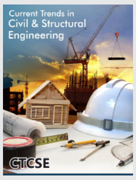

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Review Article

A Review of Pit Latrine Emptying Technologies for Low-Income Densely-Populated Settlements of Developing Countries

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Abstract

A significant proportion of household sanitation needs for low-income densely-populated settlements of developing countries is met by pit latrines, which must be either emptied or relocated when full. New latrine construction cost and space scarcity suggest that pit latrine emptying (PLE) may be the only practical option for the peri-urban poor. PLE, however, has challenges – it is expensive, not well planned, lack of transportation access to disposal sites, often infeasible use of conventional vacuum truck in overcrowded and inaccessible areas, poorly maintained vacuum tankers, and poor households are often missed out of services. One of the major challenges to efficient PLE is technology. Several credible, past and current, literature and bibliographies were gathered to support the review process. This paper explores, through a review, the limitations and challenges of PLE technologies, prompted by the need for more efficient pit emptying options and services. The review reveals that the absence of a suitable, hygienic and low-cost method (preferably mechanical) capable of emptying all pit types remains a technological gap. Developing a solution capable of accessing densely-populated settlements, efficiently emptying and appropriately disposing of dense sludge (including 'non-pit elements'), yet remaining affordable and easy to operate and maintain, is today's challenge. The author argues that current innovations so far focus largely on scaling down the conventional vacuum tanker, which may not be the correct way forward, as the fundamental challenge is that less liquid sludge is difficult to effectively deal with. It is recommended that rather than adopting existing current technologies, investment in new and innovative non-vacuum-based PLE technologies that use local materials and based on scooping rather than vacuum action, while drawing lessons from research could be the way forward. The author therefore concludes that a solution may take time, as difficulties cannot be identified and rectified until technologies are developed, tried and tested for a sufficient period. However, as more innovations are developed, tested and improved, progress can be made towards a satisfactory PLE solution.

Keywords: Pit latrine emptying (PLE); Technologies; Low-income High-density settlements; Developing countries

Introduction

A significant global proportion of households rely on pit latrines to defecate, which must periodically be either emptied or relocated when full [1]. Lack of space and new latrine construction cost however mean that the only practical and cost-effective option for low-income high-density peri-urban poor is pit latrine emptying (PLE) [2]. Such pit latrine misuse contributes to the current PLE challenges. Pit latrines' filling rate is directly proportional to the quantity of excreta addition to the pit per person per year Strande et al., [1]. PLE allows the facility to be a permanent one, relocated in-house, and makes excreta use possible. However, excreta require arrangements not only for emptying, but also containment, transportation, treatment, and safe disposal or reuse. Pit latrine misuse affects latrine filling rate, which is a function of pit emptying intervals. Pit latrines general performance in Sub-Saharan Africa is unsatisfactory [3], partly due to misuse. A study found that besides pit latrine's fundamental role of excreta containment and processing for reuse or disposal, 90% of households in the Mzuzu (Malawi) peri-urban area surprisingly use pit latrines for domestic waste disposal [4]. Research conducted in a low-income high-density peri-urban Kotoko community in Kumasi (Ghana) showed that out of 44% of latrine attendants interviewed who knew how the community latrine's generated income was used, all mentioned PLE, cleaners' and latrine attendants' salaries, while 39% of the annual expenditure was on pit emptying only [5,6]. Beyond emptying pits when full, effecting minor repairs and cleaning, latrines generally require little maintenance [7].

