urine collected in urine collected chamber and stored up to 1/3$^{rd}$ left to fill and will be used after treatment.

The collected urine should be disposed in safe ways used for plant nutrients according to

WHO (2006) guideline.

Urine diverting systems

4 Fecal Matter Collecting Tanker

In this Portable ecological sanitation fecal collecting chamber critically design to prevent bad odor and microorganisms' contamination of users as wheel surrounded environment and ongoing activities will be proceed to remove moistures as while killing pathogenic microorganisms' and parasites egg and cysts by keeping the temperature of the tanker up to 105 co by solar panel.

5 Qualities of (PES) tested

During data collection the test made on the comfortably or in the qualities of PES effectiveness of the urine back flash indicate that from 37 female users of PES almost all of them are confirmed than urination bed is very comfortable, and no back flashed to the users.

6 Determination of Moisture Content

The muffle furnace was heated to 750°C and placed previously ignited porcelain crucibles covers in the furnace for 10 min. Then, the crucibles allowed cooling down in desiccators for an hour. After cooling, the crucibles, 2 g of feces have been added to each of them. Weighed to the nearest 0.1 mg, of the ground sample. Samples were placed in the oven at 105°C for 2 h. The samples were placed in desiccators for 1 hour and weighed were put in an oven again for 2 hours

The percentage loss of weight gives the percentage of moisture in the sample. Percentage of moisture content= loss in weight * 100/ wt. of sample taken then mixing with the same weight of solid wastes and reevaluate the result.

7 Determination of volatile matter

The dried samples after moisture removal were taken in a crucible and placed in an electrically heated furnace at a temperature of 925°C for seven minutes and then cooled in desiccators. The percentage of weight loss gave the volatile matter content.

Percentage of volatile matter = loss due to removal of volatile matter* 100/ wt. of sample taken

8 Determination of ash content

The remaining sample after determination of volatile matter was kept in a furnace at a temperature of 700ºC for one and half hour. The percentage of weight loss gave the ash content, /percentage of ash = weight of ash left* 100/ wt. of sample taken/.

9 Determination affixed carbon

Percentage of fixed carbon = 100- % of (moisture +volatile+ ash) content