



humanitarian
innovation fund

WASH in Emergencies
Problem Exploration Report

Faecal Sludge Management



Table of Contents

Preface	3
Contributions	5
Abbreviations	6
Glossary	8
Executive Summary	11
Part 1: The Challenge of Faecal Sludge Management in Emergencies	14
1.1 The Sanitation Service Chain in Developing Countries	14
1.2 Sanitation in Emergency Situations	15
1.3 Sanitation in the First Phase of an Emergency	16
1.4 Pit Latrines	17
1.4.1 The Problem of Rapid Sludge Accumulation	17
1.4.2 The Process of Decomposition in Pit Latrines	19
1.5 Key Sanitation Challenges for WASH Agents	22
Part 2: Past and Present Approaches to Faecal Sludge Management	23
2.1 Reducing Faecal Sludge Accumulation with Additives	23
2.1.1 Types of Additives	24
2.1.2 Research on Bio-Additives for Pit Latrines	25
2.1.3 Research on External Treatments for Pit Latrines	28
2.2 Focus of Current Research	30
Part 3: Areas for Further Exploration in Faecal Sludge Management	32
3.1 Future Research on Additives	32
3.1.1 Review of Protocols	32
3.1.2 Testing and Dosing	32
3.2 Future Research on External Treatments	34
3.3 Future Research on the Design and Operation of Raised Pit Latrines	34
3.4 Future Research on Safety Protocols and Guidelines	35
3.5 Future Research on Safe Disposal and Dumping	35
3.6 Future Research on Portable Sewage Treatment Plants	36
3.6.1 Compact Anaerobic Digestion Systems	36
3.6.2 Compact Aerobic Digestion Systems	37
3.6.3 Adaptability to Emergency Settings	40
3.7 Concluding Remarks	40
References	42
About the HIF	44

Preface

The Humanitarian Innovation Fund (HIF) is a programme of ELRHA, and we are here to support organisations and individuals to identify, nurture and share innovative and scalable solutions to the challenges facing effective humanitarian assistance.

The HIF has a dedicated fund to support innovation in water, sanitation and hygiene (WASH) in all types of emergencies, from rapid onset to protracted crisis. WASH is a broad theme with serious consequences in many other areas such as health, nutrition, protection and dignity. In the absence of functioning toilets, clean water systems, effective hygiene practices, and safe disposal of waste, pathogens can spread rapidly, most commonly causing diarrheal and respiratory infections which are among the biggest causes of mortality in emergency settings.

Despite this, there is a significant gap between the level of WASH humanitarian assistance needed and the operational reality on the ground. This is why the HIF works closely with multiple stakeholders from across many humanitarian agencies, academia and private sector to understand and overcome practical barriers in the supply and demand of effective solutions.

Over the past three years the HIF has been leading a process to identify the key opportunities for innovation in emergency WASH. Fundamental to this is having a strong understanding of the problems that need to be solved. We note that many innovations focus on improving technology because the problems can often be clearly defined, compared to more complex problems with supply chains, governance or community engagement.

Our problem research began with an extensive Gap Analysis (Bastable and Russell, 2013) consulting over 900 beneficiaries, field practitioners and donors on their most pressing concerns. From these results we prioritised a shortlist of problems including faecal sludge management. However drawing lines between where one problem ends and another starts is difficult given the feedback loops within each system. For example reducing waste from plastic bottle usage relies on the availability of other safe water options which in turn is linked to environmental sanitation and hygiene.

This report is one of a series commissioned by ELRHA to explore priority problems in emergency WASH. The researcher selected for each report was asked to explore the nature of the challenges faced, document the dominant current approaches and limitations, and also suggest potential areas for further exploration.

The primary purpose of this research is to support the HIF in identifying leverage points to fund innovation projects in response to the complexity of problems. We seek to collaborate closely with those already active in these areas, avoid duplication of efforts, build on existing experiments and learning, and take informed risks to support new ideas and approaches.

In publishing these reports we hope they will also inform and inspire our peers who share our ambitions for innovation in emergency WASH. In addition to engineers and social scientists who are crucial to this work we hope to engage non-traditional actors from a diverse range of sectors, professions and disciplines to respond to these problems with a different perspective.

The content of this report is drawn from a combination of the researcher's own experiences, qualitative research methodologies including a literature review that spanned grey and published literature and insights from semi-structured interviews with global and regional experts. The report was then edited and designed by Science Practice.

We would like to thank the members of our WASH Technical Working Group for their ongoing guidance: Andy Bastable (Chair), Brian Reed, Dominique Porteaud, Mark Buttle, Sandy Caincross, William Carter, Jenny Lamb, Peter Maes, Joos van den Noortgate, Tom Wildman, Simon Bibby, Brian Clarke, Caetano Dorea, Richard Bauer, Murray Burt, Chris Cormency, and Daniele Lantagne.

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Contributions

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The report has benefited greatly from the valuable insights and consideration provided by the following experts: François Bellet (UNICEF HUB Dakar Senegal), Chris Cormency (UNICEF Copenhagen), Caetano Dorea (University of Laval), Jean-François Fesselet (MSF-H), Grover Hector Mamani (WASTE), Claudia Perlongo (UNHCR), and Jan Spit (WASTE).

The report was edited and designed by Science Practice.

Abbreviations

BOD	Biological Oxygen Demand
BSFL	Black Soldier Fly Larvae (<i>Hermetia illucens</i>)
CFU	Colony-Forming Unit
COD	Chemical Oxygen Demand
CRCI	National Society of the Red Cross of Ivory Coast
DAD	Direction de l'Assainissement et du Drainage de Côte d'Ivoire
EEA	European Environment Agency
EPA	Environmental Protection Agency
ETU	Ebola Treatment Unit
ESP	Emergency Sanitation Project
FCR	Feed Conversion Rate
HIF	Humanitarian Innovation Fund
HLT	Hydrated Lime Treatment
IDP	Internally Displaced Person
IFRC	International Federation of the Red Cross
LAF	Lactic Acid Fermentation
MSF	Médecins Sans Frontières (Doctors Without Borders)
NGO	Non-Governmental Organisation
NPK	Nitrogen (N), phosphorus (P) and potassium (K)
TS	Total Solids
TSS	Total Suspended Solids
UN	United Nations
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organization – International Institute for Hydraulic and Environmental Engineering
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund

UT	Urea Treatment
VIP	Ventilated Improved Pit
VRS	Value Recovery System
VS	Volatile Solids
VSS	Volatile Suspended Solids
WASH	Water, Sanitation and Hygiene
WEDC	Water, Engineering and Development Centre (Loughborough University)
WHO	World Health Organisation
WRC	Water Research Commission (South Africa)

Glossary

The terms listed in this glossary are defined according to their use in this report. They may have different meanings in other contexts.

Additive — A chemical or biological product used to treat and control faecal sludge.

Aerobic process — Degradation of matter done by aerobic microorganisms. It can occur only in the presence of oxygen.

Anaerobic process — Rapid degradation of matter done by anaerobic microorganisms. It can occur in the absence of oxygen.

Bio-additive — Microorganism-based latrine additive.

Biogas — Gas produced by the breakdown of organic matter in the absence of oxygen.

Biomass — Organic matter derived from waste, used especially as a source of fuel.

Black water (Sewage water) — Wastewater containing bodily or other biological wastes, as from toilets, dishwashers, or kitchen drains.

Cesspit — A pit for the disposal of liquid waste and sewage.

Colony-forming units (CFU) — Number of viable bacterial or fungal cells in a certain unit.

Dehydration — A process involving grinding, water evaporation and sterilisation of organic wet waste.

De-sludging — Emptying and cleaning of vessels used for storing excreta, such as pit latrines or sewage tanks.

Digester — Container where anaerobic or aerobic digestion (decomposition) of waste takes place.

Drying bed — Shallow filters filled with sand and gravel with an under-drain at the bottom to collect leachate. The drying process in a drying bed is based on drainage of liquid through the sand and gravel to the bottom of the bed, and evaporation of water from the surface of the sludge to the air.

Effluent — An outflowing of water or gas from a natural body of water, or from a manmade structure.

Endogenous bacteria — Bacteria that naturally reside in a closed system.

Excreta — Waste matter discharged from the body, especially faeces and urine.

Exogenous bacteria — Bacteria introduced to closed biological systems from the external world.

Faecal coliforms — A group of facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacteria. Coliform bacteria generally originate in the intestines of warm-blooded animals and are used as an indicator of human faecal contamination of water.

Faecal sludge — All liquid and semi-liquid contents of pits and vaults accumulating in unsewered sanitation installations, such as latrines, toilets or septic tanks. Compared to wastewater, faecal sludge is normally several times more concentrated with solids.

Faecal Sludge Management — The process of storing, transporting and disposing of excreta.

Hydrolysable — The ability to undergo hydrolysis. Hydrolysis is the chemical decomposition in which a compound is split into other compounds by reacting with water.

Internally displaced person (IDP) — A person who is forced to flee his or her home but who remains within his or her country's borders.

Lagoon system — A holding and/or treatment pond provided with artificial aeration to promote the biological oxidation of wastewater and faecal sludge.

Mulch — A protective soil cover usually made up of decaying leaves, bark, or compost used to conserve moisture, reduce weed growth or improve the fertility and health of the soil.

NPK value (of a fertiliser) — The value of the three macronutrients used by plants in a fertiliser. These macronutrients are nitrogen (N), phosphorus (P) and potassium (K). The higher the number, the more concentrated the nutrient is in the fertiliser.

Pasteurisation (of sludge) — A process to reduce the number of viable pathogenic organisms in sludge to a level below that which would cause infection. The process often involves heating the sludge to a minimum temperature and holding at this temperature for a minimum time.

Pit Latrine — A type of toilet that collects human feces in a hole in the ground.

Refugee — A person who has been forced to leave their country in order to escape war, persecution, or natural disaster.

Sanitation Service Chain — The processes involved in capturing, storing, transporting, treating and disposing of excreta.

Sanitisation — The process of making something sanitary, free of germs and pathogenic microorganisms.

Saprophytic bacteria — Bacteria which obtain nutrients from dead organic matter.

Septic tank — A tank, typically underground, in which sewage is collected and allowed to decompose through bacterial activity before draining by means of a soakaway.

Sewage — Municipal or domestic wastewater (see black water).

Soda ash (Sodium carbonate) — Water-soluble sodium salt of carbonic acid (also known as washing soda or soda crystals).

Sphere Project — Launched in 1997, the aim of the Sphere Project is to develop a set of minimum standards in core areas of humanitarian assistance, improve the quality of assistance provided to people affected by disasters, and enhance the accountability of the humanitarian system in disaster response.

Stabilised faecal sludge — Sludge that has undergone biological degradation and includes no more fermentable materials.

Stereographic imaging — Techniques used to record and display three dimensional (3D) images or an illusion of depth in an image.

Thermophilic digestion — Process through which waste is decomposed at temperatures above 50°C producing biogas.

Treatment — Process of removing contaminants from wastewater. It includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safe treated wastewater.

Ventilated Improved Pit (VIP) — A latrine that offers improved sanitation by eliminating flies and smell, through air circulation.

