37th WEDC International Conference, Hanoi, Vietnam, 2014

SUSTAINABLE WATER AND SANITATION SERVICES
FOR ALL IN A FAST CHANGING WORLD

Household-level application of hydrated lime for on-site treatment and agricultural use of latrine sludge

I. Chakraborty, M. Capito, C. Jacks, & R. Pringle (Cambodia)

BRIEFING PAPER

Rural areas of Cambodia have no safe waste management strategies for household latrine waste. Household application of lime (calcium hydroxide, $Ca(OH)_2$) would enable households to treat waste easily on-site and significantly reduce the risk of latrine sludge causing negative impacts on human health and the environment, whilst transforming latrines into incubators of a valuable agricultural additive. Initial investigative work – including human centered design research, supply chain analysis and bench scale laboratory tests have demonstrated that lime treatment of sludge has potential to provide a sustainable and effective solution to closing the sanitation loop in rural Cambodia, with promising application for urban environments as well.

Background

Poor water, sanitation, and hygiene practices (WASH) are a major cause of diarrheal diseases , which are the leading cause of sickness and death amongst children in Cambodia. Access to basic and improved sanitation is increasing in Cambodia, but latrine pits are filling up. Although some advanced solutions exist, they are not appropriate for poor, rural households, who constitute 80% of Cambodia's population and 48% of the world population. As a result, the waste accrued is often ignored or disposed of unsafely, jeopardizing the health benefits that an improved, waste-segregating toilet offers.

Why lime?

Chemically stabilizing human waste with hydrated lime increases the pH of the waste material to 12, conditions which are inhospitable to pathogens and convert the waste into an effective soil amendment. Studies have shown that using lime is as effective as pasteurization and conforms to US EPA standards, killing fecal coliforms, helminth eggs and pathogenic bacteria (Smith and Surampalli 2007). The high pH also provides a vector attraction barrier, preventing flies and other insects from infecting treated biological waste (Brobst 1995). Furthermore, the efficacy of lime as a waste sterilization agent is not reduced by the presence of complementary sanitary products such as paper, cloth, or soap. Alkaline stabilization with lime has already been used for waste sterilization worldwide, from large facilities in the developed world (Wurtz 1981) to wastewater flows in the developing world (Franco-Fernandez 2003).

Lime has also been used in agricultural settings for centuries (Johnston 1849) and has been demonstrated to improve crop yields (Acosta-Martínez et al. 2000). Lime adds valuable calcium and magnesium to soils (Mitchell 2000), and the raised pH suppresses root-borne diseases such as bacterial wilt (Lemaga and Ebanyat 2004). For Cambodian households, fertilizer is a major expense, and this high cost contributes to the under-fertilization seen in the country's agricultural system (Ross 1987). Human waste can be a valuable soil amendment, and while it may will not replace all chemical fertilizer, it is estimated to have an annual value of around USD30 per household. Thus, combining lime and waste into a single product removes pathogenic concerns associated with handling untreated waste as well as leverages the soil amendment qualities of both substances (Gensch 2011).

Lime is readily available through an agricultural supply chain and is extremely affordable at USD 0.30/kg. Hydrated lime is a stable compound and with appropriate precautions can be used safely by households. Furthermore, adding lime to latrines eliminates odors, a key selling point for rural households (iDE 2013).

Project Objectives

The aim of this research is to determine if lime will serve as an effective method for waste treatment and crop enhancement for Cambodia. The phases of research covered at present are the gathering of user insights, a lime supply chain analysis and bench scale tests.

