KEMENTERIAN PENDIDIKAN KEBUDAYAAN RISET DAN TEKNOLOGI
UNIVERSITAS PEMBANGUNAN NASIONAL "VETERAN" JAWA TIMUR
FAKULTAS TEKNIK
Jl. Raya Rungkut Madya Gunung Anyar Surabaya, Telp. 031 8782179 Fax. 031 8782257

SURAT KETERANGAN
HASIL PEMERIKSAAN TINGKAT PLAGIARISME
Nomor : 109 / UN63.3/ TU.PLAGIASI/ III /2023

Yang bertanda-tangan di bawah ini,

Nama	: Dr. Dra. Jariyah, MP.
NIP	: 19650403 199103 2 001
Jabatan	: Dekan Fakultas Teknik

dengan ini menerangkan bahwa Penulis telah melakukan pemeriksaan tingkat kesamaan (plagiarisme) menggunakan *software* **Turnitin** secara mandiri dan **penulis bertanggung jawab** terhadap dokumen publikasi dalam daftar di bawah ini:

Judul Karya Tulis	: A Systematic Review: Downflow Hanging Sponge Application for Wastewater Treatment Technology
Jenis Publikasi	: Jurnal
Penulis	: Dr. Ir. Munawar Ali, MT.
Tingkat Kesamaan (%)	: 15 %

Demikian Surat Keterangan ini dibuat dengan sebenarnya, agar dapat digunakan sebagaimana mestinya.

Surabaya, 07 Maret 2023
Dekan Fakultas Teknik

Dr. Dra. Jariyah, MP.
NIP. 19650403 199103 2 001

A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology

by Munawar Ali

Submission date: 26-Apr-2023 12:32AM (UTC+0700)
Submission ID: 2005565626
File name: A_Systematic_Review_Down-flow_Hanging_Sponge_Application_for.pdf (388.58K)
Word count: 3756
Character count: 19142

2nd International Conference Eco-Innovation in Science, Engineering, and Technology
Volume 2021
http://dx.doi.org/10.11594/nstp.2021.1425

NST PROCEEDINGS

OPEN ACCESS

Conference Paper

A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology

Kyky Fadhila Cindya Putri, Aulia Ulfah Farahdiba*, Munawar Ali

Department of Environmental Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Sura-baya 60294, Indonesia

*Corresponding author:
E-mail:
auliaulfah.tl@upnjatim.ac.id

ABSTRACT

To reduce waste water pollution in Indonesia, it is necessary to conduct renewable research. One of the studies designed as an energy-efficient and easy-to-maintain alternative is the downflow hanging sponge (DHS). DHS has been studied in various countries and is being developed. from some of these studies will be summarized in this paper about the mechanism of the dhs process, the microorganisms formed in dhs, and the factors that affect the performance of dhs.

Keywords: Down-flow Hanging Sponge, Wastewater treatment

Introduction

Developing an appropriate wastewater treatment system in a country is a challenge. In Indonesia, the wastewater treatment system still has some flaws, such as requiring land, producing more sludge, and having high energy consumption. The use of this system is not suitable for developing countries like Indonesia. Still, the development of such a system is on the 2030 agenda for sustainable development and the 17 sustainable development goals (SDGs).

Several researchers have found an affordable and efficient wastewater treatment system, one of which is the down-flow hanging sponge (DHS) (Maharjan et al., 2018; Okubo et al., 2016; Khan et al., 2014; Kassab et al., 2010). This technology was created as a post-processing step for the UASB (up-flow anaerobic sludge blanket) reactor (Uemura & Harada, 2010). The down-flow hanging sponge concept is similar to the trickling filter method, except instead of media, a polyurethane sponge is used as a container for biomass capture.

The down-flow hanging sponge treatment system has had many modifications in design. It is divided into six generations. Each generation has a different pattern of media arrangement. In addition, the down-flow hanging sponge has been investigated for its usefulness to treat domestic wastewater, well water, textile wastewater, and food industry wastewater (Tawfik et al., 2014) from some of these studies it was found that the down-flow hanging sponge can reduce the cod value by 80% and the bod value by 80%

Processing mechanism

In 1995 Professor Hideki Harada and his research group at Nagaoka University of Technology Japan discovered a downflow hanging sponge (DHS) for post-treatment of wastewater using UASB. The study showed that the processing results were very efficient, removing organic loads in wastewater and toxic compounds in water such as nitrogen and pathogens (Okubo et al., 2016). The DHS concept is based on a conventional trickling filter that uses rock, gravel, or plastic as the medium. While DHS itself uses a sponge that provides a three-dimensional space as a place for

How to cite:
Putri, K. F. C., Farahdiba, A. U., & Ali, M. (2021). A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology. *2nd International Conference Eco-Innovation in Science, Engineering, and Technology*. NST Proceedings. pages 159-165. doi: 10.11594/ nstp.2021.1425

microorganisms to grow. Water will flow from the top of the DHS media and drip down according to the force of gravity. The BOD in the water is effectively oxidized due to the function of the polyurethane sponge, which can hold water, and in the sponge, there are microorganisms attached.

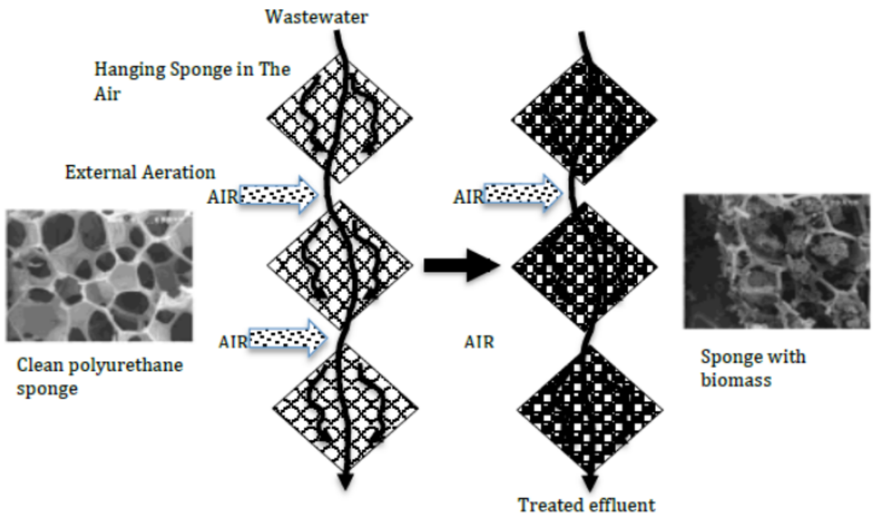

Figure 1. Concept of DHS (Harada et al. 2010)

Several studies have shown that DHS reactors generally have a height of 2-4 m with several air vents at each size with the aim that the air entering the reactor will dissolve with waste when water flows into the media. Because of that, no external aeration is needed. At the top, DHS can decompose the high organic load in the wastewater. Then at the bottom of the reactor has a stable and uniform microorganism environment so that it is suitable for nitrification, bacteria can decompose low organic loads.