PLE is an opportunity to address sanitation gaps, evaluate and update national policies and regulations, and a major sustainability factor addition to the Sustainable Development Goals (SDGs). Though excreta are a potential resource which could be tapped for development, hygienically emptying and managing them remains a challenge. PLE is expensive with high operating cost, inconvenient with its attendant sludge management concerns, use of the conventional vacuum truck for PLE is infeasible in overcrowded and inaccessible areas, and overflowing pit latrines [8]. Pit latrines' major challenge is however technological–how to deal with the excreta once a pit is full [9]. PLE challenges such as high operational cost, requirement for pit lining at an additional cost, and procurement and operation and maintenance (O & M) of special PLE equipment depending upon community type and sludge nature prompted the need to develop criteria and technologies to assist address these challenges. This review focus is therefore on PLE, with the view to improve public health through an efficient pit emptying technology. Strande et al. [1] argue that technology is one of the major challenges to PLE, though other challenges include poor latrine design, lack of baseline data sets, and poor transportation access to disposal sites.

PLE in developing countries is not well planned, vacuum tankers are poorly maintained and often poor households are not attended to. The developed technologies therefore have their individual limitations and further improvement is required. Pit emptying, for instance, in high-density housing areas with accessibility concerns means that either a pit is mechanically emptied at a distance using a system powerful enough to pump pit content to a waiting tanker, or a mechanical system small enough to enter these high-density areas. Pit access could also be limited by a small drop-hole size. Several design characteristics for an appropriate PLE technology have been identified by Thye, Templeton and Ali [2]: its ability to effectively and completely empty pits of all types (dry, liquid and dense solids); access densely-populated areas; affordable locally to construct, operate and maintain; and available appropriate infrastructure for sludge disposal.

Pit Latrine Emptying (PLE) Approaches

Two options exist when a latrine is full – stop using it and construct a new one or empty it and reuse [10]. New latrine construction cost and lack of space however suggests that pit emptying is a more practical and cost-effective option [11]. PLE in developing countries is either manual (for alternating pits only) provided they are dry, and above water table; or mechanical (for wet pits or single pit variety) by high-powered equipment because pit content is not pathogen-free [12]. Manual PLE happens when there is no health risk to workers during and after emptying, as the excreted pathogens are supposed to be dead, and the pit contents are at least two years old [13] and so only a few Ascaris ova will be viable. Alternating twin-pits are suitable manual pit emptying options because the sludge becomes pathogen-free and ready for removal after decomposing for 2 – 3 years Thye et al. [13].

A study on faecal sludge management in Madina (Accra) found that household bucket (currently outlawed since 2010), pit and VIP latrines were manually emptied and discharged untreated into bushes, open drains, and already polluted water bodies due to illegal small-scale mining (galamsey) [14]. However, if the pits are wet (or are of the single pit category), they must be emptied mechanically because of their pathogenic content. Septic tanks are also emptied (desludged) mechanically like wet or single pits. PLE could be either essential or desirable depending on local circumstances and relocation possibilities [15]: when there is insufficient space available for relocation when the pit is full, or when an in-house latrine facility is required and affordable, pit emptying is said to be essential; PLE is however desirable under shallow pit conditions – for example, to minimize groundwater pollution, or where it is necessary to apply the principle of economic cost advantage – the economic cost of pit emptying is less than the economic cost of providing a new pit.

The Gap in PLE Technology

Knowledge of sludge material nature is critical to PLE technology choices, as sludge is the most important and difficult to remove Greenhalgh [16] argues that to develop any mechanical method for PLE, consideration be given to sludge characteristics and access. VIP latrine content vary depending on users' habits, cleansing material type used, and household demographics. Therefore, technology development for containment, collection, transportation, treatment, and disposal of faecal sludge suggests that detailed knowledge of sludge properties is required Zuma et al. [17]. It is these properties that determine the emptying approach – whether vacuum tanker evacuation (mechanical), manual using spades, buckets and forks; transportation by tankers or skips; processing (as in anaerobic digestion, composting, drying or incineration; and final disposal by burial, agriculture or incineration) [18-20]. Sludge properties are therefore strong determinants of faecal sludge emptying approaches and inform future sanitation facilities design Zuma et al. [17].

