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Using of composting toilets in tropical rural areas- A risk assessment

by

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Declaration

I, Tereza Weissová, declare that this thesis, submitted in partial fulfilment of requirements for the degree of Bc, in Institute of Tropics and Subtropics of the Czech University of Life Sciences Prague, is wholly my own work unless otherwise referenced or acknowledged.

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Abstract

Through a review of available sources, differences between various types of composting toilets were evaluated and summarized. Attention was focused on the Double Vault system, which proves more beneficial than others, due to the separation of urine from faeces during defecation, which is a prerequisite to avoiding contamination of urine by faeces. The results is a fertiliser with very low presence of pathogenic organisms. Urine has a considerably high nutrients composition compared to faeces. Urine containing 90% nitrogen, 50-65% phosphorus and 50-80% potassium (H. Heinonen-Tanski et al., 1996). Therefore it can be very beneficial in improving soil quality, as a fertilizer or soil conditioner, especially for farmers with a low financial budget.

The potential occurence of pathogens in urine, including *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium* was repeatedly found. However the occurence of urine related pathogens is rare compared to pathogen in faeces, such as *Salmonella*, *Campylobacter jejuni, Escherichia coli, Vibrio cholerea, Shigella, Giardia lamblia* and *Entamoeba histolytica.* Among the worst inactivated pathogens is helminths *(Ascaris, Taenia)*, whose eggs can be extremely resistant to high temperatures and inactivation is not ensured. It was stated for *Ascaris,* that temperatures up to 50°C for at least 60 minutes will ensure inactivation. As for *Taenia* it is neccessery to reach temperature up to 70°C to inactivate the eggs (Epstein, 1997).

Other important factors for inactivation of pathogens are such as pH, the addition of ash or leaves and also competition or antagonism betweeen microorganisms.

*Keywords***:** Composting toilet, human urine, human faeces, pathogen, separation of urine, inactivation, human excreta as a fertiliser

Abstrakt

Na základě dostupných literárních zdrojů, byly popsány základní typy kompostovacích záchodů. Zvýšená pozornost byla věnována tzv. Double Vault systemu, který přináší výrazné výhody, díky separaci moči od tuhé části již během defekace. Za tohoto předpokladu se předejde kontaminaci moči a výsledkem je tak hnojivo, bez obsahu vysokého počtu pathogenů, a oproti tuhým výkalům obsahující 90% dusíku, 50-65% fosforu a 50-80% draslíku (H. Heinonen-Tanski et al., 1996), je tudíž velkým přínosem pro zúrodnění půdy obzvláště pro farmáře s nedostatkem finančních prostředků pro nákup hnojiv.

Dále byl charakterizován potencialní výskyt jednotlivých pathogenů, vyskytujících se v moči, mezi něž řadíme *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* a *Schistosoma haematobium.* Výskyt těchto pathogenů je spíše ojedinělý na rozdíl od pathogenů, vyskytujích se v tuhé části, jako je *Salmonella*, *Campylobacter jejuni, Escherichia coli, Vibrio cholerea, Shigella, Giardia lamblia* a *Entamoeba histolytica.* Mezi nejhůře zničitelné patogeny patří helminti (*Ascaris, Taenia*), jelikož jejich vajíčka odolávají i značně vysokým teplotám a inaktivace tak není zaručena. Bylo zjištěno, že v případě *Ascaris*, pokud teploty nepřesáhnou 50°C po dobu 60minut vajíčka nejsou zničena, pro dostatečnou inaktivaci *Taenia* je zapotřebí dosáhnout teplot přes 70°C (Epstein, 1997).

Důležitými faktory pro inaktivaci pathogenů byly též stanoveny pH, přítomnost přidaných materiálů, působení vzájemných vztahů mezi organismy, jako je antagonismus či kompetice.

Klíčová slova: Kompostovací záchody, lidská moč, lidské exkrementy, patogeny, separace moči, inaktivace, exkrementy jako hnojivo

Preface

Sanitation is regarded as one of the major problems worldwide, especially in developing countries. According to UNICEF (2008) it affects 2.6 billion people in the world, which do not have access to safe water and other hygienic facilities. Although public toilets are available in most countries, the majority of them are poorly maintained. As a result people are dying to banal diseases, caused by drinking unsafe water and by lack of toilets. Open defecation is a major route of contamination of enteric and parasitic diseases. Other individuals and the home environment may be affected through direct contact and also by walking barefoot. In addition, surface water sources may be heavily impacted.

Therefore in developing countries there is an urgent need for safer handling of excreta as well as for fertilisers. International organisations promote dry sanitation and the concept of regarding human excreta as a resource. Millennium Development Goal (MDG) include a target to reduce by half the proportion of people without access to basic sanitation by 2015. In December 2006, the United Nations General Assembly declared 2008 'The International Year of Sanitation', in recognition of the slow progress being made towards the MDGs sanitation target.

Composting toilets are one of a good way how to improve sanitation in these areas. It can be beneficial both enonomically and socially. The use of human excreta as fertiliser in agriculture is a common practise in parts of South East Asia benefiting production (Jensen *et al*., 2008) and as we know human excreta are natural resource which is always available in all societies. Unfotunately, their value is higly underestimated in present agriculture and horticulture including in many tropical developing countries. Especially human urine is rich in nitrogen. This „free“ fertiliser should be used as much as possible and needed (Heinonen-Tanski *et al*., 1996).

Using of composting toilets will assist in creating better living conditions as defecation is concentrated in a controlled area, which provides easier handling of excreta. Composting is a low-cost and easy to operate potential engineering option for sludge stabilisation in low and middle income countries. It is a well-known and widespread process used for organic solid waste treatment and pathogen removal. The potential health risk of pathogens needs to be considered, but we can avoid it by a well managed composting process. It will ensure safe using of material for fertilising in agriculture. Which can improve soil structure without using mineral fertilisers.

Contents

1. Introduction

1.1. *Composting toilet characterisitics*

Composting toilet systems (sometimes called biological toilets, dry toilets and waterless toilets) contain and control the composting of excrement, toilet paper, carbon additive, and optionally, food wastes. Unlike a septic system a composting toilet system relies on unsaturated conditions, where aerobic bacteria and fungi break down wastes, just as they do in a yard waste composter. Sized and operated properly, a composting toilet breaks down waste to 10 to 30 percent of its original volume. The resulting end-product is a stable soil-like material called humus. Then humus is used as a soil conditioner on edible crops.

The primary objective of the composting toilet system is to contain, immobilize or destroy pathogens that cause human disease, thereby reducing the risk of human infection to acceptable levels without contaminating the immediate or distant environment and harming its inhabitants.

A secondary objective is to transform the nutrients in human excrement into fully oxidized, stable plant-available forms that can be used as a soil conditioner for plants and trees (Del Porto, 2000).

1.2. *Composting toilets used in tropics*

We will find many different types of composting toilets. Some composting toilets are large with a significant space requirement in the room below the toilet. Others are not significantly larger than a traditional toilet. Those small systems generally do not claim to finish the composting on-site, but are preparing the human waste materials for secondary composting in another location. Some composting toilets use electricity. Some electrical systems use fans to exhaust air and increase microbial activity. Other systems require the user to rotate a composting drum or otherwise stir the composting humanure from time to time.

1.2.1. The simplest single pit composting toilet

The single pit compost toilet, or Arborloo is simple toilet made up of pit and toilet house which provide privacy.

The pit fills up with a mix of excreta, soil, wood ash and leaves. Leaves are put in the base of the pit before use and every day some soil and wood ash are added to the pit. Dry leaves are also added to the pit from time to time, if available.