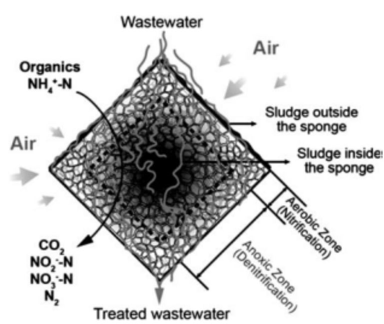

Figure 2. The concept in sponge medium

Biomass can thrive both within and outside of the media. Because of the peculiar nature of the medium, which can create an aerobic environment on the medium's surface (nitrification) and an anaerobic environment within the medium (denitrification), the nitrification-denitrification reaction can occur (Araki et al., 1999).

Down-flow hanging sponge design

From the first to the sixth generation, the DHS concept has evolved. Several research organizations have been conducting basic research on DHS as an efficient post-treatment reactor that does not compromise the advantages of UASB since the 1990s. The form of the sponge media, filling the media, and the DHS design were all improved due to the research.

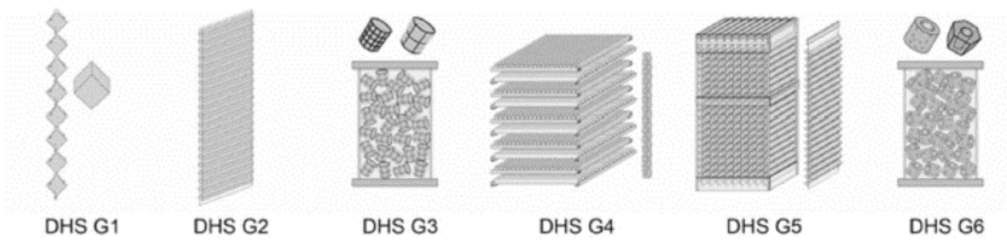

Figure 3. Down-flow Hanging Sponge Design

DHS G1

The first DHS prototype, currently known as the first generation DHS, was created in 1995. (DHS G1 or cube-type DHS). The sponges are first chopped into small cubes (1.5 cm on each side) and then linked diagonally with ropes in a series (Agrawal et al. 1997; Machdar et al., 1997). The first generation DHS was investigated for post-treatment UASB and it resulted in good efficiency values.

DHS G2

Modifications to the second generation were developed to address the shortcomings of the first. A long triangular polyurethane sponge (3 cm x 3 cm x 75 cm) is attached to both sides of a polyvinyl sheet (DHS G2 or DHS curtain type) (Machdar et al., 2000; Okubo et al., 2015). DHS G2 is applied to wastewater treatment in India and gives good performance (Tandukar et al., 2006).

DHS G3

The third generation (DHS G3) is more like a trickling filter. The sponge was cut into small pieces and put into a tubular plastic net as a supporting medium. The placement of the media in the DHS reactor is simple by placing it randomly. When wastewater flows down the DHS reactor, the water penetrates one sponge strip then exits and enters the next sponge strip (Okubo et al., 2016; Tawfik et al., 2006)

DHS G4

The fourth-generation DHS (DHS G4) is an improvement from the previous type, namely DHS G3. The DHS G4 has a box module with a long sponge medium (2.5 cm×2.5cm×50 cm) housed in a plastic mesh cover. The DHS G4 was designed to generate gaps between sponge units, allowing air and wastewater to move freely through the reactor (Tandukar et al., 2005; Tandukar et al., 2006).

DHS G5

The fifth-generation DHS (DHS G5) was made in 2004. The reactor was built using 12 DHS G2, which is a certain type. The curtains are placed side by side in a rectangular frame 4 cm apart and sequentially. All these constructs are considered as one module (Tandukar et al., 2007)

DHS G6

The sixth-generation DHS (DHS G6) is built like the DHS G3. The difference is that the polyurethane sponge is mixed using an epoxy resin, so it doesn't need a plastic net as support. The media placement in the reactor is the same as DHS G3, which is distributed randomly. As more surface area of the sponge is exposed to wastewater, it increases the interaction between wastewater, air, and biomass in the sponge (Onodera et al., 2014; Okubo et al., 2017)

Characteristics of microorganisms in the down-flow hanging sponge

Microorganisms have a special habitat in a down-flow hanging sponge. The water quality changes as the reactor height rise. However, aerobic and anaerobic microbes were found in the sludge, and diverse community architectures were discovered as the reactor height increased.

Table 1 shows the organization of the sludge microbial community in DHS based on 16S rRNA gene sequencing analysis for wastewater. According to gene sequencing analyses, the predominant microbial groupings found in DHS sludge were Phyla Proteobacteria, Firmicutes, and Bacteroidetes. In Table 1, proteobacteria are the most numerous microbes, accounting for at least 30% of each DHS sludge, which had the same tendency for wastewater treatment using activated sludge (AS) (Hatamoto et al., 2017; Zhang et al., 2011).

Tabel 1. Microbial community in down-flow hanging sponge

Type	DHS G3			DHS G3			DHS G3		
Country	India			Vietnam			Jepang		
Jurnal	Nomoto et al. 2018			Watari et al. 2017			Kubota et al. 2014		
Height	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**
Archaeabacteria	0,8	0,5	0,2	1,8	1,6	2,3	0	0	0
Alphaproteobacteria	13.5	25,1	26,2	9,8	9,4	6,3	8	4,4	9,2
Betaproteobacteria	1,8	1,6	3,7	13,5	14,4	11,7	36,2	32,8	13,8
Gammaproteobacteria	14,5	6,8	11,9	11,3	12,5	14,4	31,8	22,7	22,2
Deltaproteobacteria	8,4	1,3	1,4	2,2	2,6	2,7	2	2,7	5,1
Bacteroidetes	1,2	0,9	5	9,3	8,3	14,8	6,3	8,8	9,3
Chlorobi	0	0	0	2,5	1,8	2,3	0	0,8	0,5
Planctomycetes	1,9	2,2	5,5	0,9	1,1	2,1	0	0	3,4
Verrucomicrobia	0,6	0,3	1,2	0,2	0,5	0,7	0,8	2,6	2
Gemmatimonadetes	0	0	0,3	0,2	0,2	0,6	0	1	3,4
Acidobacteria	0,1	0,1	1,3	0,8	0,9	1,9	0,4	14,2	23,5
Nitrospira	0	0	0,2	0	0,2	0,1	0	0,9	4
Firmicutes	28,3	17,3	7,8	22,1	18,6	18,3	10,7	2	2,1
Actinobacteria	19,2	28,6	24,7	12,1	11,8	7,8	0	1,2	0
Chloroflexi	5,1	2,7	7,4	0,8	12,4	9,5	0	0	1

The microorganism community structure at the top, middle, and bottom has been compared with the water quality. At the top, the organic load shows a fairly high value, and the microorganisms show an uneven value. It is is due to the dominance of several microorganisms. Then, the microorganism community in the middle and bottom has a high evenness value so that the resulting organic load is low. This is due to the balance of groups of microorganisms. The balance is very complex and diverse.

