METHODOLOGIES & APPLICATION
FROM DOCUMENTED EXPERIENCE

Anaerobic Baffled Reactor (ABR) Design Considerations for Faecal Sludge

Anaerobic Baffled Reactor (ABR)
Design Considerations for Faecal Sludge

is part of the series

Methodologies & Application from Documented Experience
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in cooperation with Bangladesh Agricultural University
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and with the support of Bill & Melinda Gates Foundation.

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Abbreviations & Acronyms

ABR	Anaerobic Baffle Reactor
AF	Anaerobic Filter
BOD	Biological Oxygen Demand
BOD5	Biochemical Oxygen Demand measured during 5 days at 20°C
BORDA	Bremen Overseas Research and Development
°C	Celsius degree
cfu	Colony Forming Unit (in microbiology)
CH_4	Methane
COD	Chemical Oxygen Demand
C/N	ratio of Carbon to Nitrogen in organic material
CW	Constructed Wetland
d	day(s)
DEWATS	Decentralised Wastewater Treatment System
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
FC	Faecal Coliforms
g	gram(s)
kg	kilogram(s)
h	hour(s)
HRT	Hydraulic Retention Time
l	liter
m^2	square meter
m^3	cubic meter
ml	milliliter
NPO	Non Profit Organization
NH_4-N	Ammonium
OLR	Organic Loading Rate
P.E.	People-equivalent
PVC	Polyvinyl Chloride
SRT	Sludge Retention Time
SS	Settleable Solids
TP	Total Phosphorus
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket digester
USA	United States of America
VSS	Volatile Suspended Solids
WEDC	Water Engineering and Development Centre
WW	Wastewater
y	year
*****	Multiplication sign

Preface

This publication is the result of the technical assistance provided by UPM Umwelt-Projekt-Management GmbH (UPM) and its partners, the Centre for Sustainable and Ecological Sanitation (CSES) of the University of Science & Technology Beijing (USTB), and the Bureau of Socioeconomic Research and Training (BSERT) of the Bangladesh University of Agriculture (BAU) to the United Nations High Commissioner for Refugees (UNHCR), the Department of Public Health Engineering (DPHE) and the local WASH sector in Cox's Bazar, Bangladesh, in cooperation with the Bill & Melinda Gates Foundation.

The goal of this technical assistance assignment was to provide support to the emergency WASH sector and local administration, regarding sanitation and faecal sludge management, with focus on value—recovery in emergency settings, in order to sustainably improve the living conditions of displaced populations an reasonable ability to plan, design and monitor a project as an output d their hosting communities.

The present manual "Anaerobic Baffled Reactor (ABR) Design Considerations for Faecal Sludge" was elaborated in the context of a series of training workshops organised by UPM and its partners in Cox's Bazar based on a Training Needs Assessment implemented among the local WASH community.

The content of this manual was presented as part of the Training "Anaerobic Baffled Reactor and Anaerobic Filters" organized in Cox's Bazar in September 2019. The objectives of the training was to support trainees to gain reasonable ability to plan, design and monitor related project.


UNHCR
Fecal Sludge Management Facility
(Anaerobic Baffled Reactor)

Introduction

An Anaerobic Baffled Reactor (ABR) is a rectangular digester or an “improved septic tank” divided in a series of up to 6 baffles.

The first “baffled reactors” were developed in 1981 in the USA (Stanford University by McCarthy et al.). The model was adapted in China, India and some European Countries to treat high-strength organic loaded wastewater.

→ ABR simplifies more sophisticated digester models, such as UASB, fluidized beds, and others.

→ ABR is a robust technology and can treat a wide range of wastewater.

→ ABR combines the characteristics of septic tanks and the high performance and biogas production of suspended sludge bed systems.

The ABR in DEWATS is considered as an element in a treatment chain.[1] BORDA’s DEWATS Practical Guide[2] will serve as guideline for the present manual.

[1] Source: https://sswm.info/factsheet/anaerobic-baffled-reactor-%28abr%29
[2] 2009.

INTRODUCTION

Principles

The technical concept of ABR is based on the principle of anaerobic digestion by "sludge blankets" where the granules of bacteria are suspended by the wastewater pressure in upflow baffles.

By gravity, the wastewater is forced to accelerate in downflow pipes or shafts and to go up in upflow baffles. Downflow and upflow exist in each baffle. Close contact between the granules of bacteria and the organic molecules accelerate their digestion.

A limited organic load and a limited upflow velocity have to be respected to maintain the bacterial sludge in the baffles.

An ABR must be preceded by a settler to avoid accumulation of heavy solids in the baffles. The settler could either be included in the same structure or be a separated construction, such as a septic tank or a biogas digester.

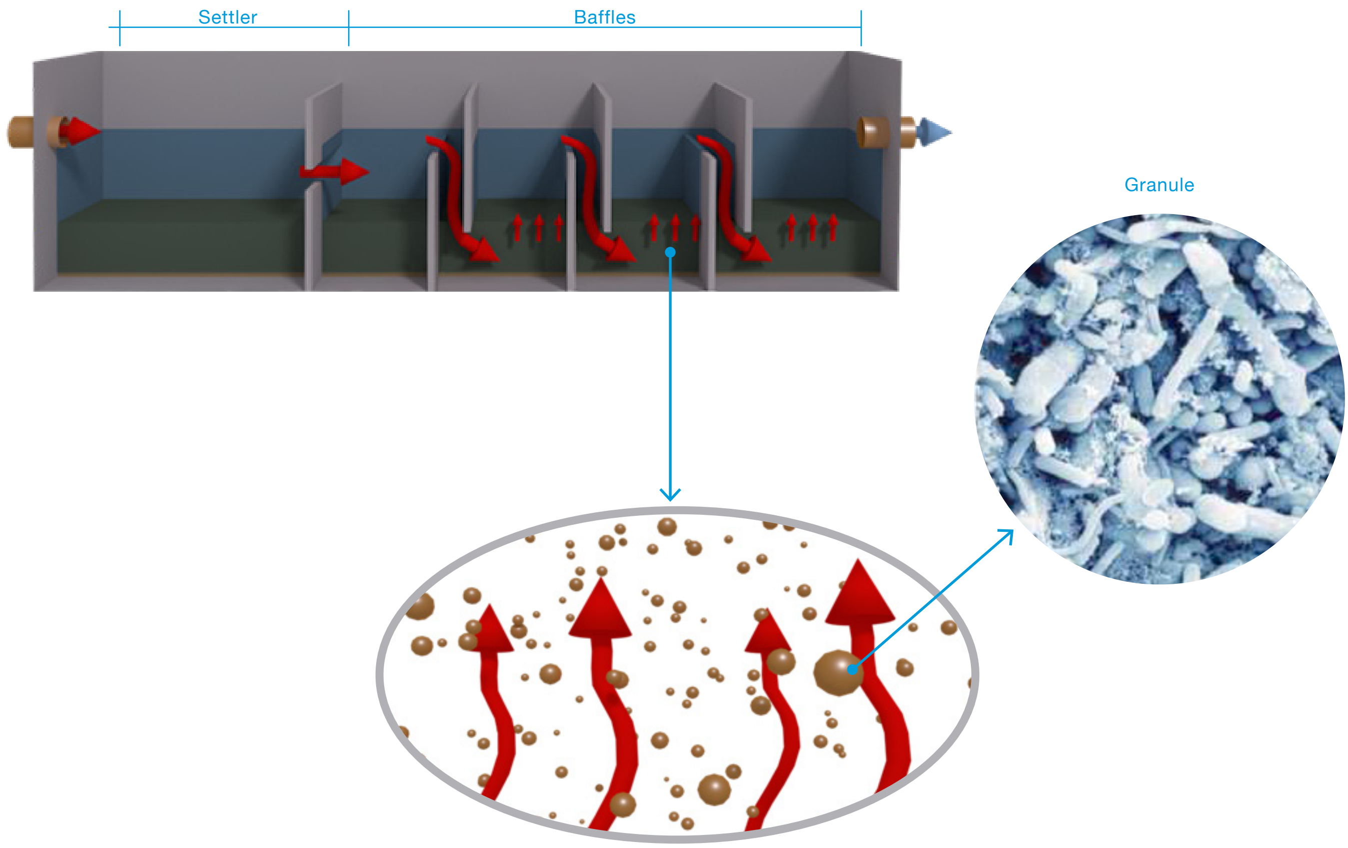


FIGURE 1: Cross-sectional view and illustration of the principles of ABR. [3]

[3] Source: Epuval NPO.

