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Chapter

Downflow Hanging Sponge System: A Self-Sustaining Option for Wastewater Treatment

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Abstract

Need of self-sustaining wastewater treatment plants (WWTPs) has become critical to cope up with dynamics of the environmental regulations and rapid advancements in the contemporary technologies. At present there are limited number of self-sustaining WWTPs around the world. The aim of this chapter is to present state -of- art of Downflow Hanging Sponge (DHS) system which was developed as a post treatment unit of Upflow Anaerobic Sludge Blanket (UASB) from sustainability perspective. DHS system is a non-submerged fixed bed trickling filter (TF) that employs a core technology of polyurethane sponges as a media where the microorganisms thrive and major treatment processes take place. This chapter reviews the introduction of DHS system (UASB+DHS) summarizes the quantitative analysis of environmental, economic and social sustainability using indicators. Furthermore, self-sustaining prospects of DHS system are assessed and discussed by comparing with conventional TF (UASB+TF).

Keywords: downflow hanging sponge, trickling filter, self-sustainability, indicators

1. Introduction

Wastewater treatment plants (WWTPs) are integral part of our society. Lately, WWTPs and its management have become an important issue in the world and also listed in many of sustainable development goals [1]. The WWTPs were initially designed to remove the pollutants depending on the flow variability to meet the certain discharge standards. However, emerging concepts and practices in WWTPs field have extended its application to energy recovery, reuse and nutrient recycling. Also, majority of WWTPs around the world are not designed with these multiple functions in mind and depend only on conventional technologies to solve these problems and fails to strike the balance between demand and supply of water. Especially, this is quite evident from the water scarcity clock which shows that there are about 2 billion of world population still living in water scarce areas [2]. Moreover, the changing dynamics of world such as accelerating energy dependent lifestyles, sudden global pandemics, economic fragmentations, climate change patterns and other major environmental concerns have affected the selection of suitable

WWTPs. Since many WWTPs have life cycle of 50–100 years, or even longer, the selection of WWTP will affect the development of that particular area. Several studies have shown that selecting and deciding the WWTPs are mostly based on their technical, economic, environment and social aspects [3]. Though extensive researches are being conducted and major strategies have been formulated, the search for long lasting technology in the wastewater treatment field is still on-going.

2. Downflow hanging sponge system

Aerobic biological treatment process can be traced back to the late nineteenth century. The biological process uses oxygen to break down organic contaminants and nutrients from wastewater. Oxygen is continuously mixed using aeration device (air blower or compressor) into the wastewater. Aerobic microorganisms then feed on the wastewater's organic matter converting it into carbon dioxide and biomass which is later removed. There are several types of aerobic treatment processes based on their designs such as fixed film system, continuous flow suspended growth aerobic system, retrofit aerobic system and composting toilets [4]. For this chapter, fixed film aerobic treatment systems called Downflow Hanging Sponge (DHS) and Trickling filter (TF) have been chosen and discussed. The rationale behind choosing these systems is the similarity in their working principle.

TFs is the second most widely used aerobic biological wastewater treatment system after activated sludge process (ASP) around the world [5]. TF is non-submerged fixed-bed, aerobic biological reactor which was applied for sewage treatment for the first time in England in 1893 [6]. Pre-settled wastewater is continuously trickled or sprayed from the top with the help of a rotating sprinkler. As the water moves through the pores of the filter, organics are aerobically degraded by the biofilm covering the filter material. The trickling filter consists of a cylindrical tank and is filled with different packing material such as stones, rocks, gravels or special pre-formed plastic filter media. Since couple of decades, various improvements have been made in TF and it has found its application as a combination unit with other treatment systems. There are 129 TFs in Latin America being operated as a post treatment unit of Upflow Anaerobic Sludge Blanket (UASB) [7]. UASB is an anaerobic treatment system originally developed for industrial wastewater treatment. With due course of time, it became popular in developing countries for domestic wastewater treatment due to its affordability, simple construction, easy operation and maintenance [6–8]. Recent studies on TF following anaerobic sewage treatment system revealed that 25% of UASB reactor employed TF as post treatment system [8–10]. The combination of anaerobic and aerobic treatment is advantageous, and this system is simpler than those involving ASP, and leads to much lower energy consumption [11]. The combination of UASB and TF exhibits the high treatability and also is economically advantageous over other treatment systems in developing countries. It has been adopted whenever compact systems were required.