Wastewater — Any water that has been adversely affected in quality by anthropogenic influence. It can originate from domestic, agricultural, and industrial activities.

Water table — The upper level of an underground surface in which the soil or rocks are permanently saturated with water.

Zeolites ('molecular sieves') — Microporous minerals made of silicon, aluminium and oxygen commonly used as commercial adsorbents and catalysts.

Executive Summary

During the immediate phase of an emergency in an urban context, the implementation of sanitation programmes takes a long time to provide suitable and sufficient facilities for the affected population.

While the emergency response for drinking water programmes has been improved with the design of standardised, rapid deployment kits, sanitation programmes in urban areas are limited to very few technologies. The construction of pit latrines and the implementation of hygiene promotion programmes are the main activities carried out by humanitarian actors to address the challenges of open-air defecation. If left unaddressed, this can lead to serious public health problems and spread dangerous diseases such as diarrhoea and cholera.

When deciding on key strategic factors such as the most appropriate number of toilets, the number of users per unit is essential. Sphere standards offer important guidance regarding these decisions. However, even if minimum standards are met the main challenge is that toilets, usually pit latrines, fill up very quickly and need to be emptied as soon as possible. Latrines that are not regularly emptied risk closure, increasing the pressure on remaining latrines to cope with the needs of the affected population. Afterwards, faecal sludge must be transported safely to a dumping site for disposal.

Humanitarian actors tend to first use the supply capacity of the local market to find relevant construction materials to quickly implement pit latrines on the ground. The quality and speed of the sanitation response may vary greatly depending on whether one chooses dug-pit latrines (where construction materials are likely to be available locally) or the erection of portable toilets (where import is often required). Nevertheless, if the local supply capacity for basic equipment and materials is not adequate, this will significantly affect the sanitation coverage for the affected population.

In addition to this, it is usually local contractors who undertake the response for de-sludging and transporting the faecal sludge to a dumping site. This means that the efficiency of the de-sludging activity and the efficacy of the faecal sludge disposal will often depend on the number of local sewer trucks available, their condition and their transport capacity. Therefore, the quality and the efficiency of sludge disposal can vary a lot from one situation to another. This is a key challenge as, if pit latrines are not emptied on a regular basis, people may resort to open-air defecation and contaminate their environment.

Lastly, the existing dumping site may not be adequate to accept the large volume of faecal sludge collected from pit latrines on a regular basis and may become a source of contamination to the environment. Therefore, the dumping site has to be secured and improved to facilitate disposal.

Despite the efforts of organisations such as WEDC, MSF and Oxfam to produce guidelines and books on standards for excreta management in an emergency, there is a lack of standardisation of safety protocols and equipment to strengthen the de-sludging, transporting and disposal of faecal sludge.

Today, the majority of WASH actors are focused on the development and testing of sanitation solutions for emergencies that can improve the disposal of faecal sludge in a quicker and safer way. In addition, they are looking for concepts and products able to reduce the rate at which latrines fill-up with faecal sludge.

For 15 years, experimental studies have tried to determine whether additives containing microorganisms were able to reduce faecal sludge. Despite inconclusive results, these technologies still have potential and should be studied with different experimental protocols using new and improved products. Such experiments are ongoing with UNHCR and the Emergency Sanitation Project (including partners such as WASTE in the Netherlands, IFRC, and Oxfam GB) and are showing positive, conclusive results.

Currently, there is a lack of available equipment and technical guidelines on how to manage excreta in emergencies. More standardised and reliable concepts need to be developed to facilitate the implementation and management of sanitation programmes.

Furthermore, the management of excreta during an emergency in an urban context has very limited options. This is because there is a lack of available space to implement suitable infrastructures for the users. Digging more pits and increasing the number of raised latrines on the ground may therefore become very difficult depending on the situation.

This report puts forward a few areas for further exploration and development.

Easy to implement, portable toilet systems: New toilet system designs are needed that can allow for the better management of faecal sludge accumulation and can facilitate regular emptying. The designs should also consider the integration of additive mixing and dosing devices.

Standardised guidelines for assessing existing sanitation equipment: Guidelines could propose a method for evaluating available local equipment such as sewer trucks (e.g. number, state, storage capacity, spare parts and connecting), and other tools such as de-sludging pumps.

New protocols for the treatment and control of faecal sludge accumulation: Studies have shown that it is more reliable to consider the control of the accumulation before the latrine is in use, than to try to absolutely reduce existing sludge volume. It is clear that some additives work but further research is needed to understand how and when to use these. Research and experimentation studies should continue to test and compare bio-additives, as well as define new protocols and objectives.

Evaluation of speedy aerobic and anaerobic treatment concepts: Additional research needs to be carried out to assess the field effectiveness of both speedy aerobic and anaerobic treatment concepts in reducing the volume of sludge collected from pits. For anaerobic process concepts, feasibility studies can also help determine if biogas resulting from the process can be used for downstream application.

Guidelines for assessing and improving dumping sites: Practical guidelines for assessing existing dumping sites would be very beneficial, as well as suggested solutions and options on how to improve the capacity of storing and disposing of faecal sludge during a period of emergency. However, even with such guidelines, the process would not be straightforward as setting up or improving a dumping site requires skilled people, qualified in the area of environmental engineering.



Part 1: The Challenge of Faecal Sludge Management in Emergencies

During an urban emergency where there is no functioning centralised sewage disposal system, many agencies build temporary raised latrines with limited storage for excreta. These latrines need to be emptied or de-sludged frequently. Often, in the absence of functioning sewage treatment works, and with other infrastructure often compromised and depleted, waste is deposited in large, purpose built pits, mixed with general waste in landfill or tankered and disposed of into streams and rivers, creating a range of health and environmental disease risks. Where sewers are working locally but pumps and pipes are broken downstream, pollution risks may be displaced. As water supplies are reinstated, wastewater quantities also increase.

1.1 The Sanitation Service Chain in Developing Countries

Sanitation service chains around the world are designed to cope with regular, predictable amounts of excreta produced by communities. Their design depends on local circumstances, level of development, and cultural differences. In developed countries, sanitation service chains usually include central sewage systems that provide a direct way of disposing of excreta produced in each household safely and hygienically. In developing countries, chains are more diverse and involve various ways of treating, managing, and disposing of excrements.

In urban areas in developing countries, only a small proportion of people, mainly those living in the city centre, are likely to be connected to a sewage network and to a sewage treatment plant. A higher rate of people are connected to septic tanks or pit latrines that have to be de-sludged by private or public contractors. These collect and then landfill waste into a dumping site.

In developing countries sanitation service chains are more diverse and involve different ways of treating, managing, and disposing off excrements.

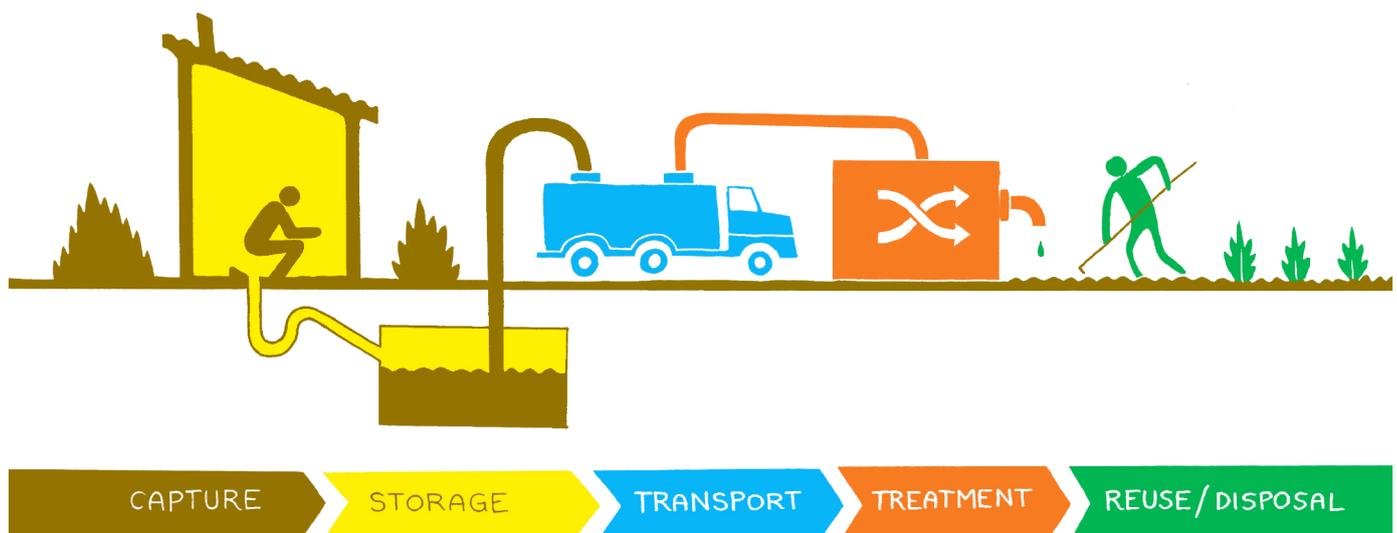


Figure 1.

The key processes in a complete sanitation service chain.

(Source: Adapted from The Bill and Melinda Gates Foundation, WASH Strategy Overview, August 2012)

If a pit is not emptied often enough, faecal sludge overflows from the pit and contaminates the household and the surrounding area. It is common for people who do not have enough income to pay for emptying services to carry out the removal by hand, using buckets and limited protection.

In a development situation, the maintenance of familial latrines often depends on the level of income of a household and whether it can afford private de-sludging services. Lime or other types of disinfectant are sometimes used to clean latrine slabs or pedestals, and to mitigate against unpleasant odours. They can also be added to latrine contents to sanitise the sludge. This is usually unnecessary when owners decide to close a filled-up pit and seal it with earth. If the household can afford an emptying service then a sewer truck will pump and collect the faecal sludge from the pit, transport and landfill it into a dumping site. Potential challenges at this stage include the distance the trucks need to travel to the household, their availability and their functionality.

At the dumping site, if the area was laid out, waste can be treated or naturally disposed of by lagoon or dry bed processes. Challenges at this stage could include a poor, or even a lack of a layout of the dumping site to allow for treatment processes, or the leaking of sewage into the surrounding environment.

All sanitation service chains have some tolerance for occasional stress. Elements of the chain may reach their capacity limits, equipment or infrastructure may malfunction, the service may even become temporarily unavailable, but the chain may still cope with demand. However, during an emergency, regular processes tend to break down because of the cumulative impacts on the sanitation service chain. In those emergency situations different measures are required to control and maintain proper sanitation at the community level.

1.2 Sanitation in Emergency Situations

Different types of situations such as earthquakes, floods, epidemic outbreaks, wars or conflicts can cause emergencies in an urban context. High densities of populations and poor construction practices can increase the level of an emergency because of the high risk of a large number of victims. Those affected may have to stay outdoors or away from their homes for an extended period of time, often sheltering, for reasons of security, in a rescue area.

An emergency can be described through different phases. Davis and Lambert (2002) define three phases in an emergency context:

- the immediate emergency phase,
- the stabilisation phase,
- the recovery phase.

