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Treatment performance of practical-scale down-flow hanging sponge reactor using sixth-generation sponge media

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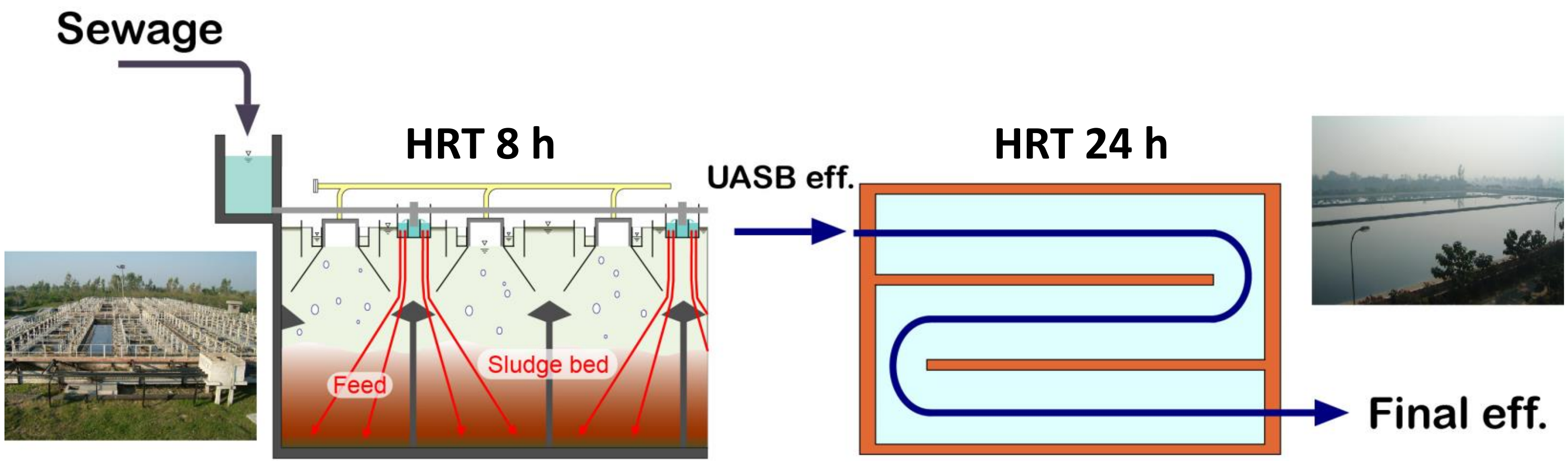


Up-flow Anaerobic Sludge Blanket (UASB)　**Final Polishing Unit (FPU)**

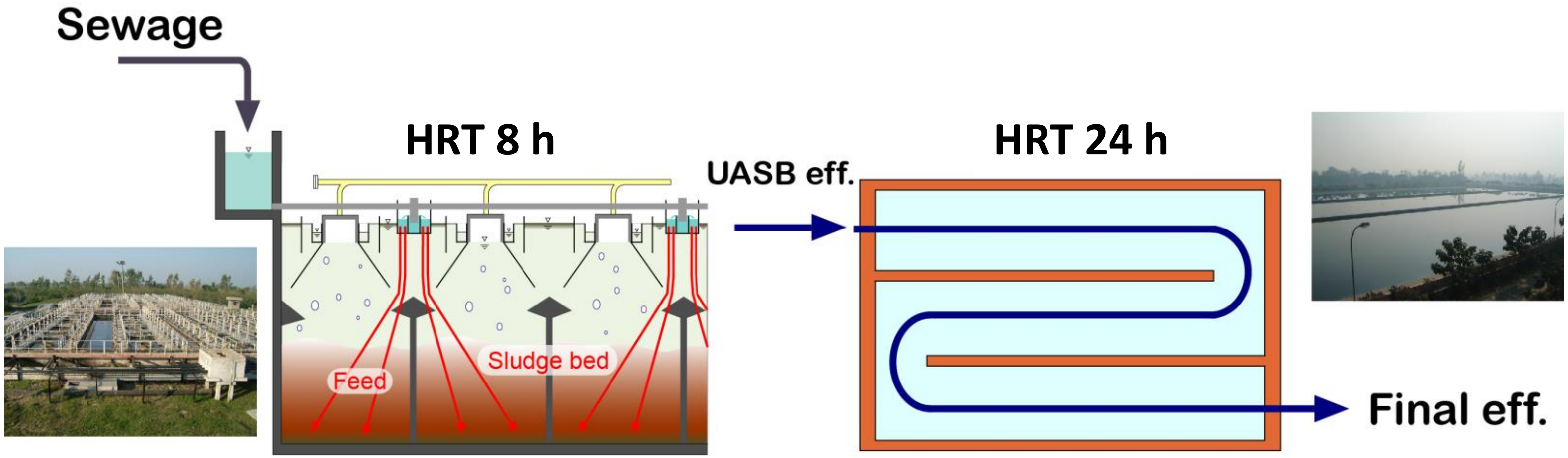
STPs	Sewage	UASB eff.	Final eff.	BOD rem.(%)
Panipat 35MLD	196	131	116	41
Faridabad 45MLD	318	111	98	69
Faridabad 50MLD	365	179	154	58
Gurgaon 30MLD	318	154	104	67
Ghaziabad 70MLD	293	151	85	71
Agra 78MLD	264	126	64	76

Standard
< 30 mgBOD L^{-1}

(Sato, N., Okubo, T. *et al*., 2007)

UASB-FPU systems constlucted under YAP-I cannot meet the discharge standard

In India, stabilization pond, which is called Final Polishing Unit (FPU), is usually employed as a post treatment process with an long HRT and huge area.



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UASB-FPU systems constlucted under YAP-I cannot meet the discharge standard

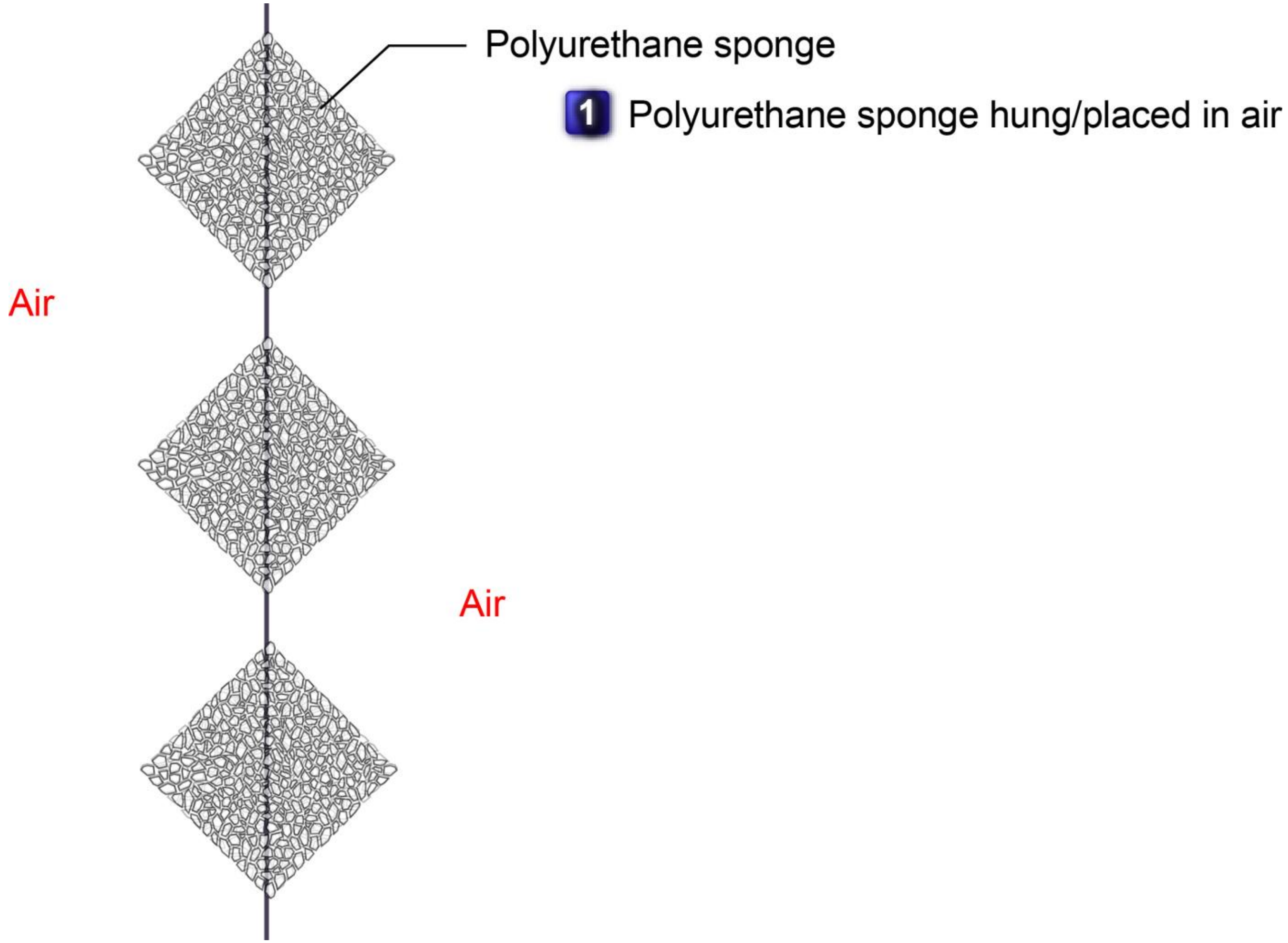
Effluent discharge standard of BOD is 30 mg/L. However, irrespective of the long HRT, it seems that almost all of the UASB+FPU systems cannot meet the effluent discharge standard.

Down-flow Hanging Sponge (DHS) reactor was proposed and developed as a novel and low cost post treatment for UASB treating sewage.