Employing the working concept of TF, in 1995 a research team of Professor Hideki Harada came up with the first concept of promising sewage treatment technology referred to as a DHS system in Japan [12]. DHS system is comparatively a new aerobic, post-treatment process where a simple polyurethane sponge act as a medium for all biological removal processes. DHS system consists of the sponge modules arranged along its height unlike the TF which use gravel, plastics, rocks as supporting media. There are six variations of sponges developed and tested through the rigorous improvement in its shape, arrangements and packing method [13]. The first generation was cube type DHS (G1), second was curtain type DHS (G2), third

was similar to TF with sponge supported by polypyrene plastic net (G3), fourth was arrayed sponge type (G4), fifth was improved design of G2 and sixth was similar with G3 but with hardened sponges (G6). The other technical details of the configurations are discussed in other study [14].

The working principle of DHS system is similar to TF. The wastewater is supplied to the top of the DHS system with the help of distributor, which trickles down through the sponge module and finally exits the system through a clarifier at the bottom. The influent with its organic matter is trapped and flows down through the sponge modules in the reactor where the biomass within the sponge degrades the organic matter. External aeration is not necessary for the operation since there is natural diffusion of air as it flows through the DHS system.

For almost two decades, DHS system was researched as the post treatment of UASB for domestic wastewater and implementation of its full-scale have justified it [15–18]. Modifications to DHS systems are mainly conducted to eliminate the shortcoming of reactor and improve the nutrient and pathogen removal efficiencies [19, 20]. At early stages, DHS reactor was developed to treat domestic wastewater, however the potential of DHS reactor for treating different types of wastewater such as aquaculture [21], industrial wastewater [22–24] (textile, arsenic, rubber processing etc.) leachates [25] are other trends observed from literatures. The full scale and pilot scale DHS systems are being operating in Japan [10, 16], Thailand [26], India [18, 27, 28], Egypt [20], and Vietnam [22, 23] for various kinds of wastewater. Besides, DHS as a standalone bioreactor for rare metal recovery [29] phosphate recovery [30], gas scrubbing [31] and methane recovery [32] have also been investigated. Since, tremendous amount of researches are being carried out, more emphasis on its self-sustainability would help to validate its application for developing countries for domestic wastewater treatment.

3. Concept of wastewater treatment sustainability

With the on-going stress on selection of WWTPs, sustainability assessment of wastewater has become standard in developed countries and aspiration for the developing countries [33]. The concept of sustainability of wastewater treatment plants is based on the observation that economy, environment and social well-being are interlinked. The term sustainability has various interpretations, however, the World Commission on Environment and Development (WCED, 1987) quoted "Sustainable Development is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [34]. To assess the sustainability of a system, various dimensions based on the short- or long-term goals have been taken into consideration. From the classic definition of sustainability indicators, it should always incorporate the three main pillars of sustainability i.e. economic, environmental and societal for holistic assessment [35, 36]. In case of developing countries, the studies were more focused on the economic affordability, convenience of end user and stakeholder, health risks, technology sustainability, environmental impacts by products, natural resource optimization and sanitation [37–39]. This pertains to the fact that choosing sustainability indicators should be contextualized to the local requirements for the decision makers to ascertain WWTPs for specific areas.

Since there is no comprehensive definition of self - sustainable WWTP, it could be defined as "a state of treatment system which can sustain itself without or less use of energy or resources from external source without causing harm or less harm to the surrounding environment". This definition is restated with reference to the definition of appropriate technology for water sanitation for developing provided in

these studies [40, 41]. The following could be some of the features that indicate the self-sustainability of WWTPs for developing countries;

- Simple design and construction

- Less carbon footprint and economic costs

- Simple operation and maintenance

- Least amount or no chemical use

- Stable and reliable performance meeting all the discharge standards

- Having energy sufficiency potential or energy recovery potential

- Productive reuse of biosolids and treated wastewater

- Promote institutional development (environmental agencies, policy makers and regulation agencies, service providers)