Advantages & Disadvantages

As for any other technology, ABR has a number of advantages & disadvantages for treatment of wastewater and therein contained fecal sludge.

Advantages:

- → High concentration of bacteria in the suspended sludge increases the biological robustness of this kind of reactor compared to an anaerobic settler or septic tank; this also enhances the digestion rate.
- → Separation of solids in the settler, or in the naturally formed bacteria flocs ("sludge blanket"), allows a long Sludge Retention Time (SRT) for thorough digestion. Meanwhile the liquid can circulate within a short Hydraulic Retention Time (HRT).
- → HRT shorter than in biogas digesters allows to reduce the volume of the ABR and its land requirement (1 to 1.5 m^2/daily flow m^3).
- → Anaerobic digestion reduces the amount of sludge.
- → Low sludge generation.
- → Low risks of clogging.
- → Anaerobic digestion produces biogas which can be valorized as fuel.
- → No moving parts, no mechanical mixing, no filling material.
- → Low capital and operating costs.
- → High performance.

Disadvantages:

- → Desludging is necessary every year or at least after 2 years of operation. It is required even more often if the daily flow of Suspended Solids is high: generally with a COD higher than about 3,000 mg/l and HRT lower than 3 days.
- → Sludge level must be regularly checked through manholes or lateral pipes.
- → Sludge has to be pumped in and out through manholes or via lateral pipes; this requires energy.
- → Limited upflow velocity in the baffles could lead to high surface/land requirements.
- → In-flow must be as constant and smooth as possible: due to short HRT, an ABR cannot be fed in batches.
- → Biogas produced must be used or evacuated properly.
- → As biological treatment, inoculation (maturation) phase can be long; adding sludge from another ABR or septic tank can reduce this starting period. Feeds should be limited during the first weeks.
- → Watery effluent and sludge have to be treated before final discharge or re-use, because of contamination by pathogens and pollutants..

TECHNOLOGY

Pre-treatment

Coarse material, such as rocks, sticks, leaves, plastics and other debris, should be removed because they could damage pumps or settlers. Screening devices such as bar racks and screens are recommended for this kind of pre-treatment.

TECHNOLOGY

Primary treatment

Primary treatment is generally achieved by a settler, which should be a gas tight tank with low hydraulic retention time (HRT). HRT should be less than 3 hours.

If COD concentrations are usually more than 20,000 mg/l, primary treatment should happen in a biogas digester. This digester could be divided in a series of tanks. Total HRT can then last more than 30 days at 25°C. Biogas should be collected and used as energy source.

To regulate the flow in the ABR, the feeding must be evenly distributed over a minimum of about 12 hours. The longer the feeding period, the smaller could be the construction volume of the ABR. If the feedings are made in batches because of fecal sludge delivery by trucks, then at least one storage tank must be placed and equipped with pumps or manual or automatic valves to properly regulate flow rates. Biogas digesters or settlers can take over a limited role as flow buffers.

Bacteria in a typical settler digest 25 to 50% of organic matter (BOD, COD) dissolved in the liquid. This biological treatment reduces the volume of sludge. A settler will also provide mechanical treatment by retaining floating greases and sediments.

Septic tank

As settler, a septic tank is placed either as independent structure or as first compartment of an ABR. In the settler, sludge accumulates, and bacteria partially digest the sludge. Floating material such as greases and papers, will swim on the surface of the liquid and will be retained by a wall separating the first and the second chambers. The opening which connects the two chambers allows only the liquid to pass. However, some suspended solids could be able to pass this overflow into the second chamber and will settle here. The construction volume of the second chamber is at least 50% smaller than the first chamber. HRT is generally between 1.5 to 3 hours. Sludge Retention Time (SRT) depends on the desludging intervals — 1 to 2 years is recommended. If the settler is integrated into the ABR, the second settler chamber is not needed.

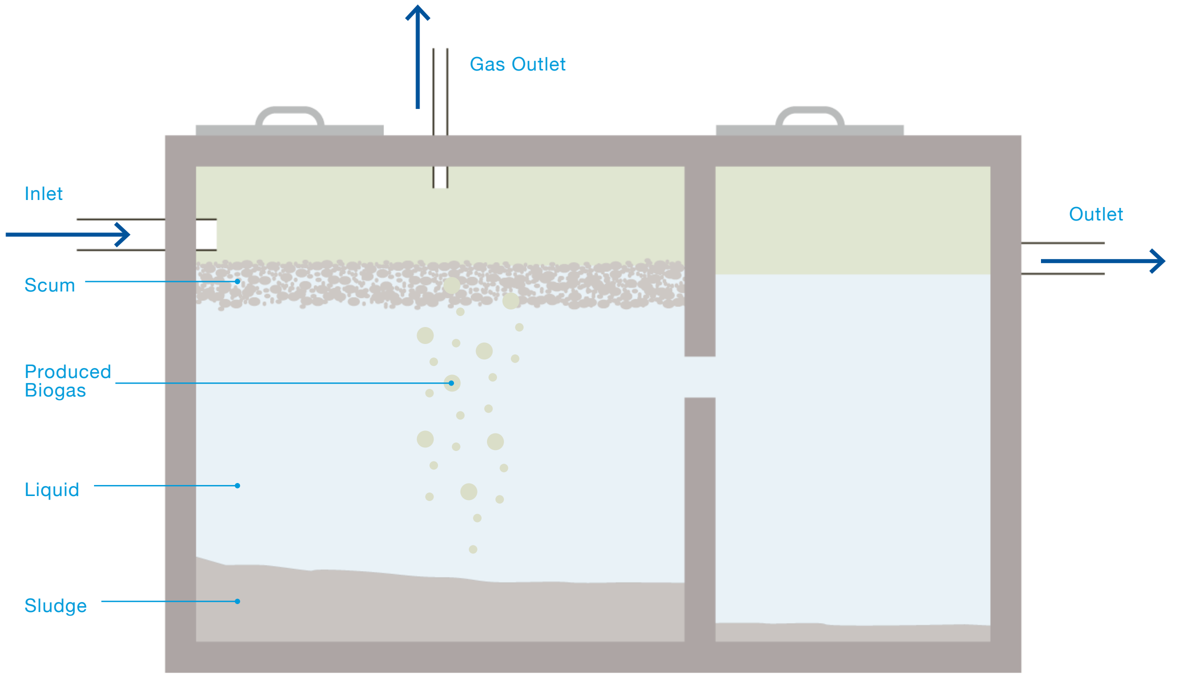


FIGURE 2: Cross-sectional view of a two-chamber septic tank. [4]

Biogas settler

A biogas plant could also be installed as settler. When the biogas production is higher than 1 m^3/d, the gas can be used as fuel for 2–3 hours cooking. As settlers, the same HRT and SRT are valid for septic tanks and biogas digesters. Prefabricated digesters and septic tanks, made of plastic or glass fibers, can be found in the international market. If produced on site, specialized masons and reliable construction material should be available. Collecting biogas requires tight lids and piping system.

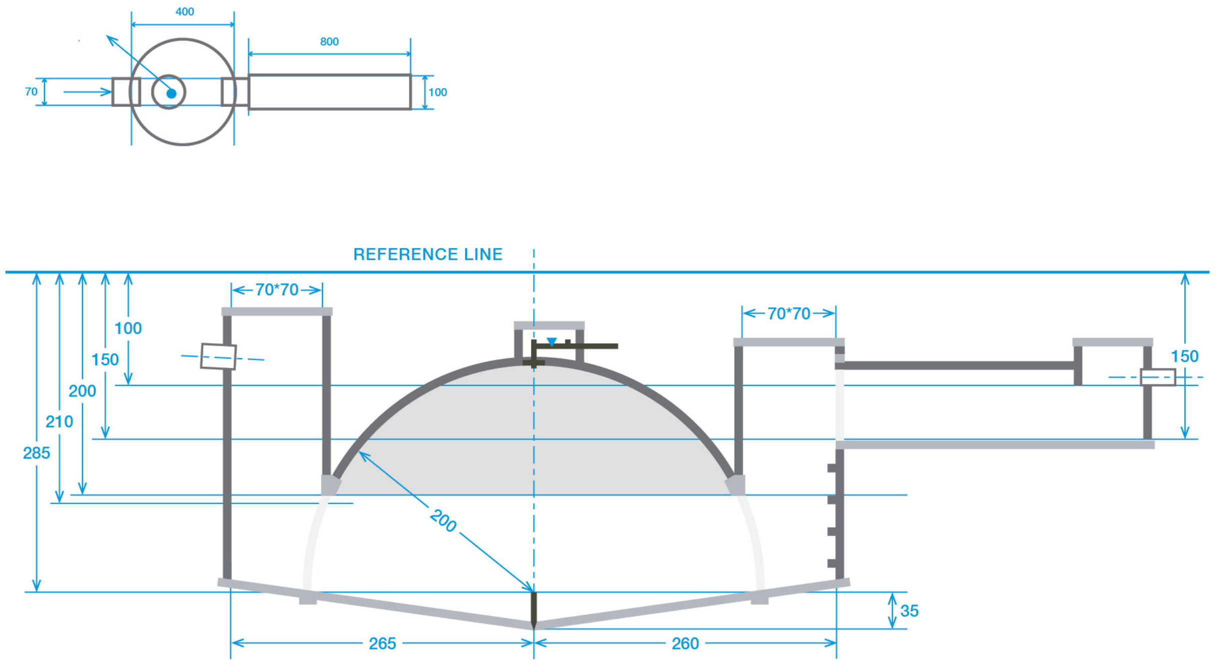


FIGURE 3: Design of a household biogas plant, without buffer. [5]