In practice, these three phases are often reduced to two. The first phase covers the 'immediate emergency' phase and typically lasts from several weeks up to three months. The second phase includes 'stabilisation' and 'recovery' and may last several months or several years depending on the type and severity of the emergency.

The first phase can be illustrated by the situations that took place just after the earthquakes in Nepal (Kathmandu, 2015) and Haiti (Port-au-Prince, 2010). In both cases, at least half of the population living in each capital decided not to stay indoors because of the fear of possible aftershocks to come. In Port-au-Prince in 2010, more than 500,000 people were living on the streets in makeshift shelters. They had access mainly to chemical portable toilets of 200 litres

capacity distributed by the implementing partners of the WASH Cluster. The toilets were emptied every day with an average person per toilet ratio often greater than 100 (figures provided by the WASH Cluster and the National Bureau of Water and Sanitation of Haiti – DINEPA). This situation led to the de-sludging of 900 m³ of excreta every day, by truck, into an improvised disposal area close to the sea.

The second phase relates more to long-term settlement areas like refugee or Internally Displaced Person (IDP) camps. Currently, there are over 12 million people living in humanitarian camps worldwide with 3.2 million of those people living in camps in Africa. The largest refugee camp in the world is situated in Dadaab, Kenya and is estimated to shelter around 500,000 people. The main challenge when the number of people within these camps becomes very high is that the context becomes quite compact and urbanised, with very little open space available for basic sanitation solutions.

1.3 Sanitation in the First Phase of an Emergency

The provision of adequate sanitation facilities is a key measure to ensure that morbidity and mortality is low immediately after a disaster.

During the first phase of an emergency, there is no access to reliable sanitation facilities. Indiscriminate disposal of faecal matter in the surrounding environment during the immediate aftermath of an emergency is a health risk as well as a challenge to the privacy and dignity of the people affected. This is particularly relevant in the cases of children, women, the elderly and those with disabilities. This report focuses primarily on the challenges posed by sanitation in the first emergency phase.

The provision of adequate sanitation facilities is one of the key measures to ensure that morbidity and mortality is low immediately after a disaster. This is done by isolating and storing the faeces in constructed toilets to prevent diarrhoeal diseases and cholera (WHO, 2005). The Sphere Project guidelines offer some relevant standards to consider when developing a sanitation infrastructure aimed to support the progress towards the stabilisation phase (Sphere Project, 2011). For example, the guidelines suggest that in the early stages of an emergency the maximum number of people per toilet should be around 50. This is expected to drop down to 20 people/toilet during the stabilisation period, as more sanitation facilities are built in the respective refugee or IDP camps.

Guidelines suggest that in the early stages of an emergency the maximum number of people per toilet should be around 50.

In the first phase of an urban emergency, humanitarian actors have limited possibilities to construct sanitation infrastructures due to the lack of space available. Potential obstructions include asphalt roads, concrete structures, buildings, and service pipes for water and sewage. The lack of space is therefore a challenge in an emergency. One has to adapt to circumstances while keeping the objective of quickly setting up a reliable sanitation infrastructure so as to avoid the very high risk of disease outbreak.

Because of this pressing risk, in the immediate phase of an emergency the priority is buying quick and simple sanitation infrastructures. These usually consist of dug pit latrines, raised pit latrines, deep trench latrines (where digging is possible), bucket latrines, packet latrines, portable chemical toilets, cat method (where faeces are rolled in sand or dirt), and as a last resort, designated defecation areas (Oudman, 1995; Reed et al., 2013). In some contexts, biodegradable pee-poo bags are also used to enable people to collect and safely dispose of their own faeces.

Pit latrines are one of the most common forms of sanitation worldwide, with an estimated 1.7 billion people relying on them on a daily basis

1.4 Pit Latrines

Pit latrines are one of the most common forms of sanitation worldwide, with an estimated 1.7 billion people relying on them on a daily basis. Latrines are relatively easy to construct compared to flushing toilets which require more water and a more complex infrastructure and space to be implemented. When properly designed, constructed and operated, pit latrines have many advantages such as acceptable cost, ease of construction and limited groundwater pollution (assuming the water table is 1.5m below the bottom of the pit).



Figure 2.
Communal pit latrine in a refugee camp in the Central African Republic (Source: Christophe Grange, UNHCR)

A person produces a total volume of around 550 litres of excreta per year. At this rate of excreta accumulation, pit latrines require frequent emptying and cleaning.

1.4.1 The Problem of Rapid Sludge Accumulation

The main challenge of a sanitation programme designed around pit latrines is their rapid filling speed. The rate at which a pit fills is determined by the interaction between a numbers of factors (Still, Foxon and O’Riordan, 2012; Buckley et al., 2008). An average individual produces between 0.12 – 0.40 litres of faeces and 0.6 – 1.5 litres of urine per day. Averaged over a year, this amounts to 110 litres of faeces and 440 litres of urine per person per year - a total volume of 550 litres of excreta per person per year.

At this rate of faecal sludge accumulation, pit latrines require frequent emptying and cleaning (de-sludging). The emptying is either done by a sewer truck or by using manual labour. Thereafter, the collected faecal sludge is either transported off site or buried. Most importantly, it has to be disposed of hygienically to prevent excreta-related diseases or the outbreak of epidemics in the camp setting.

In each new humanitarian emergency, the de-sludging frequency can vary enormously and unexpectedly, depending on the volume capacity of the pits and of the sewer trucks available. If the number of sewer trucks is not sufficient and the pits fill up quickly, then the frequency of emptying will be affected and some toilets will have to be closed because of the potential health risks they present. This then becomes a vicious circle where the de-sludging and the cleaning of toilets become increasingly urgent to prevent defecation in open air and prevent diarrhoeal and other contagious diseases (Connolly et al., 2004; JMP, 2013).

The high rate of accumulation can also be caused by anal cleansing materials, which exceed the rate of degradation in the pit (Harvey, 2007). In these cases, urine also has less time to leach away, especially in more contained facilities such as cesspits. The quick accumulation of excreta leads not only to putrefaction and odours, but also to the attraction of flies when the distance from the heap of excreta to the surface is short.

Sewer trucks are often not available in sufficient numbers, not in good condition, and may lack adequate storage capacity.

Humanitarian actors usually do not deploy sewer trucks in their response during the first phases of the emergency, but they immediately look for local public and private contractors using de-sludging sewer trucks. However, in many developing countries, sewer trucks are often not available in sufficient numbers, not in good condition, and may lack adequate storage capacity. In addition, it is common for the owners of the sewer trucks not to provide regular maintenance.

In areas where there is a high-density of shelters or roads are poor, it may be difficult for sewer trucks to access latrines. Pits are generally emptied by pumping faecal sludge through a hole in the slab (or squatting plate) with a hosepipe. In the case of raised pit latrines, pumping is carried out through connections installed directly on the pit.



Figure 3 (Left) and 4 (Right).
De-sludging operation in Malawi during an experimental project of UNESCO-IHE concerning pit latrine additives. (Source: Ednah Komboi, UNESCO-IHE & WASTE)

The emptying of latrines can become very difficult if users throw a lot of solid objects such as stones or nappies in the pit that may clog the pump. This problem can pose a huge challenge during an emergency and can mainly be addressed through the delivery of appropriate hygiene promotion programmes for the local population, closely monitored by local WASH actors.

Once sewer trucks empty the latrine pits they take the contents either to a pre-defined dumping site or to an uncontrolled place somewhere in the environment. Dumping into the environment may lead to pollution and the spread of disease if the area is not protected or isolated far away from the surrounding houses. If there is no previous technical assessment of the disposal site, there is the risk that dumping of sewage may contaminate the local water source (both surface and underground water).



Figure 5.
Municipal sludge disposal site in Makassar, Indonesia.
(Source: Jan Spit, WASTE)

The lack of de-sludging resources such as trucks or disposal sites are a challenge to setting up and monitoring an urban sanitation programme in an emergency.

In most cases, the dumping of faecal sludge into a protected area may be the most accessible and safest environmental option. Nevertheless, the disposal capacities of these dumping sites need to be assessed rapidly and regularly, on a daily basis.

Any other existing facilities such as sewage treatment plants, if these are still in working condition, are only able to provide limited support in the faecal management process. Sewage treatment plants are designed for the treatment of sewage water (black water) and not for faecal sludge (hydraulic and organic loads are very different and require different treatment processes).

Overall, the lack of resources for de-sludging (e.g. materials, transport, capacity) is a real challenge to setting up and monitoring an urban sanitation programme in an emergency. Of these, one of the key limitations is the lack of skills and experience among NGOs and UN agencies staff who could advise and actively support with de-sludging operations and excreta management.

1.4.2 The Process of Decomposition in Pit Latrines

This section provides a brief description of the decomposition process that faecal sludge goes through in pit latrines. The aim of this section is to support a better understanding of the conditions required to managing excreta in pits.

The description of the following biologic processes is mostly related to long-term sludge accumulation, and is therefore more relevant to the secondary phase of an emergency. In this phase, the sanitation infrastructures constructed are likely to have a larger volume than in the first phase. However, understanding this decomposition process is instrumental in offering informed innovation for the first emergency phase.

Pit Contents

A typical adult excretes an average of 0.4 kg of faeces per day; of this 70-80% is moisture, with 0.1 kg of dry mass (Still, Foxon and O’Riordan, 2012). Approximately 80-90% of faeces is degradable organic matter and can be broken down into the following:

- 30% undigested fibres,
- 30% bacteria (mostly non-viable, meaning that it is alive but neither grows or divides),
- 10-20% lipids (fats),
- 2-3% protein,
- some digestive residuals and gastrointestinal shed-epithelium, trace amounts of viruses, hormones, and antibiotics.

An adult also passes about 1.5 litres of urine per day, composed of:

- > 95% water,
- 1.4% inorganic electrolytes (such as Na, K, Cl, SO₄, Mg, P),
- ~ 1.3% urea,
- ~ 0.54% organic acids,
- ~ 0.4% organic ammonia salts.

The most significant elements making up the organic compounds in sewage are hydrogen, oxygen, carbon, nitrogen, phosphorus and sulphur. With time organic compounds in sewage tend to decompose into carbon dioxide, water, ammonia, and oxidised phosphorus and sulphur, assisted by various bacteria and other living organisms that are present in sludge and in the sludge environment.

Decomposition Processes

There are two biological processes that have a direct influence on the contents of a pit latrine; these are the aerobic and the anaerobic process:

- 1. The aerobic process** — when ‘fresh’ faeces are added to a pit latrine, a period of rapid degradation occurs at the surface of the sludge heap where the sludge in the pit has contact with air (oxygen). This mass of microorganisms (from newly introduced faeces, and those already in place) causes a rapid aerobic reduction of readily biodegradable organic material (aerobic bioconversion process). In this process, bacteria dependent on oxygen use the nutrients in the sludge and the oxygen available at the sludge surface to grow. During this process they convert sludge into biomass and carbon dioxide, which then exits the pit. If the pit is unlined or has open joints, aerobic digestion may also take place (to a limited extent) at the sludge/soil interface, where bacteria can use the oxygen found in unsaturated soil to carry on the decomposition process.