Merely saying DHS is a 'sustainable' system is not possible until and unless sustainability indicators indicate progress towards or away from sustainability [42]. The main goal of this chapter is to present the state-of- - art of DHS system based on sustainability indicators. Additionally, the self - sustainability potential of DHS system was compared and discussed with the similar kind of technology i.e. TF for future application of this technology in developing countries. TF is a well-known technology since ages and comparing DHS system with TF would assist in its proof of concept, scalability and deployment for its validation in the field of the sustainability science. So far, there is only one study which has addressed the sustainability of the full-scale DHS system [43]. However, self-sustainability of DHS system has not been explored yet. From here on wards, DHS system is rephrased as UASB +DHS system as majority of researches on DHS system are presented as post treatment unit of UASB system. Similarly TF is also rephrased as UASB+TF. Apparently, the literatures on performance of UASB+TF systems are scarce so some discussions are presented with only TF data.

This chapter collects and analyzes the pre-requisites of self-sustainability indicators for UASB+DHS system. To address the self-sustainability of UASB+DHS system multiple indicators are considered from literature review for the holistic assessment which is guided predominantly by these studies [44, 45]. The indicators considered for this review are discussed henceforth and are summarized in **Table 1**.

3.1 Treatment performance

Right from the first prototype of UASB+DHS system, its treatment efficiency for organic, nitrogen and pathogen have shown impressive results for domestic wastewater treatment [10, 12–20]. There are plethora of studies reporting the treatment performance of UASB+DHS system. For comparison, the treatment efficiencies for the parameters such as Total suspended solids (TSS), biological oxygen demand (BOD), ammonia (NH_4^+-N) and fecal coliform (FC) are collected and tabulated in **Table 2**. Full scale UASB+DHS system till date have shown significant TSS and BOD efficiencies of 94% and 96% respectively [18, 27]. While some of the selected UASB +TF system indicated a slightly reduced efficiency i.e. (TSS: 88–93% and BOD:89–93%). For most of the developing countries, BOD standards are regarded as the

	Indicators	Sub-indicator	Description	Calculation formula	Values	Suggested units
Environmental Sustainability	Treatment performance		Contaminant removal efficiency to mitigate environmental and health risks	$\left(\frac{C_{inf.}-C_{eff.}}{C_{inf.}}\right) \times 100$		Removal % (log removal)
				$C_{inf.}$ = Influent concentration		
				$C_{eff.}$ = Effluent concentration		
	Land area		Land area required for the wastewater treatment facility	Total area occupied /Population equivalence		m^2/p.e.
			CO_2 emissions from COD oxidation	COD removal (kg COD $m^{-3}d^{-1}$) $\times$ 0.08 kg CO_2 / kg COD		
			CO_2 emissions from CH_4 combustion			
		Global warming potential	Emissions of greenhouse gases (CO_2 and N_2O) into the atmosphere	N_2O emissions	CH_4 emission (m^3 CH_4) $\times$ 3.5 (kg CO_2 / m^3 CH_4)	(kg CO_2 equivalent $m^{-3}d^{-1}$) Atkins et al. (2005) [46, 47]
					$N_{inflent}$· $EF_{effluent}$· 44/ 28 $\times$ 298 (Emission Factor effluent =0.005)	Campos et al. (2016); IPCC [48, 49]
	Carbon Footprint	Energy sufficiency	Energy consumed during emission	CO_2 emissions from energy consumption	Energy consumption (kWhm^{-3} d^{-1}) $\times$ 0.391 (kg $CO_{2\ equivalent}$ / kWh)	(kg $CO_{2\ equivalent}$ $m^{-3}d^{-1}$)
		Reduced Sludge reduction potential	Sludge amount produced, treated water for irrigation, nutrients	$S_s = Q_{ef}(W_{in}-W_{eff})/Q(C_{in}-C_{eff})$		(kg SS kg^{-1} COD removed) [18]
				Q_{ef}(= flow rate to settler ($m^{-3}d^{-1}$)		
				Q = flow rate to the reactor ($m^{-3}d^{-1}$)		
				W_{in} = SS influent conc. (kg SS m^{-3})		