When soil, ash and leaves are regularly added to excreta, the conversion into compost takes place at a faster rate compared to excreta to which nothing has been added. The daily addition of soil and ash also helps to reduce flies and smells. If ash or leaves are not available add soil alone. When the Arborloo pit is full, the parts of the toilet are moved to another place, rebuilt and used in the same way again. A thick layer of soil is placed over the filled pit (Morgan, 2007).

1.2.2. The double pit composting toilet

The double pit compost toilet, Fossa alterna, is made up of two pits and toilet house which provides privacy for users.

Like the earlier system each pit fills up with a mix of excreta, soil, wood ash and leaves. Leaves are put in the base of the pit before use and every day some soil and wood ash are added to the pit. Dry leaves are also added to the pit. No garbage such as plastic, rags, and bottles is put down the pit. One pit fills up first. During the first season the second pit is unused or is filled with leaves. After the first year the first pit will have filled.

1.2.3. Urine-diverting toilets

Urine-diverting toilets use a special pedestal in which the urine enters the front part of the pedestal and is then diverted through a pipe and is thus separated from the faeces which fall directly downwards into a vault or container. Some dry soil and wood ash is added to cover the faeces after every visit. This covers the deposit and helps to dry out the surface of the faeces and makes them easier to handle and transfer. The distinct advantage of this method is that the urine can be collected separately, making it available as a liquid fertiliser. Also the solid component, being in a semi dry state, is much easier to handle and is safer from the beginning, even if it does initially contain pathogens. Being semi dry, it does not smell so much and its potential as a fly breeding medium is much reduced compared to the mix of urine and faeces. Eventually the faeces become completely composted.

There are many types of urine-diverting toilets available for use. Many have double vaults in which one vault is used first and when full the second vault is used.

When the second vault is full the first is emptied in the same way as the double pit composting toilet.

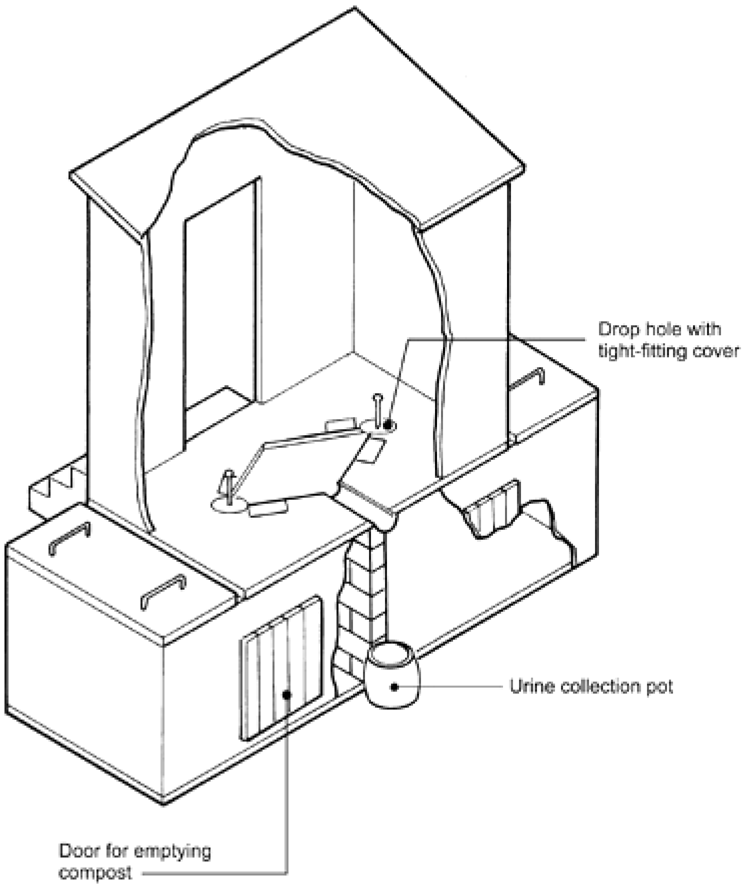

Figure 1. 1 Double Vault with urine separation

Source: IRC, 2008

The particular urine-diverting toilet described here uses a single vault in which the urine is collected in a plastic container and the faeces, together with soil and ash added to help the composting process, are collected in a 20 litre bucket held in the vault. Once the bucket is nearly full its contents are transferred to a secondary composting site like a cement jar or alternating shallow pit where the ingredients continue to compost for 6 – 12 months, before being applied to the garden to enhance the quality of soil (Morgan, 2007).

When latrine contents is collected in buckets from each household, urine is often collected separately and poured into the drain to avoid smells and to prevent the latrine from filling too quickly. Already in 1867 it was known that "the proportion of value of the fertilising ingredients held in solution in urine to that contained in faeces is as six to one". In many parts of the world it is also a tradition to keep the urine and faeces apart.

The old Japanese practice of nightsoil recovery from urban areas separated urine and faeces, since urine was regarded as a valuable fertiliser. In Yemen the urine is drained away and evaporated (Figure 1.2) to obtain the faeces as a dry fraction without smell for later use as fuel, a system that has been in use for hundreds of years (Schönning *et al.*, 2001). Evaporation of nitrogen (ammonia) through heat application will substantially reduce the number of microorganisms. Drying urine in open trenches has been tested in Sweden and Mali but will result in substantial loss of nitrogen, while phosphorous and potassium will be retained. A dry urine fraction (in the form of a powder) has not been shown to pose microbial health risks.

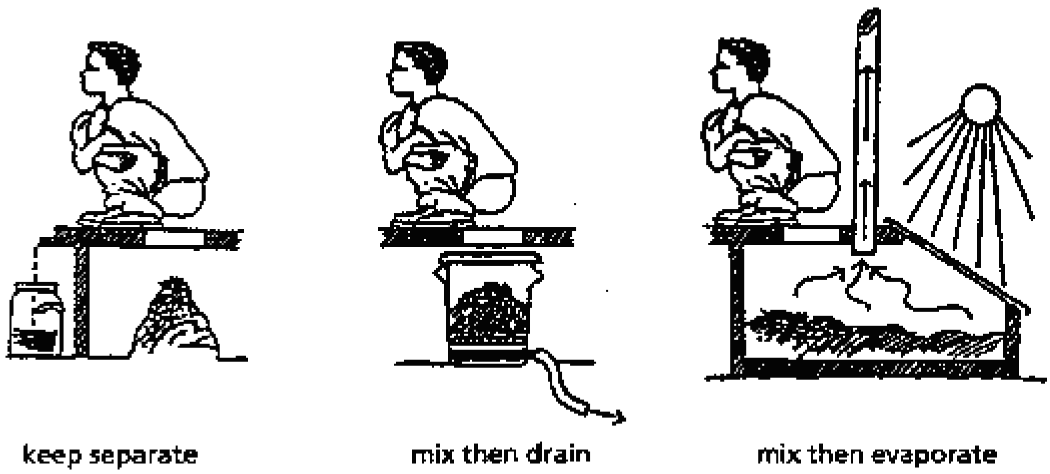

Figure 1. 2 Ways of separation urine and faeces
Source: Winblad, WHO, 1996

1.3. Human urine and faeces

Human urine is a natural resource produced by every household. In human excreta, urine contains mostly nitrogen (N), phosphorus (P), and potassium (K). Urine has a fertilizer value of N/P/K 18:2:5, and for urine mixed with flush water, the ratio can be N/P/K/S 15:1:3:1 (Pradhan *et al.*, 2007).

Each year, one person produces 500 kg of urine as compared to 50 kg of faeces. This faeces contains some 10 kg of dry matter. Thus one person produces approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium per year. Of the human excreta, urine contains some 90% of the nitrogen, 50–65% of the phosphorus and 50–80% of the potassium (H. Heinonen-Tanski *et al.*, 1996). The figures presented above depend also on the body weight of the persons involved, the climate, water intake, and diet characteristics, especially its protein content.