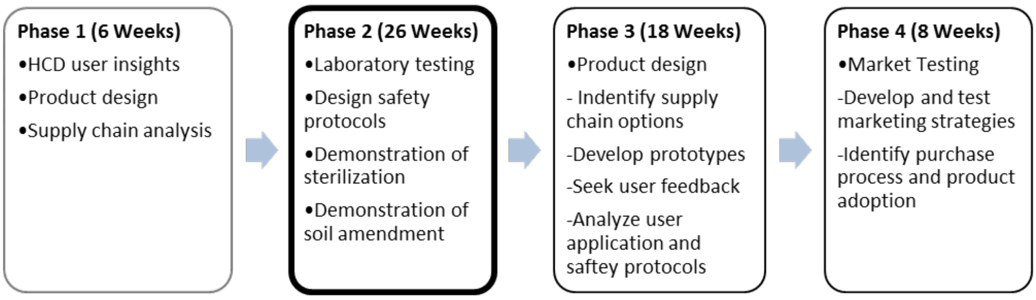

Figure 1. Key phases of project and timeline. Current research phase is in bold

User Insights: Human Centered Design Research

Prior to technical research, human-centered design (HCD) methodology was used to gather user insights to better understand current waste management practices and lime use. Residents of three villages in Kampong Cham province were interviewed on latrine use, latrine cleaning and pit emptying practices, awareness of lime, perception of treated waste reuse, and general aspirations and concerns about the waste treatment and disposal process. Key highlights of this research are summarized in Figure 2.

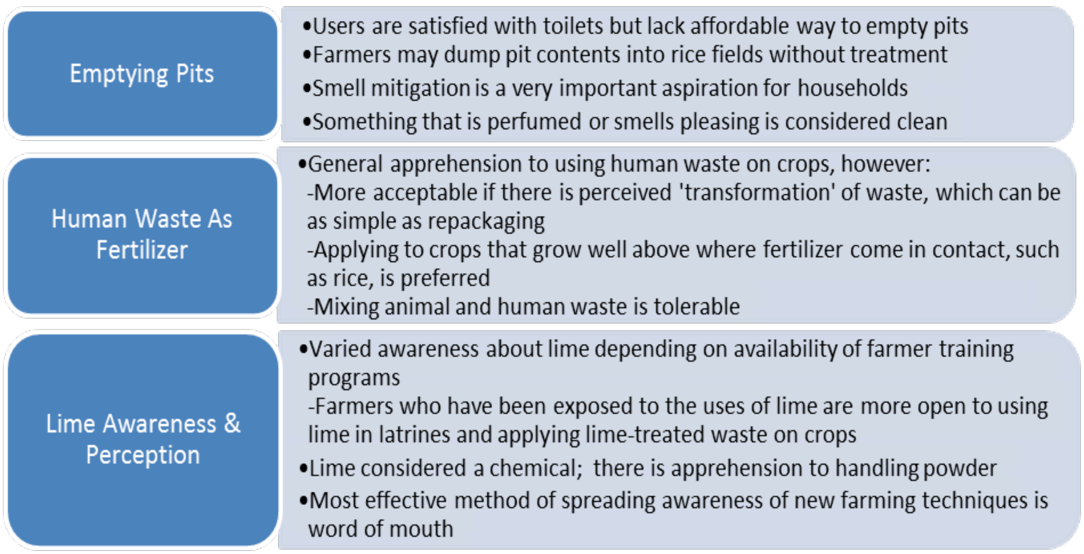

Figure 2. Key insights from HCD research

The insights emphasize the need for a user-sensitive approach to lime application, as although there currently is an urgent need for improving pit-emptying practices, households are apprehensive of using human waste, whether treated or not, in soil for food crops. However, the popularity of lime is currently increasing among farmers, and thus this may be an opportune time to promote its application to sludge disinfection. This information will direct both the development of a lime product and a strategy for its safe and effective application.

Lime Supply Chain

A supply chain assessment was mapped out for known uses of lime in construction, agriculture, and in households. Currently, lime sold in Cambodia is quarried in Cambodia, Thailand, Vietnam. A preliminary supply chain analysis in the Svay Rieng and Prey Veng provinces and the city of Phnom Penh consisted of interviews with lime wholesale and retail suppliers, users and an agronomist who trains farmers for iDE's agricultural extension program, the Farm Business Advisor (FBA) program. The goal of the analysis was to gain a better understanding of overall lime use in Cambodia, where businesses and individuals were purchasing lime and if hydrated lime may be sourced in Cambodia.