	Indicators	Sub-indicator	Description	Calculation formula	Values	Suggested units
				W_{eff} = SS effluent conc. (kg SS m^{-3})		
				C_{in} = COD influent conc. (kg COD m^{-3})		
				C_{eff} = COD effluent conc. (kg COD m^{-3})		
Economic sustainability	Capex		Cost of construction and installation of the WWTP	$TAEC = \left[\frac{r(1+r)^t}{(1+r)^t-1}\right] Capex + Opex$		$/m^3
				t = expenses at time t		$/p.e.-year
				r = discount rate (5%)		
	Opex		Operating costs per volume unit of wastewater treated	$\frac{\sum_{t=1}^{TOpex}}{(1+r)^t}$		$/p.e.
				t = expenses at time t		
				r = discount rate (5%)		
Social sustainability	Public acceptance		Opinion of the local population affected by the plant.			Qualitative
	Esthetics		Measured level of nuisance deriving from e.g. odor, noise, visual impact, insects and other pests.			Qualitative
	System manageability		Ease of construction, complexity of O & M; professional skills required for O & M			Qualitative

Table 1.
Multiple indicators chosen for assessing the sustainability. Adapted from [44, 45].

	Support media	Land area	HRT (h)	Influent (mgL^{-1})				Removal efficiency (%)				References
		m^2/p.e		BOD	TSS	NH$_4^+$-N	FC(MPN/100 ml)	BOD	TSS	NH$_4^+$-N	FC (log)	
UASB + TF	Sponge bed	0.3	3	123	79	30	—	89	88	44	3.5	[6]
UASB+DHS	G3 sponge	0.03	1.5	151	228	25	7.71×10^6	96	94	79	3.0	[27]
UASB+DHS	G3.4 sponge	0.05	1.5	161	228	16	1.22×10^9	96	94	83	3.0	[43]
UASB+TF	High rate stones	0.2	2.0	250	150	20	1.8×10^8	93	93	50	2.8	[50]

Table 2.
Treatment performance and land required for UASB+DHS system and UASB+TF system.

basic compliance discharge standard [12] which might have increased the popularity of UASB+DHS system. The data clearly shows that UASB+DHS system has benefits over UASB+TF system attributed by its unique sponges, improving the quality of effluent in terms of organic matter. Similarly, a noticeable ammonia removal efficiency ranging from 79–83% was showcased by UASB+DHS system whereas UASB+TF displayed decreased efficiency below 50%. Studies on molecular microbiology of UASB+DHS have highlighted slow growers such as nitrifiers, denitrifies and even active annamox bacteria in the inner aerobic niches of the sponges facilitating the nitrification and denitrification reaction for nitrogen removal [16, 51]. The other studies also reported that TFs have poor consistency in the removal of nitrogen and phosphorus compared to other conventional treatment systems [6]. Likewise, UASB+DHS system is also efficient for removing pathogenic bacteria from wastewater which was due to high DO condition which prevented growth of bacteria and allowed the higher micro-organisms (protozoa and metazoan) to predate on pathogens such as *E. coli* and total coliforms [52]. Moreover, the other factor for removal of pathogen in the UASB+DHS system reported was adsorption onto biomass [20]. While on the other hand, pathogen removal by UASB +TF system is promising in this case. However, the pathogen removal capacity in TFs have been observed inconsistent and varied from 1.0 log to 3 logs, depending on the operating conditions when compared to ASP [53].

3.2 Land requirements

The increasing land prices and scarcity of available land resources are becoming one of the bottlenecks for WWTP management issues [54]. Land requirement for the WWTPs directly affects its performance and costs. The land requirement per m^2/p.e. for UASB+DHS and UASB+TF systems are shown in **Table 2**. The available literatures show that the land required for the construction of UASB+DHS is almost 10 times less than UASB+TF. Though having the same external design, this difference could be explained by the supporting media. The DHS sponges are comparatively smaller and light weight in comparison to the most frequently used media such as stones, gravel, plastics etc. which implies much higher tank volumes and areas. Nonetheless, having the similar working principle, the packing of the media in DHS system resulted in smaller footprint.