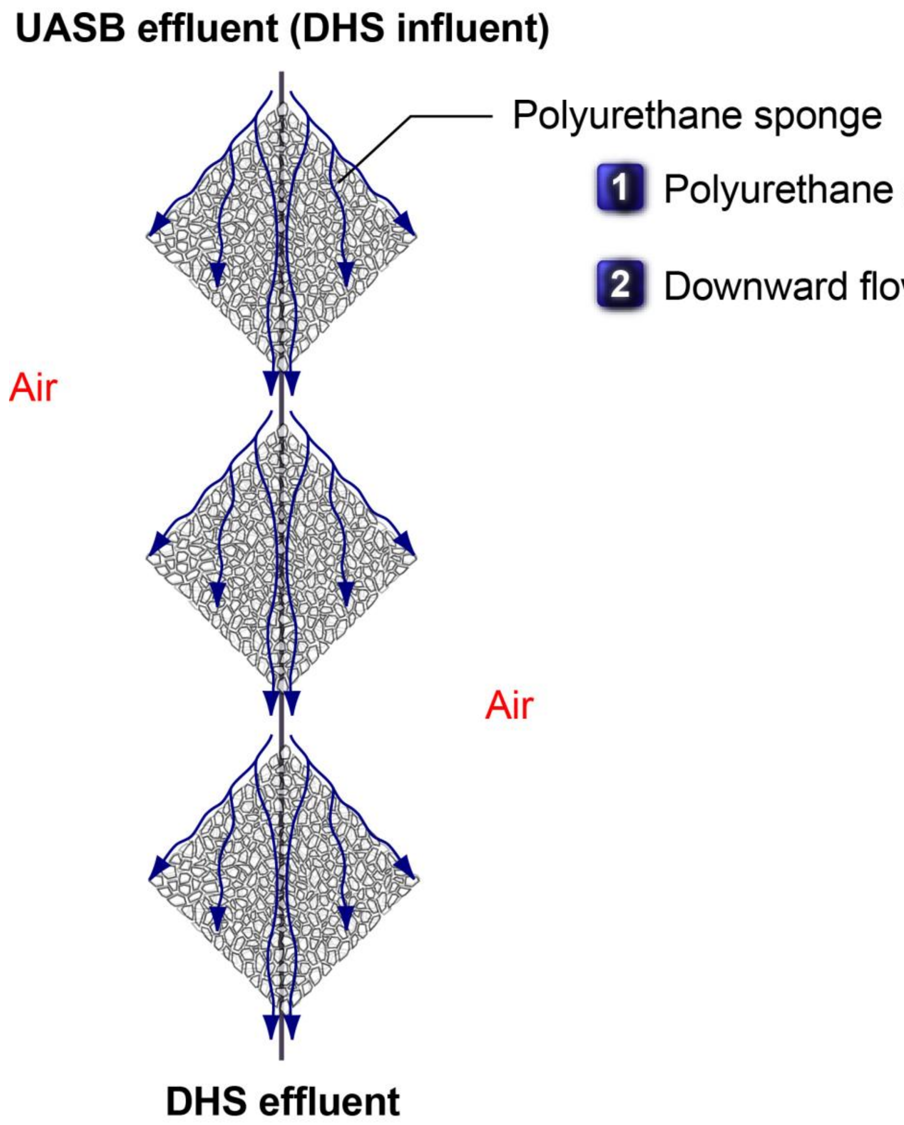
Advantage:

- **Low construction and maintenance cost**
- **No energy requirement for aeration**
- **Less amount of excess sludge** **16 – 50 % of that of ASP** (Okubo *et al*., 2015)
- **Short HRT (approximately UASB 8 h + DHS 2 h)**
- **Less area requirement**

48 m^2 1000 m^{-3} treated (DHS) -> only 6% of that required for FPU (Okubo *et al*., 2015)

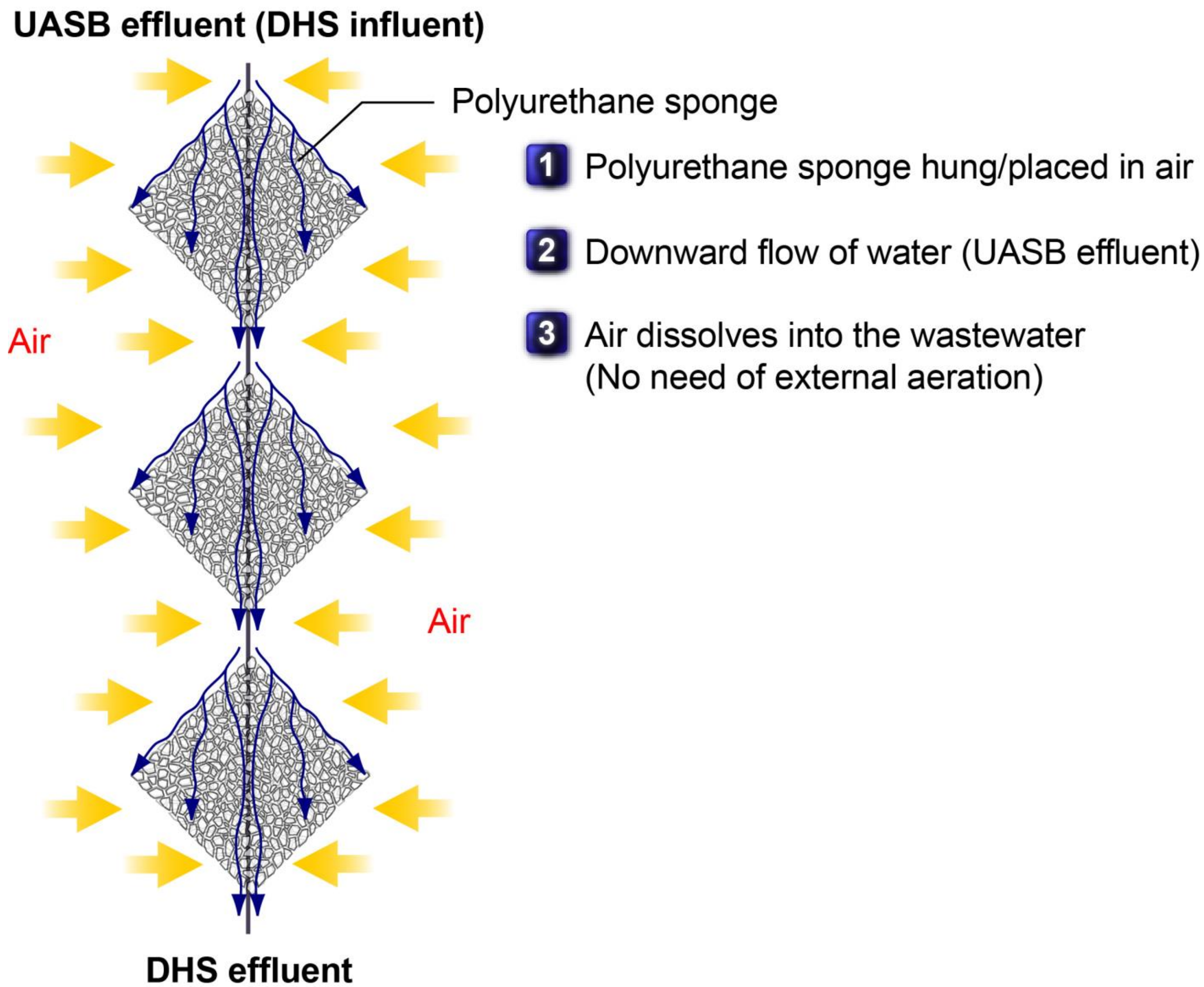


A concept of DHS is based on the conventional trickling filter process. DHS employs simple and easily available polyurethane-made sponge as a support media.



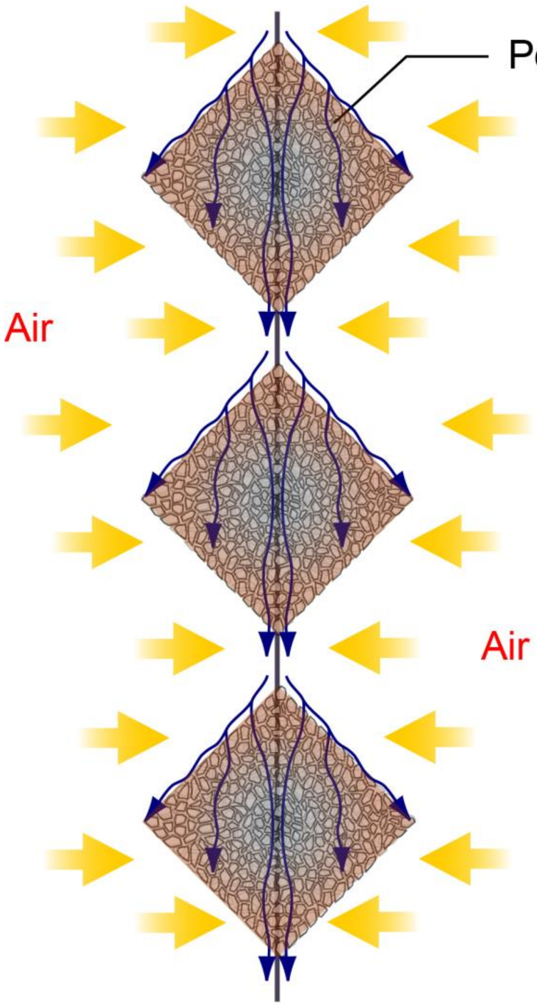
1 Polyurethane sponge hung/placed in air

2 Downward flow of water (UASB effluent)



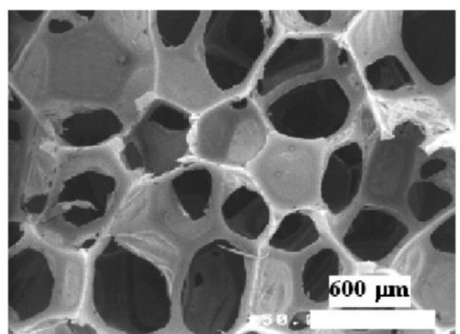
Air dissolves into the UASB effluent as it flows down the DHS, and thus there is no need of external aeration.

