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A combined up-flow anaerobic sludge blanket and biofilter as an improved alternative on-site sanitation in urban Bhutan: lab-scale to pilot studies

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Under the supervision of Dr Sherub Phuntsho & Professor Hokyong Shon

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, ***Ugyen Dorji*** declare that this thesis, is submitted in fulfilment of the requirements for the award of ***Doctor of Philosophy***, in the ***School of Civil and Environmental Engineering/Faculty of Engineering and Information Technology*** at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Signature: Production Note: Signature removed prior to publication.

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Conference Paper and Presentation

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LISTS OF ABBREVIATIONS

UASB	Up-flow anaerobic sludge blanket
ABF	Anaerobic Biofilter
HUASB	Hydrolytic Up-flow Anaerobic Sludge Bed
DEWATS	Decentralised Wastewater Treatment System
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
E. coli	Escherichia Coli
TKN	Total Kjeldahl Nitrogen
RGoB	Royal Government of Bhutan
UNSEPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant
NSBB	National Statistical Bureau of Bhutan
MoWHS	Ministry of Works and Human Settlements
WSP	Waste Stabilisation Pond
NEC	National Environment Commission
PET	Polyethylene Terephthalate
SRT	Solid Retention Time
MUASB	Modified Up-flow Anaerobic Sludge Blanket
NSSB	National Statistical Bureau of Bhutan
GLSS	Gas Liquid Solid Separator
ABR	Anaerobic Baffled Reactor
UAF	Up-flow Anaerobic Filter

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ABSTRACT

As of 2017, coverage of piped drinking water supply in Bhutan is about 98% and even higher in the urban areas. Still, Bhutan has been struggling to meet the demand for urban infrastructure following rapid and unplanned urban growth, including for domestic wastewater management. Public sewerage infrastructure and centralised wastewater treatment plants require capital for construction and operation. Therefore on-site wastewater treatment is expected to continue to play a significant role in the disposal of domestic wastewater in urban areas of Bhutan. Due to several challenges to the predominant "septic tank" situation, there is an increasing need for an alternative system for the safe disposal of combined black and grey wastewater in urban Bhutan. This Thesis aims to investigate a compact on-site domestic wastewater treatment system as an alternative to "septic tanks", some of which are used without an on-site soak-pit. The Thesis is composed of seven chapters, of which four chapters are technical studies.

The first study involved a survey in reviewing and understanding the current wastewater infrastructure and related challenges in urban Bhutan. This study observed that only about 23% of the classified towns in Bhutan are currently connected to public sewerage systems which represent the coverage of about 20% of Bhutan's total urban population, or 7.4% of Bhutan's entire population. Over 80% of Bhutan's urban population therefore depends on the on-site treatment of their domestic blackwater, with most greywater simply being discharged to surface water drains without treatment. However, over 40% of the properties with "septic tanks" lacked a soak-pit required for subsoil treatment of septic tank effluent, indicating unsafe disposal of potentially hazardous septic tank effluent posing significant risks to the public and the environment. Survey of urban plots suggests that the current practice of urban development has led to a situation where the regulation off-set/setback distances cannot be met to safely accommodate soak-pit within the plot with limited vacant space. This raised the need to explore alternative on-site treatment systems that does not require soak-pit but which could handle both black and grey water, to provide a safe solution for domestic wastewater disposal until networked public sewerage system is delivered or for areas where network sewerage is technically or financially not feasible.

The second study explores an up-flow anaerobic sludge blanket (UASB) and anaerobic biofilter (ABF) in series as an alternative on-site domestic wastewater treatment for modern urban settings in Bhutan. The UASB replaces the current septic tank for primary treatment of blackwater. In contrast, the ABF replaces the soak-pit (soil treatment) instead of further treatment of septic tank effluent combined with greywater. While septic tank and UASB can be comparable in terms of the footprint however, ABF can have much smaller footprint compared to large area required for the disposal of septic tank effluent in the soil using a soak-pit system. Hence UASB and ABF can be