3.3 Carbon footprint

Carbon footprint is relatively a new measure of sustainability in WWTPs to determine its overall impact on climate change and as a result WWTPs performance has recently been evaluated based on carbon minimization [55, 56]. To address sustainability, carbon footprint minimization has become an important environmental indicator [57]. For carbon footprint, assessment, all relevant forms of the energy demand in WWTPs, sludge production and common GHGs emissions are accounted. This review aims to investigate previously unexplored relationships between carbon footprint and sustainability in the context of UASB+DHS system, focusing particularly on the impact of energy minimization measures.

3.3.1 GHGs emission

Global Warming Potential (GWP) is generally used as a metric for weighting the climatic impact of emissions of different greenhouse gases [58]. Among GHGs stated by Kyoto Protocol, the most common GHGs emitted during operation and on-site anthropogenic activities in WWTPs are carbon dioxide (CO_2), methane

(CH_4), nitrous oxide (N_2O) [49]. According to USEPA, WWTPs are the 7th largest contributors of CH_4 and nitrous N_2O emissions in the atmosphere [59]. Particularly, WWTPs produce GHGs during the biological wastewater treatment processes. For calculation, all GHGs emission can be expressed as CO_2 equivalents (CO_2e) with respect to their GWP. CH_4 and N_2O have 28 and 265 times greater GWP compared to CO_2 in a 100-year time horizon [60]. Therefore, more stringent regulatory efforts, mandatory reports and measurements on GHGs emissions from WWTPs are being enforced to control GHGs emissions.

Since, UASB+DHS system is also an anaerobic and aerobic biological treatment process, this information would be vital for the wastewater specialists. For almost all WWTPs, CO_2 production is attributed to two main factors: biological treatment process and electricity consumption. In UASB+DHS system, CO_2 is emitted during the production of the energy required for the plant operation. Emission of N_2O is generated by nitrification and denitrification processes used to remove nitrogenous compounds from wastewater. Similar to the mainstream WWTPs, the organic carbon of wastewater is either incorporated into biomass or oxidized to CO_2. During anaerobic digestion in UASB, it is mainly converted to CO_2 and CH_4. It is assumed that all the CH_4 produced is oxidized to CO_2 during biogas combustion. Estimation of (CO_2e) is attained using units and equations summarized in **Table 1**. For the calculation of GHGs, considering the total treatment process is important. Therefore, GHGs emissions of both the system were estimated based on CO_2 emission from COD oxidation, CH_4 combustion and N_2O emission as presented in **Table 3**. The data for GHGs calculation for UASB+DHS system and UASB+TF were taken from these studies [27, 60, 62]. The value for GWP by UASB+DHS system was 0.59 kg CO_2 equivalent m^{-3} d^{-1} and that for UASB+TF was 0.50 kg CO_2 equivalent m^{-3} d^{-1}. It is to be noted that for the calculation of GWP of UASB+TF, N_2O emissions value was not available as there were no literatures reporting its values. Nevertheless, other studies associated with GHGs emission of TF + ASP system and TF+ Lagoon system showed GWP values of 1.232 kg CO_2 equivalent m^{-3} d^{-1} and 0.898 kg CO_2 equivalent m^{-3} d^{-1} respectively. Therefore, it could be assumed that the UASB+TF system might show fairly higher values compared to UASB+DHS system. The another reason behind assuming the lower GWP values by UASB+DHS system could be justified by its higher solid retention time (SRT) values of almost 92–101 days [17] compared to 2–4 days of TF [65]. Higher values of SRT supports endogenous respiration of biomass which increases the amount of COD oxidized to CO_2 thus decreasing the overall sludge production [17]. This decrease of sludge production reduces the methane production and therefore, a decrease in CO_2 emissions is associated with its combustion. Similarly, higher SRT capacity of DHS system helps to maintain low ammonia and nitrite concentrations in the media which leads to minimum N_2O emissions to the atmosphere. Despite the accuracy of estimated GWP value is not exact, conclusive potential of operating UASB+DHS system at low GHGs emission levels has been assured. Hence, the analysis of GWP revealed the potential of UASB+DHS system to become a sustainable option in the future of wastewater treatment.