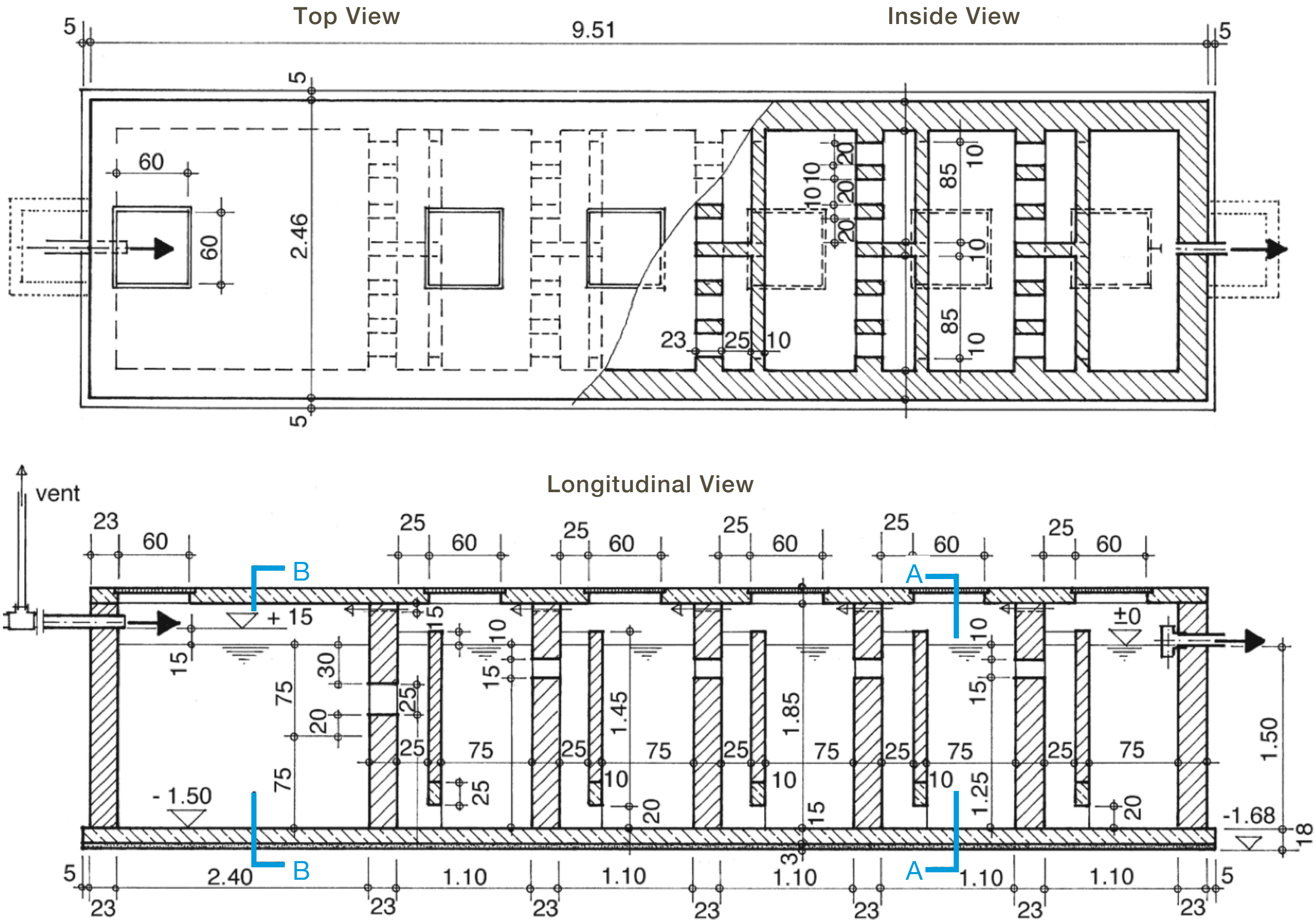
[4] [5] Source: Epuval NPO.

TECHNOLOGY

ABR Layout

The first model presented by Sasse [6] consisted entirely of standing and hanging concrete walls for 3 to 6 baffles. A primary treatment in a one-chamber-settler was included in the construction, for an HRT of 1.5 to 3 hours, or even more.

Using model calculations, it was explained how to size all the compartments, and how to evaluate the performances. Based on this model, ABR were built in several developing countries, mainly in Asia.



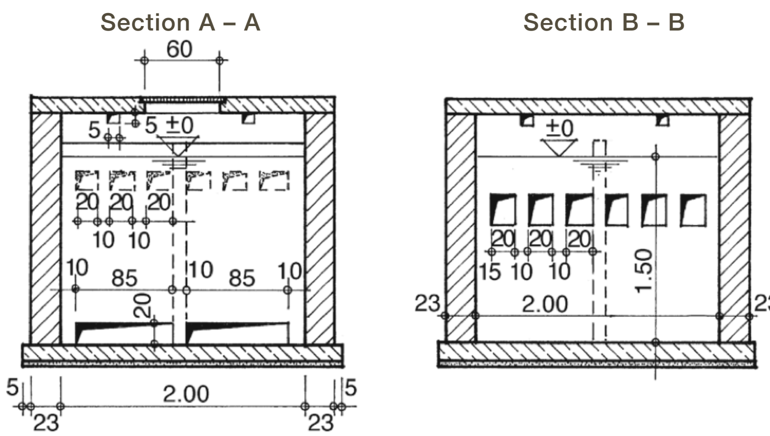


FIGURE 4: BORDA design of an Anaerobic Baffled Reactor. [6]

[6] Source: BORDA,1998 & BORDA / WEDC, 2009.

After some years, the "hanging" walls forming the downflow shafts, have been replaced by vertical PVC pipes and Tee-pieces as illustrated by EAWAG in 2014.