Studies on the physical properties and characteristics of ventilated improved pit (VIP) latrines contents in Africa gave interesting findings Hawkins [21] – pits often contained unexpected materials (or 'non-pit elements') including rubbish, bags, rags and sackings, and solids such as corncobs, stones, bottles, and wood though in smaller quantities; and small but reasonable quantities of sand (presumed to enter through the drop hole) were also found. VIP latrine composition in Africa was generally 40% sand, 48% water, and 12% organic matter Greenhalgh [16]. Another research on the chemical and thermal properties of 10 VIP latrine sludge in Durban (South Africa) shows that on average 87% of pit content was faecal sludge, and the rest predominantly constituted 'non-pit elements' such as waste paper, plastics and textiles. Sisco et al. [22] confirmed these compositions of latrines when they found that one of the main challenges confronting pit emptying technologies was thrash. Other studies conducted in peri-urban Mzuzu (Malawi) that characterized pit latrines to support pit emptying technologies selection and design concluded that PLE technology development be focused on: a maximum tool diameter of 10 cm to fit through

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the squat hole; and a maximum height of 146 cm to fit inside the superstructure and support pits ability to pump trash Chipsosa et al. [4]. Technologies for PLE could therefore be community-specific depending on the prevalent sanitation practices. A major technological gap therefore exists beyond the unhygienic manual emptying of single pit latrines – the absence of a suitable, hygienic and low-cost method (preferably a mechanical one) capable of emptying all pit types. A critical evaluation of national policies and regulations on PLE is however important. For example, a review of sanitation policies for Ghana, India, and China suggests over-ambitious policies which may be unachievable Murray et al. [23]; and Kumasi District Assembly regulations also allow for specific sites for dumping of excreta Williams and Overbo [24], which is highly unhygienic and unacceptable.

The PLE Concept and Technologies

VIP latrines faecal sludge content is degraded relatively slowly and largely under anaerobic conditions Bakare et al. [25]. A new concept likely to lead to less frequent PLE is where small sludge volumes are desludged weekly, which could change the requirements for pit technologies. Commercial pit latrine additives manufacturers contend that solids accumulation rate and pit content volume can be reduced to prevent the pit from getting full too often Bakare et al. [25]. The concept seeks to reduce sludge accumulation rate using additives to degrade the sludge based on evidence that the use of spore-forming non-pathogenic bacteria could effectively reduce sludge volumes Jere et al. [26]. However, trials of the concept gave mixed results, and further research is required to ascertain its reliability and viability Harvey, [27]. Further works that investigated additives effect on VIP latrines sludge content concluded that pit additives were unable to accelerate biodegradation rate and mass loss from pit latrine sludge, and so have no beneficial effect on pit content Bakare et al [25]; Foxon et al. [29]. The new PLE technology benefits (if successful) would include Sharpe [29]: increasing pit emptying frequency from 2 – 5 years to weekly, and reducing pit emptying load means huge reduction in pit emptying cost per trip; better job security and regularity for service providers; cheaper, smaller and more mobile emptying technologies.

Conventional vacuum tanker

Most mechanical PLE technologies are vacuum-based and centered on atmospheric pressure utilization (or high air flow rates) to suck pit contents through a hose into a container. Conventional vacuum tankers are often the favored technology provided plot and pit accessibility is possible, largely due to minimal contact with pit content and improved sludge evacuation efficiency than other alternatives Eales [30]. Developed and used in advanced countries to desludged septic tanks and vaults, conventional vacuum tankers normally incorporate a standard sliding-vane vacuum pump suitable for removing light watery sludge. They may also be suitable for desludging wet pits if there are no bulky anal cleansing materials in the sludge. Though vacuum tankers are the most common mechanical systems currently in use in developing countries for pit emptying, they are unsuitable because they cannot handle materials with air-filled voids (materials commonly found in pit latrines), and maintenance and fuel requirements are extremely high. They are also unable to service pits in high-density housing areas due to accessibility challenges and have difficulty in handling compact sludge. The manual pit emptying (MAPET) and vacutug were therefore developed as alternatives.