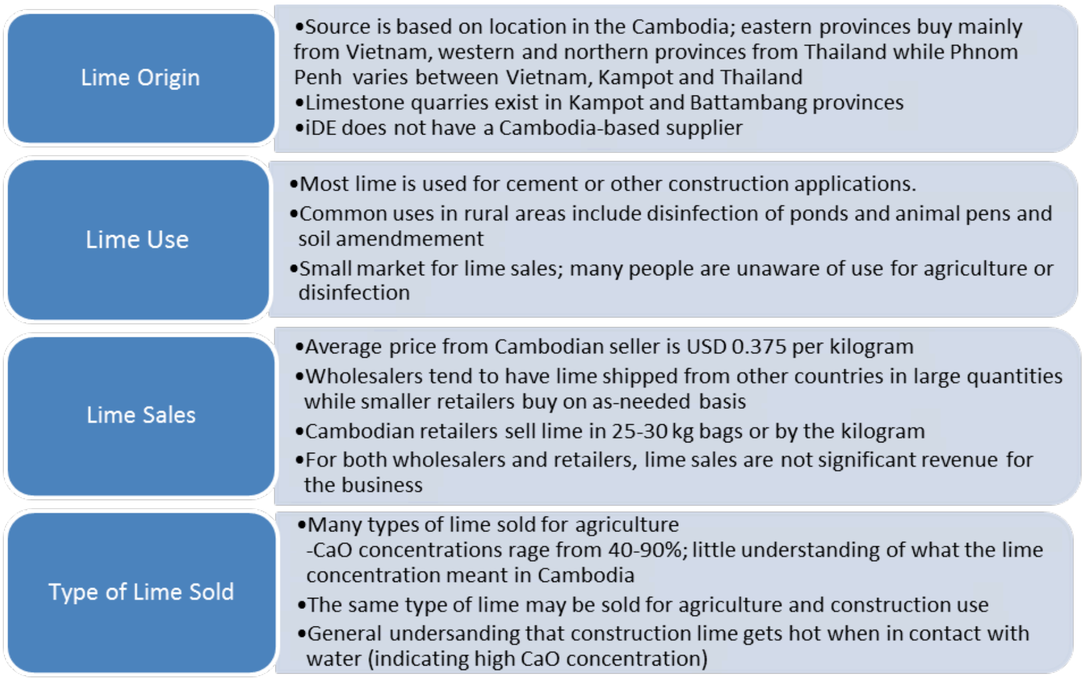

Figure 3. Key insights from supply chain analysis of lime

To ensure safety and efficacy, the project will determine the most cost-effective method of consistently procuring quality lime. Based on the research, a map of the lime supply chain was created (Figure 4).

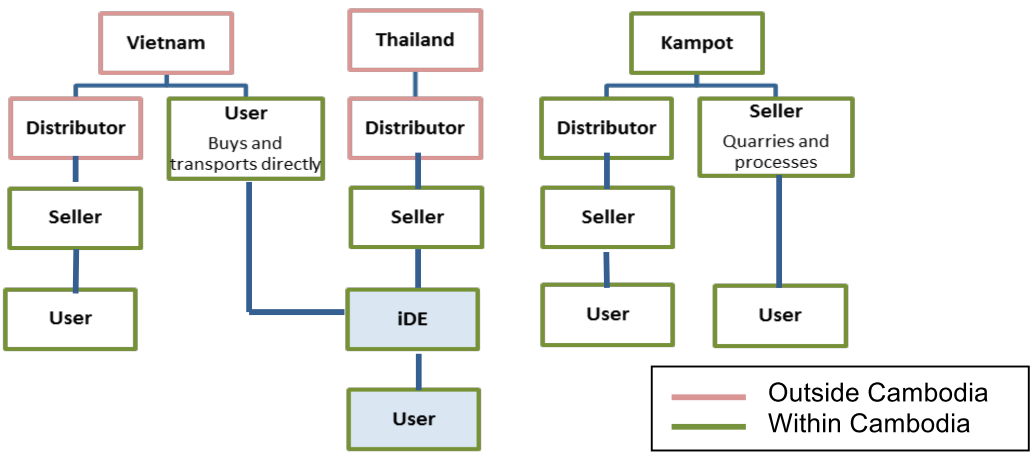

Figure 4. Summary of lime supply chain in Cambodia

While the supply chain research has clarified the use, sources and availability of lime in Cambodia, some elements will require further inquiry. There is little understanding in the rural communities exactly what type of lime is being sold and used and what the differences are between them. In addition, while limestone is quarried in Cambodia, it is unclear if hydrated lime is being produced.