In Figure 1.3. (Schouwa *et al*., 2001) are presented data based on three test persons in Southern Thailand. It shows almost same results as above, that nitrogen, phosporus, potassium and sulfur mainly are excreted via the urine, whereas calcium, magnesium, copper, zinc, nickel, cadmium, lead and mercury are mainly excreted via the faeces.

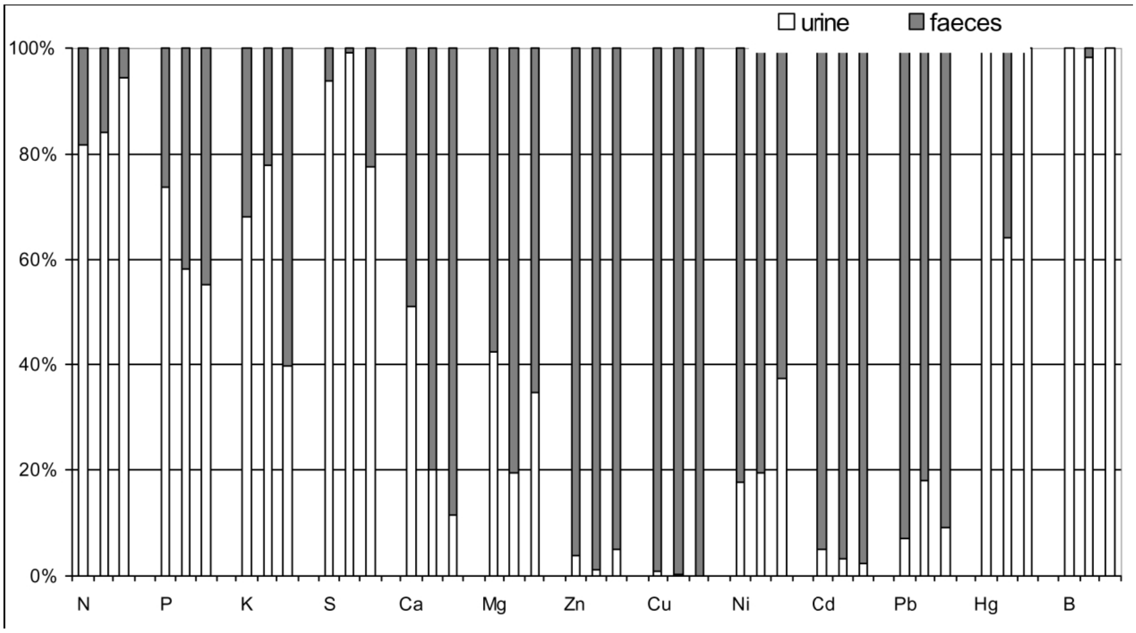

Figure 1. 3 The percentage distribution of elements in urine and faeces
Source: Schouwa *et al*., 2001

The nutrient content present in human urine may mean it can be a good fertilizer for plants. This may be increasingly important in the future, with population growth and the corresponding increased demand for food and demand to save water and energy.

1.3.1. Charasteristics of human urine

The chemical composition of urine depends on many factors. The consumption of protein-rich food increases N in urine, but this is usually expensive in developing countries, and therefore it would be predicted that N contents in urine would be lower in developing countries than in the developed countries. Nitrogen loss by sweating due to high temperatures and physical labor in tropical countries may also reduce the N content in urine (Pradhan *et al*., 2007).

Fresh urine contains only very few enteric microorganisms. Urine can become contaminated with pathogens from small particles of feces during collection, because human faeces always contain high amounts of enteric microorganisms including many pathogens and opportunistic pathogens, even when the affected person does not experience any symptoms. The role of opportunistic pathogens is important since a considerable percentage of the world population- pregnant women, children, old people and people stressed by sicknesses, malnutrition, etc.- are extra sensitive to their impact. But when the pH increases to the alkaline state (pH 9), the numbers of enteric microbes become reduced (Pradhan *et al*., 2007). Microbial reduction can happen more rapidly in tropical countries because of high temperatures.

According to Tønner-Klank *et al.* (2007) number of pathogen in diverted urine can be effectively reduced by prolonged storage for 3–6 months. In contrast, the fecal matter contains high numbers of naturally occurring enteric bacteria, and occasionally disease-causing pathogens like *Salmonella*, *Campylobacter*, enteric viruses, and parasites, of which the latter survive prolonged external environmental exposures well.

1.3.2. Benefits from separating urine and faeces

If urine and faeces can be separated, both of these fractions can easily be treated and utilised. The separation must be done so that the urine fraction is totally free of faeces, but a small amount of urine in the faeces fraction is not a problem. To get pure urine, the separation should be made already in the toilet.

If the faeces fraction is drier, the enteric microorganisms furthermore have a lower possibility to survive. This lessens the risks of leaching and transportation of enteric microorganisms to groundwater or surface water, including during periods of flooding.

The composting process always involves a loss of nitrogen which can be as much as 70%. In comparison, losses from urea are less than 20%. The separating toilet can thus mean a better nitrogen economy (Heinonen-Tanski *et al*., 1996).

1.3.3. Pathogens in human urine

In a healthy individual the urine is sterile in the bladder. When transported out of the body different types of dermal bacteria are picked up and freshly excreted urine normally contains <10 000 bacteria per ml. By urinary tract infections, which in more than 80% of cases are caused by *Escherichia coli*, significantly higher amounts of bacteria are excreted. However, these have not been reported to be transmitted to other individuals through the environment. Pathogens causing venereal diseases may occasionally be excreted in urine but there is no evidence that their potential survival outside the body would be of health significance (Jenkins, 2005).

The pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium.*

When infected with urinary schistosomiasis, caused by *Schistosoma haematobium*, the eggs are excreted in urine, sometimes during the whole life of the host. The eggs hatch in the aquatic environment and the larvae infect specific aquatic snail species, living in freshwater. If the eggs do not reach the snail host within days, the infectious cycle is broken. After a series of developmental stages, aquatic larvae emerge from the snail, ready to infect humans through penetration of the skin. If the urine is stored for days and is used on arable land, the use diminishes the risk of transmission of schistosomiasis (Schönning *et al*., 2004).

Urine may be considered safe to use as a fertiliser for any crop, if stored at 20°C for at least 6 months, whereas if stored at lower temperatures or for a shorter period, pathogens might remain in the urine. It is possible to reduce the overall risk, however, by introducing other safety barriers beside storage. For example, when applying urine as fertiliser, a close-to-ground technique that will minimise the formation of aerosols. Harrowing after spreading will further decrease the exposureand this practise is also preferred in order to minimise the losses of ammonia through evaporation (Höglund *et al.*, 2002).

1.3.4. Pathogens in faeces

Enteric infections can be transmitted by pathogenic species of bacteria, viruses, parasitic protozoa and helminths. From a risk perspective, the exposure to untreated faeces is always considered unsafe, due to the potential presence of pathogens. There are many different types of organisms causing enteric, parasitic or other types of infections which may occur, and their prevalence in a given society is often unknown.

The pathogens of concern for environmental transmission through faeces mainly cause gastrointestinal symptoms such as diarrhoea, vomiting and stomach cramps. Several may also cause symptoms involving other organs and severe sequels (Schönning *et al*., 2004).

