Title: **Solar thermal sanitisation of human faeces – an affordable solution for ensuring sustainability of EcoSan initiatives.**

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Moldova is a developing country that faces serious problems related to lack of sanitation infrastructure in rural and periurban settlements. During the last years some organizations started to promote the most progressive and convenient concept of sanitation – EcoSan, which is a real solution for Moldova. There are however the risks of failure of EcoSan projects due to lack of sufficient knowledge and attitudes of the beneficiaries, that can lead to ignorance of the recommendations of sanitisation of faecal material, their disposal in unsuitable places, exposing of people to infestation risks and loose of the trust in EcoSan initiatives. The existent sanitisation methods are not easily accepted for Moldova as they involve too much attitude and handling skills. The current research develops the idea of sanitisation of faecal material through pasteurization at relatively high temperature. Using simple and low cost solar installations, faeces sanitization is done at sufficient temperature to kill relatively quickly the pathogens, avoiding the carbonization of organic matter. The sanitized product can be further processed via composting or disposed safely in the environment without any risks to human health. Two models of installations for faeces sanitization are proposed, which can be used for household and public level and are based on solar collectors and concentrators, depending on the latitude and the average annual sunlight.

Introduction

Moldova is a developing east-European country that faces serious problems related to lack of sanitation infrastructure in rural and periurban area. During the last years some organisations started to promote EcoSan concept as a real solution for improving the situation with sanitation in Moldova. More than 110 UDDT toilets were constructed during the last 2 years, most of them at household level.

Implementation of EcoSan concept implies a radical change of the paradigm and educating of UDDT owners. Although organizations that promote EcoSan offer information and education to UDDT beneficiaries, however, given the specifics of the local population, these activities are often insufficient.

The existent sanitisation methods are not easily accepted by Moldovan people as they involve too much attitude and handling skills. The lack of knowledge and attitudes of the beneficiaries, can lead to ignorance of the recommendations on sanitisation of faecal material, their disposal in unsuitable places, exposing of people to infestation risks and loose of the trust in EcoSan initiatives. Finally these factors can lead to risks of failure of EcoSan initiatives.

The objective of this study was to investigate the possibility to apply a new approach to sanitization of faecal matter that could shorten the storage time and minimise handling. A well known fact that high temperatures (above 50°C) can inactivate pathogens, conducted to the idea of using the cheapest available energy – the solar energy – for fast thermal sanitization of faecal matter. Using simple and low cost solar installations, faeces could be heated at sufficient temperature to kill relatively quickly most of the pathogens, avoiding the burning of organic matter.

Methods

For sanitization purposes faeces from a household urine diverting dry toilet (UDDT) were used. Samples were collected from 2 containers of 60 litres each: one previously stored for 6 months in the chamber under the toilet and the other with relatively fresh faecal material. The covering material consisted of mixed dry soil, wood ash and sawdust.

Sanitization of faeces was conducted using two solar installations. The first was built from a metal barrel of 205 L, previously used for storage of car oil (fig. 1). On one side a hole was cut large enough to fit the container with faeces. Inside the barrel wooden support was fixed to maintain the container in the middle of the barrel so that the space between the wall of the barrel and the container was approximately even. In order to close airtight the barrel a metal door was mounted. The outside surface of the barrel was painted with matte black paint resistant to high temperatures. For the second installation a simple solar concentrator was used (fig. 2).

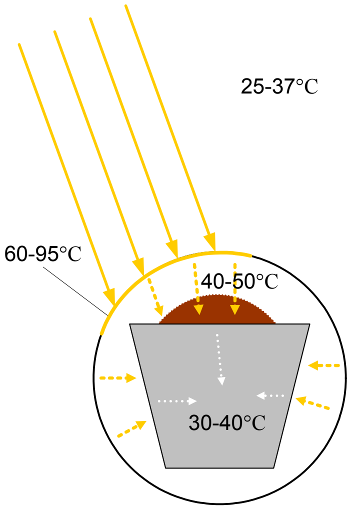


Fig. 1. Scheme of simple solar sanitization installation made from a 205 liter metal barrel.