	Units	UASB+DHS system	UASB+TF
Global warming Potential	(kg CO_2 equivalent $m^{-3}d^{-1}$)	0.59 [27, 61]	0.50 [62]
Sludge production	(kg SS kg^{-1} COD removed)	0.06 [10]	0.38 [63]
Energy consumption	(kWhm^{-3})	0.12 [27]	0.65 [64]

Table 3.
Carbon footprint assessment of UASB+DHS system and UASB+TF.

3.3.2 Sludge production

For most of the WWTPs, one of the biggest challenges is its sludge production, its post treatment and disposal. Being an aerobic system, DHS system has advantage over other biological treatment system for sludge management [61]. Any sludge accumulated in the clarifier of DHS is called as excess sludge. The sludge production in DHS reactor is calculated by taking the sum of SS volumes in the DHS effluent and the settled excess sludge in the clarifier and relative to the COD or BOD removed by the system. For bench scale experiment, the excess sludge produced by UASB+DHS system was 0.02 kg SS/kg COD removed which is basically 2.5% of the total COD removed or 7% of the total SS load removed [17]. Further, excess sludge from UASB usually varied from 0.03 to 0. 2 kg SS/kg COD removed [8]. Therefore, a total sludge from UASB+DHS system was 0.06 kg SS/kg COD removed. While, excess sludge production from UASB+TF system was 0.38 kgSS/kgCOD removed [63]. The sludge production from UASB+TF system was almost 6 times higher than UASB+DHS system. The DHS sponges are designed with the high void ratio and reticulated structure which cater as a favorable site for the attachment, adsorption and growth of active biomass [25, 61]. Further, the profiling data from same researchers stated that the majority of organic removal especially SS occurred at highest part of the reactor, however after attaining stable state, uniform distribution of sludge was observed along its height. In real scale DHS, for every liter of wastewater treated, about 0.04 kg-COD was wasted as excess sludge which is quite negligible as compared to the other treatment systems. The basic mechanism for the sludge removal in DHS is the physical entrapment of the sludge inside and outside of the sponge which lengthens the solid retention time and provide ample time for self-degradation of sludge minimizing the excess sludge production [61, 66].

3.3.3 Energy consumption

Nowadays, for developing countries energy efficiency has become the first priorities in the WWTPs hierarchy [67]. Minimizing net energy consumption for WWTPs has become mandatory [68]. Generally, for aerobic treatment processes, the aeration is the highest energy consuming process of the wastewater treatment technology which can account upto 50–60% of all electricity consumption followed by 15–25% of energy by sludge treatment and 15% by secondary sedimentation including recirculation pumps [69].

The energy consumed in UASB+DHS system is through electricity required for pumping [27]. The pumps are used for supplying UASB effluent to the top of DHS system. It is usually estimated on the basis of treatment performance and electricity utilized by pumps. Comparison of energy consumption of UASB+DHS system [27] with UASB+TF [64] is summarized in **Table 3**. From the data, it is evident that the energy consumption of UASB+TF is approximately 5 times higher than that of UASB+DHS system. For UASB+DHS system, 0.05 kWhm^{-3} of energy was consumed by main pumping from UASB unit and 0.07 kWhm-3 for the pump of the DHS system, which sums up the total energy consumption for the system of 0.12 kWh per m^3 of wastewater treated. It is noteworthy that the energy consumption for both these systems was solely by pumping. The UASB+DHS system has likelihood of becoming energy sufficient system. The energy sufficiency of UASB+DHS system can be explained by its minimized energy consumption. In addition, when constructing a UASB+DHS system, the energy sufficiency or neutrality can be achieved if UASB is designed in such a way where the outlet is positioned above the DHS distributor or maintained through gravity.

Considering the overall arguments, environmental indicators suggest that the UASB+DHS system is considerably superior in terms of high treatability, less land requirement and reduced carbon footprint. This information could assist the planners and stakeholders in developing nations for good decision making while selecting WWTPs in future.