Laboratory Bench Tests

The goal of the bench-scale tests was to determine the efficacy of locally available lime on treating sludge from a typical household latrine. A pH of 12 eliminates E. coli and most viruses within several hours, and maintaining the pH at 12 or higher for a minimum of two weeks eliminates any viable Ascaris eggs.

Parameters investigated were 1) maintenance of pH at different concentrations of lime over time; 2) efficacy of lime in removing *E. coli* and *Ascaris* from sludge; 3) effect of lime on the content of the supernatant and sediment of treated sludge; 4) adequacy of passive mixing, achieved by applying lime by user at every use, in ensuring a sufficient rise of pH; and 5) Difference in efficacy when applying lime as a slurry as opposed to in powdered form.

Methods

Sludge was collected from a latrine that was being used under conditions typical of a rural household (pour flush squat latrine, regular cleaning).

To test the concentration of lime needed to maintain pH of sludge at 12, different levels of lime were applied, and treatments were incubated for 25 day. pH was monitored on a daily basis. A sample of the sludge at the start of the incubation was analyzed for total nitrogen, ammonia, total solids, *E. coli* and *Ascaris*. At the end of the incubation, the supernatant and sediment were analyzed separately for ammonia, total nitrogen, total organic carbon, total suspended solids, calcium and E. coli; and total nitrogen, total organic carbon, total solids, calcium and E. coli, respectively.

To analyze the effect of mixing on the efficacy of lime, three mixing regiments were tested in 20 L buckets: 1) To simulate per use addition of lime, the bucket was filled by alternating 0.4 g lime with 40 ml sludge, for a total of 10 L. This represents a user adding 1.5 % lime to the waste in addition to wash water and flushing. 2)To simulate addition of lime at every cleaning event, 0.4 g lime with 40 ml sludge, for a total of 10 L. This represents a user adding 1.5 % lime to the waste during a weekly cleaning episode, for the total amount of waste expected to accumulate per week. 3)To simulate the addition of lime as a single event prior to pit emptying, the entire mass of lime for a final concentration

The goal was to simulate and test the efficiency of the "passive" mixing resulting from the repeated addition of waste; no additional mixing was performed . pH was monitored over a two week period.

Results

At 1.5 and 0.5 % (w/v) lime, pH was maintained at 12 and above for the 25 days of incubation, which is sufficient to ensure complete elimination of viable pathogens (Figure 5). Although adding 0.1 % lime initially had an effect on pH, within 6 days, the treatment was indistinguishable from unamended controls.

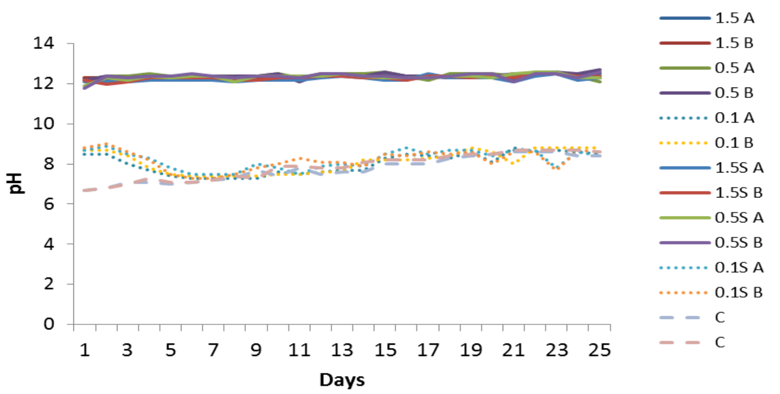

Figure 5. Effect of initial lime concentrations on pH over a 25 day incubation. A, B: duplicate incubations at the same concentration. S: lime added as a slurry C: unamended control.