UASB effluent (DHS influent)

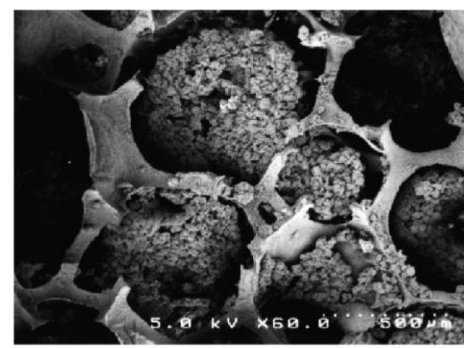


DHS effluent

1. Polyurethane sponge hung/placed in air
2. Downward flow of water (UASB effluent)
3. Air dissolves into the wastewater
   (No need of external aeration)
4. Biomas immobilized
   (Growth and attachment of active biomass,
   VSS concentration: 20-30gVSS/L-sponge)
5. Excellent quality effluent



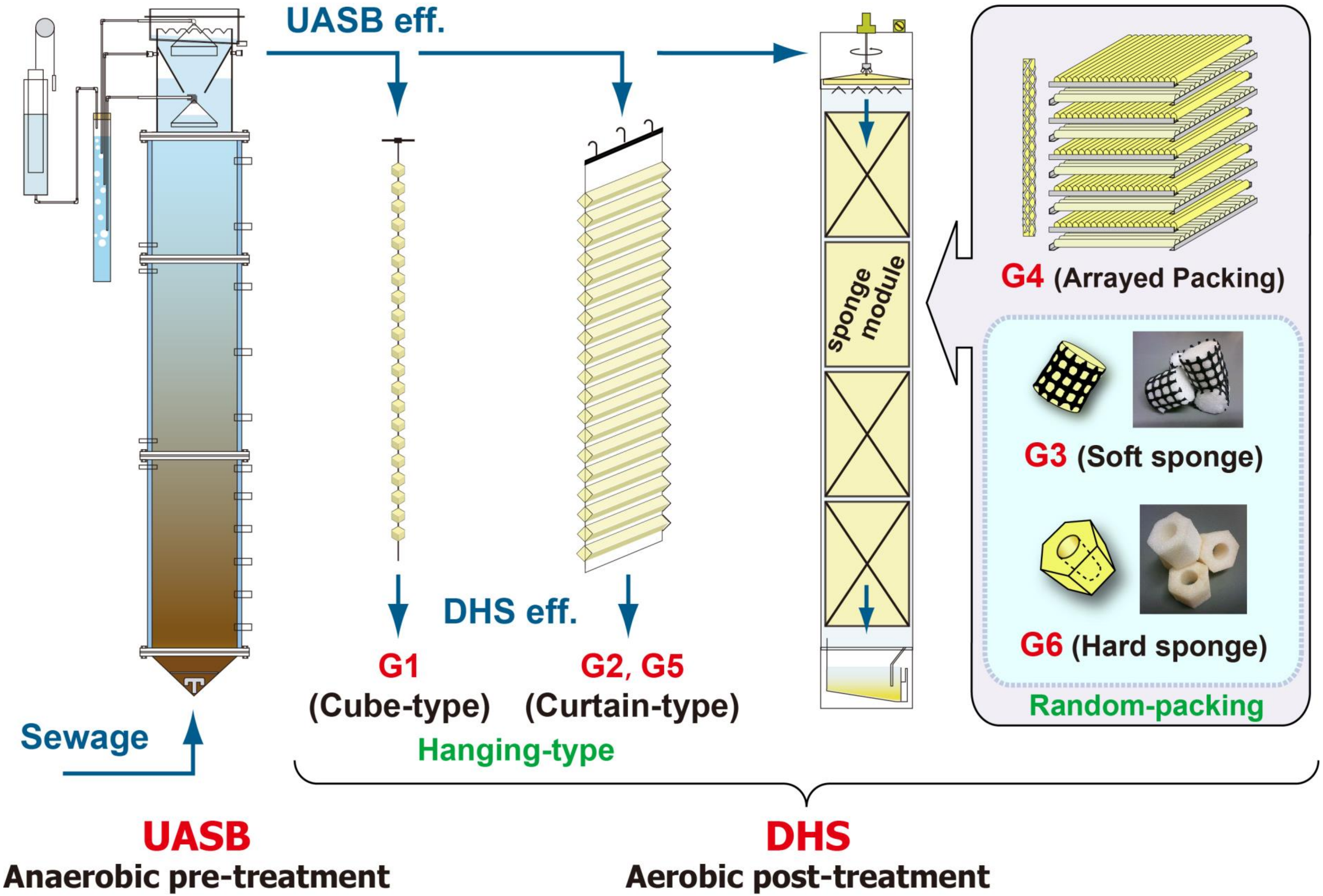
SEM images of clean sponge



SEM images of entrapped sludge

(Tandukar *et al.*, 2006)

Sponge has a void ratio of more than 95%, which provides an excellent site for growth and attachment of active biomass.


UASB eff.
sponge module
G4 (Arrayed Packing)
G3 (Soft sponge)
G6 (Hard sponge)
Random-packing
DHS eff.
G1
(Cube-type)
G2, G5
(Curtain-type)
Hanging-type
Sewage
UASB
Anaerobic pre-treatment
DHS
Aerobic post-treatment

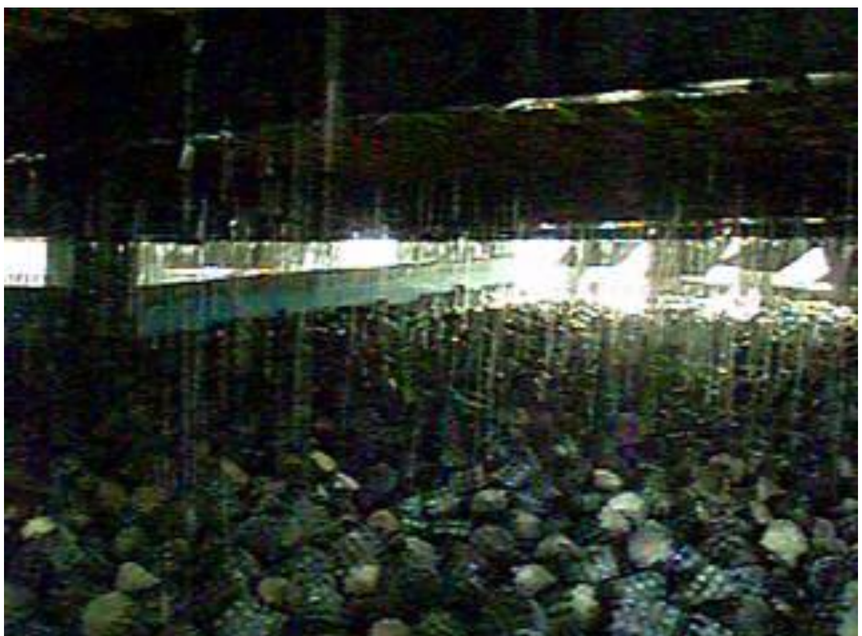
Random Packing Sponge Media

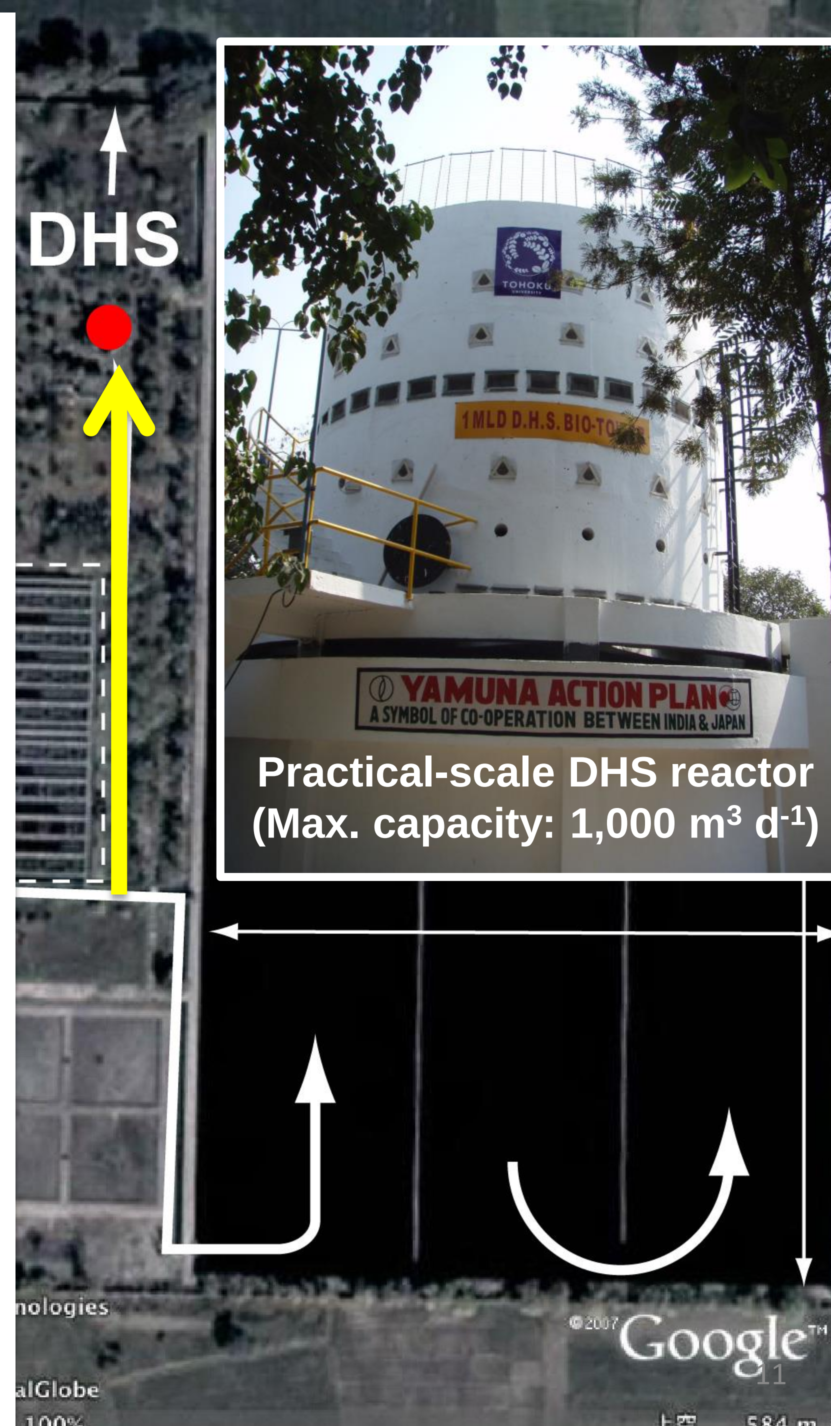
Currently, the best packing arrangement with regard to workability is "random packing".