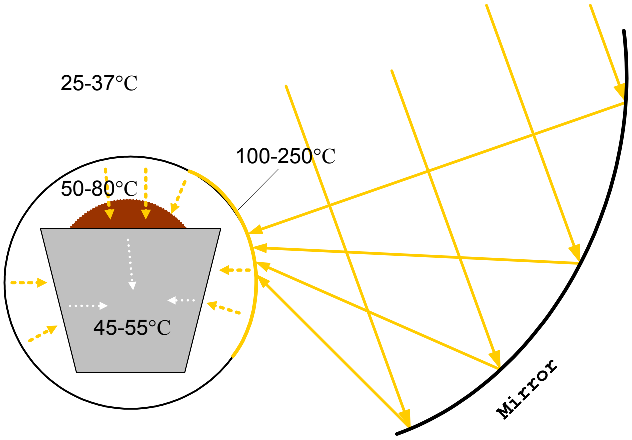


Fig. 2. The solar sanitization installation with concentration parabolic mirror.

In order to track the transmission rate of heat from the barrel surface through the air layer inside the barrel the dynamics of heating a vessel filled with cold water (19.0°C) was tested. The temperature measurement was taken at 1 hour intervals for 9 hours. The experiment was repeated during three consecutive days. The installation was heated using the solar concentrator. The second installation was distinct from the first by the fact that besides the barrel a simple solar concentrator was used (fig. 2). The installation support was built of wood and the mirror of plywood. These materials are available at local market. The parabolic shape of the mirror was calculated using a specialized software *Parabola Calculator v1.0*. Mirror surface was covered with mirror film.

A series of microbiological measurements were performed to assess microbial inactivation. The experiments were performed under three conditions: thermally treated samples in Petri dishes at 55°C in the laboratory, thermally treated samples using the installations with concentrator and without concentrator.

Microbial indicators (fecal coliforms, *Escherichia coli* total titer, *Escherichia coli haemolyticus*, *Staphylococcus aureus* and total number of Enteroccocus spp.) were selected as models for the survival of enteric bacterial and helminth pathogens. For each experiment, a composite sample was prepared by mixing the samples collected at the top, centre and bottom of the pile. The composite sample was suspended in sterile water and then an aliquot for microbiological tests was collected. Moisture content was measured by comparing the initial weight of a 10 gram sample with the one kept in the oven at 105°C overnight and weighed in the following day.

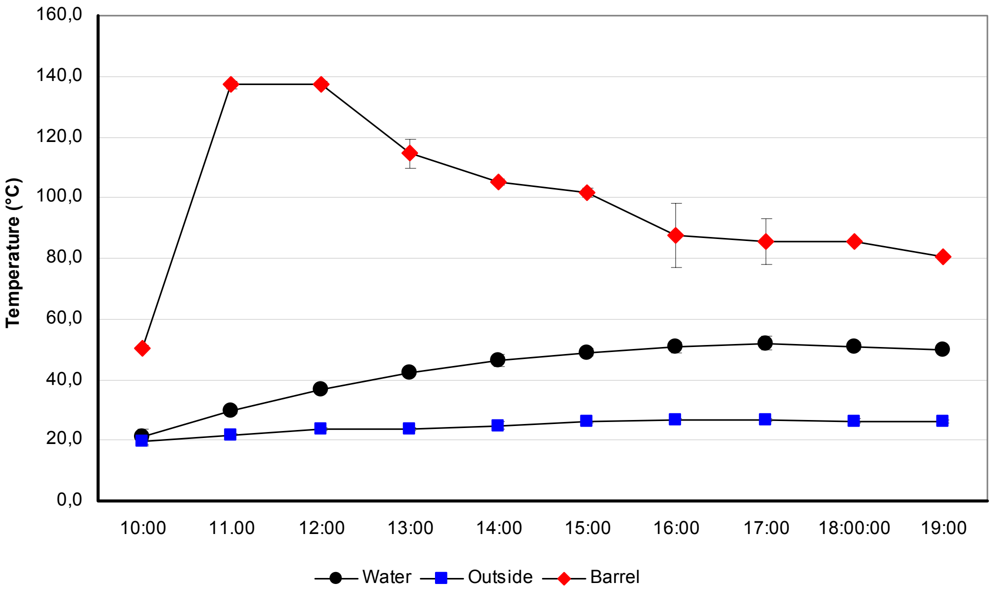
During solar sanitization the samples were collected at the end of each day. They were analyzed microbiologically and parasitologically in the laboratories of the National Centre for Preventive Medicine according to national medical protocols for human excreta analysis.