Once existing faeces have been covered over by new pit contents the rate of degradation drops dramatically.

For the decomposition process to take place, the average total moisture of the sludge content should account for around 50-60% of its total weight.

2. The anaerobic process — where no oxygen is available, bacteria that do not require oxygen convert the sludge into additional biomass, methane, and carbon dioxide, which escape from the pit. Anaerobic processes tend to take a much longer time than aerobic processes. This is why once existing faeces have been covered over by new pit contents the rate of degradation drops dramatically. Firstly, readily biodegradable organic material has been depleted, and secondly, the digestion process becomes anaerobic due to the lack of oxygen and is therefore slower and incomplete. For intensely used shared latrines, the covering of faeces by a new layer occurs before the degradation of the most degradable material. This leads to a reduction in the overall speed of the process of organic matter reduction.

As a result of these two processes, matter that enters the pit can naturally exit it through either evaporation, the transportation of dissolved particles into the surrounding soil, or the degradation of organic matter into liquids and gases (primarily methane, carbon dioxide, ammonia and nitrogen) by bacteria present in the pit (Still, Foxon and O’Riordan, 2012; Foxon et al., 2008).

In order for these bacterial processes to take place, the average total moisture of the content should account for around 50-60% of its total weight (Peavy et al., 1985; EPA, 1995).

Field trial analyses carried out by Still, Foxon and O’Riordan (2012) demonstrate that the moisture content in pits generally decreases with increasing depth (when no groundwater enters the pit). If the pit is lined-up, moisture decreases only through evaporation and biodegradation; otherwise, water soaks out of the pit into the surrounding soil (Still, Foxon and O’Riordan, 2012). Even so, their observations showed that there was an average of 77% mean moisture content at the surface layer of the pit (from surface to 1m depth), and 67% moisture content in the lower layers (around 1m), with little to no further change from 1m to 1.5m. Therefore, biological activity in most latrine pits is unlikely to cease as a result of low moisture content.

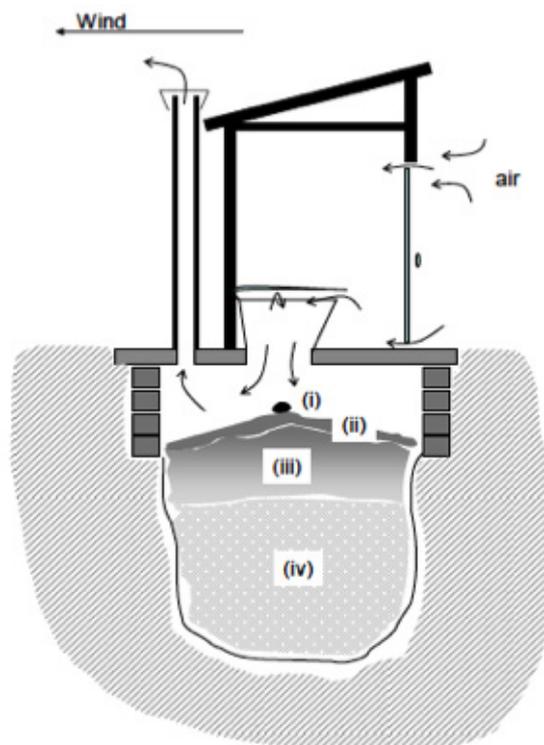
Pit contents left stagnant for a sufficiently long period of time become fully stabilised. The amount of degradation that will occur after this stage is negligible. This is a typical characteristic of faecal content located in the deeper layers of a pit.

Keeping in mind these two biological processes, the pit contents may be divided into four theoretical layers:

- 1.** The first layer is fresh sludge where readily biodegradable components are still present, and wherein rapid aerobic degradation occurs. This layer is neither deep nor easily measurable in practice.
- 2.** The second layer is still aerobic but consists of complex molecules that do not benefit from oxygen. Aerobic degradation of hydrolysable organic material occurs at a rate limited by the aerobic hydrolysis of complex organic molecules to convert them into simpler compounds.
- 3.** The third layer is anaerobic due to the lack of oxygen caused by the covering material. Anaerobic digestion proceeds at a significantly slower rate than in the layer above, and is controlled by the rate of anaerobic hydrolysis of complex organic molecules to simpler molecules.
- 4.** In the lowest layer, no further conversion of organic material occurs within the remaining life of the pit contents and the sludge becomes stabilised and compacted.

Figure 6.

The division of pit contents into four layers based on their decomposition process. (Source: WRC Buckley, 2008)



In practice, during the immediate phase of an emergency, the faecal sludge may remain fresh between two de-sludging operations if the rate of filling-up the pit is high and the capacity of the pit storage limited. An example of such a scenario was the situation following the 2010 earthquake in Haiti, when UNICEF provided 200-litre capacity portable toilets. In general, this scenario is more likely to occur in urban environments where digging pits is difficult and raised pit latrines are usually constructed. These tend to have a small storage capacity, whereas the number of users can be very high and thus lead to a quick filling of the pits.

Key excreta management challenges faced in an urban emergency are coping with the rapid accumulation of faecal sludge in pit latrines or toilets, the organisation of regular emptying, and the safe disposal of waste.

1.5 Key Sanitation Challenges for WASH Agents

Interviews with WASH programme managers from MSF, UNICEF, and UNHCR for this report have highlighted key excreta management challenges faced in an urban emergency. These are: coping with the rapid accumulation of faecal sludge in pit latrines or toilets, the organisation of regular emptying, and the safe disposal of waste. These challenges are directly linked with:

- The lack of ground support, technologies and equipment to either remove sludge from the pits, ensure its appropriate disposal in a dumping site, or reduce its accumulation. WASH actors are looking for more efficient and rapid solutions that are easy to implement and monitor on the ground. Consequently, many studies have been carried out over the past decades to look for specific concepts that can be applied in the processes of emptying, reducing and sanitising faecal sludge.
- The lack of guidelines and protocols to monitor safely all operations regarding the emptying, transportation and disposal of faecal sludge during the first and the second phase of an emergency.

Therefore, this report aims to provide an overview of existing research and solutions around emergency community-level sanitation and propose some directions for innovation.

Part 2: Past and Present Approaches to Faecal Sludge Management

In the past, there has been a tendency for innovation projects in sanitation to lag behind those in other key areas such as the distribution, processing and analysis of drinking water. So far, innovations in sanitation concerned mainly the elaboration of tools and guidelines to monitor hygiene promotion programmes with the local population, and the safe and regular disposal of faecal sludge (Harvey, 2007).

Regarding research in infrastructure and equipment, very few innovation projects have been carried out. Humanitarian actors usually prefer to look at the local market for relevant equipment. This decision can be justified both by the lower costs associated with using local equipment, as well as by the greater flexibility this gives to adapt the response according to the situation on the ground.

A number of institutions and research groups have carried out studies and experimental projects to review the technologies for pit latrine emptying in developing countries and in development contexts (Thye, Templeton and Mansoor, 2012; Tilley et al., 2012; Still, Foxon and O’Riordan, 2012; Strande, Ronteltap and Brdjanovic, 2014). Most of these publications include studies on how to improve the management of latrines in development contexts such as slums or informal settlements in highly dense urban areas, where pit emptying is a serious challenge.

However, as the main excreta management problem faced by WASH humanitarian agencies is the rapid accumulation of faecal sludge during the first phase of an emergency, a number of studies have been carried out to look at concepts and products able to reduce and sanitise faecal sludge. The main studies carried out in this area are described below.

2.1 Reducing Faecal Sludge Accumulation with Additives

In the context of this report, ‘additives’ refer to products able to treat and control faecal sludge by:

- Sanitising and stabilising the faecal matter so that it is safe for disposal, and
- Reducing or stopping the accumulation of faecal sludge, thus slowing down the filling-up of the pit.

Additives have a huge potential in reducing and controlling faecal sludge. Using additives can provide a simple and reliable solution under certain conditions of application.

A comprehensive description and analysis of all past research projects conducted on the use of additives in pit latrines is presented below, together with recommendations for further development of innovations in this topic.

Many of the most relevant publications are provided by the Water Research Commission (WRC), on behalf of the Pollution Research Group, School of Chemical Engineering at the University of KwaZulu-Natal, South Africa, and are easily found on the internet. This group of researchers published a number of scientific and technical support documents for the design and operation of latrines in South Africa, including an assessment of the efficacy of bio-additives for reducing organic matter in pit latrines.

Additives have a huge potential in reducing and controlling faecal sludge.

2.1.1 Types of Additives

There are three kinds of treatment technologies for pit latrines:

Chemical additives:

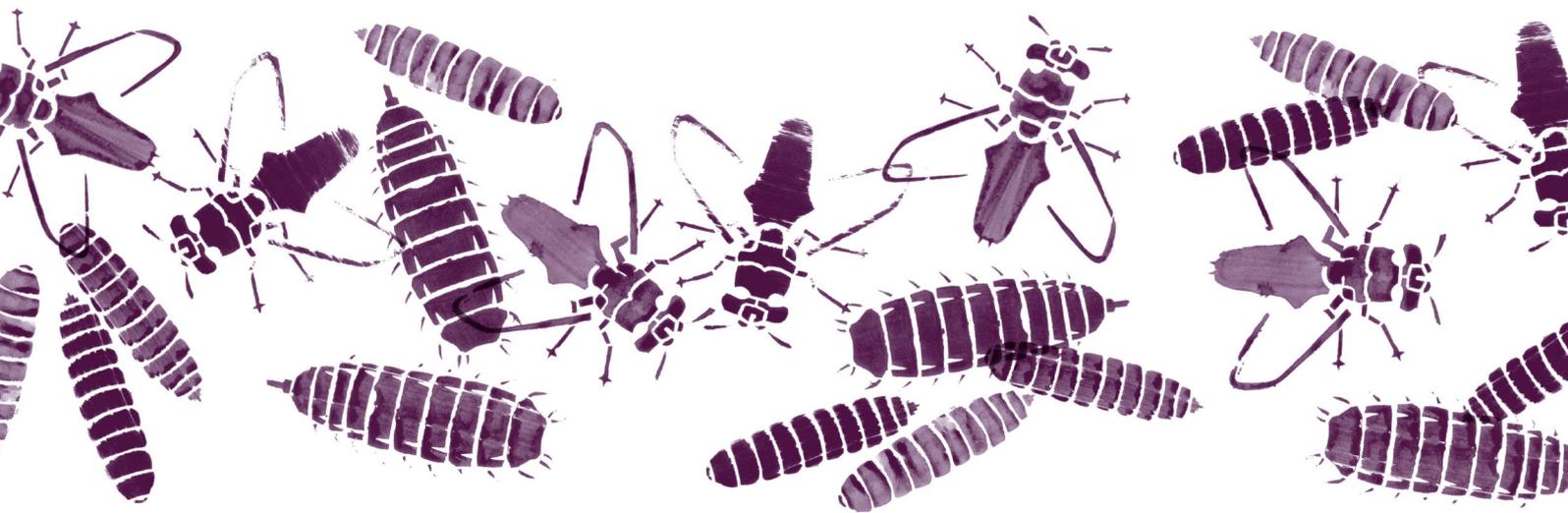
- Strong acids and alkalis (such as sodium carbonate — soda crystals);
- Organic solvents;
- Ammonia (considered as a Bio-Chemical treatment);

Biological additives (Bio-additives):

- Organic microorganisms (bacteria and extracellular enzymes — typically used in septic tanks);
- Lactic Acid (considered as a Biological treatment);

Biological external concepts:

- Earthworms and black soldier fly larvae (BSFL), which will be considered as an additive for this proposal (rather than a concept). The key distinction made here is that, while other additives can simply be added to the sludge, earthworms, for example, can only be active through a support such as a filter media (e.g. Vermifilters).