Using quantitative PCR (qPCR) of the amoA gene, the presence of ammonia and nitrite-oxidizing bacteria in the middle and bottom of the reactor was detected, revealing a clear correlation between the presence of ammonia-oxidizing bacteria and a decrease in the concentration of ammonium nitrogen. DHS contained archaea microorganisms that act as ammonia oxidizers, according to the qPCR data. On the other hand, Archaea bacteria are only found in the center and bottom of the tank, where the ammonia load is low, and the amount of archaea bacteria is only 10%.

Nomoto et al. (2017) The microbial community composition of a full-scale DHS built in Agra, India, was examined. The reactor's diameter is 16 meters, which explains the disparity in microbial community organization in the horizontal direction. They came to the conclusion that the change in the microbial community structure along the reactor's height was bigger than the change in the horizontal direction. DHS functions at high organic loading rates and accommodates high COD and sulfate contents. The number of anaerobic bacteria, such as sulfate-reducing bacteria from Deltaproteobacteria and Clostridial species from Firmicutes, increases in the top half of the DHS and declines in the bottom (Table 1).

Kubota et al. (2014) descriptions of community structures are compared. Nomoto et al. (2017), in Table 1, demonstrate that the organization of the DHS microbial community varies significantly depending on important wastewater parameters, including COD and sulfate concentrations and the operating circumstances of the organic loading system. For industrial treatment, changes in microbial community structure were also recorded along with the height of the DHS reactor (Watari et al., 2017). This explains the dramatic variation in water quality, which is thought to be caused by DHS sponges, which have distinct microbial groups depending on the water quality and reactor height.

Factors affecting DHS reactor performance

The DHS system is similar to a trickling filter. The medium is replaced by a small sponge that is inserted into a plastic cover like a net. DHS appears to overcome some of the problems from trickling filters (TF). In the TF system, microorganisms only adhere to the media's surface, forming a biological filter or mucus layer; whereas, in the DHS system, microorganisms are kept both outsides and inside the sponge, resulting in a long sludge residence period (>100 days) (Tawfik et al., 2006) and eventually achieves complete nitrification and produces very low amounts of sludge. The following are some of the factors that influence the DHS reactor's performance:

Hydraulic Retention Time (HRT)

The hydraulic retention time (HRT) is expressed as the time required for wastewater to flow through the DHS reactor. Wastewater is very important to stay in the reactor and contact the microbes that stick to the sponge media. The HRT depends on the wastewater flow rate to the DHS reactor, the volume, and the porosity of the sponge medium.

The longer the wastewater remains in the reactor in contact with microbes, the greater the organic removal efficiency. The performance of DHS in treating domestic wastewater with different HRT (6, 4, and 2 hours). The results showed that the COD removal efficiency was 89, 80, and 56% for HRT of 6, 4, and 2 hours, respectively. The results are the same for other parameters such as ammonia and phosphorus.

Hydraulic Loading Rate (HLR)

The volume of wastewater used per unit area of sponge media per unit time (m3/m.d) is known as the hydraulic loading rate (HLR). High HLR causes a decrease in HRT in the DHS reactor and can reduce processing efficiency. COD removal was strongly influenced by an increase in the organic loading rate (OLR) and hydraulic loading rate (HLR).

Organic Loading Rate (OLR)

Different influent loadings to the DHS reactor were investigated. The increase in organic loading rate (OLR) and hydraulic loading rate in the DHS reactor significantly impacts COD elimination (HLR). The OLR used varies between 1.2 and 3.4 kg COD/m3d. With this load, the COD removal effectiveness of the DHS system dropped from 89 to 55 percent. Long-term evaluation by Tandukar et al. (2006) The increase in OLR did not substantially impact COD removal efficiency. However, when substantial organic loads are applied, the reactor performance, particularly nitrogen removal, deteriorates.

Sponge size

The effect of sponge size on the performance of the DHS reactor, showing three identical reactors but having sponge media with different sizes. The results showed that all concentrations of SS and COD in the three reactors were less than ten mg/L. But reactor 1 with the smallest sponge had the best COD removal performance.

In short, the smaller the sponge size, the better. The author assumes that the smaller sponge allows better oxygen uptake for the downflow reactor. The DO concentration in the reactor evidence this, the highest DO concentration is in reactor 1, and the lowest DO concentration is in reactor 3 (the largest sponge size). In addition, the smaller sponge provides a higher surface area, resulting in better contact between the sludge and wastewater and possibly increased organic removal.

Reactor height

The analysis that DO increases gradually as wastewater flows downwards. it was also found by Tandukar et al. (2006). Data show a steady increase in DO concentration from zero in the DHS reactor influent to 7.2mg O2/l in the DHS final effluent. This could be due to a rise in the DO value to wastewater due to an increase in wastewater flow rate at a lower HRT. The height of the reactor also affects the growth and spread of microorganisms. This explains the drastic change in water quality, estimated to be produced from DHS sponges with different microbial groups in each water quality condition and reactor height.

Ventilation

Ventilation in the DHS reactor is very important because it is the only source of oxygen entering the reactor. Microorganisms need oxygen in DHS sponges. The effect of ventilation and oxygen concentration in the DHS G6 reactor by opening or closing the vents in the three connecting segments. In the first stage, all vents are closed. In the second stage, all the vents are opened. In the third stage, only the first ventilation is opened. The results showed no substantial difference between the characteristics of the DHS influent in stages 1, 2, or 3. However, the concentration of TKN in the DHS effluent during stages 1, 2, and 3 was 3.8±1, 21.5±7, and 14.0±4 mg/L. This study indicates that ventilation in the DHS reactor is very important to improve its performance.