- **G3 type -> Soft type made of polyurethane sponge**
- **G6 type -> Hard type made of polyethylene sponge stiffened with epoxy resin**

Distributor (top of the reactor)

Inside the reactor





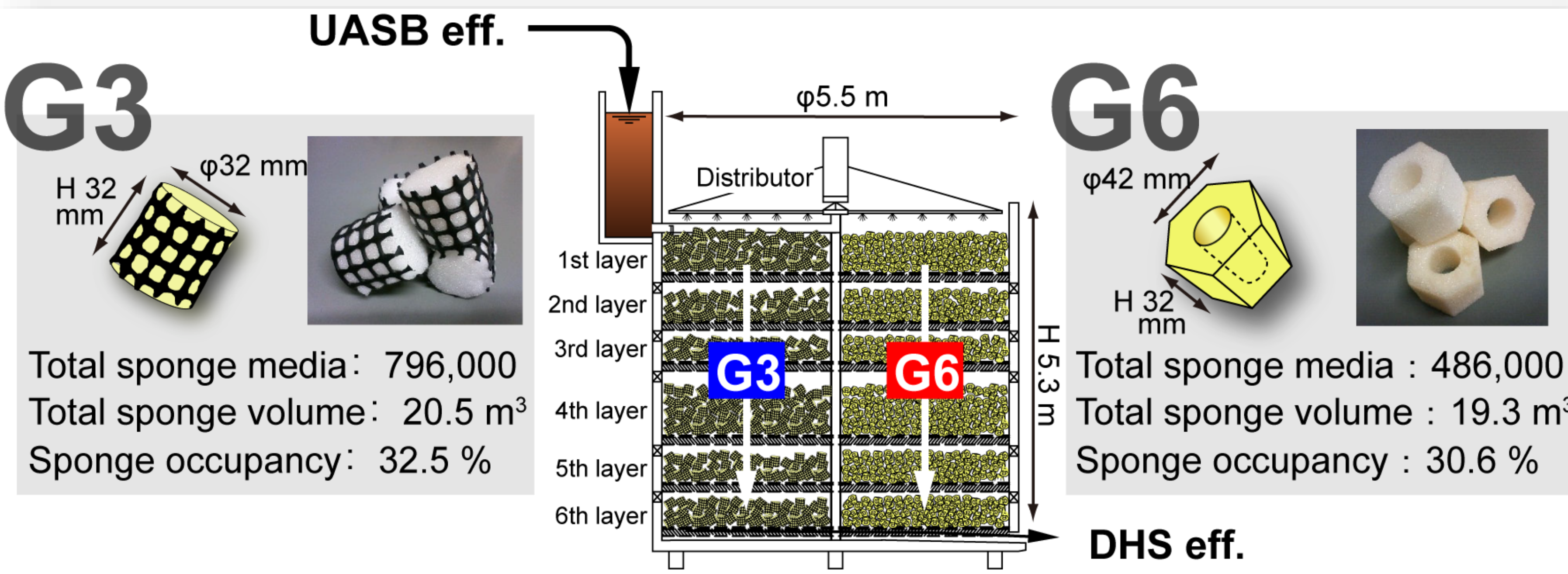
Practical-scale DHS reactor
(Max. capacity: 1,000 m^3 d^{-1})

Specification of DHS reactor

・The reactor consisted of a concrete cylinder 5.5 mφ and 5.3 mH.
・There are 6 sponge layers in the reactor.
・Ventilation ports were incorporated into the reactor to improve air uptake.
・A lateral partition was installed in the reaction zone in the DHS reactor, and each side was filled with G3 and G6 media in a random-packing arrangement.

Objective

To compare and evaluate the treatment performance of G3 and G6 sponge media under same practical conditions.



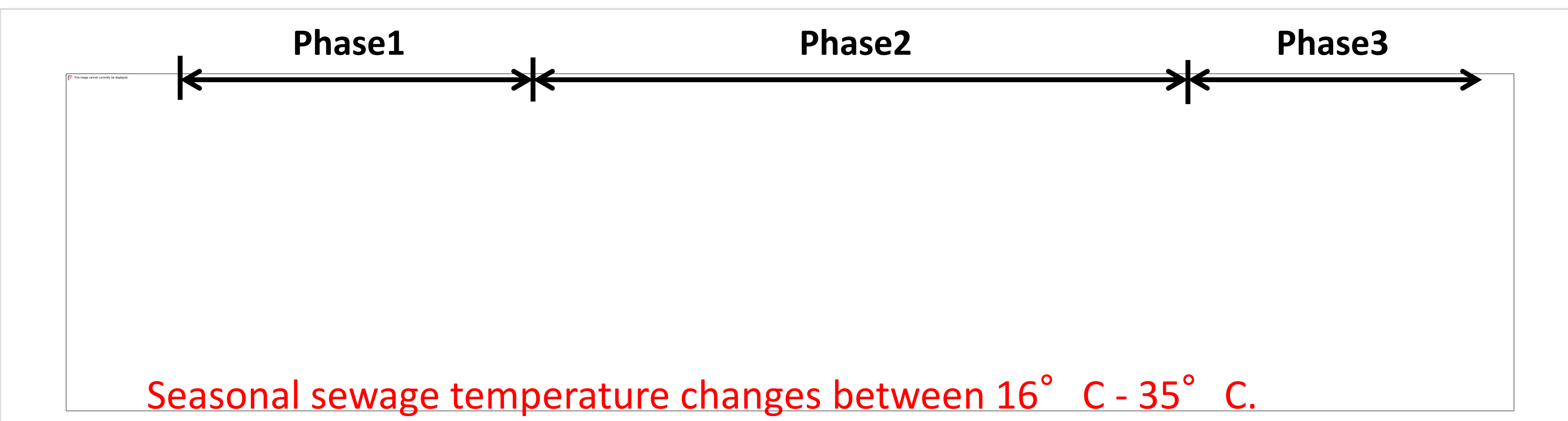
	Temp. (°C)	Flow rate (m^3 d^{-1})	HRT (h)	Organic loading rate (kgBOD m^{-3}-sponge d^{-1})
Phase 1 (day 0 - 111)	16 - 29	500	G3: 1.97 G6: 1.85	G3: 0.80 (±0.12) G6: 0.85 (±0.13)
Phase 2 (day 112 – 317)	20 - 35	1,000	G3: 0.98 G6: 0.93	G3: 1.59 (±0.50) G6: 1.69 (±0.53)
Phase 3 (day 318 – 390)	25 - 31	750	G3: 1.31 G6: 1.24	G3: 1.10 (±0.30) G6: 1.17 (±0.32)

Note: HRT and ORL were calculated based on sponge volume. A 13-day (day 323-335) stoppage of operation of the DHS to repair a water pump.