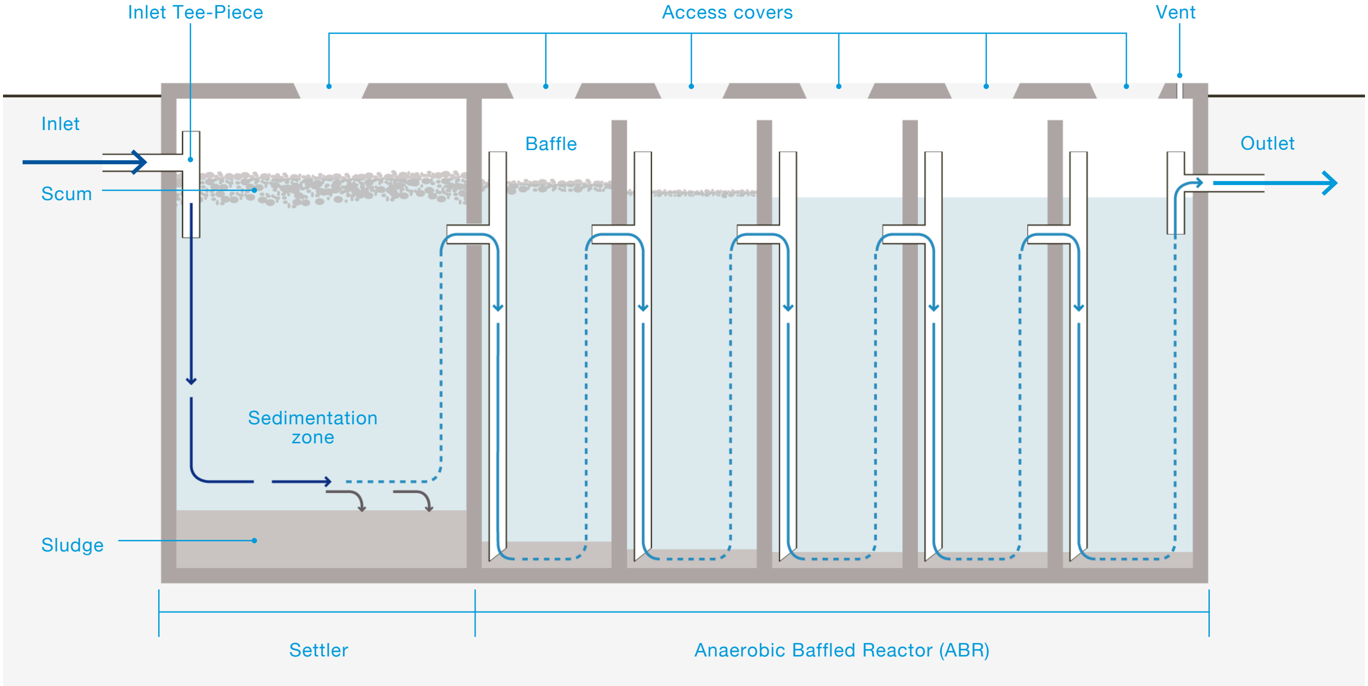


FIGURE 5: Schematic of the Anaerobic Baffled Reactor. [7]

Access cover must be installed for each baffle, including the settler. Access to the top of the PVC Tee-pieces and pipes should be possible through covers for desludging. In case biogas is collected and used, all covers must be gastight and fitted with a gas pipe. Plastic and glass fiber prefabricated models of ABR are now available in the international market. Plastic tanks could also be used.

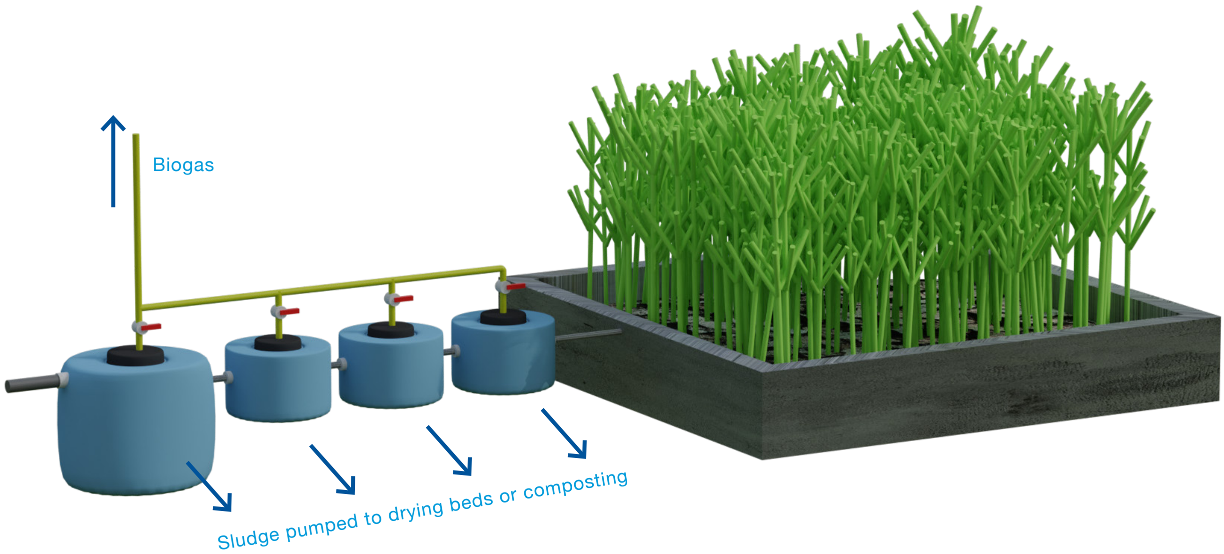


FIGURE 6: Plastic tanks as settler and baffles of an ABR, here followed by a constructed wetland for further treatment. [8]

[7] Source: Tilley et al. EAWAG, 2014.
[8] Source: Epuval NPO.

FIGURE 7: Construction of several toilet blocks connected to two pre-fabricated fiberglass ABR including a settling chamber, baffled reactor and an anaerobic filter unit (top). [9]

FIGURE 8: Lesotho: ABR with Biogas digester as settler (center) and with integrated settler chamber (bottom). [10]

[9] Source: BORDA, 2009.
[10] Source: TED, Sustainable Sanitation Practice Journal Issue, 2011.

FIGURE 9: ABR in South Africa (top).[11]

FIGURE 10: ABR in Zambia (center).[12]

FIGURE 11: ABR in a Rohingya Camp, Bangladesh (bottom).[13]

[11] Source: M. Khiyati, 2011.
[12] Source: R. Ingle, 2010.
[13] Source: UPM, 2019.

Basics

Baffles

Their task is to increase the contact time of organic fresh matter with active biomass maintained in suspension by smooth upflow. The bacterial granules form a fluidized biofilm or “sludge blanket”. The wastewater that enters a tank should be distributed over the floor area as evenly as possible. This is facilitated by relatively short compartments (length < 50% to 60% of the height) or, in the case of down-pipes, a distance of less than 75cm between pipes. Baffle outlets are placed under the liquid level (to retain floating materials): -30 cm.

Maximum width and flow distribution

It is necessary to distribute the liquid to be treated over the entire width of the tanks. Although an ABR can stabilize in a certain way feed fluctuations across reactor chambers [14], it should be considered that an ABR cannot accept high hydraulic shocks through batch feed.

Provision of parallel treatment streams

To ensure flexibility of operation during maintenance events, the design should include at least two baffled reactor streams in parallel. To ensure good mixing and avoid high structural costs, individual streams should not be more than 2.5–3 m wide.

Number of chambers

Minimum 3, maximum 6. By compartmentalization, the anaerobic digestion phases —hydrolysis, acidogenesis, acetogenesis and methanogenesis, can follow one another in successive baffles. It can contribute to high performances. If the calculations result in more than 6 chambers, then it is recommended to place two or more ABRs in parallel.

Ratio Settleable Solids (SS) / COD

(In mg/l / mg/l) of fresh domestic wastewater or sludge is about 0.35 to 0.45. This ratio can strongly decrease after the settler.

[14] Source: Reynaud and Buckley, 2016.
[15] Source: BORDA, 2009.

Sludge storage

Up to 5 l sludge volume are produced in the settler per kg of COD influent. Anaerobic digestion will reduce this volume by 40% for 2 years. About 1.5 l sludge volume are produced in the baffles; this amount decreases from each baffle to the next. These volumes should be linked to the temperatures (digestion rate), the WW characteristics, the HRT’s, loads and velocity.

Desludging / effective capacity

Desludging every year, or at least every second year, is recommended; if the ABR is equipped with lateral pipes to drain the sludge, weekly or monthly desludging is also possible. Too much accumulation of sludge reduces the effectiveness of the baffles and the HRT of the wastewater.

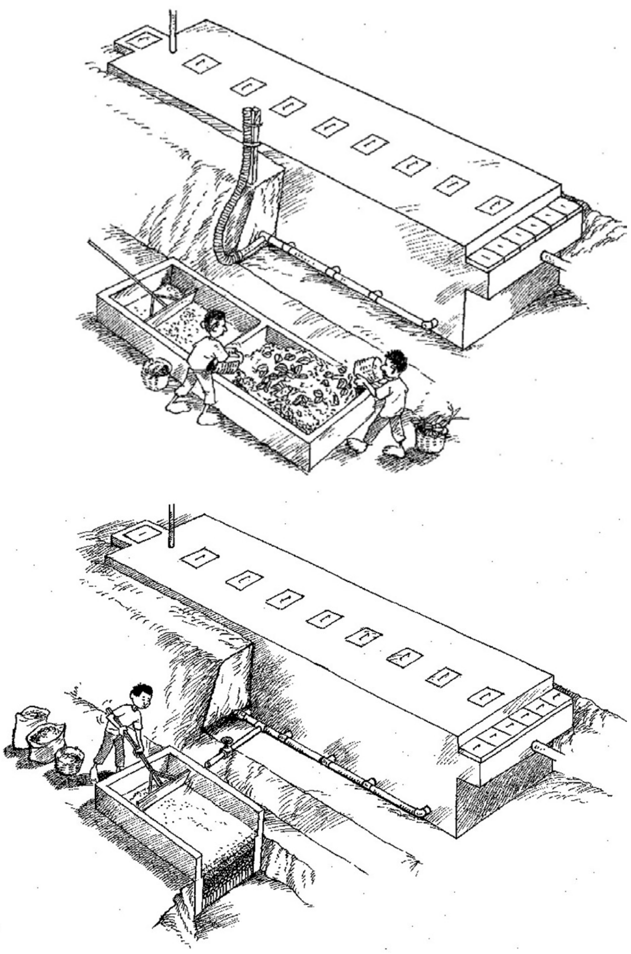


FIGURE 12: Lateral pipes for periodic desludging of an ABR. [15]

SIZING

Factors to optimize anaerobic digestion

Temperature

Best performances are achieved between 25–30°C. Temperature must be as constant as possible. [16]

Oxygen

The ABR needs strict anaerobic conditions.

pH

It must be stable between 6 to 8; no toxics should be contained in the wastewater, and the C/N ratio should be between 15 and 30.