In comparison with the control and 0.1 % of lime amendment, addition of 0.5 and 1.5 % of lime followed by thorough mixing, resulted in an almost instantaneous precipitation of solids to the bottom of the containers, and the formation of a clear supernatant. A distinct ammonia odor was detected. This odor persisted over the length of incubation. In contrast, the unamended control and at 0.1 % of lime, the liquid remained turbid for several days, and emitted a more typical, slightly sulfidic sewage odor.

No difference was seen between applying the lime as a powder or a 50 % slurry in water. A pH of 12 was reached immediately following mixing with both application methods.

The sludge used for incubations was found to be free of viable *Ascaris* eggs. An additional analysis of pig manure also showed a negative results. Thus *Ascaris* was not tested for upon completion of the incubation.

Characteristics of the unamended controls were similar to those of the 0.1 % treatment level. 0.5 % and 1.5 % were similar to each other. In the results presented in Figures 6 and 7, 0.1 % treatment is grouped with the control ("low treatment", and the 0.5 % is grouped with 1.5 % lime amendment ("high treatment").

In the supernatant of sludge following the 25 day incubation, no difference was seen between the high and low treatments in ammonia, total nitrogen, or total suspended solids. As expected, the high treatment had more than twice the concentration of calcium, and no detectable *E. coli*. Total organic carbon was also almost twice as high in the high treatment samples (Figure 6).

High treatment samples had significantly lower total nitrogen and total organic carbon in the sediment (Figure 7). No viable *E. coli* was detected in high treatment sediment samples, whereas low treatment samples had similar *E. coli* numbers to the supernatant (4.4 x10^3 cfu/100 ml). The addition of excess lime in high treatment sediments was reflected in the significantly higher value for total solids in comparison to the low treatment sediments.

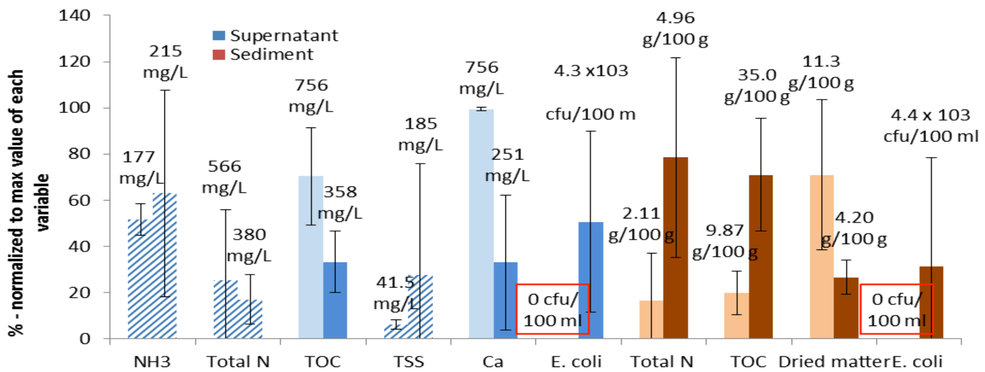

Figure 6. Characteristics of supernatant and sediment after incubation. For each parameter, the left column is average of high lime-amended ("high treatment", 0.5 and 1.5 % w/v lime) incubations and the right column is average of control and amendment at 0.1 % (w/v) lime ("low treatment). Hashed columns are not significantly difference. Solid fill represents difference at p(same) < 0.05.

Incremental addition of lime and sludge to a final concentration of 1.5 % (w/v) lime was sufficient to raise and maintain the pH at 12 (data not shown). An application of fewer increments, to simulate addition of lime at weekly cleaning events had the same effect. With both applications, a clear supernatant was formed, with rapid settling of solids. However, a one-time addition of the same mass of lime was not sufficient to raise the pH of the sludge to 12, with pH reaching 10 at the time of application and falling to 8 within one week.

Based on the outcome of the bench-scale studies, a concentration of 1.5 % (w/v) lime will be used in household trials, to reliably ensure the desired increase in pH and clear supernatant. Lime treated sludge provides a nitrogen-rich supernatant, with low suspended solid content and is pathogen-free. The clarity of the supernatant is a favorable property that is likely to increase its desirability as a soil amendment, because it bears very little resemblance to the turbid content of freshly opened latrine pits.