Commercially available additives are primarily used for the treatment of domestic septic tanks. There is little evidence around their effectiveness in pit latrines.

Many global manufacturers develop and successfully commercialise additives primarily for the maintenance and treatment of domestic septic tanks. Additives for pit latrines are also commercially available, but most manufacturers have very little or no experience of use of these products on pit latrines. This is especially typical among suppliers from developing countries.

Most likely, their working hypothesis is that if additives provide a satisfactory service for the septic tank market by reducing the frequency of de-sludging by tanker, they may also reduce organic matter or reduce the rate of latrine fill-up by rapidly degrading organic material. Manufacturers claim that these additives contain natural microorganisms and enzymes able to degrade organic matter at a higher rate than those naturally present in faecal sludge.

Therefore, following this assumption, the hypothesis of having an effective reduction of organic matter in pit latrines with the ‘same kind of microorganisms’ coming from additives is coherent. The same kind of link can be highlighted, considering that the microorganisms brought by the additives are very similar to those naturally occurring which are very effective.

Over the past decades, several research groups and organisations have looked at demonstrating this hypothesis through lab and field studies. Their results are presented below.

2.1.2 Research on Bio-Additives for Pit Latrines

After conducting a literature review of existing scientific publications and on-line publications, and interviewing key players in the WASH Cluster, eight main studies on bio-additives for pit latrines were identified, extending over the past 17 years. The objective of these studies focused on the analysis of the efficacy of bio-additives to either increase the decomposition of pit latrine contents or stabilise the sludge, especially in intensively used latrines (e.g. shared latrines or those available in emergency situations). The ultimate goal of the research was to assess whether a chosen additive was able to significantly reduce existing sludge to reach a point of stabilisation of volume for continued use.

All bio-additives were evaluated in scale laboratory experiments followed by an on-site evaluation of selected products. All dosing applied during the experimental phases, both in the laboratory and the field, followed the manufacturer's recommendations.

Jere et al. (1998) from the Ministry of Health and Child Welfare of Zimbabwe and the Blair Research Laboratory carried out a study to determine the efficacy of a bio-additive to degrade organic solid matter in four lined-wall pit latrines that were 100% full. The pits were lined except at the bottom which allowed most of the effluent to seep underground.

The bio-organic breakdown compound was described as a ‘non-pathogenic spore forming bacteria’ and was injected at the same dosing for all pits, through a perforated tube. This allowed adequate mixing of the pit contents and the additive. A perforated pressure tube was used to inject the mixed breakdown compound into the pits by creating pressure from the Micravac latrine emptying vehicle for mixing the breakdown compound and the pit contents.

It is important to emphasize that the pits were 100% full, not in use, and stratified between aerobic and anaerobic zones. In addition, no control pits were studied, thus it was not possible to quantify statistically, how significant the reported changes actually were.

The lab scale showed that the BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) reduced continuously during treatment but increased after the treatment had stopped. The results indicated that the additives led to a significant reduction in the height of the contents of the pit during the field trial. The reduction in COD and BOD in the study is attributed to the additive, which increased the rate of degradation.

Although the results presented showed some changes, Foxon et al. (2008) noted some shortfalls of the study, including the possible positive effect of the application injection method (injection under pressure) leading to the mixing, oxygenation and increased hydration of the sludge. This positive effect cannot be attributed to the action of the additives and therefore a conclusive positive result could not be determined.

Despite the identified shortfalls during the field trial, the positive lab results and height reduction of the pit content have allowed the authors to indicate that the additives used do have the potential to break down latrine organics and could thereby slow down fill-up rates.

Taljaard et al. (2003) from the Water Research Commission (WRC), undertook an experiment using two products selected as being the most performant from an array of 12 products aimed at volume reduction. The initial selection lab test was carried out under aerobic conditions in a fully automated Respirometer where measurements of oxygen consumption and/ or carbon dioxide production were used to determine biodegradability. The two chosen additives were subsequently tested in the field. The first was a consortium of aerobes and anaerobes (≈ 108 CFU/g) mixed with enzymes; the second contained five strains of bacteria (≈ 106 CFU/g), yeast, and enzymes.

The field-testing involved tests on blocks of latrines each with three pits. The individual pits were dosed according to the recommendation stipulated by the manufacturers. A control was set up that had an equal amount of water added to compensate for the volume of the daily product inputs. The change in height was measured using a marked pole; the maximum decrease in level was 13% on the best replicate. The local population reported that the fly problem was eliminated and the odour was reduced in those pits treated with the first product, whereas those treated with the second product still had an odour and a reduced, but still existent, fly population.

The results showed that the control had no change with regards to height, odour and fly problems. The variance in height measurements recorded for the treated pits did not allow the difference in efficiency of treatments to be statistically evaluated. However, as a conclusion the author noted that the additives have potential to increase degradation of organics and thus reduce pit volumes.

From 2005 to 2011, Foxon et al. (2008), Buckley et al. (2008) and Bakare (2011) from the Water Research Commission (WRC) carried out three studies and provided notable publications, experimentation, protocol and process analyses.

The field study carried out by Buckley et al. (2008) looked at one of the brand additives and aimed to calculate the reduction in volume by measuring the change in height of the latrine contents. No significant results were obtained that provided a noticeable positive trend between the height lost and the selected bio-additive. However, it was noticed that due to the changes in the shape of the latrine contents (the surface area did not remain flat), the simple measurement of height loss was subjective. The change could be attributed to water increase, which led to the flattening of heaps that were previously not uniform in surface height, as well as the ownership and management of the pit, as the addition of other waste items not of human origin such as household rubbish created volume changes.

The inadequate evidence linking additives and biodegradation (Buckley et al., 2008) and the shortfalls of the previously evaluated studies led to the development of protocols to guide further tests into the efficacy of additives (Foxon et al., 2008). These protocols led to an experimental setup established to single out the effects of an additive on the degradation process. As a result, the experiment demonstrated that mass loss under anaerobic conditions was negligible whereas under aerobic conditions it was 22 times higher and was most significantly observed at the rate of $0.8 \text{ kg/m}^2/\text{day}$. However, the comparison of replicates within treatments and between treatments, and the controls in the aerobic setup

Past research around the use of bio-additives for pit latrines has lead to inconclusive results but also to the development of better measurement protocols.

showed negligible differences in COD removal and moisture. Consequently, mass loss was attributed to dehydration and biological activity mediated by microorganisms naturally present in faeces. Therefore, the conclusion was that additives do not improve the rate of degradation.

Following this, Bakare (2011) applied the protocol developed by Foxon et al. (2008) to test the efficacy of two additives in reducing faecal sludge mass. The additives were tested in field trials using improved distance measurements for the height of the heaps, as well as in a laboratory scale experiment on Ventilated Improved Pit (VIP) latrine sludge. The lab results showed insignificant mass loss during the 30 days of treatment with the products and water control jar. Thereafter, the two products were tested in the field each on eight pit latrines against seven pit latrines used as controls. The reduction in height of pit contents was evaluated over six months by using an infrared device and stereographic imaging techniques. The results showed that the pits treated with water only had a significant reduction compared to the control. This was attributed to the effect of water flattening the topmost part of the heap despite the stereographic imaging that refuted this result. As a conclusion, VIP sludge treated with these additives showed neither improved degradation nor volume reduction.

The Dutch organisation WASTE and Ednah Komboi (2015) in Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, the Netherlands carried out a study to determine the efficacy of commercial additives to sanitise and stabilise faecal sludge.

Suppliers of additives were difficult to identify for this study; most of the additives tested were obtained through a PhD student working at Sanergy Lab in Kenya. Two other products were bought via the internet, a distributor in Blantyre, Malawi provided another and WASTE's partners sent a further three products.

In the first instance a laboratory scale test was undertaken in the Netherlands on black water coming from a waste treatment plant. While the characteristics of black water are very different from excreta, this test was done to establish and analyse the performance of five additives with the determination of the Chemical Oxygen Demand (COD), Volatile Solids (VS), and Total Solids (TS), *E. coli*, and *Enterococcus* numbers. At the end of the lab experimentation, the residual amounts of *E. coli* and *Enterococci* were measured to determine if they meet WHO standards to be re-used in restricted agricultural settings (indicative for safe disposal into the environment). VS reduction was compared to the minimal value ($\geq 38\%$) that is expected in digesters to represent stabilised sludge (EEA, 1997; EPA, 1993).

Following the results of the laboratory experiments, field studies were carried out in Blantyre, Malawi. Pit latrines were treated for two weeks and five more additives were included in the study (bringing the total up to 10 products). The treated latrines were compared with the control ones (where neither water nor additives were added) and with the water reference (where only water was added to the black water to compensate for volume changes by adding additives).

As a result, the additives tested showed no significant difference with the controls, except for two chemical products containing sodium carbonate (soda ash). The two week long field experimentation period was too short to allow the bio-additives to be effective in showing significant results in faecal mass loss in the pits.

Moreover, final results showed a similarity with the study of Buckley et al. (2008) in that the additives did not show a significant reduction compared to the controls.



Research has looked at the ability of additives to reduce or slow down the accumulation of sludge in pit latrines, but also reduce the smell and presence of flies.

However, the soda ash products did significantly reduce pathogen levels, which is probably attributable to the higher pH maintained throughout the treatment period. A slight positive performance was also noticed with the sodium carbonate product regarding reduction in the TS and VS concentrations, but this was not sufficient to demonstrate a significant result.

From 2013 to 2015 The International Federation of the Red Cross (IFRC)

conducted a small scale study looking at the treatment of one pit latrine in a school, using one bio-additive. The three-month on-site field trial was undertaken in 2013 in the Ivory Coast.

No control pit latrine was established to compare the results but the seeding was implemented a short time after a de-sludging operation of the pit (3m³ of sludge were present at the start of the test). The number of users was recorded daily and the additive was added at each entry in the toilet (220 entries per day on average).

It should be noted that there was no laboratory analysis of the product before the trial and the school de-sludged the pit two to three times a year before the trial commenced.

The field trial was implemented between September and December 2013. It was monitored and supervised jointly with the International Federation of the Red Cross (IFRC), the National Society of the Red Cross of Ivory Coast (CRCI) and the DAD (Direction de l'Assainissement et du Drainage de Côte d'Ivoire).

Results showed that the level of excreta volume decreased to almost 1 cm (from 30 cm) within the first 12 days and levels did not change from then until May 2015 (the last official check). These results were obtained without pouring any additional product (following the end of the trial) or emptying the pit by de-sludging. The General Secretary of the Red Cross of Ivory Coast in Abidjan officially validated the results.