Hydraulic Retention Time

(HRT) = Vh/Q, where Vh is the effective capacity. HRT should be 2–3 days minimum at 25°C to reach 80–90% estimated COD removal. Cost increases with the increase of the total volume and the HRT of the ABR.

→ Sasse (2009) suggests at least 8 h for the HRT in the baffles and 2 h in the settler.

→ Foxon and Buckley (2006) suggested that repeated passes through the sludge bed have a greater beneficial effect on treatment performance than maintaining a low upflow velocity.

Solid Retention Time (SRT)

Over 100 days are required for a effective digestion of the complex molecules in organic matter or bacteria.

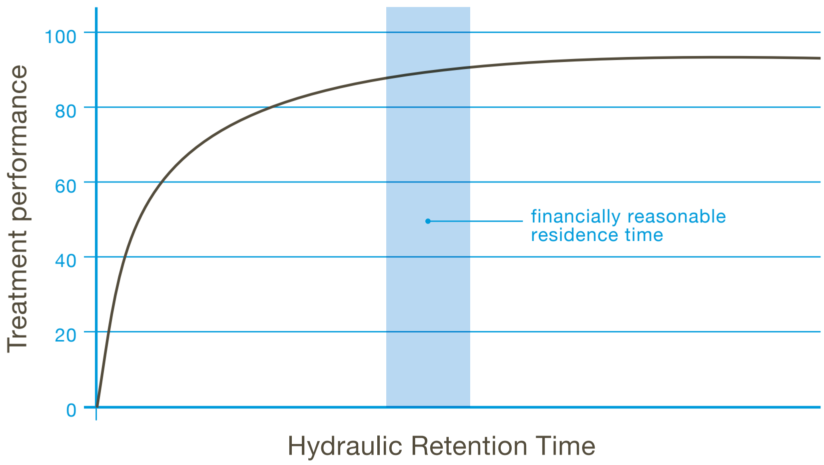


FIGURE 13: **Relation between Hydraulic Retention Time and financially reasonable residence time.** [17]

SIZING

Operation & Maintenance

Manual emptying and sludge handling are very dangerous because of the presence of gases and pathogens. Never enter an ABR even after complete emptying. It is only after several days of ventilation that a test can be carried out with an animal. Personal protective equipment is necessary like rubber boots, masks, glasses, waterproof clothing and gloves.

After desludging, it is recommended to keep some of the sludge to have a high concentration of bacteria and a buffer against variations in loads and quality.

[16] Source: Sasse, BORDA, 2009.
[17] Source: Based on Foxon & al. 2006.

Design and engineering considerations

Upflow velocity

Vmax = Qmax / S upflow baffle.
To ensure strong contacts between bacteria (granules of 0.5 to 1mm diameter forming the sludge) and molecules to be treated:

→ Sufficient flow, as constant as possible, to keep the sludge in suspension as long as possible.

→ Flow not too important to limit the peak upflow velocity (max 0.7–1 m / h) [a] and avoid flotation of bacterial aggregates and their loss in ABR effluents (washout of solids).
[a] Sasse, 2009: max.: 1m / h; Moletta: UASB: max. 0.7 m / h; Ghangrekar: 0.25 – 0.7m / h, IWTC: 1m/h max Wp mucdr; Huong Nguyen; 0.7 m in NPTEL IIT Kharagpur Web Courses, Xanthoulis, 2008.

→ Several compartments to increase the suspension of sludge and to optimize the stages of anaerobic digestion are recommended. [18]

BOD/COD load

Max. 3 kg COD / d per m^3 of ABR; [19] low loads give better performances.

Biogas production

Feces + urine from 1 person produce about 15–27 l biogas / d in the ABR; or COD produced per person: 38g feces + 9g urine / d * 0.35 l methane / COD removed.

→ max 16 l methane / P.E. * d [b] if 100% COD is removed in the ABR
[b] 16 l CH_4 / P.E. * d / 70% methane in the biogas → 23 l biogas/P.E. * d.

FIGURE 14: Biogas stove. [20]

[18] Source: Plumb & al 2001, Langenhoff et al, 2000.
[19] Source: Sasse, 2009.
[20] Source: Epucal NPO.

Performances

Performances are directly linked to the composition of wastewater. Carbohydrates are easy to digest, fibers are more resistant.

Relative performances are higher for raw wastewater compared to wastewater pumped from a septic tank. Foxon and Buckley (2006) noted that COD reduction occurs almost exclusively in the first three baffle chambers. Performances can reach up to 90% for BOD5; [21] up to 95 % for COD. [22]

If the HRT is insufficient to effectively eliminate pathogens (E. coli > 1 * 106 cfu / 100 ml in effluents) [23], post-treatment is necessary (such as wetland, sand filter or trickling filter).

FIGURE 15: Performance efficiency against various organic loading rates (OLR). [24]

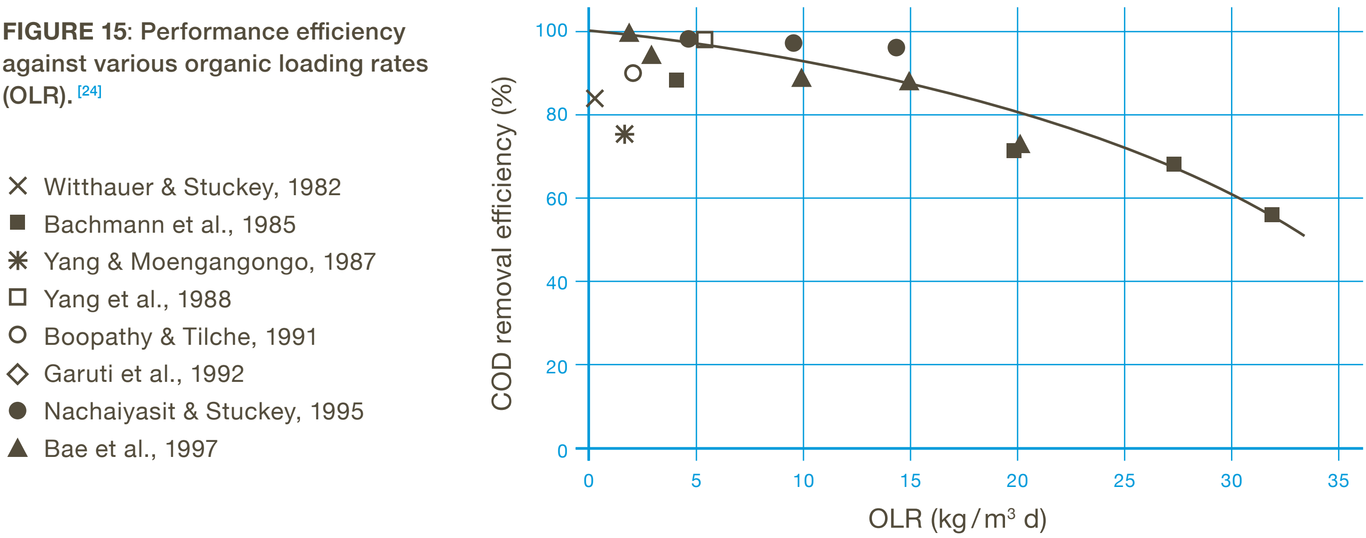


TABLE 1: COD removal of ABR fed by various substrates. [25]

Substrate	Volume (l)	Chambers	Biomass (g VSS/l)	Inlet COD (mg COD/l)	Loading rate (kg/m³/d)	COD removal (%)	HRT (9h)	Temp. (°C)
Municipal wastewater	350	3		264–906	2.17	90	4.8–15	18–28
Domestic sewage / industrial waste	394,000	8		315	0.85	70	10.3	15
Carbohydrate-protein	10	8	18	4,000	1.2–4.8	75–83, 93–97, 96	20, 20, 20	15, 25, 25
Carbohydrate-protein	10	8	18	4,000	4.8–9.6	90–98	20	35

[21] Source: Liu & al; 2010.
[22] Source: Sasse, 2009.
[23] Source: Nasr & al; 2009.
[24] [25] Source: http://wp.wpi.edu/capetown/files/2010/12/Anaerobic-Baffled-Reactor-for-Wastewater-Treatment.pdf

Examples of results

Examples of measured performances

- → Continuous ABR with HRT 8 to 24 h
0.67 to 2.1 kg COD/m³ * d (laboratory). [26]
- → COD removal: 68 to 82%. [26]
- → Fecal coliforms removal: 1–2 logs. [26]
- → Close results for 12 and 18 h HRT
(12 h HRT estimated as a financial good solution). [27]
- → Information about ABR performances is based on laboratory and pilot-scale studies, with COD removal > 80%. [27]

Results in Myanmar, India, Indonesia, Tanzania [28]

- → 37 to 80% COD removals.