Among bacteria, at least *Salmonella*, *Campylobacter* and *E. coli* are generally of importance, in both industrialized and developing countries, when evaluating microbial risks from various fertilizer products including faeces, sewage sludge and animal manure. They are also important as zoonotic agents (transmission between humans and animals, as well as their faeces/manure). In areas with insufficient sanitation, typhoid fever (*Salmonella typhi*) and cholera (*Vibrio cholera*) constitute major risks in relation to improper sanitation and contamination of water. *Shigella* is also a common cause of diarrhoea in developing countries, especially in settings where hygiene and sanitation is poor. The parasitic protozoa, *Giardia lamblia* and *Entamoeba histolytica* ares also recognized as an infection of concern. In developing countries, helminth infections are of greater concern. The eggs (ova) of especially *Ascaris* and *Taenia* are very persistent in the environment. Hookworm disease is widespread in moist tropics and subtropics, and affects nearly one billion people worldwide.

The uninfective eggs from *Ascaris* and hookworms that are excreted in the faeces require a latency period and favourable conditions in soil or deposited faeces to hatch into larvae and become infectious (CDC, 2005).

Schistosoma haematobium has earlier been mentioned in relation to excretion with urine. Other types of *Schistosoma*, e.g. *S. japonicum* and *S. mansoni* are excreted in faeces. The use of faeces, as for urine, should not have an impact unless fresh and untreated faecal material is applied close to freshwater sources where the snail is present (Schönning *et al*., 2004).

1.4. Inactivation of the microorganisms

The increasing interest in many countries for the use of recycled sewage sludge as fertilizer on agricultural land demands research in effective methods for removal of pathogens (Eriksen *et al*., 1995).

The faeces contain approximately 10^{10} microorganisms per gram dry matter and some of them can be pathogenic, therefore the faecal matter has to be disinfected before use as a fertiliser or soil conditioner. In cases of diarrhoea, large amounts of pathogens are excreted and then it is even more important that the excreta are disinfected to avoid transmission of disease (Vinnerås *et al*., 2003a).

Different methods are available for inactivation of the microorganisms. Microbial inactivation depends on chemical or thermal disinfection to reduce pathogens and it is accomplished by containment, competition and antagonism between organisms, environmental factors and pasteurisation.

1.4.1. Containment

Pathogens can not survive for long time they have left the human host. Like all organisms, human pathogens have specific lifetimes. An organism’s lifetime is shortened in the hostile environmental of an aerobic composter. Containing the excreta for an extended period of time brings about the death of pathogens and reduces the risk of infecting new hosts through ingestion, the primary pathway for enteric pathogen transmission (Del Porto *et al*., 2000).

1.4.2. Competition

The competititon among composting organisms for available carbon and other nutrients is intense. Human pathogens become food for the well-adapted aerobic soil organisms that thrive in the compost. When available nutrients are consumed, the microorganisms begin to consume their own protoplasm to obtain energy for cell maintenance. When these organisms die, their protoplasm and cellular matter is digested by other organisms. Eventually if no new food sources are presented, all of the energy will be released and the matter fully oxidized (Del Porto *et al*., 2000).

However it is not proven to what degree this is an effective method of sanitation, especially for viruses, which are inactive outside the human body. After disinfection has been carried out, a risk for regrowth of pathogenic bacteria exists. This risk for regrowth is drastically reduced if the material is properly decomposed by aerobic or anaerobic treatment, both by the higher concentrations of other microorganisms and the lower content of available organic matter (Vinnerås *et al*., 2003a).

1.4.3. Antagonism

Some composting organisms produce toxic substances (Del Porto *et al*., 2000; Lui, 2000) which harm, inhibit or kill other organisms. For example the actinomycete *Streptomyces griseus* produces streptomycin, a well-known antibiotic. The soil bacteria *Bdellovibrio bacteriovorus* parasitizes the infamous *Escherichia coli*, and multiplies within the host cell, eventually killing it (Del Porto *et al*., 2000).

According other source, when pathogenic microbial antagonism was studied, was indicated that the development of inhibitors originated in the presence of actinomycetes and molds and concluded that this phenomen is due to an unknown antibiotic-producing organism. Although the optimum temperature that produces the antibiotic was not determined. Was indicated that 50-55°C appeared to be the temperature at which these substance are generated.

On other hand was state that no antagonistic material in compost was found. But it was also said that inidgenous organisms are in a better position to compete for nutrients than pathogenic microorganisms. Furthermore, was indicated that since thermal destruction is not instantaneous, time acts as a factor, providing for the combination of several inhibitory factors to act on pathogenic organisms (Epstein, 1997).

1.4.4. Environmental factors

1.4.4.1. pH

Collected waste is often acidic, with pH normally ranging between 4.5 and 6. The acidity is due to the presence of short-chain organic acids, mainly lactic and acetic acid. These acids are found in raw material, and their concentrations increase during the initial phase of composting. The presence of short-chain fatty acids under acidic conditions and their absence during alkaline conditions indicate that they are a key factor regulating the pH in composting. During successful and fully developed composting, the pH often rises to 8-9 (Sundberg *et al.*, 2004).

One common method for disinfection of faecal matter in developing countries is the use of ash for raising the pH, which disinfects the faeces. The effects of this method depend on the amount of ash used and the origin of the ash, since the amount of available hydroxide ions varies. Studies on *Salmonella typhimurium* and faeces treated with ash have shown a die-off of from 8 $\log_{10}$ after three weeks of storage down to 2 $\log_{10}$ in seven weeks, in different toilets in Vietnam. In the same study, the reduction in viable *Ascaris* was also monitored. During the nine weeks of monitoring, the reduction compared to the blank reference was between 50% and 100% (no viable eggs were found) (Vinnerås *et al.*, 2003a).

Most pathogens favour a neutral pH, around 7. A pH of 9 and above will reduce the pathogen load with time, but for rapid inactivation a pH of 11-12 is desired in treatments where lime is added.

The addition of ash or lime to excreta, practised for a long time, has several benefits. It reduces the smell, covers the material, which in turn reduces the risk for flies, decreases the moisture content, promotes pathogen die-off through the elevated pH effect (Schönning *et al.*, 2004).

Results from a study of urine-diverting latrines in Vietnam showed that it is possible to achieve a total die-off of *Ascaris* ova and indicator viruses within a six-month period if one to two cups of ash were added after each visit (defecation). The mean temperature ranged from 31-37°C (overall maximum was 40°C), the pH in the faecal material was 8.5-10.3 and the moisture content 24-55%. The inactivation was described as a combination of factors but pH for the bacteriophage inactivation was shown to be statistically significant as a single factor (Schönning *et al.,* 2004).

1.4.4.2. Temperature-time relation

There are two primary factors leading to the death of pathogens in humanure. The first is temperature. The second factor is time. The lower the temperature of the compost, the longer the subsequent retention time needed for the destruction of pathogens. Given enough time, the wide biodiversity of microorganisms in the compost will destroy pathogens by the antagonism, competition, consumption, and antibiotic inhibitors provided by the beneficial microorganisms.

A thermophilic compost will destroy pathogens, including worm eggs, quickly, possibly in a matter of minutes. Lower temperatures require longer periods of time, possibly hours, days, weeks, or months, to effectively destroy pathogens. One need not strive for extremely high temperatures such as 65°C in a compost pile to feel confident about the destruction of pathogens. It may be more realistic to maintain lower temperatures in a compost pile for longer periods of time, such as 50°C for 24 hours, or 46°C for a week (Jenkins, 2005).

Intensity of temperature depends on substrate, separation of urine, amendments, aeration and structure of matter. The different substrate mixtures were tested (Vinnerås *et al*., 2003a). The mixtures used in addition to the straw amendment were: (1) faeces only (2) faeces and food waste (3) faeces, urine and food waste and (4) faeces and urine.