Conclusion

The downflow hanging sponge is a new type of reactor that several researchers are investigating to improve performance and expand the application field of DHS. Research and development phases are underway in various countries. From the results of this study, it can be seen that there are six types of preparation/design of DHS reactors, namely from the first generation to the sixth generation. The design has its advantages and disadvantages, but it does not reduce the original function of DHS, namely to treat wastewater optimally and efficiently. There are several factors that affect the performance of the reactor, one of which is the height of the reactor which makes the diversity of microorganisms at each height in the DHS reactor. This will improve the quality of the water produced.

References

Agrawal, L. K., Ohashi, Y., Mochida, E., Okui, H., Ueki, Y., Harada, H., & Ohashi, A. (1997). Treatment of raw sewage in a temperate climate using a UASB reactor and the hanging sponge cubes process. *Water Science and Technology*, *36*(6-7), 433-440.

Araki, N., Ohashi, A., Machdar, I., & Harada, H. (1999). Behaviors of nitrifiers in a novel biofilm reactor employing hanging sponge-cubes as attachment site. *Water Science and Technology, 39*(7), 23-31.

Hatamoto, M., Kaneko, T., Takimoto, Y., Ito, T., Miyazato, N., Maki, S., Yamaguchi, T., & Aoi, T. (2017). Microbial community structure and enumeration of Bacillus species in activated sludge. *J Water Environ Technol*., *15,* 233–240.

Kassab, G., Halalsheh, M., Klapwijk, A., Fayyad, M., & Van Lier, J. B. (2010). Sequential anaerobic–aerobic treatment for domestic wastewater–a review. *Bioresource Technology*, *101*(10), 3299-3310.

Khan, A. A., Gaur, R. Z., Mehrotra, I., Diamantis, V., Lew, B., & Kazmi, A. A. (2014). Performance assessment of different STPs based on UASB followed by aerobic post treatment systems. *Journal of Environmental Health Science and Engineering*, *12*(1), 1-13.

Kubota, K., Hayashi, M., Matsunaga, K., Iguchi, A., Ohashi, A., Li, Y. Y., Yamaguchi, T., & Harada, H. (2014). Microbial community composition of a down-flow hanging sponge (DHS) reactor combined with an up-flow anaerobic sludge blanket (UASB) reactor for the treatment of municipal sewage. *Bioresour Technol., 151,* 144–150.

Machdar, I., Harada, H., Ohashi, A., Sekiguchi, Y., Okui, H., & Ueki, K. (1997). A novel and cost-effective sewage treatment system consisting of UASB pre-treatment and aerobic post-treatment units for developing countries. *Water Sci Technol., 36,*189–197.

Machdar, I., Sekiguchi, Y., Sumino, H., Ohashi, A., & Harada, H. (2000). Combination of a UASB reactor and a curtain type DHS (downflow hanging sponge) reactor as a cost-effective sewage treatment system for developing countries. *Water Sci Technol., 42,* 83–88

Maharjan N, Nomoto N, Tagawa T, Okubo T, Uemura S, Khalil N, Hatamoto M, Yamaguchi T, Harada H (2018) Assessment of UASB–DHS technology for sewage treatment: a comparative study from a sustainability perspective. *Environ Technol* 1–8

Nomoto, N., Tyagi, V. K., Ali, M., Jayaswal, K., Maharjan, N., Iguchi, A., ... & Harada, H. (2017). Application of DHS reactor to sewage treatment in a developing country: performance during start-up period and under high organic load condition. *J Jpn Soc Water Environ*, 40, 11-19.

Okubo, T., Iguchi, A., Takahashi, M., Kubota, K., Uemura, S., & Harada, H. (2017). Treatment performance of practical-scale down-flow hanging sponge reactor using sixth-generation hard sponge media. *Desalin Water Treat., 91,* 48–54.

Okubo, T., Kubota, K., Yamaguchi, T., Uemura, S., & Harada, H. (2016). Development of a new non-aeration-based sewage treatment technology: performance evaluation of a full-scale down-flow hanging sponge reactor employing third-generation sponge carriers. *Water Res., 102,*138–146.

Okubo, T., Onodera, T., Uemura, S., Yamaguchi, T., Ohashi, A., & Harada, H. (2015). On-site evaluation of the performance of a full-scale downflow hanging sponge reactor as a post-treatment process of an upflow anaerobic sludge blanket reactor for treating sewage in India. *Bioresour Technol., 194,*156–164.

Onodera, T., Tandukar, M., Sugiyana, D., Uemura, S., Ohashi, A., & Harada, H. (2014). Development of a sixth-generation down-flow hanging sponge (DHS) reactor using rigid sponge media for post-treatment of UASB treating municipal sewage. *Bioresour Technol., 152,* 93–100.

Tandukar, M., Ohashi, A., & Harada, H. (2007). Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater. *Water Res., 41*, 2697–2705.

Tandukar, M., Uemura, S., Machdar, I., Ohashi, A., & Harada, H. (2005). A lowcost municipal sewage treatment system with a combination of UASB and the Bfourth-generation downflow hanging sponge reactors. *Water Sci Technol., 52*, 323–329

Tandukar, M., Uemura, S., Ohashi, A., & Harada, H. (2006). Combining UASB and the Bfourth generation down-flow hanging sponge reactor for municipal wastewater treatment. *Water Sci Technol., 53,* 209–218.

Tawfik, A., El-Gohary, F., Ohashi, A., & Harada, H. (2006a). The influence of physical-chemical and biological factors on the removal of faecal coliform through down-flow hanging sponge (DHS) system treating UASB reactor effluent. *Water Res., 40,* 1877–1883.

Tawfik, A., Zaki, D. F., & Zahran, M. K. (2014). Degradation of reactive dyes wastewater supplemented with cationic polymer (Organo Pol.) in a down flow hanging sponge (DHS) system. *J Ind Eng Chem., 20,* 2059–2065.

Uemura, S., & Harada, H. (2010). Application of UASB technology for sewage treatment with a novel post-treatment process. In: Fang HHP (ed) Environmental anaerobic technology applications and new developments. *Imperial College Press, London*, 91–112

Watari, T., Mai, T. C., Tanikawa, D., Hirakata, Y., Hatamoto, M., Syutsubo, K., Fukuda, M., Nguyen, N. B., & Yamaguchi, T. (2017). Development of downflow hanging sponge (DHS) reactor as post treatment of existing combined anaerobic tank treating natural rubber processing wastewater. *Water Sci Technol., 75,* 57–68.