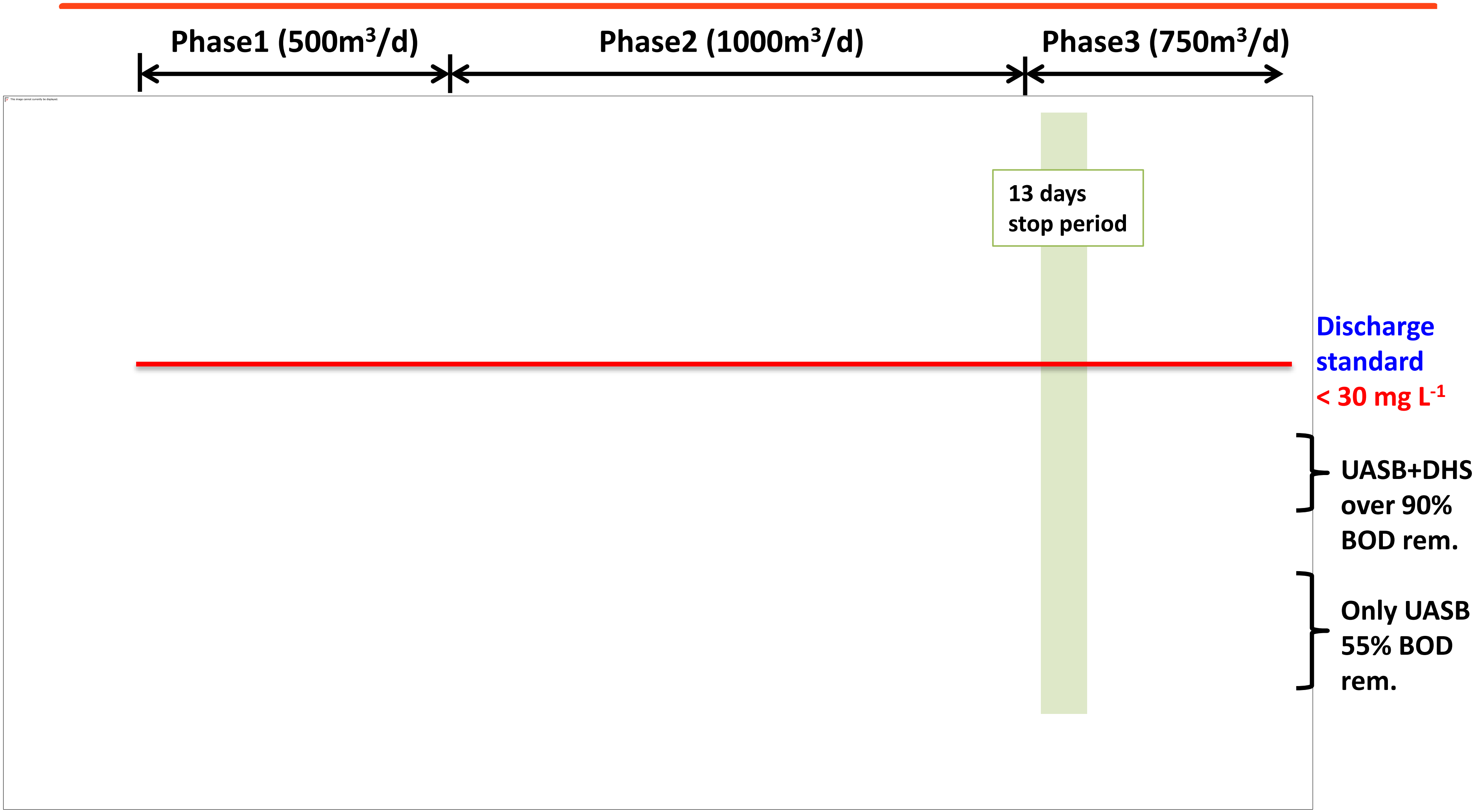
Analytical samples

Samples: Raw sewage, UASB eff., DHS-G3 eff., DHS-G6 eff.

Parameters: COD_{Cr}, BOD_5, NH_4^+-N, Fecal coliform (FC), SS (data not shown)

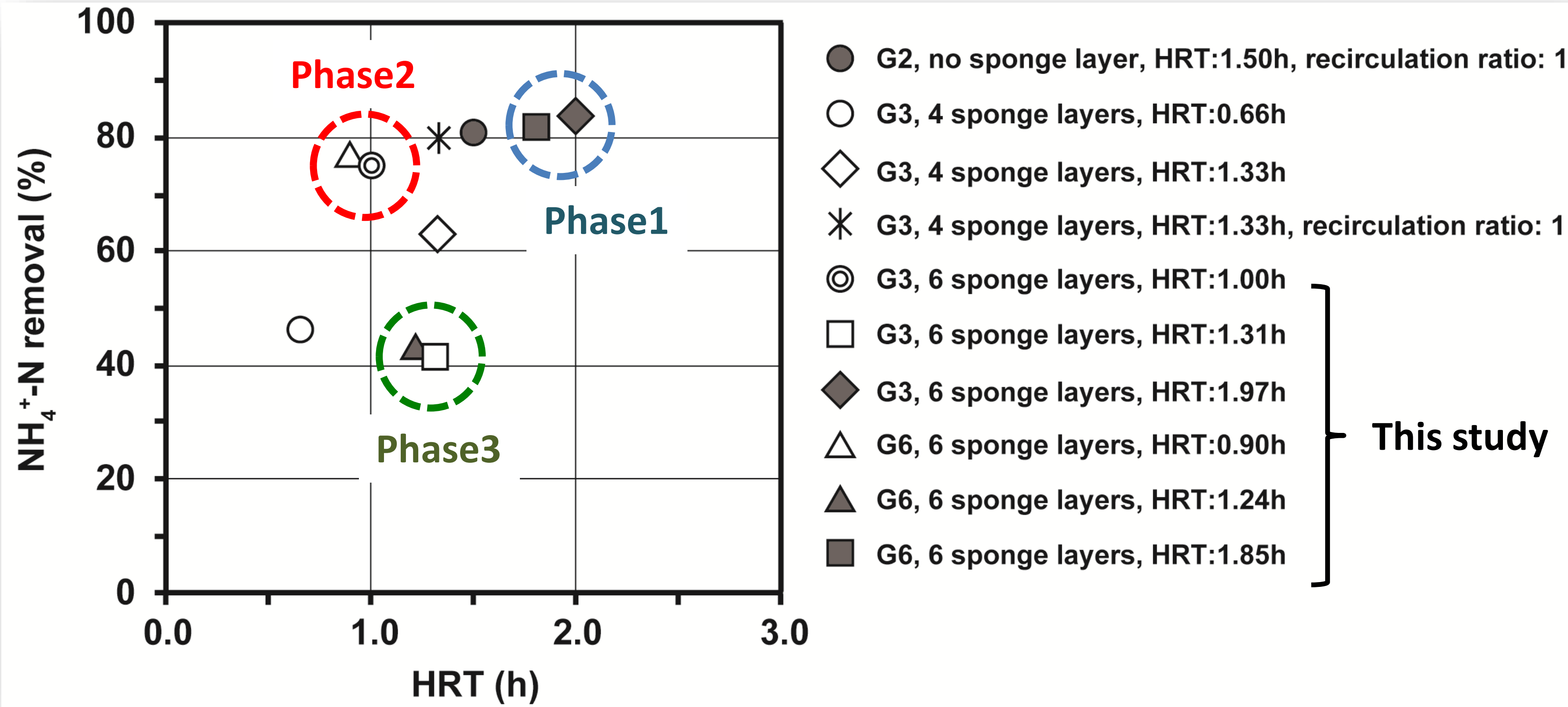


Seasonal sewage temperature changes between 16°C - 35°C.



Parameters	Sewage	UASB eff.	DHS-G3 eff.			DHS-G6 eff.		
			Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
BOD (mg L^{-1})	153 (58)	66 (17)	5 (4)	7 (3)	12 (7)	7 (5)	7 (3)	11 (5)

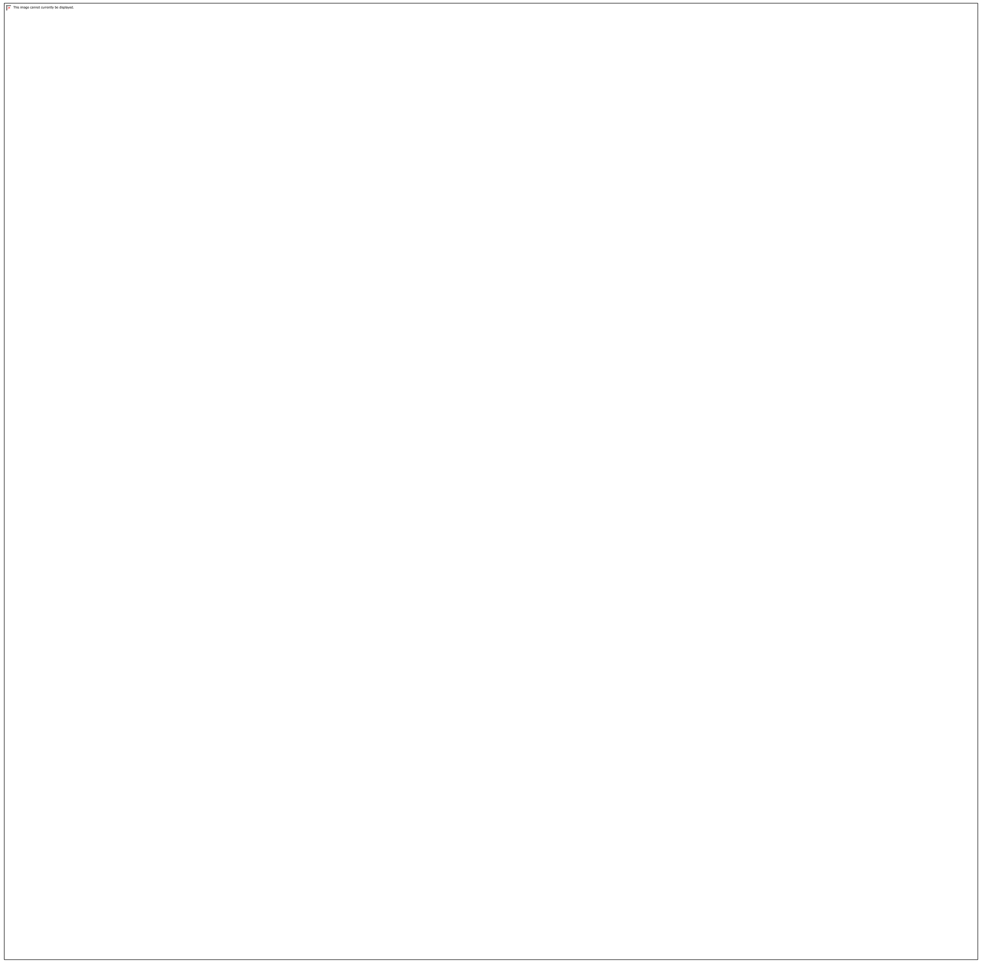
The variation in the NH_4^+-N removal with HRT in DHS



- This figure indicates that improvement of the NH_4^+-N removal can be expected if the HRT is lengthened.
- Reaching levels exceeding 80% NH_4^+-N removal when the HRT of the DHS is controlled to be longer than approximately 1.5 h HRT.
- If removal of NH_4^+-N is a priority, effluent recirculation is an effective approach.

The variation in the NH_4^+-N removal with sewage temperature in Phase 2 (HRT ≒ 2 h)

Sewage temperature in the range 20 – 35 ° C



- The nitrification efficiency decreased at lower temperature.
- No clear differences between the difference media.

Day 116

Day 213

(DHS inf.)

Focus on BOD removal

- **The UASB effluent had a relatively high BOD of 60 mg L^{-1} (day 116), BOD decreased in a nearly linear manner from the DHS influent to the DHS effluent.**
- **The incoming water had the relatively low BOD of 38 mg L^{-1} (day 213), the degradation also tended to decrease linearly through the first and second layers, but the degradation pattern became more moderate in the third layer in which the BOD had decreased below 15 mg L^{-1}.**

→As seen on day 116, low-quality UASB effluent may worsen the quality of DHS effluent. Maintenance and management of the upstream UASB reactor is essential to obtain high-quality effluent by DHS treatment.