Results and Discussion

In figure 3 the results of average temperature of air, barrel surface and water performed during a 3 day period in July are shown. According to this data, the maximum temperature was reached during the first half of the day (11.00-12.00). The optimal temperature of water necessary for sanitization process (50°C) was reached at about 15.00. Water temperature remained constantly during 4-5 hours, after which steadily decreased. It should be mentioned that such weather temperature maxima as those encountered during the experiment are not typical for July period in Moldova, which are usually higher. Nevertheless, this temperature was sufficient for sanitization process to occur.

The temperature of water rose steadily throughout the experiment with a speed of about 4.5°C / hour. It can be assumed that under normal conditions of exposure for 10 hours in the sun, when the surface of the barrel can reach more than 200°C, water temperature could raise over 60°C.

Fig. 3 The three day average temperature for 2009, July month



During the night the water temperature decreases up to 20°C that may cause faeces recontamination (Feachim, 1983). However, this process is slowed by substratum dehydration. Such process is synergic with the process of heating and amplifies faeces sanitization.

According to Wheeler and Carroll (1989), dehydration of faeces maximises the destruction of enteric microorganisms and reduces health risks during handling. Experimental data show that dry storage for a minimum period of one year can lead to improved microbiological quality of faeces. The main factors influencing die-off over time are temperature, dryness and UV light (Feachem et al., 1983).

In our research the microbial inactivation was expected to be a function of temperature, moisture content in the pile and storage time. High temperature and rapid dehydration increases the die-off of microbial pathogens in excreta. According to Feachem (1983) the microorganisms could be inactivated by exposing samples in thermostat at 55°C. Various authors showed different exposure time for microorganism inactivation in biosolids, which varied between 10 to 15 days (Jepsen, 1997). Our laboratory experimental data showed that a total number of 21 days was necessary for complete microbial inactivation in faeces.

Fecal coliform, facultatively-anaerobic, non-sporulating bacteria, ranged from $2x10^7$ cfu per gram of sample in the beginning of experiments (0 day thermostat) to 5 $x10^6$ at the 8th day and less than 10^4 cfu per gram of sample at the 14 day of thermostating. Along the whole experiment period *Escherichia coli* was detected in all samples in concentrations of 10^3–10^5 cfu/g, regardless of collecting time. In the case of thermostating the concentration was 10^3 cfu/g with a weak tendency for reduction. At the 21st day *E. coli* was below the detection limit 4log10 cfu/g. In whole experiments the concentration of the *Escherichia coli haemolyticus* was estimated. This bacteria represented less than 10% of the total number of detected *E.coli* and above the limits for right titer appreciation. *Staphylococcus aur*eus with concentrations ranging from undetectable levels ($<10^2$ cfu per gram) to 1.3 $x10^4$ cfu per gram of sample was detected. The decreasing rate was variable. At the 21st day of experiment the titer was still high $>10^2$ cfu per gram. The total number of *Enteroccocus spp*. in the control accounted for 2 x 10^8 cfu/g. It is important to mention that cfu/g of enterococcus during 14th and day 18th slowly increased. After 21 days of treatment, *Enterococcus spp*. remained detectable (detection limit 10^2 cfu/g) in all repetitions.

These laboratory results suggested us to use for thermal microbial inactivation solar installations. Analysis of faecal matter heated in a barrel without solar concentrator, compared with the control sample analysis, showed a moderate decrease in the contents of both pathogenic microorganisms, and parasites. Faeces sanitization with solar concentrator installation has led to a decrease in the concentration of pathogens in comparison with the control. These results are in accordance with other studies which indicated that for thermal sanitization of faeces they should be treated at temperature of above 50°C for 1 week (Schönning and Stenström, 2004). However, because of the small number of potential pathogens in our experiments, the evidence contained in the control on the decrease in the number of pathogens was not significant enough to make firm conclusions.