Results in Nepal [29]

- → ABR + Constructed Wetland (CW) / Horizontal Filter, Vertical Filter; wastewater from 80 households = 400 P.E.; 1.2 d HRT; reactor up to two-third filled with sludge: effective volume of 42m³.
- → Holes at the bottom of each compartment facilitate easy sludge withdrawal; closed with a PVC pipe.
- → ABR could achieve TSS removal up to 91%; BOD5 up to 78% and COD up to 77%. The average removal efficiency of the ABR + CW is 96% TSS, 90% BOD5, 90% COD, 70% NH_4–N, 26% TP and 98% FC.

Results in Kingsburgh / South Africa [30]

- → Pilot reactor of 3,000 l; HRT: 22 h; COD removal of 72 ± 3 %
- → Removal efficiencies of 68% and 61% were obtained respectively for E. coli and total coliforms. Some post treatment will be required before the effluent may be safely reused in horticulture.
- → HRT is considered too short: by respecting a 3d HRT and an Organic Load Rate limited at 3 kg COD/m³ reactor per day, the concentration of the influent should be lower than 9 kg COD/m³ (9,000 mg COD/l). Influents with higher concentrations should be first treated in biogas digesters.

[26] Source: Nasr & al; 2009. https://link.springer.com/article/10.1007/s10669-008-9188-y
[27] Source: Tayler, 2018. https://www.developmentbookshelf.com/doi/full/10.3362/9781780449869.008
[28] Source: Singh & al; 2009. http://www.ecs.umass.edu/cee/reckhow/courses/697w/papers/Vaidya1.pdf
[29] Source: www.bvsde.paho.org/bvsacd/cd27/reactor.pdf.
[30] Source: Foxon et al., 2004. https://www.pseau.org/outils/ouvrages/wrc_the_anaerobic_baffled_reactor_abr_an_appropriate_technology_for_on_site_sanitation_2004.pdf

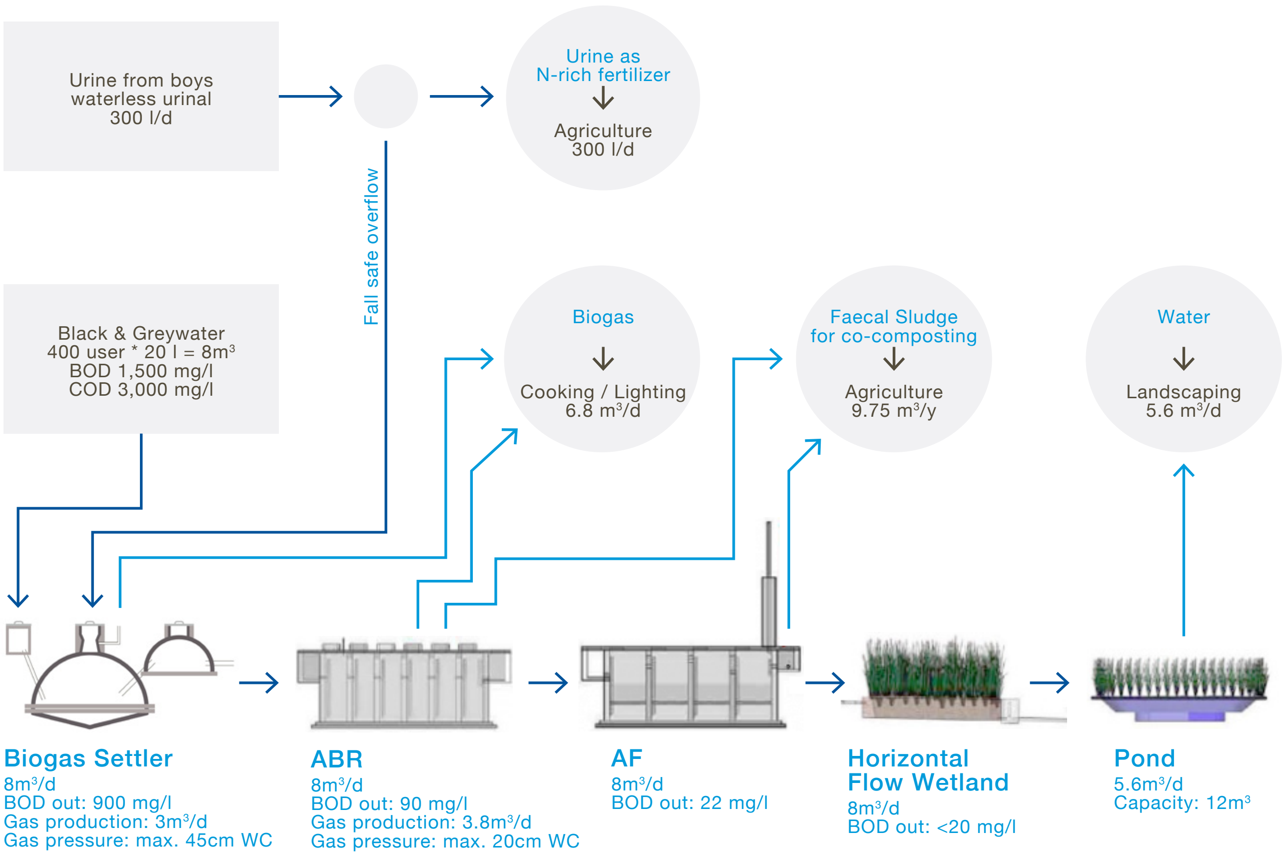
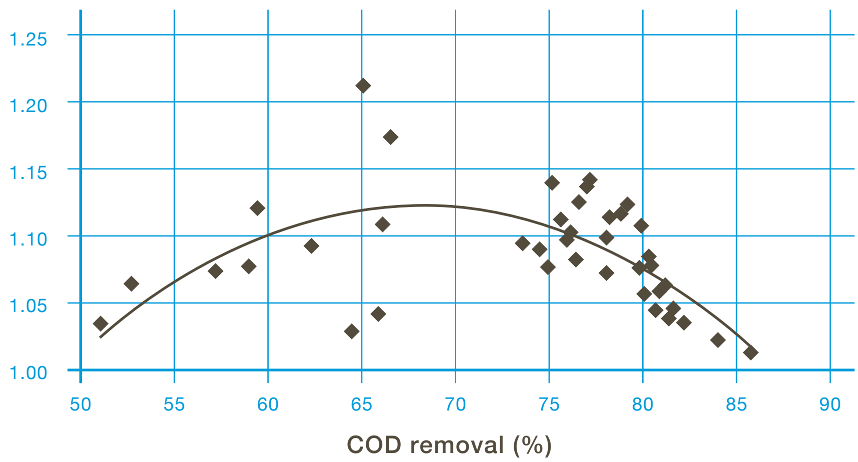


FIGURE 16: Decentralized Wastewater Management at Adarsh College Badalapur Maharashtra India. [31]

Sizing calculations based on the "Practical Guide, DEWATS, 2009"

"Factors of performances" are based on curves obtained in laboratories. [32]

FIGURE 17: COD removal in relation to temperature in anaerobic reactors. Change of COD/BOD ratio during anaerobic treatment. The samples have been taken by SIITRAT from anaerobic filters, most of them serving schools in the suburbs of Delhi, India.