The largest heat production and thereby the best increase in temperature was achieved with the substrate that contained faeces and food waste (Fig. 1.4). High temperatures were also attained in the compost containing faeces only and in that containing the urine, faeces and food waste mix. The mix of faeces and food waste contains large amounts of energy that easily can be biologically transformed into heat. Therefore, the mix of faeces and food waste proved to give the highest temperatures, and thus the best mixture for disinfection of faeces by thermal composting.

It is also important to maintain the structure and thereby to keep the porosity and pore size as high as possible. The easiest way to do this is by mixing the material once the temperatures have increased. It was found that during the 18 days of composting, the highest degradation of organic matter was obtained with the mix of faeces and food waste (53%), followed by the mix of faeces, urine and food waste (39%). These two mixtures were those that reached the highest temperatures during the composting. The degradation of the other two mixes was lower, 21% and 11% for faeces only and faeces plus urine, respectively (Vinnerås *et al.*, 2003a).

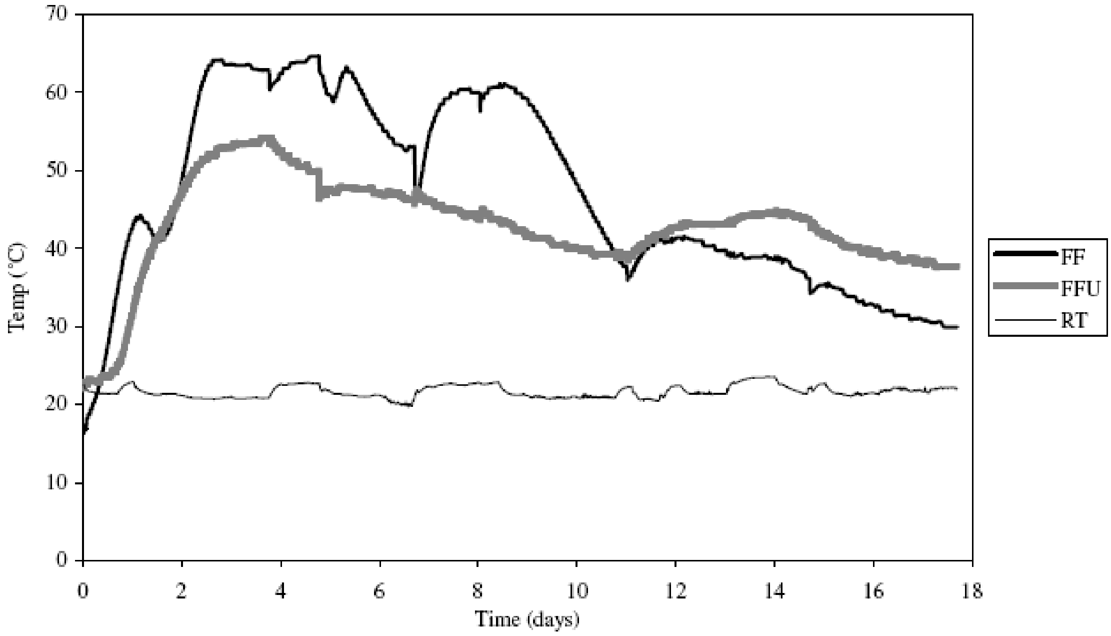

Figure 1. 4 The temperatures in the laboratory-scale composting experiment in the two mixtures of material that produced the highest temperatures, compared to the surrounding room temperature (RT), food waste and faeces (FF), food waste, faeces and urine (FFU)

Source: Vinnerås *et al.*, 2003a

During the study was also calculated difference between safety margins for total die-off of different pathogens in faecal, food waste mix (FF) and mix of faeces, food faste and urine (FFU).

The lowest safety margin was found for the Enteroviruses, where the faecal and food waste mix (FF) had a safety margin of 130 times, which must be considered an extremely high margin (Tab.1.1). The mix of faeces, food waste and urine (FFU) did not reach as high temperatures as FF. The safety margins were therefore much smaller, for Enteroviruses only 8 times and for *Salmonella* and *Ascaris* only 14 and 15 times, respectively (Vinnearås *et al.*, 2003a). However, this is still a reasonable margin of safety considering the type of material and how it is expected to be used. This experiment showed that by mixing faeces, food waste and amendment it is possible to reach high temperatures, thus securing the disinfection of pathogens in the material.

Spores of bacteria will probably not be affected by these temperatures, although the fluctuation in temperature arising from mixing and adding water is reminiscent of a tyndalisation process that will affect the number of surviving spores. However, there is still a risk for regrowth of pathogenic bacteria if any survive the treatment. This risk for regrowth is drastically reduced by the high degradation of the organic matter and the high concentration of other microorganisms that will hamper the regrowth of pathogenic bacteria (Epstein, 1997).

Table 1. 1 The safety margin for desinfection of faecal compost as the number of times the limit of no viable organisms found was fulfilled in the two most prominent mixes tested

	Ent. Virus	*Salmonella*	*V. cholera*	*Shigella*	*Ascaris*	*Schistosoma*	*Taenia*
FF	130	670	700	1800	2300	24	4100
FFU	8	14	3000	50	15	200	120

*** Higher safety margin better level of inactivation. Results showed faecal, food waste mix (FF) had higher safety margin than mix of faeces, food waste and urine (FFU).**

Source: Vinnerås *et al.* , 2003a

Other study was done by Tønner-Klank *et al.* (2007) in Denmark, they measured inactivation of pathogens, course of temperature under the different conditions. In one container collected fecal material was homogenised manually, amendments (sucrose, fertiliser, ryegrass) added and mixed.

A maximum temperature of 56.8°C was reached after 8–9 days and a temperature above 55°C was maintained for 52.3 hours. Temperatures at all depth levels in the container were below 40°C after 13–14 days and were below 30°C at day 21. A similar temperature development was observed in the other container (Figure 1.5).

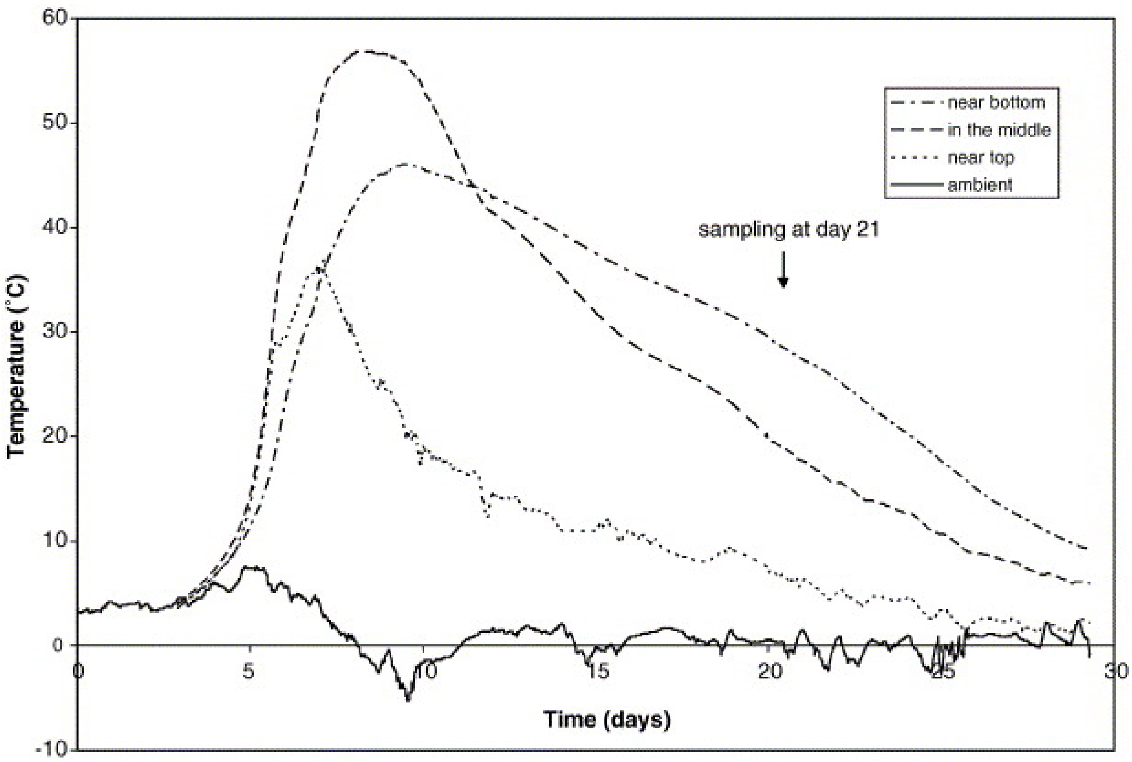

Figure 1.5 Temperature development in 220-l composting container. The temperature was measured 15 cm (near top), 30 cm (in the middle) and 45 cm (near bottom) below the surface of the fecal material. The material consisted of faeces material amended with grass clippings and a solution of sugar and inorganic fertiliser.