Zhang, T., Shao, M-F., & Ye, L. (2011). 454 pyrosequencing reveals bacterial diversity of activated sludge from 14 sewage treatment plants. *ISMEJ, 6,* 1137–1147.

A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology

ORIGINALITY REPORT

15%	13%	15%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	link.springer.com Internet Source	11%
2	Submitted to UPN Veteran Jawa Timur Student Paper	2%
3	eprints.utar.edu.my Internet Source	2%

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	On		

2nd International Conference Eco-Innovation in Science, Engineering, and Technology
Volume 2021
http://dx.doi.org/10.11594/nstp.2021.1425

NST PROCEEDINGS

OPEN ACCESS

Conference Paper

A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology

Kyky Fadhila Cindya Putri, Aulia Ulfah Farahdiba*, Munawar Ali

Department of Environmental Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Sura-baya 60294, Indonesia

*Corresponding author:
E-mail:
auliaulfah.tl@upnjatim.ac.id

ABSTRACT

To reduce waste water pollution in Indonesia, it is necessary to conduct renewable research. One of the studies designed as an energy-efficient and easy-to-maintain alternative is the downflow hanging sponge (DHS). DHS has been studied in various countries and is being developed. from some of these studies will be summarized in this paper about the mechanism of the dhs process, the microorganisms formed in dhs, and the factors that affect the performance of dhs.

Keywords: Down-flow Hanging Sponge, Wastewater treatment

Introduction

Developing an appropriate wastewater treatment system in a country is a challenge. In Indonesia, the wastewater treatment system still has some flaws, such as requiring land, producing more sludge, and having high energy consumption. The use of this system is not suitable for developing countries like Indonesia. Still, the development of such a system is on the 2030 agenda for sustainable development and the 17 sustainable development goals (SDGs).

Several researchers have found an affordable and efficient wastewater treatment system, one of which is the down-flow hanging sponge (DHS) (Maharjan et al., 2018; Okubo et al., 2016; Khan et al., 2014; Kassab et al., 2010). This technology was created as a post-processing step for the UASB (up-flow anaerobic sludge blanket) reactor (Uemura & Harada, 2010). The down-flow hanging sponge concept is similar to the trickling filter method, except instead of media, a polyurethane sponge is used as a container for biomass capture.

The down-flow hanging sponge treatment system has had many modifications in design. It is divided into six generations. Each generation has a different pattern of media arrangement. In addition, the down-flow hanging sponge has been investigated for its usefulness to treat domestic wastewater, well water, textile wastewater, and food industry wastewater (Tawfik et al., 2014) from some of these studies it was found that the down-flow hanging sponge can reduce the cod value by 80% and the bod value by 80%

Processing mechanism

In 1995 Professor Hideki Harada and his research group at Nagaoka University of Technology Japan discovered a downflow hanging sponge (DHS) for post-treatment of wastewater using UASB. The study showed that the processing results were very efficient, removing organic loads in wastewater and toxic compounds in water such as nitrogen and pathogens (Okubo et al., 2016). The DHS concept is based on a conventional trickling filter that uses rock, gravel, or plastic as the medium. While DHS itself uses a sponge that provides a three-dimensional space as a place for

How to cite:
Putri, K. F. C., Farahdiba, A. U., & Ali, M. (2021). A Systematic Review: Down-flow Hanging Sponge Application for Wastewater Treatment Technology. *2nd International Conference Eco-Innovation in Science, Engineering, and Technology*. NST Proceedings. pages 159-165. doi: 10.11594/ nstp.2021.1425

microorganisms to grow. Water will flow from the top of the DHS media and drip down according to the force of gravity. The BOD in the water is effectively oxidized due to the function of the polyurethane sponge, which can hold water, and in the sponge, there are microorganisms attached.

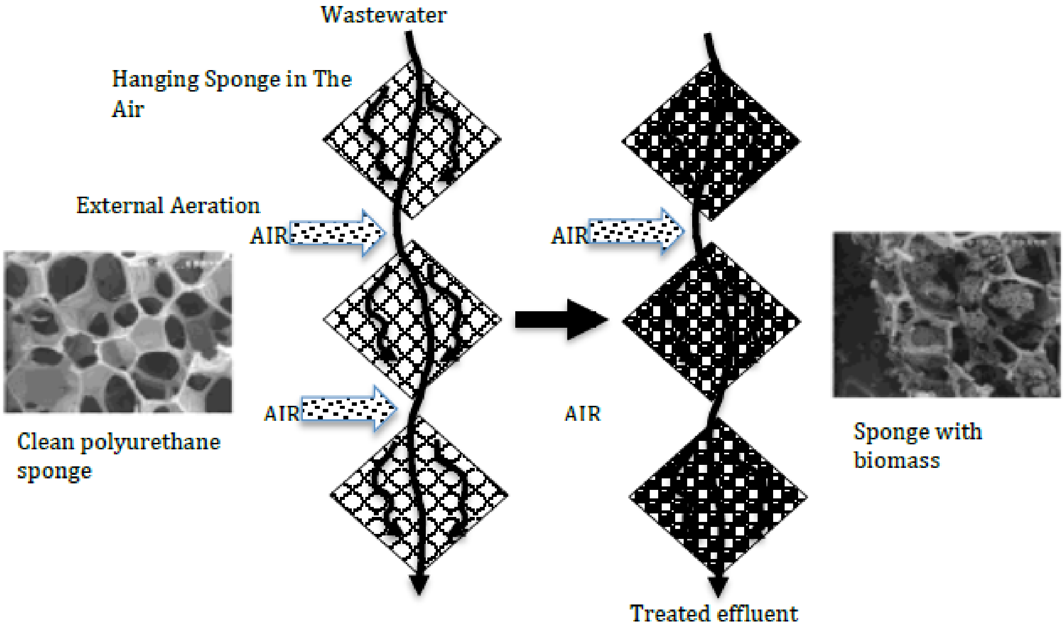

Figure 1. Concept of DHS (Harada et al. 2010)

Several studies have shown that DHS reactors generally have a height of 2-4 m with several air vents at each size with the aim that the air entering the reactor will dissolve with waste when water flows into the media. Because of that, no external aeration is needed. At the top, DHS can decompose the high organic load in the wastewater. Then at the bottom of the reactor has a stable and uniform microorganism environment so that it is suitable for nitrification, bacteria can decompose low organic loads.