4. Economic sustainability

Economic sustainability of WWTPs refers to the economic factors affecting social, environmental and cultural aspects of the treatment systems. Economic efficiency of WWTPs presents the scenario of investments in terms of input and effluent quality as the output [70]. Decision and policy makers in developing countries are challenged with the fact that poor urban residents cannot afford costly conventional sewage treatment systems [71]. Fortunately, a broad range of cost-effective technological options are extensively being studied to cater this category of people. Therefore, economic factors become vital to address these issues. For any WWTPs, economic indicators generally represent the costs associated with the construction and the operation of treatment management during its life time [72]. These are driving factors for decision making while selecting a technology in a practical situation.

For the economic assessment, the two most common indicators called capital expenditure (Capex) and operational expenditure (Opex) were calculated using the equations provided by [73]. The capital expenditure included cost of construction and life cycle costs. Operational expenditure included number of mechanical equipment, skilled workers, power consumption, labor, chemicals, and consumables. The data were taken from the state-of-art literatures [43, 74, 75] for calculating the construction and operating costs for economic evaluation for both the systems. For the comparison in the same scale few considerations were made:

Capex is annualized by taking the means of the initial investment costs by the life period of the project accounting for the time value of money while Opex is total discounted lifetime operational expenses.

- life span of each treatment plant was considered as 20 years.

- All costs were expressed in US dollars ($) /Population equivalence (p.e.).

- The cost of implementing and operating the WWTPs are adjusted to 2015 as the base year and was discounted to 2015 values using equations given in **Table 1**.

The economic costs comparison **Table 4** showed that capex and opex costs of UASB+DHS system of 9740 p.e. is almost equal to the UASB+TF of 50,000 pe.

Process system	Country	Treatment volume (PE)	CAPEX US$/PE	OPEX US$/PE/year	References
UASB+DHS	India	9740	86.2	0.36	[43]
UASB+TF	Egypt	50,000	92.14	2.07	[74]
UASB+TF	Egypt	2337	519.31	8.25	[75]

Table 4.
Economic assessment of UASB+DHS system and UASB+TF system.

While for the UASB+TF of 2337 p.e. UASB+DHS system expressed significantly less capex and opex values. For most of the UASB+TF, among the various costs, cost of personnel is the maximum for opex [50]. This could be also the reason for the decreased economic costs for UASB+DHS system. The another rationale for reduced economic costs of UASB+DHS system could be less manpower required due to the simple O&M processes including cleaning of the mechanical parts, chemical free operation and easy handling of sludge [76]. It is interesting to note that DHS inclination is towards negative value for economic assessment which means it is economically fit for the developing countries as capex and opex costs are negative indicators of sustainability and qualifies the criteria to be considered as self-sustainable WWTP system.

5. Social sustainability

Social assessment based on indicators portrays a big picture of multidimensional issues and facilitate decision making. Many key aspects such as community management aspects, satisfaction and opinions of users, service quality, materials and personnel managements, etc. have to be profoundly analyzed before and after the establishment of WWTPs [45]. In this light, social indicators are rapidly becoming the preferred tools for policymakers and public communicators for disseminating the information on the advantages and disadvantages of the WWTPs [77]. However, societal indicators are generally difficult to quantify and often their meaning and relevance is based on the local stakeholders [78]. The data on social indicators for UASB+TF in this review is lacking since data availability on TF. This does not impair our comparison as it's combinations with other systems is a disadvantage identified at the global level in developing countries [79]. Hence, assessment of the chosen indicators is based on TF studied [43]. Caution should be exercised that all the data for social assessment do not represent any generic weighting. The chosen indicators for this assessment are (i) simplicity of the system (ii) esthetics, and (iii) public acceptance of the technology.

5.1 System manageability

System manageability includes ease of construction, complexity of O&M issues and professional skills required for the troubleshooting of the issues during the O&M of the WWTPs. Studies on the social sustainability of WWTPs in India demonstrated that the UASB+DHS system has fewer mechanical parts than TF. The simple configuration of UASB+DHS system makes it easy for construction and several intensive studies have followed up the ramifications of sponge designs for the easy packaging and enhanced efficiency [76]. For developing countries, simplicity of the system might be a key factor in the selection of the WWTP. Due to simple construction, there are few mechanical parts for O&M issues and UASB +DHS system has already been proven to be no laborious maintenance system [80]. Supplementary to this, the operators do not need to have a high technical knowledge.