Source: Tønner-Klank *et al.*, 2007

1.4.4.3. Ammonia content

In source separated urine, as well as other nitrogen-rich materials, uncharged ammonia, NH_3, has been recognised to be microbiocidal and manure, sewage sludge and faecal material have been amended with ammonia for the evaluation of microorganism inactivation (Nordin, 2007).

The large ammonia content in the material gives a higher total ammonia emission during composting, with negative environmental effects, especially since there is no lack of nitrogen either in the faeces or in the food waste. High temperatures combined with high exchange rates of the air will increase the ammonia losses (Vinnerås *et al.*, 2003a).

The concentrations of ammonia in sludges varies widely, depending on such factors as the source of sludge, the amount of dilution, and prior treatment and storage. Thought ammonia concentrations in sludge are rarely reported in the literature, its presence could have an important effect on treatment convert NH_4^+ to NH_3, a chemical species known to inactivate many organisms (Pecson *et al.*, 2007).

1.4.5. Pasteurisation

One of the more reliable methods for sanitation is the use of heat inactivation (pasteurisation). There are a lot of methods that can be used for heat production. One way is to use the biological matter in the collected faeces for heating, and the heat production can either be done by incineration or by aerobic digestion. By using the biodegradable matter in the faeces the volume also decreases and if the material is composted a good soil conditioner will be produced. To attain temperatures high enough for heat inactivation in the compost throughout, the vessel has to be insulated to retain the heat produced (Vinnerås *et al*., 2003a). Pasteurisation is commonly used as a pre-sanitation step to anaerobic digestion of animal-by products, but at present is not commonly included in the digestion of sewage sludge (Nordin, 2007).

This method will destroyed pathogens by heating the matter in for one hour at 62°C, then cooling it rapidly to prevent re-inoculation. Pasteurization can be accomplished by a variety of means, but the most common is by applying sufficient heat from external sources such as electric or propan heaters. In some causes, the use of microwave or solar energy is used (Del Porto *et al*., 2000).

1.4.6. Liming

Liming destroys sludge pathogens in two key ways: sludge pH increase and temperature rise (Capizzi-Banas *et al.*, 2004). Among the pathogens of epidemiological relevance *Ascaris* eggs are the most resistant to liming.

1.4.7. Incineration

Incineration of the faeces will minimize the risk for transmission of disease related to the final use of the ash since essentially all pathogens will be removed. Systems utilizing incineration have not been introduced on a planned level so far. The primary handling will still involve hygienic risks but systems with incineration in direct connection to the toilet may be developed in the future. As an alternative, high temperature levels will have the same beneficial effect from a microbial point of view. The ash is a potent fertilizer with phosphorous and potassium retained, although the nitrogen will be lost (Schönning *et al*., 2004). According to Nordin (2007) approximately 90% of the nitrogen is lost.

1.5. *An example of Ascaris lumbricoides*

Ascaris eggs, together with *Salmonella* bacteria are known to survive and maintain infectivity for a long time in sewage sludge (Eriksen *et al.,* 1995). Of the classes of pathogens present in biosolids, helminth eggs are the most resistant to many types of inactivation. Eggs of the genus Ascaris have the highest resistance and survive under numerous treatment conditions (Pescon *et al.,* 2007) and have therefore fro many years used as important hygiene indicators in assessing the quality of compsted faeces. Most published work used *Ascaris suum* as an indicator of helminth egg survival (Tønner-Klank *et al*., 2007).

1.5.1. Effect of temperature

The inactivation rate of helminth eggs was strongly dependent on temperature, in agreement with earlier studies. In all cases, each 10°C increase in temperature caused a statistically significant decrease in t_{99}. At pH 7 and 12 with zero added ammonia, t_{99} decreased from several hundred days at 20°C to about 100minutes at 50°C. In the samples amended with ammonia, large decreases were also seen as the temperature was increased. At 50°C, the effect of temperature became dominant, and no significant difference in t_{99} values was observed with a change in pH or with addition of 5000 mg/l ammonia (Pescon *et al.*, 2007).

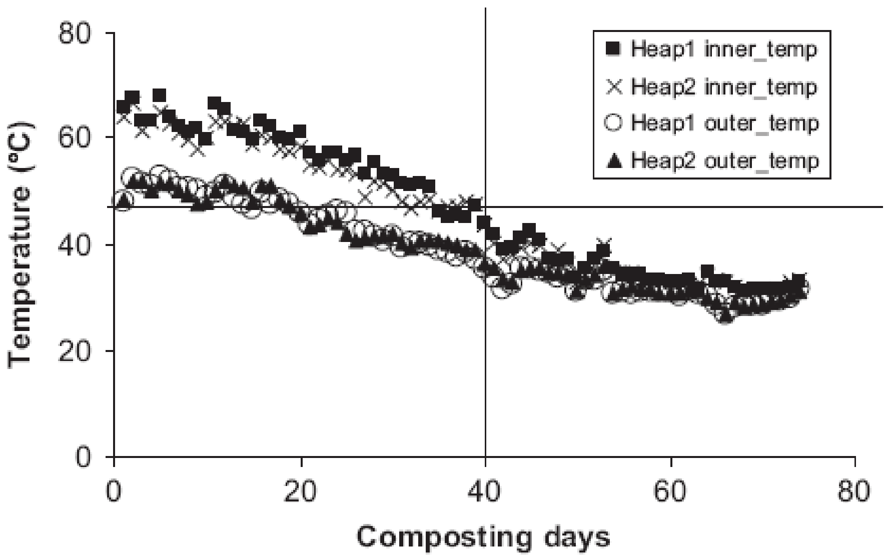

Figure 1.6 Temperature pattern during faecal sludge and organic waste composting

Source: Koné *et al.,* 2007

According other study, the temperature at the centre of the compost heaps was maintained at >45°C for 40 days, thus indicating the positive effect of temperature on the inactivation of Ascaris eggs. In both setups, viability of Ascaris eggs was reduced from 58% to less than 20% and 10% within 40 and 60 days, respectively (Figure 1.7) (Koné *et al*., 2007).

Course of temperature was measured by Koné *et al*. (2007) (Figure 1.6). The inner temperature of the compost heaps decreased from 68 to 65°C at the beginning of the process and reached about 60°C 20 days later. In both cases, the inner temperature was equal to or higher than 45°C during 40 days of composting. The outer temperature exhibited less variation, i.e. from 50 to 53°C at the beginning of the composting process and 45°C 20 days temperature pattern. Exposure to temperatures over 45°C for at least 5 days is known to inactivate Ascaris eggs. Higher temperatures speed up the desiccation rate of Ascaris cells and destroy the cells ability to slow down desiccation.