Although lime treated sludge has approximately the same concentration of ammonia as untreated sludge, high pH in lime-treated incubations results in predominance of the highly volatile deprotonated form, and thus a consistently pungent odour. A strong focus of the household level trials will be to evaluate the perceived importance of ammonia odours to users.

The presence of lower levels of total nitrogen and total organic carbon in the sediment, and higher levels of both in the supernatant (if volatilization of ammonia is accounted for), indicates that lime treated sludge provides a more readily available source of both nutrients to soil, which can have an additional positive impact on crop yields, beyond reducing acidity and increasing calcium content.

On-going and Future work

The project seeks to further understand the potential for lime disinfection of sludge by investigating household usage of lime, and application of lime-treated sludge to small-scale vegetable cultivation.

1. **Test lime application protocols at the household-level:** Participating households will be advised on a range of protocols for adding lime to latrine pits. Compliance to different addition methods and effectiveness of disinfection, along with user feedback will be evaluated.
2. **Agricultural benefit:** Lime treated sludge will be used in agricultural field trials to determine its effect on the yield on vegetable crops. Plots will be set up to measure the difference in yield between plants grown on lime treated-sludge amended soil and non-amended soil.
3. **Pilot marketing and sales:** Different business models will be prototyped based on identified potential producers, sellers, and value proposition for customers. Further iterations on the product and business model will be made based on market feedback, which will inform opportunities and constraints for commercialization.

Acknowledgements

The author/s would like to extend thanks to the Canada Grand Challenges Program and the Stanford Design for Extreme Affordability Class for their continued support of this project.

References

Acosta-Martínez, V. et al. (2000) *Enzyme Activities in a Limed Agricultural Soil*. Biology and Fertility of Soils Vol 31, No.1, pp 85-91.

Brobst, Robert.(1995) *Biosolids Management Handbook*. US Environmental Protection Agency .

Wurtz, William O (1981) *Method for Lime Stabilization of Wastewater Treatment Plant Sludges.* Willow Technology, Inc.

Franco-Hernandez, O. (2003) *Dynamics of Carbon, Nitrogen and Phosphorus in Soil Amended with Irradiated, Pasteurized and Limed Biosolids*. Bioresource Technology Vol 87, No 1, pp. 93-102.

Gensch, Robert et al (2011). *Urine as Liquid Fertilizer In Agricultural Production in The Philippines: A Practical Field Guide.* Tech. Xavier University Press

iDE (2013) Sanitation Marketing Pilot Project Household Surveys, Internal Report

Johnston, J. F. W (1984). *On the Use of Lime in Agriculture.* Edinburgh and London: W. Blackwood and Sons

Lemaga, Berga D. and P. Ebanyat (2004). *Effect of Soil Amendments on Bacterial Wilt Incidence and Yield of Potatoes in Southwestern Uganda.* African Crop and Science Journal. Vol 9, No.1, pp 267-278.

Mitchell, Charles C. (2000) *Soil Acidity and Liming (Part II)*. Soil Acidity and Liming (Overview). Clemson University.

Ross, Russell (1987) *Cambodia: A Country Study.* Washington: GPO for the Library of Congress.

Smith, J. and R. Y. Surampalli (2007) *Disinfection processes and stability refinements to biosolids treatment technologies: past, present and future.* US Environmental Protection Agency.

Contact details

Name of Principal Author: Irina Chakraborty
Address: PO Box 1577
House 97A, Street 15BT (Ta Phon), Sansom Kosal 1, Boeung Tumpun
Phnom Penh, Cambodia
Tel: +855 95 970 271
Fax:-
Email: ichakraborty@ide-cambodia.org
www: ide-cambodia.org

Name of Second Author: Rachel Pringle
Address: PO Box 1577
House 97A, Street 15BT (Ta Phon), Sansom Kosal 1, Boeung Tumpun
Phnom Penh, Cambodia
Tel: +855 78 687 058
Fax: -
Email: rpringle@ide-cambodia.org
www: ide-cambodia.org