[31] Source: EcoSan Foundation, 2010
[32] Source: DEWATS Practical Guide, 2009.

FIGURE 18: COD Removal relative to wastewater strength in anaerobic filters. Simplified curve of Figure 17, which is used in the spreadsheet formulas.

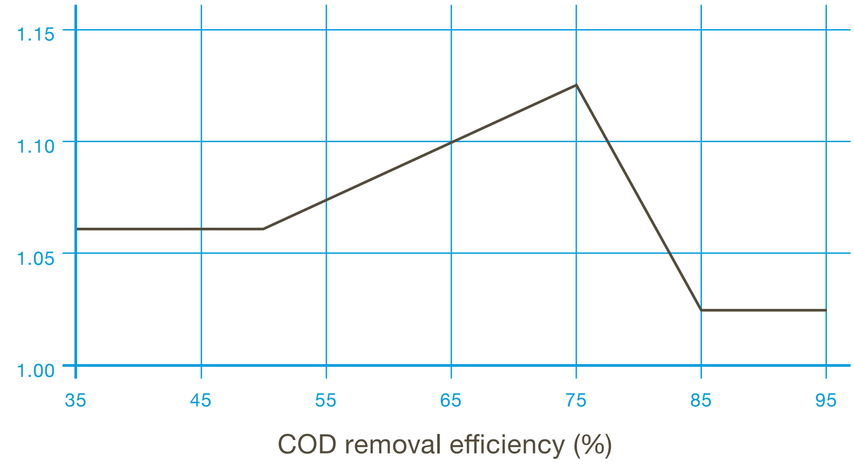


FIGURE 19: Reduction of sludge volume during storage.

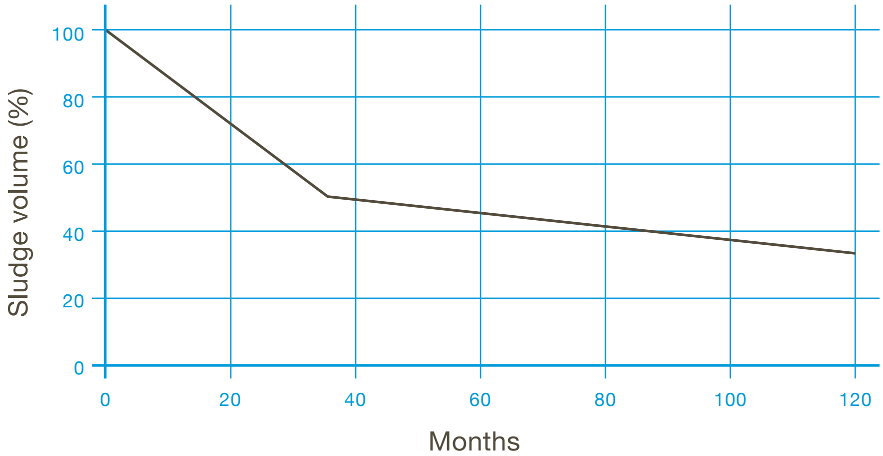


FIGURE 20: COD removal in settlers.

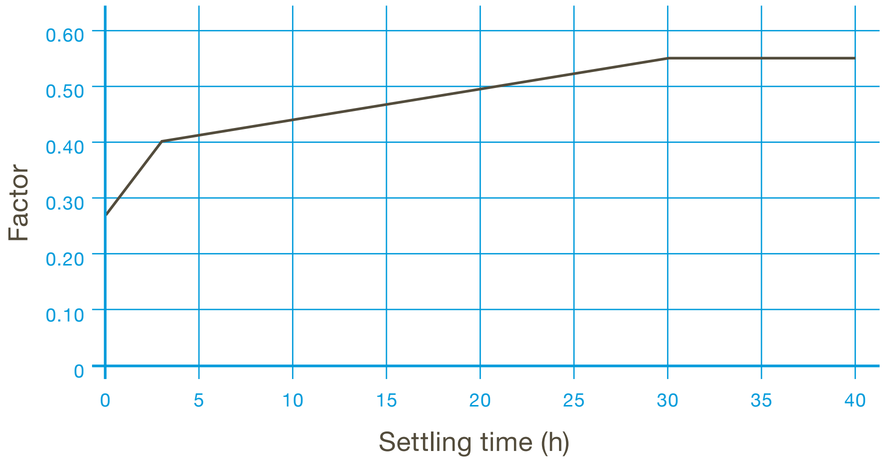


FIGURE 21: BOD removal in relation to HRT in baffled reactors.

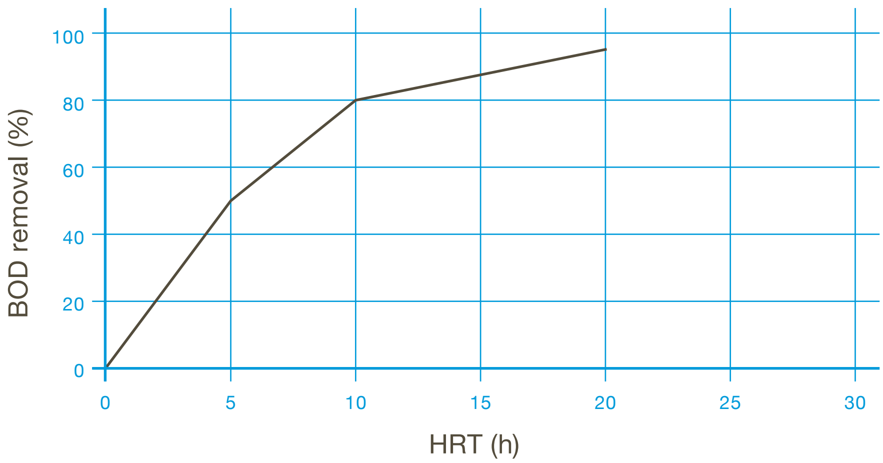


FIGURE 22: BOD removal affected by organic overloading baffled reactors.

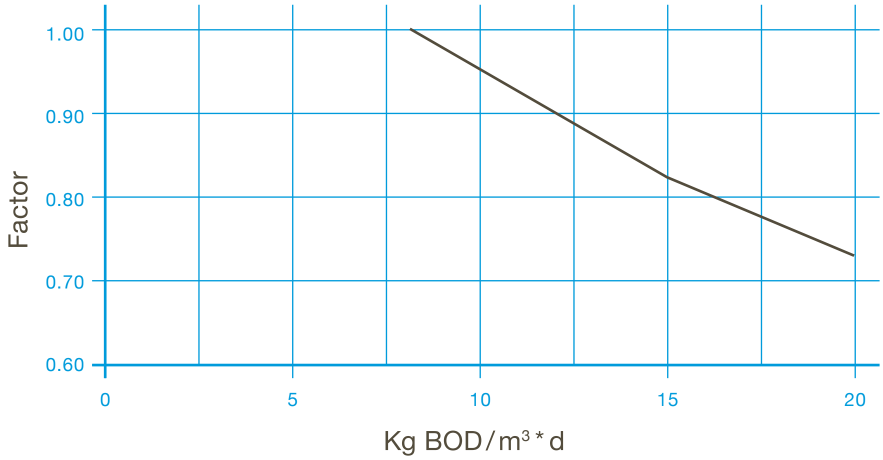


FIGURE 23: BOD removal in baffled reactors in relation to wastewater strength.