In 2015 UNICEF's Supply Division conducted a four-week study on the effectiveness of pit latrine additives. Three products and one placebo were tested in 155 school pit latrines in Uganda's Jinja district.

The products were evaluated on their ability to reduce or slow down sludge accumulation rates, reduce smell, and reduce the presence of flies. Findings show that the pits treated with bio-additives were able to marginally reduce accumulation rates compared to the placebo, with varying statistical significance.

All four groups, including the placebo, showed a statistically significant reduction on smell and flies. As such, the study does not provide evidence on additive impact on smell or flies. This study also includes a sample cost/benefit analysis in order to guide government decision-making on the potential use of the selected latrine additive products in schools.

2.1.3 Research on External Treatments for Pit Latrines

In addition to bio-additives for pit latrines, research aiming at reducing or sanitising pit latrine faecal sludge has also considered a range of external treatments. The three studies below review some of these approaches.

In 2014, the Dutch organisation WASTE undertook a three-month investigation on small-scale field trials with pit latrines in Blantyre, Malawi. The focus of the research was primarily on sanitation aspects rather than the ability to reduce faecal sludge. Lactic Acid Fermentation (LAF), Urea Treatment (UT), and Hydrated Lime Treatment (HLT) were selected to sanitise faecal sludge with the use of a de-sludging technology involving high-pressure fluidisation and a vacuum suction pump.

Preliminary testing has indicated that based on the small-scale field trials, the three selected approaches are promising low-tech faecal sludge treatment technologies and are all potentially applicable to emergency situations.

The study showed that all three treatment processes, under certain conditions, are able to sanitise faecal sludge to comply with the WHO guideline limit of 103 *E. coli* CFU/100ml.

In 2014, The London School of Hygiene and Tropical Medicine determined the capacity of black soldier fly larvae (BSFL) (*Hermetia illucens*) to convert fresh human faeces into larval biomass under different feeding regimes. They also set out to determine how effective BSFL are as a means of human faecal waste management (Banks, Gibson and Cameron, 2014).

Black soldier fly larvae can be effective at waste reduction and converting waste into valuable biomass.

For the purpose of this study, BSFL were fed fresh human faeces. The frequency of feeding, the number of larvae and the feeding ratio were altered to determine their effects on larval growth, prepupal weight, waste reduction, bioconversion and feed conversion rate. In summary, the study has demonstrated that BSFL feeding on fresh human faeces can develop successfully.

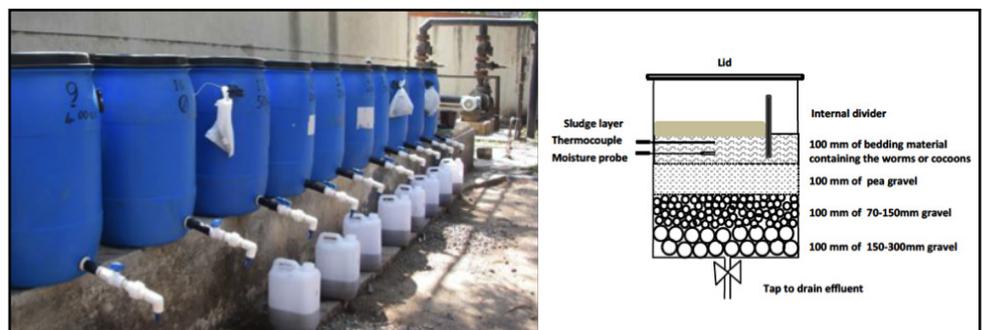
The largest prepupae are produced when given a large quantity of feed, resulting in prepupae of a higher mass than previous studies. The larvae are effective at waste reduction and converting the waste into a valuable biomass but further research is needed in this area. Also, in spite of the promising results, this approach is unlikely to represent a solution in an emergency response.

In 2015, the International Federation of the Red Cross commissioned Claire Furlong from Bear Valley Ventures Ltd and Red Crescent Societies (IFRC) to determine if composting worms had the capability of digesting faecal sludge to improve sanitation provision in the humanitarian sector (Furlong, 2015). The study was also tasked to evaluate the efficacy of this method to reduce the pathogen rate in the final effluent.

Figure 7 and 8.

Vermifilters used in the field to treat faecal sludge (left) and a diagram of a Vermifilter unit (right).

(Source: Claire Furlong, 2015)



Vermifilters make use of composting worms to achieve a reduction in the volume and solid content of faecal sludge, as well as its pathogen load.

The technology, called Vermifilters, implies a process for composting using worms. The claim is that this technology could potentially achieve a reduction not only in the volume and solids content of faecal sludge by over 90%, but also reduce the pathogen load (including parasitic worm eggs). The end product would be reduced to an acceptable level allowing it to be safely added to landfill sites.

The concept consists of a filter system containing worms, which process waste by trapping the solids on top of the filter. Liquid separated from the solids passes through the filter providing a better quality effluent. There are two important phases for the implementation of the worm filters following the setup of the devices: the feeding phase and the sludge digestion phase.

This study was undertaken in India over a seven-week period and involved a local partner, PriMove Infrastructure Development Consultants PVT. An additional objective of this study was to prepare a design brief for a prototype treatment system.

The experimentation method consisted of a set-up of 18 plastic cylindrical Vermifilters working as a filter (see Figure 7), with the sludge passing through different layers of pea gravels seeded with worms. The system could only work under aerobic conditions and with a consistent level of moisture. Initially, the Vermifilters were seeded with different masses of worms and cocoons to study the impact of worm density on the system.

Faecal sludge was collected from pour-flush portable toilets to feed the Vermifilters with a very diluted effluent.

Parameter analyses from the sludge coming into the filters and effluent were pH, Total Suspended Solids (TSS) (mg/l), Volatile Suspended Solids (VSS) (mg/l), ratio VSS/TSS, Total Solids (mg/l), COD (mg/l), Faecal coliforms (CFU/100ml), *Ascaris* spp. (total eggs/g) and *Ascaris* spp. viability (eggs/g).

After three days of setting up, the Vermifilters ran for a period of 52 days including 11 days for the feeding phase (which lasted longer than expected) and 38 days for the sludge digestion and composting. This period was too short because the worms took approximately six weeks to acclimatise to a new food source.

In addition, constant watering has to be carefully managed to avoid fungal growth, maggots and fruit flies, all of which were observed during the test period. It is noted that a suitable solution would be to reintroduce into the system the resulting effluent, when facing water scarcity.

As a conclusion, although there were a few difficulties monitoring the pilot, the study clearly showed that worms are capable of digesting faecal sludge and converting it into compost, as well as being efficient at reducing solids and removing pathogens. Although there were problems with sludge analysis as any undigested sludge could not be recovered from the system, the conversion from sludge to Vermicompost was assumed to be at the rate of 1 kg of sludge to 0.2 kg of Vermicompost.

The conversion from sludge to Vermicompost was assumed to be at the rate of 1 kg of sludge to 0.2 kg of Vermicompost.

2.2 Focus of Current Research

Past and present research in this field has focused specifically on what humanitarian actors outline as key challenges — suitable solutions to cope with the issues of faecal sludge accumulation, sanitation, and new designs for pit latrines. While past research has focused mostly on the use of additives and alternative external treatments to address latrine sludge accumulation, new studies are increasingly taking a broader approach by exploring new designs for sanitation facilities, or the use of existing treatment technologies to sanitise sludge.

Two such projects, one looking at advancing established research on additives and a second looking to explore alternative innovations in sanitation, are detailed below.

Additives Research (UNHCR)

UNHCR has started a very promising pilot project in Chad in May 2015, to test the same successful additive used in the Ivory Coast by the IFRC in 2013. The objective of this pilot is slightly different from other existing projects in that it aims to determine whether or not faecal sludge accumulation can be stopped before people use the latrine. Two phases are being implemented with 10 family-owned pit latrines, with around 10–13 users per toilet. There is no laboratory scale support



Figure 9 and 10.
Measuring the height of faecal sludge (left) and pouring additive in a pit (right) during field trials in Chad.
(Source: Christophe Grange, UNHCR)

planned for this field experimentation. For this field trial, UNHCR placed a particular focus on the construction of new lined latrines; other latrines were also included as a control.

For the first phase, 10 pit latrines were constructed for the treatment, and 10 for use as controls. The second phase maintained the same number of latrines for treatment but used only two for control (due to budget and logistical constraints).

Two different dosing protocols will be tested and the results and official report are expected before the end of the year (2015). First feedback indicates that the results are very promising with a total absence of accumulation for the 10 latrines treated after three weeks from the start of the pilot.

A third phase will start on October 2015 in Kenya with UNESCO-IHE for further testing. This phase will also include a laboratory analysis.

Broader Sanitation Research (WASTE)

Between 2015 and 2016, WASTE will undertake a range of innovation projects in sanitation research for urban disasters. WASTE are currently part of two consortiums called SPEEDKITS and ESP (Emergency Sanitation Project). Key partners involved in these include the International Federation of Red Cross and Red Crescent Societies (IFRC), and Oxfam GB.

These consortiums aim to increase global understanding of current and future emergency sanitation and to propose new concepts and modular technologies for safe excreta disposal in a variety of emergency types and settings. The main objective of these projects is to develop a proper description of requirements for appropriate sanitation systems in emergency areas. The consortiums are working towards a set of criteria for:

- a) Elevated toilets:** two new concepts for mass-producible raised latrines were developed and tested.
- b) De-sludging equipment:** four different de-sludging devices with auxiliary equipment such as fluidisers, fishing equipment, and temporary storage bladders were tested in Malawi, East Africa. Test reports and recommendations for adaptation of standard equipment were finalised.
- c) Sludge disposal and treatment facilities:** three low-tech treatment processes (Lactic Acid Fermentation; Urea Treatment and Hydrated Lime Treatment) have been selected for rapid deployment upon the event of an emergency and were tested successfully in laboratories in the Netherlands and on a small scale field test in Malawi (as described in section 2.1.3). All three treatment processes were able to sanitise the sludge within a short period of time. Additional tests followed to prove the applicability on a larger scale in Malawi. The results were widely disseminated.
- d) Sludge pasteurisation:** a small-scale pasteuriser has been developed, prototyped, and lab-tested to demonstrate the concept and the effectiveness of sludge pasteurisation with respect to reducing the risk of faecal-oral transmitted diseases (e.g. cholera).

Several workshops are planned to discuss the resulting criteria and, at a later stage, suppliers and developers will be encouraged to use these when developing products for emergency situations.

Part 3: Areas for Further Exploration in Faecal Sludge Management

While Part Two of the report introduced past and present research conducted in the field, this section is aimed at highlighting some of the potential areas for future research around emergency faecal sludge management. Although some of the technologies presented in this section have been tested in different settings, their potential for being used in an emergency context would benefit from further exploration.

3.1 Future Research on Additives

Despite the variety of outcomes from past studies, research in this area must continue due to the high potential of bio-additives. This option for faecal sludge control is still a big hope to ease the monitoring requirements of sanitation programmes.