5.2 Esthetics

UASB+DHS system has a slightly better stance on esthetics than the other TFs. Hydrogen sulphide (H_2S) and ammonia (NH_3) are the predominant objectionable

odors in wastewater [81]. TF has been reported to have limited and passive aeration which might create an anaerobic condition which degrades organic matter and nutrients to release malodorous by-products. Also, TF is very sensitive to temperature change especially high temperatures which generate odors [5]. However, till this date, there are no evidences of odor problems in UASB+DHS system though it was operated at the high temperature in India (~40°C). Nonetheless, both the systems have one common problem i.e. flies and snails which might affect the visual aethetics. Whilst none of the insects found have been found as a nuisance to the surrounding people and there is no evidences of any diseases caused by these insects. However, this issue could be resolved by the installation of nets or covers and cleaning with water sprays [82].

5.3 Public acceptance of the technology

One of the major problems faced during the establishment of WWTPs is its location. Very often resistance and protests from the local people significantly impact on the implementation of any social infrastructure plan [83, 84]. Therefore, "Public acceptance" is a key component when it comes to establishing a new WWTP [85]. In most of the researches, public acceptance of WWTPs facilities are based on concepts such as LULU (locally unwanted land use) and NIMBY (not in my backyard [86, 87]. These studies have highlighted the preferability of TF over activated sludge process. Besides, the result of investigation of Indian WWTPs has also exhibited that moderate value for the public acceptance of TF over UASB+DHS system and suggested WWTPs' location far from the settlement zones. Besides, the sludge and treated water from UASB+DHS system was used by the nearby farmers for agriculture and did not show any social concerns. It is clear that further studies need to be undertaken analyzing local conditions in a stepwise manner towards the acceptance of these technologies.

The above discussions on sustainability indicators assessment support the notion that DHS system could have a wide range of commercial applications for different kinds of wastewater. In most of the developing countries, centralized WWTP are limited to urban areas due to the several financial and social constraints. Likewise, many institutions such as large-scale apartments, complexes, hospitals, hotels, etc. need to maintain their own onsite WWTPs. Until now, the most preferred WWTP option was ASP based treatment plants. However, these systems are expensive due to its high operational and maintenance cost. On this verge, there is a potential use of DHS system as a substitute for ASP which would lead to huge commercial benefit. The technology validation of DHS system over ASP for developing countries has already been reported in several research investigations [12–18, 43]. Another area of commercial application of this system could be in aquaculture industry. Most of the aquariums and fish farms require frequent exchange of water leading to huge financial burden and increased workload. Current progressive researches on the application of DHS system for aquarium water treatment and live seafood transportation by minimizing the exchange of water and decreasing workload have broaden its scalability for aquaculture industry [21, 88]. In line with the environmental, economic and social sustainability of DHS system, it could have prospective applications in industrial wastewater treatment specifically for developing nations. Moreover, DHS reactor has commercial applications in the industries such as food processing industry, beverage industries, rubber processing industries and many agriculture products processing industries. Therefore, it could be concluded that with more researches and real scale implementation of this system, there could be a huge commercial demand for DHS system in near future.

6. Conclusion

From the retrospection of the state-of-art of DHS system, it has always been considered a sustainable system for developing countries. Even though, there are extensive researches being carried out for the performance improvement and application of DHS for other types of wastewater, few efforts have been made for testing and validating the sustainability of DHS system. This chapter introduced and analyzed the sustainability indicators of DHS system based on environment, economic and social indicators. By assessing the range of environmental performance indicators, including treatment performance, land requirement, carbon footprint along with economic costs and social factors, this review provides information on DHS system pursuing positively towards sustainability than UASB+TF. However, the availability of data is still an issue in this context for both the systems. It is recommended to conceptualize the sustainability assessment framework that will also encourage and support data collection for better and more quantitative analysis to ensure the applicability and usefulness of DHS technology. Considering the outcomes from sustainability assessment, regardless of data insufficiency, the DHS system fulfilled the criteria of self-sustaining WWTP to a greater extent. Nevertheless, more comprehensive studies are suggested for understanding the other aspects of self-sustainability which are not discussed in this chapter.

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