Parameters	Sewage	UASB eff.	DHS-G3 eff.			DHS-G6 eff.		
			Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
Temp. (^{o} C)	26 (5)	26 (5)	19 (5)	26 (4)	28 (1)	19 (5)	26 (4)	28 (1)
COD_{Cr} (mg L^{-1})	402 (139)	175 (42)	25 (13)	32 (9)	40 (16)	34 (18)	34 (9)	40 (15)
BOD (mg L^{-1})	153 (58)	66 (17)	5 (4)	7 (3)	12 (7)	7 (5)	7 (3)	11 (5)
FC (MPN 100mL^{-1})	$1.9x10^7$	$1.3x10^7$	$3.2x10^4$	$3.8x10^4$	$8.2x10^5$	$3.9x10^4$	$4.9x10^4$	$1.9x10^5$
NH_4^+-N (mg L^{-1})	24 (8)	26 (7)	4 (6)	6 (6)	14 (3)	6 (7)	6 (5)	15 (1)

Removal	By UASB	By UASB+DHS-G3			By UASB+DHS-G6		
		Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
COD_{Cr} (%)	53 (14)	93 (5)	91 (4)	89 (6)	90 (7)	91 (4)	89 (5)
BOD (%)	54 (15)	96 (4)	95 (3)	93 (3)	94 (4)	95 (3)	93 (4)
FC ($\log_{10}$)	0.5	2.4	2.2	1.1	2.3	2.1	1.6
NH_4^+-N (%)		84 (22)	75 (16)	36 (16)	82 (18)	77 (16)	36 (19)

The both DHS effluents satisfied the Indian discharge standard on all parameters except for FC.

✔ BOD < 30 mg L^{-1} ✔ COD_{Cr} < 50 mg L^{-1} ✔ SS < 50 mg L^{-1} ✔ NH_4^+-N < 50 mg L^{-1}
FC < 10^4 MPN/100mL (for irrigation), < 10^3 MPN/100mL (for bathing)

- **DHS-G3 and DHS-G6 have similar treatment performances**

  Analysis of variance in the effluent quality from DHS-G3 and DHS-G6 did not reveal any significant differences in any of the quality items (critical region, $p > 0.05$)

- **An HRT of 2 h should be an appropriate operating condition**

  The lowest concentrations of FC were found under the flow rate condition of 500 m^3 d^{-1} (Phase1, HRT≒2 h); NH_4^+-N levels also showed good levels, around 5 mg L^{-1}.

According to the results obtained in this study, DHS-G6 is promising technology, not only for treatment of municipal sewage at a large scale, but also for domestic wastewater treatment at a small scale for rural areas in developing countries.

Thank you for your kind attention.

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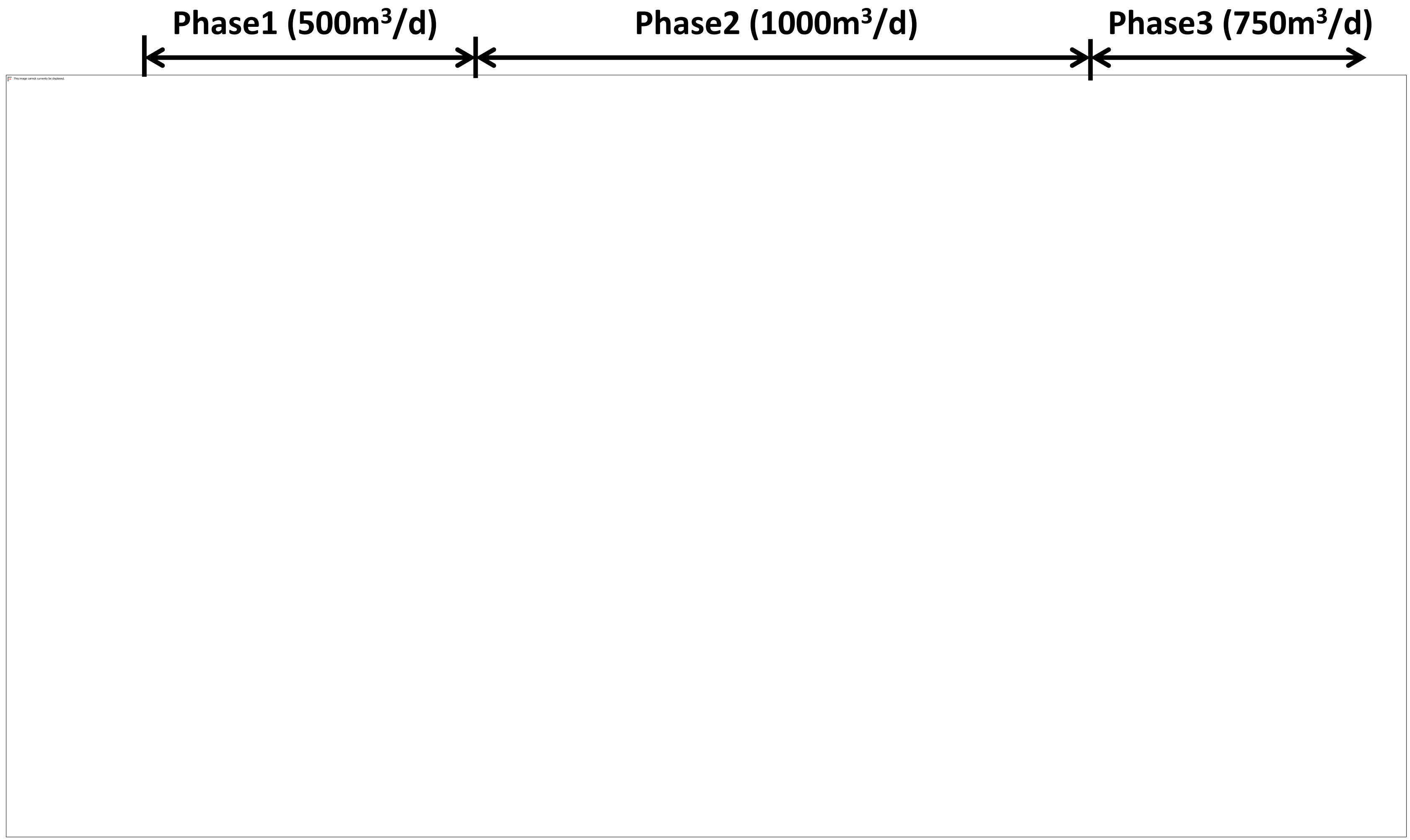


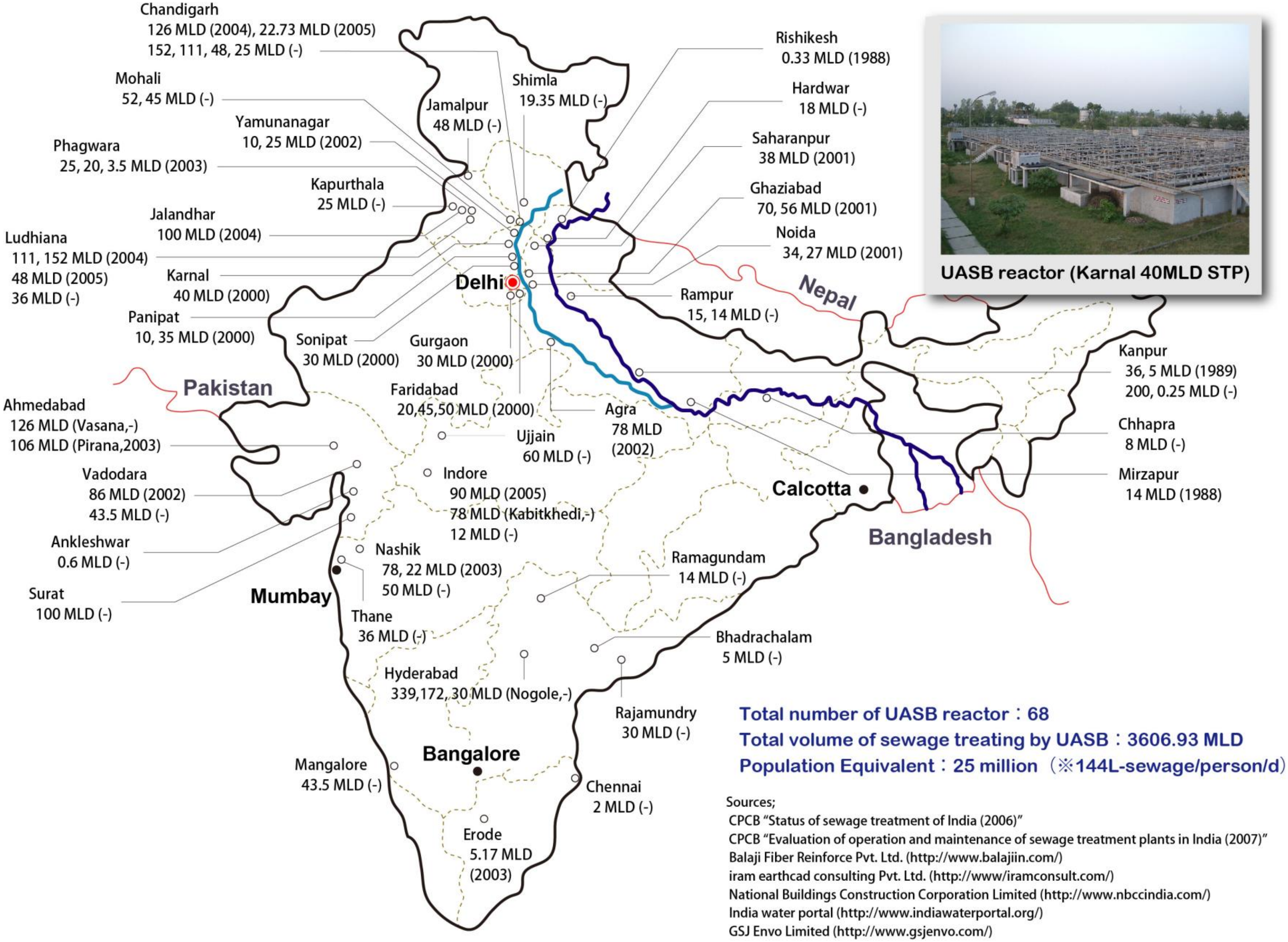
Parameters	Sewage	UASB eff.	DHS-G3 eff.			DHS-G6 eff.		
			Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
NH_4^+-N (mg L^{-1})	24 (8)	26 (7)	4 (6)	6 (6)	14 (3)	6 (7)	6 (5)	15 (1)

Phase1

- NH_4^+-N rem. reached 40% by day 20 of operation and ranged between 40-80% thereafter.
- In the upper portion of the reactor favors heterotrophic bacteria. Nitrifying bacteria is established in the lower portion of the reactor under the low BOD concentration.