much more compact solving the space constraints faced by the urban plots, unlike the extended space occupied by the septic tank and soak-pit system restricting the utility of limited urban space. The proposed alternative system used shredded waste plastic bottles as a novel biofilter media providing a large surface area for attached biological growth. The use of waste plastic bottles not only mitigate waste plastic problems in Bhutan but provide a locally available alternative biofilter media in place of commercial biofilter media which would have to be imported. A lab-scale UASB+ABF was operated for 188 days using synthetic wastewater (simulated black water and combined UASB effluent and greywater). At 2-day hydraulic retention time (HRT), the UASB achieved a chemical oxygen demand (COD) removal of 70 - 80%, biogas production of 200 - 230 L CH_4/ Kg COD removed with stable methane composition of above 70%. The best COD removal of 90 - 98% at 8 h HRT was achieved using the smallest (10 mm square) shredded plastic media size, attributed to large surface area per unit volume facilitating more significant attached growth of biomass compared to the larger media sizes (20 mm and 30 mm). The COD removal of the ABF decreased significantly at HRT of 6 h from the initial HRT of 5 days. The combined UASB and ABF at optimal HRT of 8.8 h achieved a final effluent with COD of less than 125 mg/L that meets the National Environment Commission or NEC's effluent discharge standard of Bhutan 2020. This lab-scale study showed that combined UASB and ABF treatment using shredded waste plastic bottle media has the potential for use as an alternative on-site sanitation wastewater treatment.

In the third study, the combined UASB and ABF treatment system was operated at pilot-scale in the field in Bhutan for one year with a capacity of 1000 L/day, equivalent to 2 households (10 population equivalent). The UASB received 200 L/day of blackwater while the ABF received 1000 litres of combined UASB effluent and greywater. Operated at 2-day HRT, the UASB achieved a COD removal of 43 - 74% while ABF with plastic media (40 mm square) achieved a COD removal of 29 - 71% at 8.8 h HRT. The combined UASB-ABF treatment achieved final effluent COD of less than 125 mg/L, BOD less than 30 mg/L and TSS less than 100 mg/L which meets Bhutan's NEC 2020 effluent discharge standards. The UASB and ABF reactors recorded a methane production of 0.80 - 26.09 L/d and 0.81 - 11.95 L/d with methane yield of 66.49 mL/g VSS removed and 45.96 mL/g VSS removed, respectively.

In the fourth study, three different locally available biofilter media were explored and tested for use in the ABF for treatment of a combined UASB effluent and the greywater and their performances compared to a commercial biofilter. The locally available biofilter media included shredded waste plastic bundles (3, 5 and 7 mm strip width), charred bamboo beads (cut fraction of 1/8 (~ 10 mm), 1/4 (~ 20 mm), 1/2 (~ 40 mm)), industrial slags (8, 10 and 12.5 mm sizes) and commercial media (10.5 mm). This lab-scale study was carried out initially using synthetic wastewater and then finally using real wastewater (obtained from the pilot UASB effluent mixed with domestic greywater from the pilot site). These lab-scale experiments were operated under different HRTs of 12 h, 8 h and 6 h.

All three test media were able to achieve effluent COD concentrations that meet the equivalent national COD effluent standard, at all three different HRTs. The effluent turbidity of all the biofilters were above the NEC 2020 water standard of 5 NTU. The biofilter media sizes influenced COD removal rates, although HRT had the primary influence on COD removal. During the 150 days of operation, the smaller sized slag and bamboo medias achieved better removal under longer HRT of 20 h. While, the larger media sizes of slag and bamboo achieved better efficiency under the shorter HRT of 6 h. The smaller plastic strips of 3 mm with large surface area achieved better removal efficiency under the different HRTs. The smaller media sizes provide larger surface area for the attached growth and hence are expected to have better COD removal rates; however, it seems media porosity also significantly influences the hydrodynamics and mixing of the influent within the columns which further impacted the COD removal efficiency.

From the above studies, it can be concluded that UASB and ABF in series have the potential for use as an on-site treatment alternative to the current “septic tank” and soak-pit system which currently predominates in urban Bhutan, especially where soil treatment by soak-pit is not feasible due to limited space or impervious soils. Shredded waste plastic flakes, which are low-cost and readily available locally, may be an effective biofilter media for wastewater treatment. Their use as biofilter media could help reduce the mounting plastic waste problems in Bhutan. Improvement and optimisation of the process design and media design (shape and sizes) would help further improve the treatment capacity of this combined treatment system. However recently, the presence of microplastics in the aquatic environment has been acknowledged as one of the major environment concerns as this could pass through the food chain. The plastic biofilter flakes used in this pilot study were subjected to abrasion in order to increase the surface roughness of the generally highly smooth surfaces of the plastic bottles so as to enhance biofilm formation thereby possibly reducing the start-up time of the ABF. This abrasive force could increase the potential of producing micro-plastic during the preparation of biofilter media as well as its slow release during the long-term operations. Therefore, this is another area of research that needs to be considered in the future.