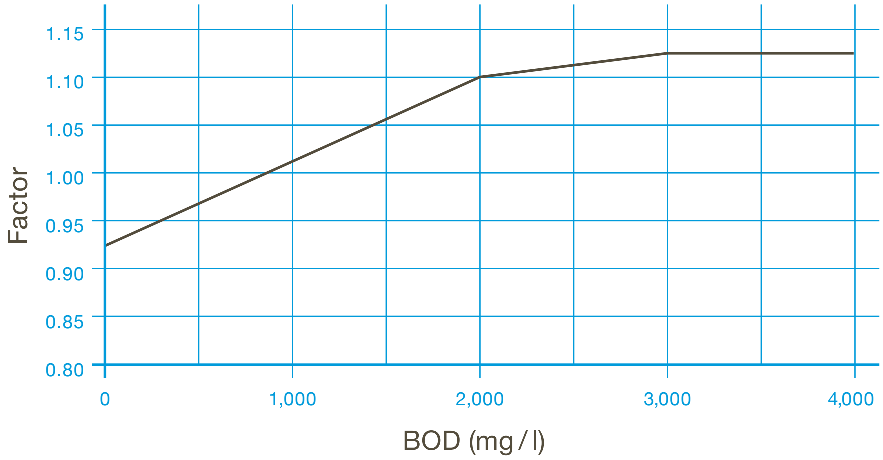
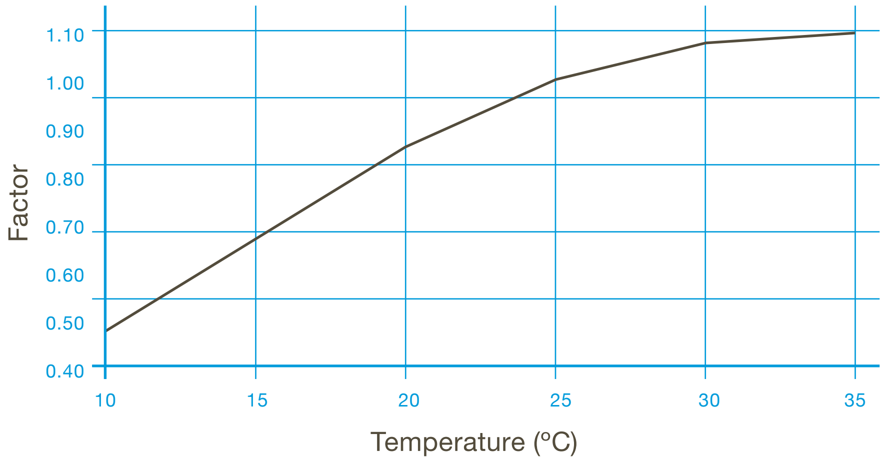


FIGURE 24: COD removal in relation to temperature in anaerobic reactors.



The spreadsheet in Figure 25 uses the curves and the basics of sizing. The performances are based on tests in laboratory and extrapolated. It must be considered as theoritical. Some factors are above 1 and it can result in a performance higher than 100% (See J11 in the spreadsheet). The cell J12 limits it at 95%.

Nevertheless, the spreadsheet helps optimizing the amount and dimensions of the different elements of the ABR system and analyzing the different impacts of the parameters (peak flow, COD, BOD, etc). It also make it possible to check whether the conditions for proper operation are met (organic load, HRT).

	A	B	C	D	E	F	G	H	I	J	K
1	**General spread sheet for anaerobic baffled reactor with integrated settler**										
2	**Daily waste water flow**	**time of most waste water flow**	max peak flow per hour	**COD inflow**	**BOD5 inflow**	COD/BOD	settleable SS/COD	***lowest*** digester temp	**desludging interval**	**HRT in settler**	COD removal rate in settler
3	avg.	given	max.	given	given	calcul	given	given	chosen	chosen	calcul
4	m3/day	h	m3/h	mg/l	mg/l	ratio	ratio	°C	months	h	%
5	10	10	1,00	10000	4000	2,50	0,42	25	24	2,5	26%
6							Domestic 0,35<x<0.45		max. 24 months	1.5 - 2,5 h	
7	**treatment data**										
8	BOD removal rate in settler	**Inflow into baffled reactor**		COD/BOD ratio after settler	**factors to calcultate BOD removal rate of baffled reactor**			**BOD rem, 25deg, 900 mg/l**	theor. Rem, rate acc. To factors	**BOD rem. Rate baffle only**	**BOD out**
9	calcul	COD	BOD	calcul	Calculated according to graphs				calcul	calcul	calcul
10	%	mg/l	mg/l	ratio	f-overload	f-strength	f-temp	f-HRT	ratio	%	mg/l
11	28%	7375,00	2887,00	2,55	1,00	1,12	1,00	0,95	1,06	113%	144,35
12	1,06	<--CoD/BOD removal factor							**Applied --> max. 95%**	95%	1,03
13	**GLOBAL treatment perf**			**dimensions settler**					**baffled septic tank**		
14	**Total BOD rem. Rate**	**Total COD rem. Rate**	**COD out**	**inner masonery measurments chosen acc. To requiered volume**		Sludge accum. Rate	length of settler	**length of settler**	**max upflow velocity**	**number of upflow chambers**	**Height at outlet**
15	calcul	calcul	calcul	width	depth	calcul	calcul	chosen	chosen	chosen	chosen
16	%	%	mg/l	m	m	l/g COD	m	m	m/h	No.	m
17	96%	94%	595,98	3	3	0,00332	3,23	3,23	0,6	6	3
18				max. 3 m (if higher: 2 or more parallel ABRs)	max. 3 m	Settler volume =	29,11		max. 1 m/h, 0,7 m/h recommended	between 3 and 6	Between 1 and 3
19	**Dimensions of baffled septic tank**								**Status and gp**		
20	length of chambers should not exeed half depth		area of single upflow chamber	width of chambers		actual upflow velocity	width downflow shaft	actual volume of baffled reactor	actual total HRT	organic load COD/m3 of reactor	biogas
21	calcul	chosen	calcul	calcul	chosen	calcul	given	calcul	calcul	calcul	calcul
22	m	m	m2	m	m	m/h	m	m3	h	kg/(m3*day)	m3/day
23	1,50	1,5	1,67	1,11	2,2	0,30	0	59,40	59,40	2,98	24,64
24						!!! Should not be > 0,7 !!!	added to the actual volume if baffled downflow shaft. In case of pipe, should be 0			!!! Should not be > 3 kg/m^3 reactor /days !!!	

FIGURE 25: Spreadsheet for calculations.

**Due to mismatches with the curves,
some formulas have been modified for the present manual:**

C5=A5/B5
F5=D5/E5
K5=G5/0.6*IF(J5<1;J5*0.3;IF(J5<3;(J5-1)*0.1/2+0.3;IF(J5<30;(J5-3)*0.15/27+0.4;0.55)))
The formula relates to Figure 20.
The number 0.6 is a correction factor based on practical experience.

A11=K5*A12
A12=IF(K5<0.5;1.06;IF(K5<0.75;(K5-0.5)*0.065/0.25+1.06;IF(K5<0.85;1.125-(K5-0.75)*0.1/0.1;1.025)))
B11==D5*(1-K5)
C11=E5*(1-A11)
D11=B11/C11
E11=IF(J23/D11<8;1;IF(J23<15;1-(J23/D11-8)*0.18/7;0.82-(J23/D11-15)*0.9/5))
The formula relates to Figure 22.

F11=IF(B11/D11<2000;B11/D11*0.17/2000+0.93;IF(B11/D11<3000;(B11/D11-2000)*0.02/1000+1.1;1.13))
The formula relates to Figure 23.

G11=IF(H5<20;((H5-10)*0.39)/(20-10)+0.47;IF(H5<25;(H5-20)*0.14/5+0.86;IF(H5<30;(H5-25)*0.08/5+1;1.1)))
The formula relates to Figure 24.

H11=IF(I23<5;I23*0.51/5;IF(I23<10;(I23-5)*0.21/5+0.51;IF(I23<20;(I23-10)*0.13/10+0.82;0.95)))
I11=E11*F11*G11*H11
The formula relates to Figure 21.

J11=IF(J17<7;E11*F11*G11*H11*(J17*0.04+0.82);E11*F11*G11*H11*0.98)
The formula considers improved treatment by increasing the number of chambers; J12 gives a limit of 0.95.

J12=IF(J11<0.95;J11;IF(J11>0.95;0.95))
K11=(1-J12)*C11
The formula relates to Figure 18.

K12=IF(A17<0.5;1.06;IF(A17<0.75;(A17-0.5)*0.065/0.25+1.06;IF(A17<0.85;1.125-(A17-0.75)*0.1/0.1;1.025)))
The formula relates to Figure 18.

A17=1-K11/E5
B17=A17*K12
C17=B11*(1-J12*K12)
F17=0.005*IF(I5<36;1-I5*0.014;IF(I5<120;0.5-(I5-36)*0.002;1/3))
The formula relates to Figure 19.

G17=IF(A11>0;IF(F17*(E5-C11)/1000*30*I5*A5+J5*C5<2*J5*C5;2*J5*C5;F17*(E5-
C11)/1000*30*I5*A5+J5*C5);0)/D17/E17
The formula considers that sludge volume is less than half of the total volume; a settler may be omitted.

G18=D17*E17*H17
A23=K17*0.5
C23=C5/I17
D23=C23/B23
F23=C5/B23/E23
H23=(G23+B23)*J17*K17*E23
I23=H23/C5
J23=B11*C5*24/H23/1000
K23=(D5-K11)*A5*0.35/1000/0.7*0.5
350 l methane are produced from each kg COD removed (ass: CH_4 70%; 50% dissolved).

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