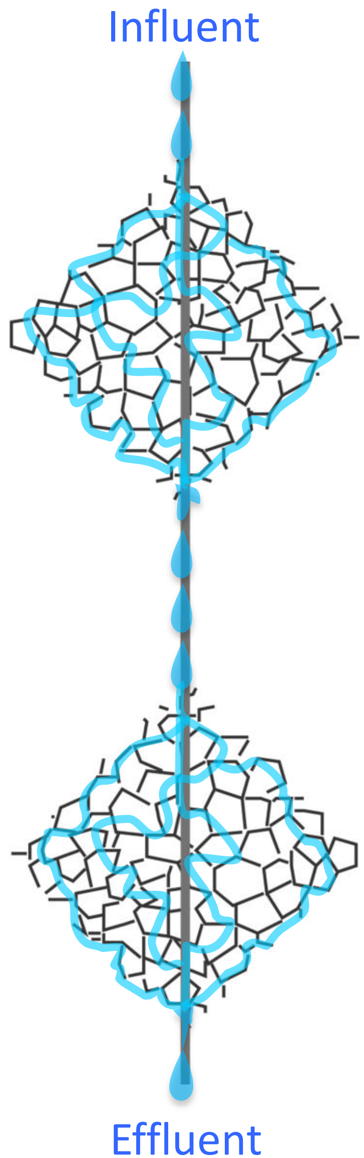
Phase3

- NH_4^+-N rem. decreased to about 30%. The decline in the quality of treated water favored heterotrophic bacteria over nitrifying bacteria, which reproduce slowly in the lower portion of the reactor.

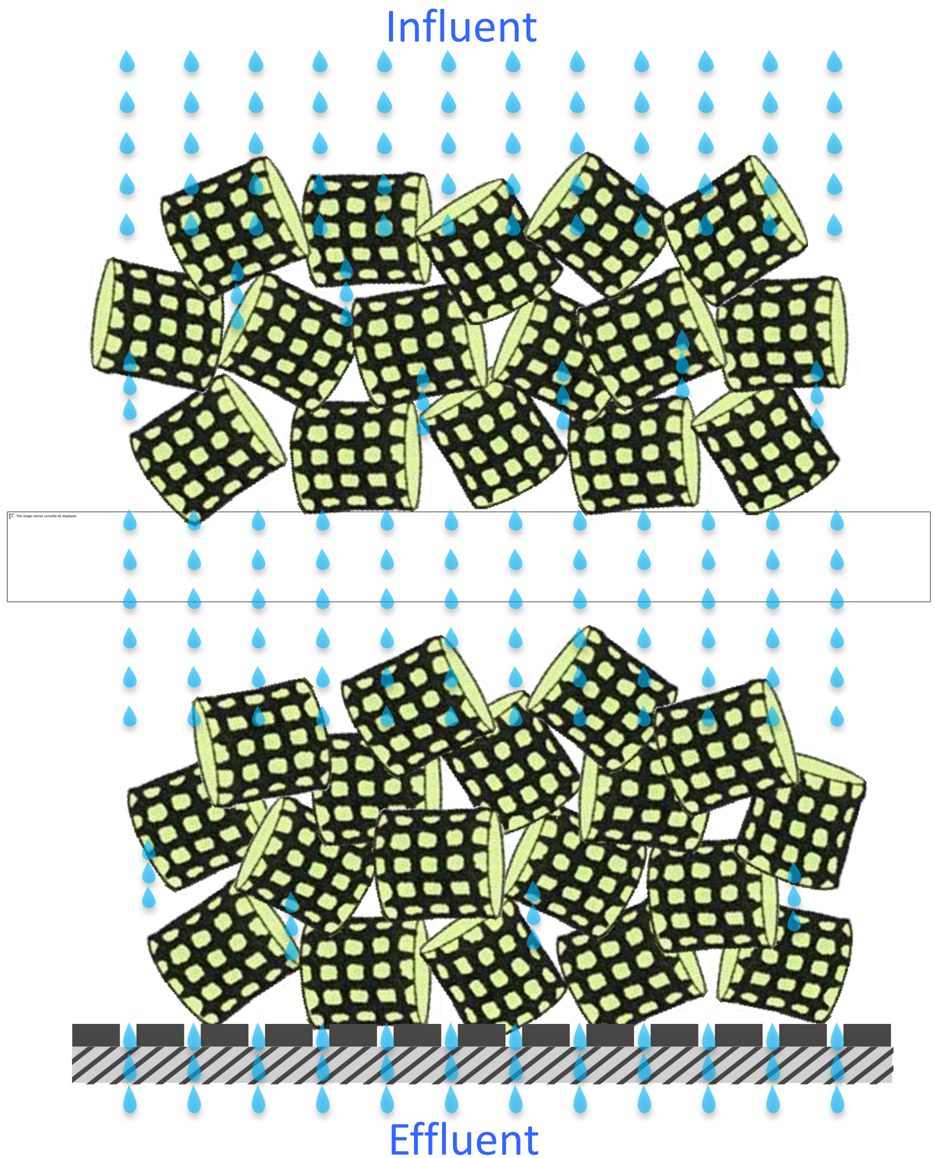


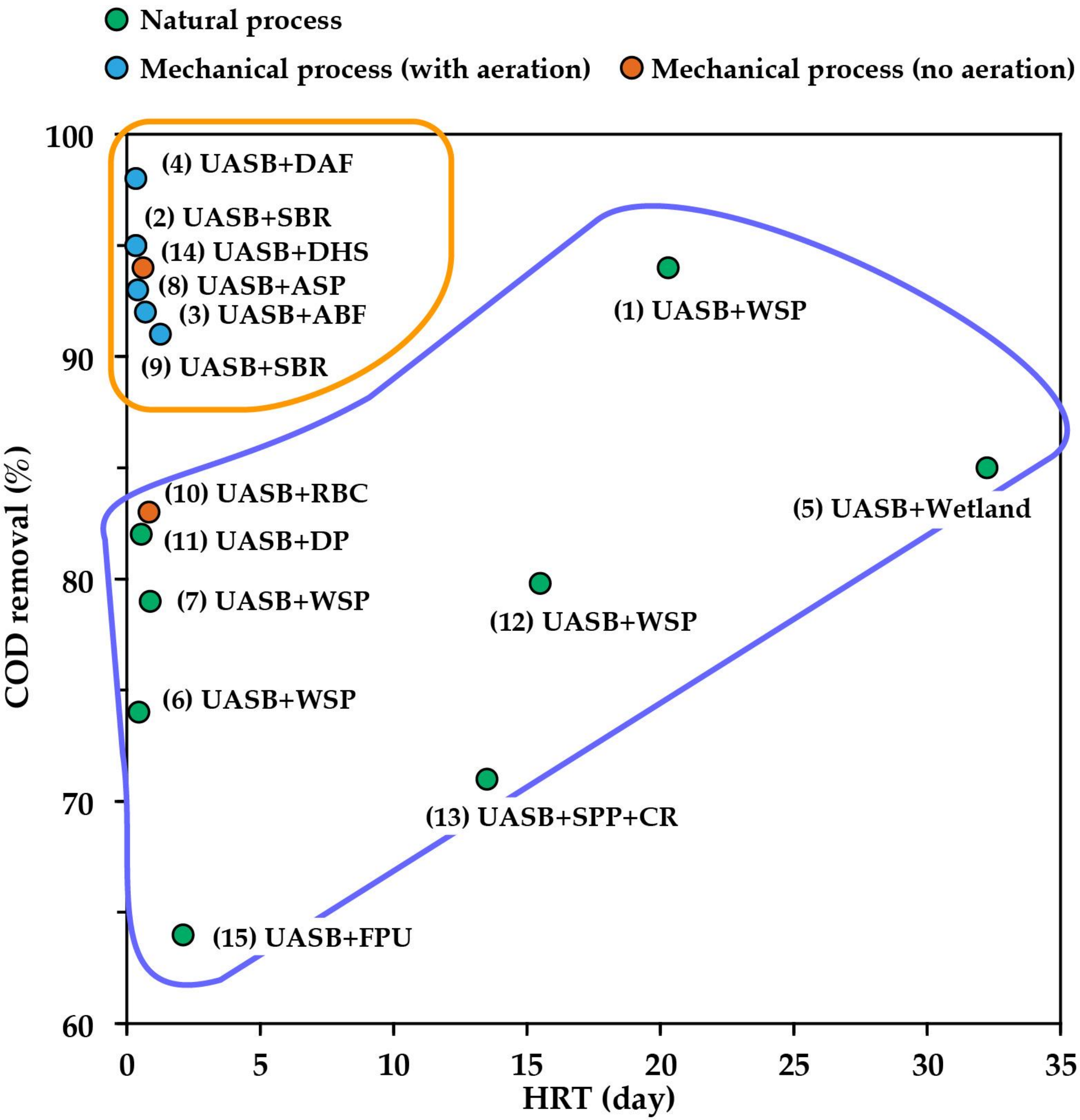
Now, the total number of UASB reactor is 68 in India. Total volume of sewage treatment by UASB is 3606 Million Liter per Day (MLD). Population Equivalent is around 25 million people.