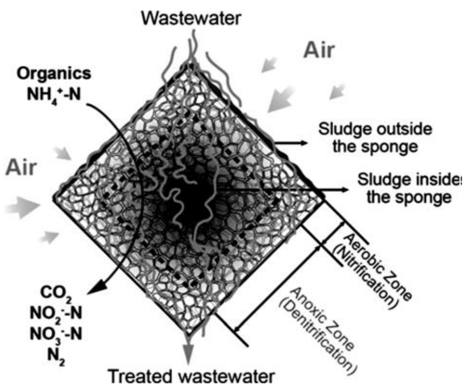

Figure 2. The concept in sponge medium

Biomass can thrive both within and outside of the media. Because of the peculiar nature of the medium, which can create an aerobic environment on the medium's surface (nitrification) and an anaerobic environment within the medium (denitrification), the nitrification-denitrification reaction can occur (Araki et al., 1999).

Down-flow hanging sponge design

From the first to the sixth generation, the DHS concept has evolved. Several research organizations have been conducting basic research on DHS as an efficient post-treatment reactor that does not compromise the advantages of UASB since the 1990s. The form of the sponge media, filling the media, and the DHS design were all improved due to the research.

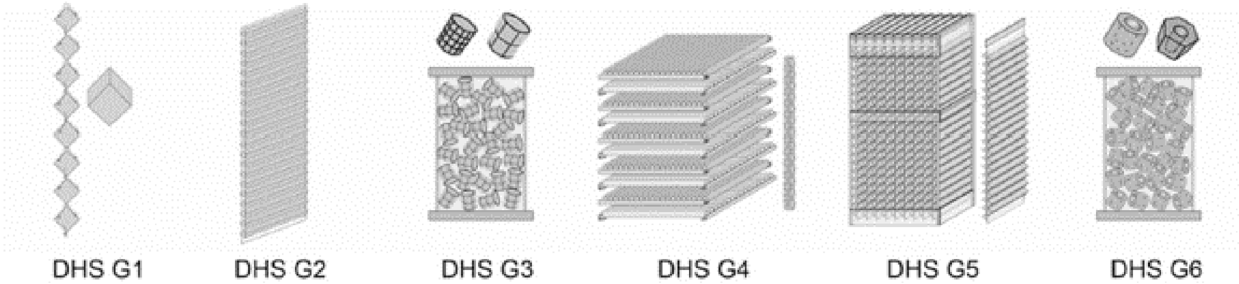

Figure 3. Down-flow Hanging Sponge Design

DHS G1

The first DHS prototype, currently known as the first generation DHS, was created in 1995. (DHS G1 or cube-type DHS). The sponges are first chopped into small cubes (1.5 cm on each side) and then linked diagonally with ropes in a series (Agrawal et al. 1997; Machdar et al., 1997). The first generation DHS was investigated for post-treatment UASB and it resulted in good efficiency values.

DHS G2

Modifications to the second generation were developed to address the shortcomings of the first. A long triangular polyurethane sponge (3 cm x 3 cm x 75 cm) is attached to both sides of a polyvinyl sheet (DHS G2 or DHS curtain type) (Machdar et al., 2000; Okubo et al., 2015). DHS G2 is applied to wastewater treatment in India and gives good performance (Tandukar et al., 2006).

DHS G3

The third generation (DHS G3) is more like a trickling filter. The sponge was cut into small pieces and put into a tubular plastic net as a supporting medium. The placement of the media in the DHS reactor is simple by placing it randomly. When wastewater flows down the DHS reactor, the water penetrates one sponge strip then exits and enters the next sponge strip (Okubo et al., 2016; Tawfik et al., 2006)

DHS G4

The fourth-generation DHS (DHS G4) is an improvement from the previous type, namely DHS G3. The DHS G4 has a box module with a long sponge medium (2.5 cm×2.5cm×50 cm) housed in a plastic mesh cover. The DHS G4 was designed to generate gaps between sponge units, allowing air and wastewater to move freely through the reactor (Tandukar et al., 2005; Tandukar et al., 2006).

DHS G5

The fifth-generation DHS (DHS G5) was made in 2004. The reactor was built using 12 DHS G2, which is a certain type. The curtains are placed side by side in a rectangular frame 4 cm apart and sequentially. All these constructs are considered as one module (Tandukar et al., 2007)

DHS G6

The sixth-generation DHS (DHS G6) is built like the DHS G3. The difference is that the polyurethane sponge is mixed using an epoxy resin, so it doesn't need a plastic net as support. The media placement in the reactor is the same as DHS G3, which is distributed randomly. As more surface area of the sponge is exposed to wastewater, it increases the interaction between wastewater, air, and biomass in the sponge (Onodera et al., 2014; Okubo et al., 2017)

Characteristics of microorganisms in the down-flow hanging sponge

Microorganisms have a special habitat in a down-flow hanging sponge. The water quality changes as the reactor height rise. However, aerobic and anaerobic microbes were found in the sludge, and diverse community architectures were discovered as the reactor height increased.

Table 1 shows the organization of the sludge microbial community in DHS based on 16S rRNA gene sequencing analysis for wastewater. According to gene sequencing analyses, the predominant microbial groupings found in DHS sludge were Phyla Proteobacteria, Firmicutes, and Bacteroidetes. In Table 1, proteobacteria are the most numerous microbes, accounting for at least 30% of each DHS sludge, which had the same tendency for wastewater treatment using activated sludge (AS) (Hatamoto et al., 2017; Zhang et al., 2011).

Tabel 1. Microbial community in down-flow hanging sponge

Type	DHS G3			DHS G3			DHS G3		
Country	India			Vietnam			Jepang		
Jurnal	Nomoto et al. 2018			Watari et al. 2017			Kubota et al. 2014		
Height	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**
Archaeabacteria	0,8	0,5	0,2	1,8	1,6	2,3	0	0	0
Alphaproteobacteria	13.5	25,1	26,2	9,8	9,4	6,3	8	4,4	9,2
Betaproteobacteria	1,8	1,6	3,7	13,5	14,4	11,7	36,2	32,8	13,8
Gammaproteobacteria	14,5	6,8	11,9	11,3	12,5	14,4	31,8	22,7	22,2
Deltaproteobacteria	8,4	1,3	1,4	2,2	2,6	2,7	2	2,7	5,1
Bacteroidetes	1,2	0,9	5	9,3	8,3	14,8	6,3	8,8	9,3
Chlorobi	0	0	0	2,5	1,8	2,3	0	0,8	0,5
Planctomycetes	1,9	2,2	5,5	0,9	1,1	2,1	0	0	3,4
Verrucomicrobia	0,6	0,3	1,2	0,2	0,5	0,7	0,8	2,6	2
Gemmatimonadetes	0	0	0,3	0,2	0,2	0,6	0	1	3,4
Acidobacteria	0,1	0,1	1,3	0,8	0,9	1,9	0,4	14,2	23,5
Nitrospira	0	0	0,2	0	0,2	0,1	0	0,9	4
Firmicutes	28,3	17,3	7,8	22,1	18,6	18,3	10,7	2	2,1
Actinobacteria	19,2	28,6	24,7	12,1	11,8	7,8	0	1,2	0
Chloroflexi	5,1	2,7	7,4	0,8	12,4	9,5	0	0	1

The microorganism community structure at the top, middle, and bottom has been compared with the water quality. At the top, the organic load shows a fairly high value, and the microorganisms show an uneven value. It is is due to the dominance of several microorganisms. Then, the microorganism community in the middle and bottom has a high evenness value so that the resulting organic load is low. This is due to the balance of groups of microorganisms. The balance is very complex and diverse.