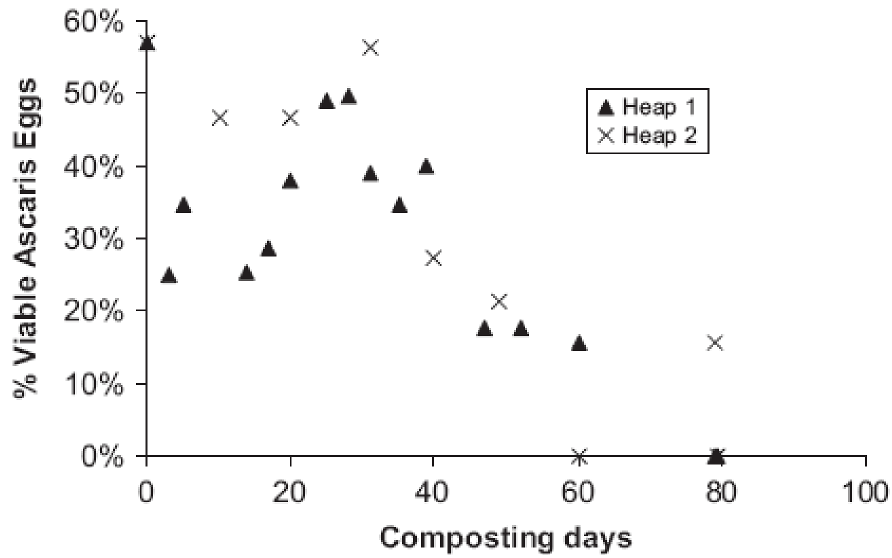

Figure 1.7 Dynamics of Ascaris eggs viability reduction during composting of faecal sludge and organic solid waste

Source: Koné *et al.*, 2007

1.5.2. Effect of pH

Alkaline stabilization is one option but the effectiveness of this option varies greatly. The choice of alkalinizing agent may also affect the temperature profile. Of the three chemicals most often used for stabilization (CaO, $Ca(OH)_2$, and ash), only CaO undergoes an exothermic hydration reaction that produces heat and raises sludge temperatures (Pescon *et al*., 2007).

Pescon *et al*. (2007) showed that uncharged ammonia causes inactivation of Ascaris eggs, and inactivation was directly proportional to the activity of NH_3. High pH alone did not cause inactivation, but played an indirect role by converting ammonia into its uncharged form.

Liming was used as a treatment to destroy pathogens by Capizzi-Banas *et al.* (2004). It was state that liming must produce a homogenous mixture at a pH of 12 or more and must maintain this mixture in a time-temperature regime leading to a negligible level of viable Ascaris egss. This study has demonstrated that 75 minutes at 55°C or 8 minutes at 60°C will lead to a negligible level of viable Ascaris eggs.

1.5.3. Effect of ammonia

Another factor that may cause variability is ammonia. At 20, 30, and 40°C, ammonia caused a dose-dependent increase in inactivation and led to a 7.5 x decrease in t_{99} at the highest ammonia concentration tested (5000mg/l NH_3-N) compared to unamended sludge (Pescon *et al.,* 2007).

1.5.4. Other treatment

According study done by Koné *et al*. (2007) where dewatering and co-composting was used to inactivate helminth eggs. Was found that the high concentration of helminth eggs contained in the raw faecal sludge could not be inactivated by dewatering or drying beds.

2. Work objective

The objective of this study was to investigate ways to process human waste in order to decrease the presence of pathogens which can potentially cause human diseases. Furthermore to ensure the waste can then be used as agricultural fertiliser or conditioner improving soil quality.

3. Materials and Methods

A systematic literature review was performed using an electronic search of Agricola, Biological Abstracts, ScienceDirect, Springer, EBSCOhost. Primary search terms used were „human faeces“, „human urine“, „pathogen“, „Vietnam“, „composting“, „nightsoil as a fertiliser“, „composting toilet“, „temperature-time“, „inactivation of pathogens“, „*Ascaris*“ Also manual search of books and journals was used.

4. Results and Discussion

Research has shown that pathogens are present during the composting process. Most of it, will survive well at low temperatures and die off at high temperatures. To ensure inactivation in composting processes, it is necessary to reach adequate temperatures and pH. The differences in inactivation are seen in Table 1.2, however the information for the corresponding effective time is currently lacking.

As a important factor influencing health risk by pathogens occuring in matter was state separation of urine from faeces is considered an important factor in lowering the potential health risk presented by pathogens. As it was stated before, diverted urine contains only small amounts of pathogens, which mostly originate from faecal contamination. Other benefits are obtained through separation, including a lower volume of faecal material, less smell and a more convenient and acceptable use of the toilet and handling excreta. Drier faecal fraction will cause less risk for leaching and transmission of pathogens through fluids to the groundwater and the surrounding environment.

The main discussion focuses on the inactivation of pathogens because this is a highly significant factor when using human waste as a fertiliser in agriculture. Thermal treatments are known to be very effective for inactivating pathogens. The inactivation degree obtained by thermal treatment differs from pathogen to pathogen and mainly depends on the duration and the temperature of the treatment (Capizzi-Banas *et al*., 2004). According to a study done by Vinnerås *et al.* (2003a), Table 1.1, a high temperature is also dependent on the composition of the mixture. The temperature of faecal, food waste mix (FF) was significantly higher than in mix of faeces, food waste and urine (FFU). Also measured safety margin showed a higher number of inactivation in the faecal food waste mix (FF). This experiment showed that by mixing faeces, food waste and an amendment, it is possible to reach high temperatures, thus providing better conditions for inactivation of pathogens in the material.

To reach high temperatures in the mixture we can use liming as a treatment, as it will increase pH and temperature at the same time. Liming was studied on example of *Ascaris*. It was stated that liming must produce a homogenous mixture at a pH of 12 or more and must maintain this mixture in a time-temperature regime leading to a negligible level of viable *Ascaris* egss. This study has demonstrated that 75 minutes at 55°C or 8 minutes at 60°C will lead to a negligible level of viable *Ascaris* eggs

(Capizzi-Banas *et al*., 2004). However, temperature is not the only factor contributing to pathogen inactivation. Among the pathogens of epidemiological relevance, *Ascaris* eggs are the most resistant to liming (Capizzi-Banas *et al*., 2004), also during alkaline sludge stabilization inactivation is higly variable (Pecson *et al*., 2007). The predominance of *Ascaris* in faecal sludge and the environment can be explained by its higher egg production and capacity to survive. The female *Ascaris lumbricoides* worms produce 200,000 eggs per day, compared to *Trichuris trichiura,* for example, which can produce only 2000–10,000 eggs daily (Koné *et al*., 2007).

Inactivation of pathogens is highly dependent on specific conditions in treatment, such as pH, temperature, moisture and content of ammonia. As we can see in Table 1.2, addition of ash, leaves or lime influenced the duration of inactivation. The biggest differences are found with *Ascaris*, where pH was identified as the most important single factor determining inactivation. A pH of 9-11 gave faster inactivation of faecal coliforms and *Ascaris* than a pH of <9. A surprising result was that even at these high pH levels, faecal coliforms were refound after 500 days, with a smaller fraction surviving >1,000 days in the latrines with pH >11. For *Ascaris* the survival was around 450 days and 700 days for pH ranges >11 and 9-11, respectively.

Various studies have showed quite different results. According to Capizzi-Banas *et al.* (2004) 40% of the *Ascaris* eggs were still viable after 60 minutes at 51°C, all *Ascaris* eggs were killed after 75 minutes at 55°C and no egg was viable after 5 minutes at 58°C. In another study, high *Ascaris* removal efficiency (90–100%) was reached after 80 days due to heat generation during the composting process, thus exposing the helminth eggs for more than 1 month to temperatures over 45°C (Koné *et al.,* 2007).