Hanging type



Random Packing





(1) Dixo *et al.*, 1995

(2) Sousa & Foresti, 1996

(3) Gonçalves *et al.*, 1998

(4) Penetra *et al.*,1999

(5) Dixo *et al.*, 2001

(6),(7) Cavalcanti *et al.*, 2001

(8) Sperling *et al.*, 2001

(9) Torres & Foresti, 2001

(10) Tawfik *et al.*, 2002,

(11) Caicedo *et al.*, 2002

(12) Seghezzo *et al.*, 2003

(13) Sperling *et al.*, 2008

(14), (15) Okubo *et al.*, 2008

Note:

WSP: west stabilization pond
SBR: sequence batch reactor
AeF: submerged aerated filter
DAF: dissolved air flotation
ASP: activated sludge process
RBC: rotating biological contactor
DP: duckweed pond
SPP: shallow stabilization pond
CR: crushed rock

Process	Land required (m^2/person)	Final effluent (mgCOD/L)	Power required (kWh/person/year)	Reference
UASB	0.014	166 (47)	3.4	Okubo *et al.*, 2008
UASB + ASP	0.04 - 0.1	50 (16)	14 - 20	Sperling et al., 2001; Soli, 2004
UASB + AeF	0.03 - 0.08	38 (9)	14 - 20	Gonçalves *et al.*, 1998; Soli, 2004
UASB + DAF	0.03 - 0.08	17	8 - 12	Penetra *et al.*,1999; Soli, 2004
UASB + DHS(G2)	0.018	33 (14)	7.8	Okubo *et al.*, 2008
UASB + FPU	0.164	131 (36)	3.4	Okubo *et al.*, 2008

Figures in parentheses represent standard deviations.

Cost estimation (per 1,000 m3)

・Construction cost (civil work, pump etc.): 50,000 US$

・Sponge media cost

G2 (curtain type, HRT 1.5h): 40,000 US$ (made by Indian company in India)

$$\text{Sludge Retention Time} = \frac{(S_{1st}V_{1st} + S_{2nd}V_{2nd} + S_{3rd}V_{3rd} + S_{4th}V_{4th})}{QX}$$

Numerator: Amount of retained sludge in the DHS reactor

Denominator: Amount of sludge discharged from DHS eff.

where

$S_{1st\sim4th}$: average sludge concentration in each sponge layer of the DHS ($kgVSS/m^3$-sponge)

$V_{1st\sim4th}$: total sponge volume in each sponge layer of the DHS (m^3-sponge)

Q : volumetric flow rate of effluent wastewater (m^3/d)

X : VSS concentration in the DHS effluent ($kgVSS/m^3$)

- Assigned value (Phase1 (day 299))

S_{1st}: 49.44 $kgVSS/m^3$-sponge, S_{2nd}: 13.97 $kgVSS/m^3$-sponge, S_{3rd}: 0.92 $kgVSS/m^3$-sponge, S_{4th}: 0.65 $kgVSS/m^3$-sponge, $V_{1st\sim4th}$: 6.925 m^3-sponge, Q: 500 m^3/d, X: 0.010 kg/m^3

∴ SRT 90 days (Phase1)

- Assigned value (Phase3 (day 356))

S_{1st}: 41.35 $kgVSS/m^3$-sponge, S_{2nd}: 22.13 $kgVSS/m^3$-sponge, S_{3rd}: 9.18 $kgVSS/m^3$-sponge, S_{4th}: 10.49 $kgVSS/m^3$-sponge, $V_{1st\sim4th}$: 6.925 m^3-sponge, Q: 1000 m^3/d, X: 0.012 kg/m^3

∴ SRT 48 days (Phase3)

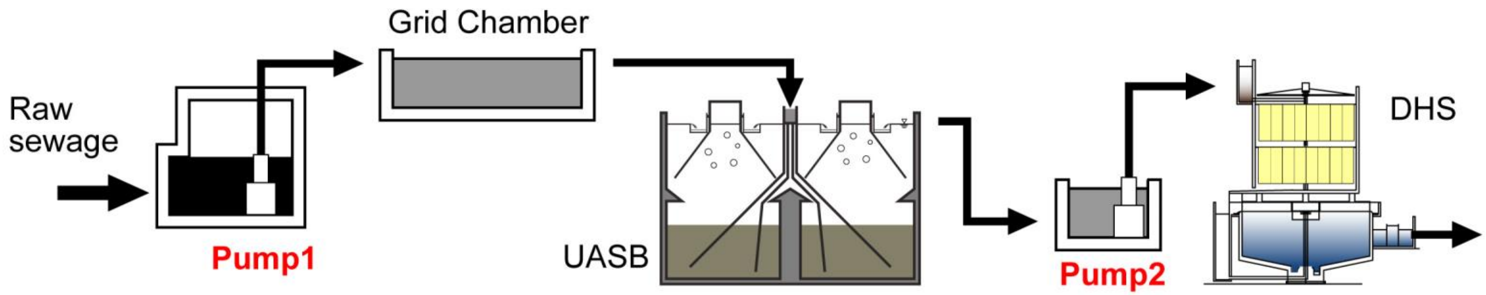
The calculated SRT of the DHS was approximately 90 days in Phase1, which was extremely long. This results indicate that the DHS process is almost twenty times longer than that of conventional ASP.

	Process	HRT (h)	Excess sludge production		Reference
	ASP	-	0.42-0.46	kg-VSS/kg-COD removed	Henze *et al.*, 2000
	UASB	12	0.03-0.2	kg-SS/kg-COD removed	Lettinga *et al.*, 1983 Cavalcanti *et al.*, 1999
Post-treatment of UASB-treated sewage	DHS (G5, lab. scale)	2.5	0.02	kg-SS/kg-COD removed	Tandukar *et al.*, 2007
	ABF	0.5	0.37	kg-TS/kg-COD removed	Gonçalves *et al.*, 1998
	RBC	1.5	0.29-0.33	kg-VSS/kg-BOD removed	Castillo *et al.*, 1997
	DHS (G2, practical-scale)	1.5	0.04	kg-SS/kg-COD removed	Okubo *et al.*, 2008
	DHS (G3, practical-scale)	1.3	0.02	kg-SS/kg-COD removed	This study (Phase1)
	DHS (G3, practical-scale)	1.3	0.01	kg-SS/kg-COD removed	This study (Phase2)
	DHS (G3, practical-scale)	0.7	0.04	kg-SS/kg-COD removed	This study (Phase3)

Note: ASP: activated sludge process, UASB: up-flow anaerobic sludge blanket, DHS: down-flow hanging sponge, ABF: submerged aerated biofilter, RBC: rotating biological conductor

Based on this amount, excess sludge production from the UASB+DHS system can be 0.05-0.22 kgSS/kgCOD removed (Phase1).
Excess sludge production from ASP was 0.42-0.46 kgSS/kgCOD removed, which was 2-8 times higher than that from UASB+DHS system.

除去有機物量あたりの消費電力



UASB/DHSシステムでは2台のポンプを使用

- 流入下水をグリッドチャンバーまで揚水するポンプ（UASB流入ポンプ）: 0.05 kWh/m^3-sewage
- UASB処理水をDHS上部まで揚水するポンプ: 0.066 kWh/m^3-wastewater

UASB/DHSシステムで、1m^{3}の下水を処理するのに必要な消費電力

0.05 + 0.066 = **0.116 kWh/m^3-sewage**

UASB/DHSシステムで除去されるBOD：

151 mg-BOD/L (sewage) - 6 mg-BOD/L (DHS eff.) = 0.145 kg-BOD/m^3-sewage

よって、UASB/DHSシステムの除去BODあたりの消費電力は、

0.116 kWh/m^3-sewage / 0.145 kg-BOD/m^3-sewage = **0.8 kWh/kg-BOD rem.**

ASPの消費電力（汚泥処理を含まない, 曝気とポンプ電力）は, 2.95 kWh/kg-BOD rem. (Young, 1991)
UASB/DHSシステムは、ASPと比較して,消費電力を1/4から1/8に削減可能

$$\text{Excess sludge production} = \frac{Q_{eff}\,(W_{in} - W_{eff})}{[Q\,(C_{in} - C_{eff})]}$$

- $Q_{eff}(W_{in} - W_{eff})$: Accumulated sludge volume in DHS per day
- $[Q(C_{in} - C_{eff})]$: Removed COD in DHS per day

where

Q_{eff} : volumetric flow rate to the clarifier (m^3/d), Q : volumetric flow rate to the DHS (m^3/d)

W_{in} : SS concentration in the influent of the clarifier (mg/L)

W_{eff} : SS concentration in the clarifier effluent (mg/L)

C_{in} : unfiltered COD concentration in the DHS influent (mg/L)

C_{eff} : unfiltered COD concentration in the DHS effluent (mg/L)

- **Assigned value (Phase1)**

  Q_{eff}: 500 m^3/d, Q: 500 m^3/d, W_{inf}: 14.4 mgSS/L, W_{eff}: 11.4 mgSS/L, C_{in}: 162.4 mgCOD/L, C_{eff}: 44.5 mgCOD/L

  ∴ 0.02 kgSS/kg-COD removed

- **Assigned value (Phase2)**

  Q_{eff}: 1000 m^3/d, Q: 500 m^3/d, W_{inf}: 10.5 mgSS/L, W_{eff}: 9.9 mgSS/L, C_{in}: 214.1 mgCOD/L, C_{eff}: 44.8 mgCOD/L

  ∴ 0.01 kgSS/kg-COD removed

- **Assigned value (Phase3)**

  Q_{eff}: 1000 m^3/d, Q: 1000 m^3/d, W_{inf}: 20.3 mgSS/L, W_{eff}: 14.9 mgSS/L, C_{in}: 178.5 mgCOD/L, C_{eff}: 49 mgCOD/L

  ∴ 0.04 kgSS/kg-COD removed


Dismantling of old steel frame
Fixing of FRP grating
Installing sponge media
After installing G3-type media
(top layer)