3.1.1 Review of Protocols

Existing protocols should be reviewed, with priority given to investigating the feasibility of stopping the accumulation of faecal sludge from the beginning of latrine use rather than reducing existing sludge. Promising results coming from the UNHCR field pilot project in Chad show the high potential of more development and the need to establish other experimental protocols.

Past studies on additives showed that it is almost impossible for exogenous bacteria introduced through an additive to a pit to take over from endogenous bacteria present in the faecal sludge. This is because of the strong competition between microorganisms and the difficulty in breaking down a naturally occurring bio-system.

For the evaluation to be robust, it is necessary to identify and survey product on the international market. It is advisable to interview manufacturers regarding their experiences and the results they have obtained in sanitation or waste treatment applications.

It is also suggested that further research is required to identify products that use another product for nestling support. For example, the additive used by the UNHCR uses a mineral absorbent called zeolite. This enhances the establishment and development of exogenous bacteria in faecal sludge. The mineral absorbent is used as a seeding/nestling support for the selected bacteria and provides full protection from endogenous ones.

3.1.2 Testing and Dosing

Since almost all of the additive products on the market have been created for application in septic tanks, the selected products should be evaluated according to different dosing rates, starting from those recommended by the manufacturer and gradually increasing to a higher dosage.

Protocol should be varied according to the type of additive being tested. For example, starting with an empty pit at the beginning of the trial or starting with a pit latrine that is already partially filled.

New protocols are needed to explore the possibilities of stopping sludge accumulation at the beginning of the use of a latrine.

Once this has been done, it could be possible to adapt a protocol for each product (even if this is not foreseen by the manufacturer). The protocol could take into account different important phases such as seeding, boosting and regular maintenance up to the 'colonisation' of the new microorganisms. At this latter point, no further additive is required and the pit maintains itself at zero or near zero accumulation.

This new protocol proposal is a hypothesis, which suggests an alternative method for testing and comparing the additives in the studies carried out by Foxon et al. (2008) and Buckley et al. (2008), among others. Key to this protocol is the aim to stop the accumulation at the beginning of the use of the latrine, instead of reducing the existing sludge in place.

The lab scale analysis would have to represent the start-up condition of the pit, the high rate of sludge accumulation every day, and the characteristics of fresh faeces.

The protocol could be determined as follows:

- Add a sample of faecal sludge every day in a jar; this will represent the total amount accumulated in the pit each day by fresh faeces.
- Water and oxygen will be controlled and adapted in the lab experiment according to the condition found in the pit on start-up and until the filling-up.
- Increase every day the same amount of sludge sample in the jar (e.g. 50 users × 3 entries every day in a 2m³).
- As in the previous research studies, the parameters of the protocol should include Chemical Oxygen Demand (COD), Volatile Solids (VS), Total Solids (TS) and *E. coli*, and *Enterococcus* numbers. The latter (*Enterococcus*) would be a more reliable indicator than *E. coli* in terms of resistance to treatment.

Further field trials should be conducted in brand new pit latrines or after a de-sludging operation, with 10 latrines minimum per treatment, following the recommended dosing from manufacturer, plus the recommended optimum efficacy dosing from the step-by-step laboratory investigation. This would help obtain comparative statistical results for each treatment rate. Lab scale experimentation should provide information for the selection of products or for the improvement of the dosing to be applied in pits in the field trial conditions.

In addition, in order to make a fair comparison of each treatment and product, all pits must be constructed with the same volume, have the same number of users, and use the same materials for lining the pit walls.

The recommended duration of the field trials should be a minimum of two months. This is necessary in order to observe a reduction in the organic content in the pit as exogenous bacteria need time to settle down and take over from the endogenous bacteria.

As faecal sludge consistency in emergency situations is fresh and liquid, the application of additives at the start of the filling of the pit is recommended.

The long-term potential of using external treatments such as black soldier fly larvae or composting worms needs to be further explored.

3.2 Future Research on External Treatments

Further innovation projects around external treatments can be developed from the recommendations of the London School of Hygiene and Tropical Medicine regarding the use of black soldier fly larvae, and from Claire Furlong’s research around Vermifilters and the use of composting worms.

Despite the fact that these technologies cannot provide a reliable solution due to the high quantities of sludge to be disposed of per day, further assessment should be carried out to understand the feasibility of implementing and monitoring such systems during the second phase of an emergency. Research should assess the extent to which a system could be designed to pump the sludge from the pits into the filters. Similar projects can be implemented in parallel using black soldier fly larvae. These should look at the adequate conditions for properly monitoring the concept on the ground.

3.3 Future Research on the Design and Operation of Raised Pit Latrines

There is a need for research in this area to develop new prototypes for raised latrines. Some of the key features for these latrines should include:

- Devices for mixing sludge and a system for dosing additives. This way faecal sludge can be continuously oxygenated and mixed, thus accelerating the bio-degradation of organic matter.
- A connecting system to allow trucks to safely and effectively empty the pit (see Figure 11 for example).

In 2016, the Dutch organisation WASTE will be exploring new designs for raised latrines, using HIF funding.



Figure 11.

A standardised de-sludging network for faecal sludge contaminated with the Ebola virus. This system was implemented by MSF at each ETU to monitor the safe emptying of pit latrines in Liberia, 2014.

(Source: Christophe Grange, ICRC)

3.4 Future Research on Safety Protocols and Guidelines

Besides improvements in infrastructure and equipment, there is a need to develop safer and more effective procedures for the collection, transportation and disposal of faecal sludge. Supportive guidelines should include all pumping and sewer truck procedures.

Safety protocols should provide guidelines for security procedures regarding the protection of staff and the transport of sludge to disposal areas (e.g. modus operandi and emergency contingency plan in case of accidents or if passers-by are exposed to the sludge).

As a starting point, the existing protocol established in Liberia in 2015 by the WASH Cluster for the collection and disposal of sewage contaminated with the Ebola virus from the ETU (Ebola Treatment Unit) can be used as a model for further process evaluation and development.



Figure 12.
Sludge drying beds in Busia, Kenya.
(Source: Jan Spit, WASTE)

3.5 Future Research on Safe Disposal and Dumping

During an emergency situation, a dumping site for storing collected sludge volumes from the affected population is quickly found and evaluated from the available infrastructures provided by local authorities. If there is no dumping site it has to be implemented in a safe way to receive and dispose of the sludge collected from the pits. If there is an official and existing dumping site, the WASH Cluster should support the responsible local authorities to better evaluate the impact of an increased sludge load due to the emergency.

In general, the defined options vary from one emergency context to another. As an example, ponds can sometimes be quickly dug by excavators in a protected area to suit the daily volume collected during the first months following the beginning of an emergency response (this was the process followed in Haiti after the 2010 earthquake). In other situations, a reservoir located in a sewage treatment plant can store the faecal sludge collected during this time (this happened in the case of the contaminated Ebola sludge coming from the ETUs in Monrovia, Liberia).

If there is enough space, lagoon systems or drying beds can be designed for sludge disposal.

If the dumping site has enough space, a lagoon system or drying beds can be designed according to the daily volume of sludge to be disposed. Implementing actors need technical capacities to design such a system. If the disposal capacity is low and space not available, it will be required to equip the ponds with treatment devices to improve the reduction of the disposed faecal sludge.

Future research in this area could target the development of simpler and more effective ways of reducing organic matter. Some of these are included in the following sections.

3.6 Future Research on Portable Sewage Treatment Plants

Existing portable treatment plants can be divided into two groups:

- Compact anaerobic digestion systems: convert organic matter into biogas and carbon dioxide;
- Compact aerobic digestion systems: convert organic materials into biomass and carbon dioxide.

While aerobic treatment systems imply relatively simple technical processes, anaerobic treatments are more complex and can require comparatively large investments. Either way, some of these special compacted systems have great potential to treat on site sludge collected from latrine pits.

3.6.1 Compact Anaerobic Digestion Systems

When thinking about the use of compact anaerobic digestion systems in developing settings during a crisis, attention needs to be paid to the direct applications of the resulting biogas, as well as any ground security constraints for safely storing gas.

Other considerations should include the volume of sludge that needs treating per day and the speed of the reduction of faecal material to be processed. Depending on these estimations, research in this area may consider whether such concepts can meet practical uses in terms of processing capacity, compact size units, the use of biogas and its safe management.



Figure 13.
SEaB Energy's compact anaerobic digestion system design.
(Source: SEaB Energy)

EXAMPLE — SEaB Energy's compact anaerobic digestion concept

SEaB Energy's compact anaerobic digestion systems can produce biogas, energy, a liquid fertiliser and mulch with as little as half a ton of incoming organic waste per day (150-250 tons/year). A key advantage of these small on-site units is that they minimise transportation costs for wastes from food processors, breweries, restaurants, farms and food retailers.

Nevertheless, as the bio-processing of organic matter reduction is slow under anaerobic condition, these solutions may be more suitable during the second phase of stabilisation in an emergency. The capacity of faecal sludge reduction has to be assessed according to different manufacturers to determine if these compact anaerobic treatment concepts can be suitable on the ground.

3.6.2 Compact Aerobic Digestion Systems

Portable aerobic digestion systems may be more suitable in an emergency setting because they are capable of treating a wide range of organic wastes by reducing their weight and volume through a speedy composting process. The main advantages presented are:

- The final result, which is a stabilised compost (i.e. it has no odour and no more fermentable materials, and is easy to landfill);
- The increased safety of transporting and landfilling of the compost produced;
- The treatment capacity of faecal of sludge per day is up to 50 tons;
- The sanitisation of the faecal sludge and compost.

Some of these systems are patented and have proved effective in different applications from manure and food waste, to green waste. Future research in this area should assess whether such systems may provide potential solutions for the on-site treatment of excreta in an emergency.

Aerobic systems of reducing organic waste tend to be much more efficient than anaerobic ones and may provide interest for further experimentation.

The different approaches could be divided into two categories:

- Systems which reduce waste by dehydration: the weight and volume of the waste are reduced using high temperatures (above 100°C);
- Systems which reduce organic waste by biodegradation: the reduction is accelerated by either thermophilic saprophytic bacteria and/or specific enzymes that are very active under constant and controlled temperatures (from 60°C to 80°C).

Each of these aerobic approaches will be discussed in the following, accompanied by example systems.

Waste Reduction Through Dehydration

EXAMPLE — The VRS system (Value Recovery Systems Inc.)

The VRS system, developed by Value Recovery Systems Inc., relies on a dehydration process. The process involves grinding, water evaporation and the sterilisation of the organic wet waste.

The final product is a sterile and stable powder which will not degrade any further. The electricity consumption of the equipment is between 0.75–1.25 kW/h per litre of evaporated water, depending on the temperature of the surrounding environment.

After loading the chamber with wet waste, a stabiliser is added (5–10% wheat bran or sawdust), along with a neutraliser. The waste is decomposed under a temperature of 100°C leading to water evaporation, sterilisation and grinding. Depending on the volume and moisture level of food waste, each treatment cycle can take between 6 to 11 hours.

The advantages of this system include:

- Portability;
- A short treatment cycle (6–11 hours; this is half that of other systems that use bacteria and enzymes).