Inactivation of other pathogens have showed quite similar conditions, such as with *Shigella,* in which a temperature of 55°C for 60 minutes is required to destroy all viable pathogens by Haug (2000) and Liu (2000). *Necator americanus* inactivation rate was stated by Haug (2000) as being 50°C for 50 minutes and by Liu (2000) 45°C for 50 minutes. Significant conditions to inactivate *Salmonella paratyphi* and *Leprospira* were not found. Helminth can be considered the most difficult pathogen to inactivate owing to multiple factors. Their eggs can survive in soil for long periods of time and faeces were found to contain fertile eggs about 60 days after ingestion of embryonated eggs. They also have high viability and do not require an intermediate host.

Table 1.2 Pathogenic organisms that can potentially be transmitted by nightsoil

	Causative agent	Disease- Symptoms	Presence of urine	Presence of faeces	Inactivation	Remarks	References
Bacteria	*Campylobacter jejuni*	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea; arthritis		X	cannot tolerate drying; in feaces survive up to 9 days	highly sensitive to gamma irradiation and UV radiation	3, 5, 12
	Escherichia coli	Diarrhea	X	X	* 60°C for 60minutes * 70°C for 5minutes * 55°C for 60minutes	symptoms of infections vary for each person- often include severe stomach cramps, diarrhea (often bloody), and vomiting; some infections are very mild, but others are severe or even life-threatening	1, 2, 3, 15
	Salmonella typhi	Typhoid fever - headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough	x	X	* 60°C for 25 days, with addition of peracetic acid * 60°C for 30minutes * ash and leaves added; pH: 8.5-10.3; 31.1-37.2°C; moisture: 24-55%; die off in 24days	transmitted by insects, feeding on faeces; can survive in water for week or more; survival in faeces up to 62 days	1, 3, 6, 9, 12
	Salmonella paratyphi	Parathyphoid fever - headache, fever, malaise, anorexia, cough, bradycardia, splenomegaly,	x	X		an estimation is 12.5 million cases per year, urine-oral transmission is probably unusual compared to faecal-oral transmission	3, 5
	Leptospira	Leptospirosis- influenza	X			transmitted by urine from infected animals, symptoms with 5-10% mortality	3, 5

Table 1.2 Pathogenic organisms that can potentially be transmitted by nightsoil *(Continued)*

	Causative agent	Disease- Symptoms	Presence of urine	Presence of faeces	Inactivation	Remarks	References
Bacteria	*Shigella* spp.	Shigellosis - dysentery (bloody diarrhoea), vomiting, cramps, fever; Reiter's syndrome		X	* 50°C for 60minutes * boiled water for 1-3minutes * 55°C for 60minutes	resistant to acid, salt and low pH	1, 2, 3, 14, 15
	Brucella abortus	Brucellosis- symptoms are similar to the flu- fever, sweats, headaches, back pains and physical weakness	NR		* 55°C for 60minutes * 63°C for 30minutes under pasteurization * 62°C for 3minutes	humans become infected by coming in contact with animals or animal products that are contaminated with these bacteria	1, 2, 13, 15
	Mycobacterium tuberculosis	Tuberculosis- chest pain, coughing up blood, fever, chills, night sweats, appetite loss, weight loss, pallor, tendency to fatigue very easily	NR		* 70°C for 20minutes * 121°C for at least 15 minutes * 66°C for 20minutes		1, 2, 12, 15
	Yersinia enterocolitica	Yersinioses - fever, abdominal pain, diarrhoea, joint pains, rash	X	X	* 121°C for at least 15 minutes * 160-170°C for at least 1hour	sensitive to moist and dry heat	3, 5, 12
	Vibrio cholerae	Cholera - watery diarrhoea, lethal if severe and untreated		X	* outside host survives up to 50days in faeces	disease often terminates in death, transmitted in water	3, 5, 12
Helminths	*Trichuris trichiura*	Trichuriasis- napparent through vague digestive tract distress to emaciation with dry skin and diarrhoea		X	* sensitive to drying and freezing	infections are acquired by direct ingestion of the infective eggs passed in the faeces; eggs appears in feaces about 70-90 days after ingestion; carriers may shed eggs for years if not treated	2, 3, 12

Table 1.2 Pathogenic organisms that can potentially be transmitted by nightsoil *(Continued)*

	Causative agent	Disease- Symptoms	Presence of urine	Presence of faeces	Inactivation	Remarks	References
Helminths	*Ascaris lumbricoides*	Ascariasis- generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia		X	* viability 0-5% after 9weeks- pH: 8.5-10.3; t=31.1- 37.2°C; added ash and leaves * inactivated after 450days (pH>11), after 700days (pH 9-11), added lime, ash and soil * inactivation within 120days (pH>8) * 50°C for 60minutes * ash and leaves added; pH: 8.5-10.3; 31.1-37.2°C; moisture: 24-55%; viability 0-5% after 9 weeks * 45°C for 80days * 50°C for 60minutes	danger to man from sewage effluents and dried sludge used as a fertliser; does not required an intermediate host; faeces contain fertile eggs about 60 days after ingestion of embryonated eggs	1, 2, 3, 5, 7, 8, 12, 15
	Necator americanus	Hookworm- itch; rash; cough; anaemia; protein deficiency		X	* 50°C for 50minutes * 45°C for 50minutes	larvae can survive up to 3-4 weeks in moist, optimal survival in moist, sandy or loamy soil with ambient temperatures of 24-32°C, but sensitive to desiccation and freezing	1, 3, 12, 15

Table 1.2 Pathogenic organisms that can potentially be transmitted by nightsoil *(Continued)*

	Causative agent	Disease- Symptoms	Presence of urine	Presence of faeces	Inactivation	Remarks	References
Protozoa	*Entamoeba hystolica*	Amoebiasis - often asymptomatic, dysentery, chills, abdominal discomfort, fever		X	* 50°C for 5minutes * cysts sensitive to heating above 50° C	fecal-oral transmissionm, through fecal contaminated food or water; cysts are sensitive to drying, trophozoites are rapidly killed by drying, water, urine and barium	1, 2, 3, 5, 12
	Giardia lambia	Giardiasis - diarrhoea, abdominal cramps, malaise, weight loss		X	* 46°C for 10minutes * boiling for 1 minute	person to person, from uncooked food contaminated with cysts	1, 3, 5, 10, 12

X - the pathogen is present in feaces or urine mainly

NR - not reported

(1) Haug, 2000 **(2)** CDC, 2008 **(3)** Schönning *et al.*, 2004 **(4)** Jenkins, 2005 **(5)** Epstein, 1997 **(6)** Vinnerås *et al.*, 2003b **(7)** WHO, 2006 **(8)** Koné *et al.*, 2007 **(9)** Hassen *et al.*, 2001 **(10)** Capizzi-Banas *et al.*, 2004 **(11)** Eriksen *et al.*, 1995 **(12)** Public Health of Canada Agency, 2006 **(13)** Kronnenwett *et al.*, 1954 **(14)** Zaika, 2005 **(15)** Liu, 2000

5. Conclusions

Human excreta has high valuable potential for agriculture. But a risk of pathogens which can potentially cause human diseases needs to be considered. Therefore it was necessary to find means of inactivating these pathogens to reduce the risk of disease.

Through several research studies, we found human excreta safe to use for fertilizing after well managed composting process. Even thought inactivation of pathogens is not reach well, other advantages can be seen as improving of soil structure, better sanitation facilities in area and other socio-economical aspects.

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Appendix A