Using quantitative PCR (qPCR) of the amoA gene, the presence of ammonia and nitrite-oxidizing bacteria in the middle and bottom of the reactor was detected, revealing a clear correlation between the presence of ammonia-oxidizing bacteria and a decrease in the concentration of ammonium nitrogen. DHS contained archaea microorganisms that act as ammonia oxidizers, according to the qPCR data. On the other hand, Archaea bacteria are only found in the center and bottom of the tank, where the ammonia load is low, and the amount of archaea bacteria is only 10%.

Nomoto et al. (2017) The microbial community composition of a full-scale DHS built in Agra, India, was examined. The reactor's diameter is 16 meters, which explains the disparity in microbial community organization in the horizontal direction. They came to the conclusion that the change in the microbial community structure along the reactor's height was bigger than the change in the horizontal direction. DHS functions at high organic loading rates and accommodates high COD and sulfate contents. The number of anaerobic bacteria, such as sulfate-reducing bacteria from Deltaproteobacteria and Clostridial species from Firmicutes, increases in the top half of the DHS and declines in the bottom (Table 1).

Kubota et al. (2014) descriptions of community structures are compared. Nomoto et al. (2017), in Table 1, demonstrate that the organization of the DHS microbial community varies significantly depending on important wastewater parameters, including COD and sulfate concentrations and the operating circumstances of the organic loading system. For industrial treatment, changes in microbial community structure were also recorded along with the height of the DHS reactor (Watari et al., 2017). This explains the dramatic variation in water quality, which is thought to be caused by DHS sponges, which have distinct microbial groups depending on the water quality and reactor height.

Factors affecting DHS reactor performance

The DHS system is similar to a trickling filter. The medium is replaced by a small sponge that is inserted into a plastic cover like a net. DHS appears to overcome some of the problems from trickling filters (TF). In the TF system, microorganisms only adhere to the media's surface, forming a biological filter or mucus layer; whereas, in the DHS system, microorganisms are kept both outsides and inside the sponge, resulting in a long sludge residence period (>100 days) (Tawfik et al., 2006) and eventually achieves complete nitrification and produces very low amounts of sludge. The following are some of the factors that influence the DHS reactor's performance:

Hydraulic Retention Time (HRT)

The hydraulic retention time (HRT) is expressed as the time required for wastewater to flow through the DHS reactor. Wastewater is very important to stay in the reactor and contact the microbes that stick to the sponge media. The HRT depends on the wastewater flow rate to the DHS reactor, the volume, and the porosity of the sponge medium.

The longer the wastewater remains in the reactor in contact with microbes, the greater the organic removal efficiency. The performance of DHS in treating domestic wastewater with different HRT (6, 4, and 2 hours). The results showed that the COD removal efficiency was 89, 80, and 56% for HRT of 6, 4, and 2 hours, respectively. The results are the same for other parameters such as ammonia and phosphorus.

Hydraulic Loading Rate (HLR)

The volume of wastewater used per unit area of sponge media per unit time (m3/m.d) is known as the hydraulic loading rate (HLR). High HLR causes a decrease in HRT in the DHS reactor and can reduce processing efficiency. COD removal was strongly influenced by an increase in the organic loading rate (OLR) and hydraulic loading rate (HLR).

Organic Loading Rate (OLR)

Different influent loadings to the DHS reactor were investigated. The increase in organic loading rate (OLR) and hydraulic loading rate in the DHS reactor significantly impacts COD elimination (HLR). The OLR used varies between 1.2 and 3.4 kg COD/m3d. With this load, the COD removal effectiveness of the DHS system dropped from 89 to 55 percent. Long-term evaluation by Tandukar et al. (2006) The increase in OLR did not substantially impact COD removal efficiency. However, when substantial organic loads are applied, the reactor performance, particularly nitrogen removal, deteriorates.

Sponge size

The effect of sponge size on the performance of the DHS reactor, showing three identical reactors but having sponge media with different sizes. The results showed that all concentrations of SS and COD in the three reactors were less than ten mg/L. But reactor 1 with the smallest sponge had the best COD removal performance.

In short, the smaller the sponge size, the better. The author assumes that the smaller sponge allows better oxygen uptake for the downflow reactor. The DO concentration in the reactor evidence this, the highest DO concentration is in reactor 1, and the lowest DO concentration is in reactor 3 (the largest sponge size). In addition, the smaller sponge provides a higher surface area, resulting in better contact between the sludge and wastewater and possibly increased organic removal.

Reactor height

The analysis that DO increases gradually as wastewater flows downwards. it was also found by Tandukar et al. (2006). Data show a steady increase in DO concentration from zero in the DHS reactor influent to 7.2mg O2/l in the DHS final effluent. This could be due to a rise in the DO value to wastewater due to an increase in wastewater flow rate at a lower HRT. The height of the reactor also affects the growth and spread of microorganisms. This explains the drastic change in water quality, estimated to be produced from DHS sponges with different microbial groups in each water quality condition and reactor height.

Ventilation

Ventilation in the DHS reactor is very important because it is the only source of oxygen entering the reactor. Microorganisms need oxygen in DHS sponges. The effect of ventilation and oxygen concentration in the DHS G6 reactor by opening or closing the vents in the three connecting segments. In the first stage, all vents are closed. In the second stage, all the vents are opened. In the third stage, only the first ventilation is opened. The results showed no substantial difference between the characteristics of the DHS influent in stages 1, 2, or 3. However, the concentration of TKN in the DHS effluent during stages 1, 2, and 3 was 3.8±1, 21.5±7, and 14.0±4 mg/L. This study indicates that ventilation in the DHS reactor is very important to improve its performance.