Mini-vacuum tanker, MAPET and vacutug

Mini-vacuum tankers, which are smaller versions of the conventional vacuum tankers, are developed to improve accessibility in densely-populated low-income settlements with limited space, and improve hygiene, excreta collection and disposal in developing countries. Outcomes of these efforts are the UN-HABITAT vacutug and MAPET. The MAPET is a manually-operated vacuum mini-tanker developed in Dar es Salaam in the 1980s by WASTE Consultants and Dar es Salaam's Sewerage and Sanitation Company. Its two core features are the piston pump with a flywheel and 200-litre vacuum tank, each mounted on a pushcart incorporating tricycle wheels; and a vacuum pump made from 150-mm polyvinyl chloride (PVC) sewer pipe with a leather piston and an 800-mm diameter flywheel. Vacuum tankers of the MAPET category are commonly employed in developing countries for desludging septic tanks because the sludge is much less dense than pit latrine sludge, and so a medium-powered vacuum pump is strong enough to lift sludge from them. The Gulper (or manual desludging hand pump) also developed to empty septic tanks operates by an up-and-down action with one or two operators raising and lowering the handle. The manual pump is small-scale equipment developed based on vacuum pump technology which operates manually. The technology uses sophisticated tools that may improve efficiency and safety compared to manual PLE. Comprehensive literature on the MAPET can be found in Muller and Rijnsburger [31].

First developed and tested in Nairobi (Kenya) to address the huge sanitation challenges of developing countries, the vacutug is a small sturdy vehicle of dimension 1 m wide × 1.5 m long capable of emptying excreta from pit latrines TVE/ITDG [32]. It is made up of an articulated vacuum tank fabricated from mild steel with a nominal volume of 500 litres, and a pump assembly. The vacutug has proven to be a viable PLE technology after its successful operation in Nairobi (Kenya) for the following reasons UN-Habitat [33]; Thye et al., [13]: its service and capital cost are affordable to slum communities and local entrepreneurs; is capable of accessing densely-populated settlements with limited space; its operating costs recoverable from generated revenue; it can be constructed, operated and maintained using local materials and skills; it is capable of transporting waste to an appropriate disposal point; and it has sufficient vacuum provision to enable pumping of densely-compacted sludge from latrines. Both the MAPET and the vacutug technologies have the disadvantage of low capacity Tayler [9]: 200 litres for MAPET and 500 litres for vacutug, and a limited range because of their low speed. Low capacity means increased operational cost, and low speed implies that the disposal point cannot be far from the collection point. A detailed description of the vacutug technology is offered in TVE/ITDG [34].

Submersible centrifugal pump

An alternative pit emptying technology employed in developing countries is the submersible centrifugal pump. It is not however

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considered a viable option because the size of solids it can handle is limited to approximately a quarter the diameter of the suction hose, and it requires regular maintenance (including spare parts replacement) that can be very expensive. It has the added disadvantage of more laborious cleaning operations as compared to vacuum tankers. Its advantage is however that it has no limit to the delivery head achievable Schulz [35] contends that hydraulically-driven submersible pumps could be used as an alternative to PLE in developing countries, but their application is limited as they can only empty vaults and septic tanks unless mechanical mixer is incorporated to fluidize the contents of the pit. The broader issue however is that before hydraulically-driven submersible pumps can be considered more viable than vacuum tankers, the health risk exposed to operators in handling pumps submersed in fresh excreta ought to be addressed. Literature on other outmoded PLE technologies such as diaphragm pump, air-drag system, peristaltic pumps, helical rotor pumps, auger pumps, and bucket conveyors is found in Carroll [12], Hawkins [21], Muller and Rijnsburger [31] and Schulz [35]. The limitations and high cost associated with PLE technologies prompted the need for more efficient pit emptying services.