The current research revealed that faeces sanitization has occurred, but at lower rate than we expected. Due to unstable weather conditions during the period of research the faeces could not be sanitized continuously for several days. A serious barrier was also low thermal conductibility of the air layer inside the barrel. The problem was worsened by the fact that the mixture of faeces and cover material had relatively low density. Being loose and porous, this mixture has a low thermal conductivity, which lowered the heating rate and made it uneven.

In the light of current research the following facts were revealed:

- Both installations, including passive absorption of sunlight heat, and collecting it with a concentrator are effective and can generate temperatures high enough for sanitization purposes. The solar concentrator can be the fastest method by which a black surface can be heated to more than 200°C in a fairly short time. Without the concentrator, the sanitization installation is less efficient but simpler in construction. The sanitization time using such a facility should be longer.

- Transmission of collected solar heat is a decisive factor that determines the success and effectiveness of faeces sanitization. In the installations tested by the authors, approximately 110 L of the barrel, that is almost two times more than the volume of faeces, are occupied by the air. It has a low density and low thermal conductivity, which creates a serious barrier to heat penetration to the faeces. The solution would be modifying the construction in order to reduce or exclude the air layer.
- The mixture of faeces and cover material has also a relatively low density, which prevents penetration of heat from the surface to depth. An adequate solution would be changing the surface/volume ratio in favour of surface exposed to the heat.

Conclusions:
Solar energy can be used for faeces sanitization if the efficient transmission of collected heat is ensured. Depending on the construction of sanitization installations, faeces sanitization can occur at different rates. In all tested conditions the concentration of the microbial indicators decreased at different rates. The current research suggests that solar sanitization of faeces can increase the health safety and shorten the storage time.

Requirements for solar sanitization facilities for faeces sanitization from UDDT are:

- Regardless of the method for solar heat collecting, an efficient transmission of heat to faeces should be ensured.
- To avoid heat losses caused by low thermal permeability of air layers and faeces is important to reduce or eliminate the air layer, and increase the contact surface with faecal masses in relation to their volume.
- The installations should ensure minimum handling of faeces. The idea behind the solar sanitization rose from the need to reduce the handling to a minimum.
- The sanitization installations should be simple, cheap, made of accessible materials and sustainable.

Learning from the experience of this research the authors propose a solution that requires further research. The proposed installation consists of a flat metal box with longitudinal rooms, separated by metal septa.

The total room volume of the metal box may be calculated to be equal to that of faeces, so as to exclude air layer. The facility should be painted in black and with widest surface turned toward the sun. The metal septa will facilitate deep penetration of the heat to faecal material. In temperate, subtropical or tropical climates, such installations would not require a solar concentrator. Otherwise heat produced by the concentrator would be too high, which may cause the incineration of organic material contained in the faeces.

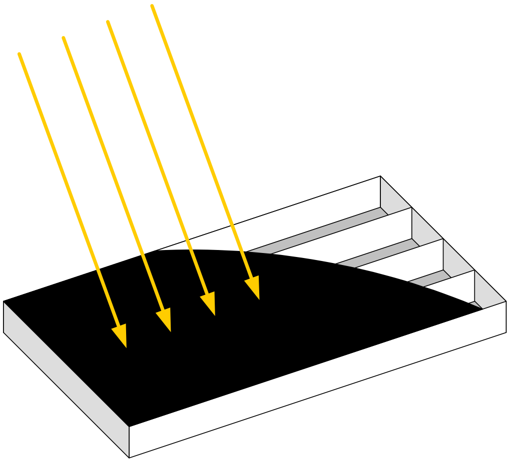


Fig. 4. A proposed solar faeces sanitization installation that could reduce the heat loss and shorten the sanitization time.

Further research is needed to identify and understand the determinants of success for solar faeces sanitization and the health protection measures that are necessary to sustain successful implementation of Ecosan concepts in rural and periurban settlements.

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