Conclusion

The downflow hanging sponge is a new type of reactor that several researchers are investigating to improve performance and expand the application field of DHS. Research and development phases are underway in various countries. From the results of this study, it can be seen that there are six types of preparation/design of DHS reactors, namely from the first generation to the sixth generation. The design has its advantages and disadvantages, but it does not reduce the original function of DHS, namely to treat wastewater optimally and efficiently. There are several factors that affect the performance of the reactor, one of which is the height of the reactor which makes the diversity of microorganisms at each height in the DHS reactor. This will improve the quality of the water produced.

References

Agrawal, L. K., Ohashi, Y., Mochida, E., Okui, H., Ueki, Y., Harada, H., & Ohashi, A. (1997). Treatment of raw sewage in a temperate climate using a UASB reactor and the hanging sponge cubes process. *Water Science and Technology*, *36*(6-7), 433-440.

Araki, N., Ohashi, A., Machdar, I., & Harada, H. (1999). Behaviors of nitrifiers in a novel biofilm reactor employing hanging sponge-cubes as attachment site. *Water Science and Technology, 39*(7), 23-31.

Hatamoto, M., Kaneko, T., Takimoto, Y., Ito, T., Miyazato, N., Maki, S., Yamaguchi, T., & Aoi, T. (2017). Microbial community structure and enumeration of Bacillus species in activated sludge. *J Water Environ Technol*., *15,* 233–240.

Kassab, G., Halalsheh, M., Klapwijk, A., Fayyad, M., & Van Lier, J. B. (2010). Sequential anaerobic–aerobic treatment for domestic wastewater–a review. *Bioresource Technology*, *101*(10), 3299-3310.

Khan, A. A., Gaur, R. Z., Mehrotra, I., Diamantis, V., Lew, B., & Kazmi, A. A. (2014). Performance assessment of different STPs based on UASB followed by aerobic post treatment systems. *Journal of Environmental Health Science and Engineering*, *12*(1), 1-13.

Kubota, K., Hayashi, M., Matsunaga, K., Iguchi, A., Ohashi, A., Li, Y. Y., Yamaguchi, T., & Harada, H. (2014). Microbial community composition of a down-flow hanging sponge (DHS) reactor combined with an up-flow anaerobic sludge blanket (UASB) reactor for the treatment of municipal sewage. *Bioresour Technol., 151,* 144–150.

Machdar, I., Harada, H., Ohashi, A., Sekiguchi, Y., Okui, H., & Ueki, K. (1997). A novel and cost-effective sewage treatment system consisting of UASB pre-treatment and aerobic post-treatment units for developing countries. *Water Sci Technol., 36,*189–197.

Machdar, I., Sekiguchi, Y., Sumino, H., Ohashi, A., & Harada, H. (2000). Combination of a UASB reactor and a curtain type DHS (downflow hanging sponge) reactor as a cost-effective sewage treatment system for developing countries. *Water Sci Technol., 42,* 83–88

Maharjan N, Nomoto N, Tagawa T, Okubo T, Uemura S, Khalil N, Hatamoto M, Yamaguchi T, Harada H (2018) Assessment of UASB–DHS technology for sewage treatment: a comparative study from a sustainability perspective. *Environ Technol* 1–8

Nomoto, N., Tyagi, V. K., Ali, M., Jayaswal, K., Maharjan, N., Iguchi, A., ... & Harada, H. (2017). Application of DHS reactor to sewage treatment in a developing country: performance during start-up period and under high organic load condition. *J Jpn Soc Water Environ*, 40, 11-19.

Okubo, T., Iguchi, A., Takahashi, M., Kubota, K., Uemura, S., & Harada, H. (2017). Treatment performance of practical-scale down-flow hanging sponge reactor using sixth-generation hard sponge media. *Desalin Water Treat., 91,* 48–54.

Okubo, T., Kubota, K., Yamaguchi, T., Uemura, S., & Harada, H. (2016). Development of a new non-aeration-based sewage treatment technology: performance evaluation of a full-scale down-flow hanging sponge reactor employing third-generation sponge carriers. *Water Res., 102,*138–146.

Okubo, T., Onodera, T., Uemura, S., Yamaguchi, T., Ohashi, A., & Harada, H. (2015). On-site evaluation of the performance of a full-scale downflow hanging sponge reactor as a post-treatment process of an upflow anaerobic sludge blanket reactor for treating sewage in India. *Bioresour Technol*., *194,*156–164.

Onodera, T., Tandukar, M., Sugiyana, D., Uemura, S., Ohashi, A., & Harada, H. (2014). Development of a sixth-generation down-flow hanging sponge (DHS) reactor using rigid sponge media for post-treatment of UASB treating municipal sewage. *Bioresour Technol., 152,* 93–100.

Tandukar, M., Ohashi, A., & Harada, H. (2007). Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater. *Water Res., 41*, 2697–2705.

Tandukar, M., Uemura, S., Machdar, I., Ohashi, A., & Harada, H. (2005). A lowcost municipal sewage treatment system with a combination of UASB and the Bfourth-generation downflow hanging sponge reactors. *Water Sci Technol., 52*, 323–329

Tandukar, M., Uemura, S., Ohashi, A., & Harada, H. (2006). Combining UASB and the Bfourth generation down-flow hanging sponge reactor for municipal wastewater treatment. *Water Sci Technol., 53,* 209–218.

Tawfik, A., El-Gohary, F., Ohashi, A., & Harada, H. (2006a). The influence of physical-chemical and biological factors on the removal of faecal coliform through down-flow hanging sponge (DHS) system treating UASB reactor effluent. *Water Res., 40,* 1877–1883.

Tawfik, A., Zaki, D. F., & Zahran, M. K. (2014). Degradation of reactive dyes wastewater supplemented with cationic polymer (Organo Pol.) in a down flow hanging sponge (DHS) system. *J Ind Eng Chem., 20,* 2059–2065.

Uemura, S., & Harada, H. (2010). Application of UASB technology for sewage treatment with a novel post-treatment process. In: Fang HHP (ed) Environmental anaerobic technology applications and new developments. *Imperial College Press, London*, 91–112

Watari, T., Mai, T. C., Tanikawa, D., Hirakata, Y., Hatamoto, M., Syutsubo, K., Fukuda, M., Nguyen, N. B., & Yamaguchi, T. (2017). Development of downflow hanging sponge (DHS) reactor as post treatment of existing combined anaerobic tank treating natural rubber processing wastewater. *Water Sci Technol., 75,* 57–68.

Zhang, T., Shao, M-F., & Ye, L. (2011). 454 pyrosequencing reveals bacterial diversity of activated sludge from 14 sewage treatment plants. *ISMEJ, 6,* 1137–1147.