Pit Emptying Services

The need for PLE services is informed by the requirement for a balance between the rising demand and space limitation for household sanitation facilities in low-income high-density peri-urban communities Chipsosa et al. [4]. The continual functioning of the sanitation ladder is partly attributable to pit emptying services. Management limitations and technological inappropriateness have thus largely contributed to vacutug-based pit emptying services unsustainability Opel and Bashar [36]. It is critical that haulage, storage, transfer and final sludge disposal are jointly considered with the PLE stage, since once sludge is collected it must be hygienically disposed. Inadequate provision of facilities would likely result in inappropriate and unhygienic sludge disposal to rivers, open drains, the sea, or other open spaces Water Utility Partnership [37]. Research shows that most pit latrine emptiers dispose excreta indiscriminately into the environment Strauss et al. [38]: pit content ends up buried or left in the open environment, such as open drains to avoid high transportation costs. Inappropriate disposal becomes more pronounced if the PLE technology does not have haulage capacity for long distances, effective policy is not a place, and local capacity is weak. Transfer stations (fixed or mobile) reduce the distance pit emptiers would have to go to dispose sludge, thereby allowing them more time to generate income through PLE Müller and Rijnsburger, [11].

The MAPET has significantly contributed to sanitation improvement in unplanned areas in Dar es Salaam through effective and hygienic pit emptying services Cotton et al. [39]. Vacuum tankers are widely used for pit emptying in South Africa, and identifiable factors in the design of an efficient pit emptying service are Hawkins [40]: vacuum tankers performance may be measured in terms of the number of full loads removed per tanker per year (or the number of litres removed per man hour); fixed and regular schedules minimize administration costs and allow for optimal routing of collection journeys and accurate predictions of tanker requirements to be made; zoning makes administration simple and allows operators to know their respective areas well; and large tankers could be allowed to transport sludge over long distances for optimal use of vacuum equipment. The limitations associated with current PLE services prompted the need for improvement. Developing a solution capable of accessing densely-populated settlements, efficiently emptying and appropriate disposal of dense sludge while remaining affordable and easy to operate and maintain remains a gap and challenge in PLE literature. A recent study that investigated trash removal methods for improved mechanical emptying of pit latrines concluded that though manual trash removal is not the best of options, it effectively separates trash from excreta, thereby making downstream excreta treatment easier Sisco et al. [22].

Misplaced Priorities

Literature available shows that significant contributions are already made to address PLE challenges, particularly within the context of technological innovation, but further research is necessary Nakagiri et al. [3]. It is however suggested that any PLE technological innovation apply scientifically-based approaches. The continued focus on vacuum-based pit emptying technologies despite their inability to deal holistically and effectively with less fluidized sludge is therefore misplaced. A shift in focus from vacuum-based technologies to new non-vacuum-based ones that rely on scooping action could be the way forward. These new innovations when developed, tried and tested over time could gradually lead to satisfactory solution for emptying pits of all types.

Conclusion and Recommendations

One of the major challenges to PLE is technology. PLE in low-income densely-populated settlements of developing countries is confronted with complex challenges compounded by the variable (and often difficult) conditions in which emptying technologies ought to operate, particularly when pit content (often including 'non-pit elements') and what happens in the pit is not well understood. Current innovations so far focus on scaling down the conventional vacuum tanker, which might not be the correct way forward, as the fundamental challenge is that they are unable to effectively deal with less liquid sludge. A technological gap in PLE is the absence of a hygienic and low-cost method capable of emptying pits of all types. To fill this gap requires the development of a solution capable of accessing densely-populated settlements, efficient emptying and disposal of dense sludge at low-cost while easy to operate and maintain. Rather than adopting current PLE technologies, investing in new and innovative ways of PLE while drawing lessons from research could be the way forward. A better approach would be to focus on non-vacuum-based technology using local materials and based on scooping rather than vacuum action. In conclusion, a solution may take time, as difficulties cannot be identified and rectified until technologies are developed, tried and tested for a sufficient time period. However, as more innovative technologies are developed, tested and improved, progress can be made towards a satisfactory solution.

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Conflict of Interest

No conflict of interest.

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