Figure 14.

The VRS system has a treatment capacity of 150 kg/day. (Source: Value Recovering Systems Inc.)

Some of the limitations of this system include:

- Limited treatment capacity due to electricity consumption required for heating (even though the intention is to treat 150 kg/day, the manufacturers claim that the maximum capacity could be as much as 500 kg/day — however, this has not been tested);
- High electricity consumption (85 kW/h);
- Dependency on a permanent structure and neutraliser products.

Waste Reduction Through Biodegradation

Another type of aerobic waste reduction process is rapid thermophilic digestion. Systems using this approach are easy to instal on-site and treat organic waste such as faecal sludge.

When organic waste is loaded into an enclosed (but ventilated) aerobic digester, it is mixed with enzymes and selected microorganisms.

The enzymes accelerate the digestion time by activating microorganisms at a temperature of around 60°C or 80°C (depending on the manufacturer's design). The sanitisation of waste is achieved when the temperature in the digester exceeds 70°C. If the moisture of the faecal sludge is higher than 50%, these machines use structuring products such as straw or paper to better process the waste.

EXAMPLE — The Biomax System (Biomax Technologies)

Biomax Technologies is a Singapore based company on the cutting edge of research and development in sustainable green technology. They develop various enzymes to support sustainable bio-businesses.

Their concept of digesting waste on-site has been patented and is called 'Biomax Rapid Thermophilic Digestion Technology'. This process is capable of converting all types of organic waste into premium organic fertiliser in 24 hours, at a temperature of 80°C.

The biological process is achieved by adding BM1 Enzymes into the machine (at a ratio of 1 kg per 1 ton of waste).

Biomax currently make digesters in two sizes, which can process between 15 and 50 tons of waste daily.

The conversion of input waste to output fertiliser is 70%, which means that 15 tons of raw material will yield about 10 tons of fertiliser within 24 hours.

The system has been used to treat different types of biomass such as maize chaff, sugarcane bagasse, fruit pulp, other horticulture waste, livestock waste (animal manure, bedding and straw, slaughtering and hatchery waste), municipal waste (food waste and sewage sludge) and sludge from biogas operations.

The end-product is a pathogen-free and odourless, enriched organic fertiliser. Since it is produced at a high temperature, all harmful microorganisms are killed during the process. The end-product can be directly applied as a fertiliser. It has a high NPK value and an organic matter content of more than 70%. The moisture level of the fertiliser is approximately 20% and this can be controlled during the process.



Figure 15.
The complete Biomax system with a treatment capacity of 15 tons/day. (Source: Biomax Technologies)



Figure 16.
The RMO system has an average treatment capacity of three tons/day. (Source: Christophe Grange)

EXAMPLE — The RMO ('Reduction de Matière Organique') System (Natura Viva)

The RMO concept is an international patented technology, designed and manufactured by the French company Natura Viva. It is very similar to Biomax, but has a different biological rate of composition and final end-product. The RMO can treat a large daily capacity, from 20 kg up to a maximum of 9 tons.

As with the Biomax solution, the RMO reduces the weight and volume of organic waste but with a rate of 85% within three hours, and 95% within 20 hours. Conversion into stabilised compost occurs within 24 hours, with a moisture content of 10%.

The biological process occurs using microorganisms that have been selected based upon their ability to degrade and transform any type of organic waste (these primarily include saprophytic bacteria). The carbon chain element of the waste is converted into carbon dioxide and water.

According to Natura Viva, the recyclable fertiliser by-product has a high nutrient content as confirmed by laboratory analysis. There are zero emissions of harmful gas and the residue is odour neutral.

Some of the advantages of this concept include its compact size, the very low running cost, as well as the very good biologic yield of organic reduction. For example, a six tons/day treatment capacity has an average consumption of 170 kW/h for a total power of 33 kW for a net weight of 2.5 tons and a size of 4.2 m × 2 m × 2.4 m.

It should be noted that this concept could also generate on-site microorganisms (seeded in the by-product compost) that can be injected into pit latrines as an additive that will reduce the faecal sludge volume and stop the accumulation.

However, for the time being, the RMO system has mainly been used in developed contexts, on farms in the French Alps. For example, one such farm in Megève near Geneva, has a machine that has a capacity to treat three tons of sludge per day. Another farm has a machine that can treat nine tons of sludge per day in Bourg-Saint-Maurice in Savoy, while a third farm has a machine that can treat six tons of sludge per day at Lans-le-Bourg near Grenoble.

RMO: Biodegradation Process

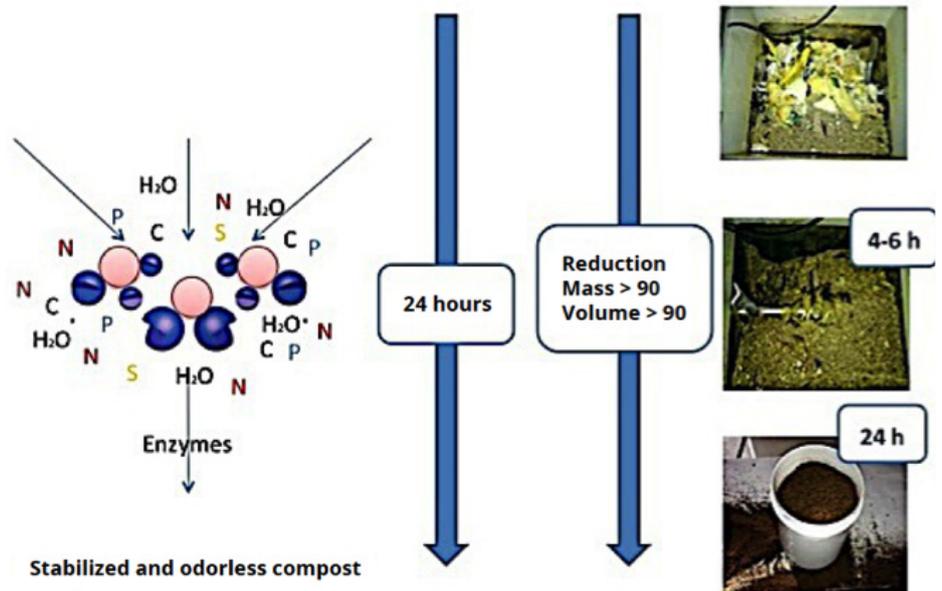


Figure 17.
The RMO biodegradation process. (Source: Christophe Grange)

These concepts have potential for controlling and reducing faecal sludge in emergencies, to treat sludge on-site, and to complement the use of additives.

3.6.3 Adaptability to Emergency Settings

These reduction concepts have huge potential for controlling and reducing faecal sludge in emergencies. They may respond very fast to treat sludge on-site and can work as a complement to additives.

For systems using an aerobic process, any residue is stable and free of pathogens and can therefore be removed safely from a site and placed in landfill. In addition, the compost produced every day may be used as a bio-additive in pit latrines, or in ponds if a lagoon system is selected to accelerate the degradation of organic matter. However, further research and investigations are required to respond to the following questions:

- Are these machines capable of being adapted for field use in an emergency?
- Can they be easily transported by air or sea and installed, maintained, and powered from available networks or generator fleets?
- As the composting process is limited depending on the rate of dryness of sludge, would it be possible to transport structuring products to the site or source them locally (e.g. wheat or corn stubble, straw)?

For systems using an anaerobic process, evaluation has to consider the use of biogas produced according to the efficacy of faecal sludge volume reduction on a daily basis. Feasibility studies have to be carried out to assess if these concepts can represent a viable solution to reducing faecal sludge volumes in an emergency. In this assessment, both the volume of sludge treated per day, as well as the speed of reduction need to be considered.

According to these estimates, future research may assess whether such concepts can meet practical uses in terms of processing capacity, compact size units, the use of biogas and its safety management.

The manufacturers of these systems need to be consulted with regards to the feasibility of adapting their technologies and processes to the needs of WASH humanitarian actors. Each of these machines could be sent to the field to be tested in situ (or tested in the country of residence of the manufacturer). Testing should also include lab scale experimentation to determine the efficacy of the process, including mass balance and compost analysis.

3.7 Concluding Remarks

For the time being, there is a lack of available equipment and technical guidelines on how to manage excreta in emergencies. More standardised and reliable concepts need to be developed to facilitate the implementation and management of sanitation programmes.

The management of excreta during an emergency in an urban context has very limited options. This is because there is a lack of available space to implement suitable infrastructures for users. Digging more pits and increasing the number of raised latrines on the ground may therefore become very difficult depending on the situation.

This report puts forward a few areas for further exploration and development.

Easy to implement, portable toilet systems: New toilet system designs are needed that can allow for the better management of faecal sludge accumulation and can facilitate regular emptying. The proposed devices should be easy to standardise, or scale up, and should allow for easy maintenance and servicing for de-sludging operations.

Another desired feature would be the integration of additive mixing and dosing devices. These could support the development of research into the effectiveness of special mixing and additive injection. These features could be integrated into the design of the new toilets or could be developed as optional emergency kits, to be used depending on their feasibility (i.e. potential running cost of the whole system, and available monitoring facilities).

Standardised guidelines for assessing existing sanitation equipment:

There is currently a lack of standardised methods or guidelines on how to assess and monitor the local availability of equipment for emptying faecal sludge from portable latrines, pipes, pumps, or standby sewer trucks.

Research in this area could focus on developing guidelines to assess the local market in areas of the world that are at a high risk of emergency. These guidelines could propose a method for evaluating available local equipment such as sewer trucks (e.g. number, state, storage capacity, spare parts), and other tools such as de-sludging pumps.

New protocols and applications for the treatment and control of faecal sludge accumulation:

Studies in this area have shown that it is more reliable to consider the control of the accumulation before the latrine is in use, than to try to absolutely reduce the existing sludge volume. It is clear that some additives work, but further research is needed to understand how and when to use these. Research and experimentation studies have to continue to test and compare bio-additives but with the definition of new protocols and objectives.

In addition, the efficiency of additives in reducing faecal sludge has to be experimented with using the support of mixing and dosing devices. These can facilitate a greater efficacy of the aerobic degradation process (as proposed above for the development of new generation models of portable latrines).

Evaluation of speedy aerobic and anaerobic treatment concepts: Additional research needs to be carried out to assess the field effectiveness of speedy aerobic treatment concepts in reducing the volume of sludge collected from pits. Research studies could evaluate if these concepts can be used in the field to treat the sludge on-site and thus avoid transport and dumping. In the treatment of animal manure in farms, aerobic digestion concepts have a high efficiency of 90% reduction of organic waste into stabilised compost within a day.

For anaerobic process concepts, feasibility studies could also help determine the level of daily waste reductions that can be achieved using this approach, as well as whether biogas resulting from the process can be used for downstream application.

Guidelines for assessing and improving dumping sites: Practical guidelines for assessing existing dumping sites would be very beneficial. Guidelines should also include solutions and options on how to improve the capacity of storing and disposing of faecal sludge during a period of emergency. However, even with such guidelines, the process would not be straightforward as setting up or improving a dumping site requires skilled people, qualified in the area of environmental engineering.

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