Abstract

A performance evaluation of three first generation fixed dome anaerobic reactors installed in Kenya was undertaken to understand emerging design and operational deficiencies and inform design and scheme management improvements. These reactors were designed for decentralized human waste treatment and bio-resources recovery. Scheme management and reactor design configuration were explored while sixteen operating and performance parameters were monitored over 42 weeks using standard wastewater measurement techniques. The study results showed treatment efficiencies ranging from 26% to 51% for physicochemical parameters and 44% to 80% for microbiological indicators. However, effluent quality consistently failed to meet than World Health Organization and Food and Agriculture Organization (WHO/FAO) standards. Notably, Total Suspended Solids (TSS) in the effluent ranged from 1,843 to 2,299 mg/L—substantially higher than typical raw wastewater levels of 155 to 330 mg/L (median ~250 mg/L)—indicating poor solids removal. Chemical Oxygen Demand (COD) levels were between 735 and 2,522 mg/L (higher than WHO limit: ≤250 mg/L), Electrical Conductivity (EC) reached 5,140 µS/cm (WHO/FAO limit: ≤700 µS/cm for unrestricted irrigation), while microbial contaminants E. coli (2,254–2,370 MPN/100 mL) and helminths (31–52 eggs/100 mL) far exceeded limits for restricted irrigation (<1,000 MPN/100 mL and ≤1 egg/L, respectively). Additionally, the microbial log reduction value (LRV) was only 0.3, well below the WHO recommended LRV > 2 for secondary treatment. These findings confirm the reactors' inadequate pathogen attenuation and pollutant removal, limiting safe effluent reuse. Design flaws that include straight-line inlet-outlet pipe configuration, low hydraulic retention times (2–5 days), and operation under psychrophilic temperatures (27–28 °C resulted in dead zones and poor flow dynamics. Systems that received more diluted influent (e.g., Gachoire) performed slightly better than those handling concentrated waste (e.g., Kibera). Still, none achieved adequate treatment. The computed Treatment Index (TI) values—0.58 (Gachoire), 0.52 (Naivasha), and 0.46 (Kibera)—confirmed the reactors' inadequacy in reducing both microbial and chemical pollutants. Bioresource recovery potential was however demonstrated, with daily nitrogen recovery of 496.2 kg and biogas production of 60 m^3. The findings underscore that single-stage fixed dome systems adapted from livestock applications are inadequately suited for human waste treatment. Advanced modelling, adoption of baffled or hybrid designs and integration of dual-metric performance evaluation (percentage removal and absolute concentrations) are recommended to improve treatment efficiency, ensure safe reuse, and achieve environmental compliance in future deployments.