

10 Designing DEWATS

If the planning engineer knows his or her craft and recognises his or her limitations, designing DEWATS is relatively simple. Treatment-system performance cannot be precisely predicted and, therefore, calculating of dimensions should not involve ambitious procedures; in the case of small- and medium-scale DEWATS, a slightly oversized plant volume adds to operational safety.

Based on local conditions, needs and preferences, plants of varying sizes can be chosen as standard designs. On-site adaptations can then be made by less-qualified site supervisors or technicians.

In the case of specific demands, calculations and design must be carried out individually; the structural details of the standardised plants can be integrated. In this chapter we introduce a simplified, quasi-standardised method of calculating dimensions using spreadsheets.

Co-operative plant systems that require interconnecting sewerage must be designed individually by an experienced engineer, who is able to place plants and sewers according to contours and other site requirements.

10.1 Technical spreadsheets – background

10.1.1 Usefulness of computer calculation

The purpose of this chapter is to provide the engineer with tools to produce his or her own spreadsheets for sizing DEWATS in any computer programme that he or she is familiar with. The exercise of producing one's own tables will compel engineers to deepen their understanding of design.

The curves that have been used as the basis for calculation in the formulas applied in the computer spreadsheets may also be of interest to those who do not use a computer (these are found in this chapter). As these curves visualise the most important relationships between various parameters, they will enhance understanding of the factors that influence the treatment process. It should be noticed that the graphs have been developed on the basis of mixed information; the methods of calculation, therefore, do not always follow the same logic.

Computerised calculations can be very helpful, particularly if the formulas and the input data are correct. Flawed assumptions or wrong data, on the other hand, will definitely result in worthless results. Nevertheless, assuming the input data is correct, spreadsheets provide a quick impression of the plant's space requirement and what treatment performance can be expected. Ready-to-use computer spreadsheets are especially helpful to those who do not design DEWATS on a daily basis and would otherwise need to recollect the entire theory for sizing a plant before starting to design.

Please bear in mind that DEWATS provides a set of approaches. The equations used in the technical spreadsheets do rely on certain assumptions. Because of the very different parameters that are relevant for the performances of a plant (temperature, materials to be used, composition of the wastewater etc.) there is not a "right way" to calculate dimensions. It is the experience and understanding of the planner that is crucial to create the designs most appropriate to local conditions – i. e. the wastewater problem.

10.1.2 Risks of using simplified formulas

The formulas applied in the spreadsheets have been developed by practitioners, who are not overly concerned with theoretical knowledge. But the formulas are based on scientific findings, which have been simplified in the light of practical experience.

Even if the formulas were to be 100% correct, the results would not be 100% accurate, as input data is not fully reliable. But the accuracy of the formulas is likely to be greater than the accuracy of wastewater sampling and analysis. There are many unknown factors influencing treatment efficiency and "scientific" handbooks provide a possible range of results. But this book, although "scientifically" based, is written for people who have to build a real plant out of real building materials. The supervisor cannot tell the mason to make a concrete tank "about 4.90m to 5.60m long"; he or she must say: "The length should be 5.35m". The following spreadsheets were designed in this spirit. Anyone who already uses more variable methods of calculation and who is not the target reader of this book is free to modify the formulas and curves according to his or her experience and ability (the authors welcome any information that would help to improve the spreadsheets).

As the formulas represent simplifications of complex natural processes, there is a certain risk that they do not reflect reality adequately. However, the risk of changes in the assumed reality is even greater; for example, expanding a factory without enlarging the treatment system is obviously more significant than an assumed BOD of 350mg/l, when in reality it is only 300mg/l.

Listed below are some examples of incorrect assumptions and their consequences:

- underestimating sludge accumulation in septic tanks, sedimentation ponds, Imhoff tanks and anaerobic reactors results in shorter desludging intervals
- in the case of anaerobic reactors, severe under-sizing could lead to a collapse of the process, while over-sizing may require longer maturation time at the beginning
- incorrect treatment performance of primary or secondary treatment steps could be the cause of over- or undersized post-treatment facilities. This may result in unnecessarily high investment costs or having to enlarge the post-treatment facilities
- undersized anaerobic ponds will develop odour, while slightly oversized ponds may not develop sufficient scum, also resulting in smells
- undersized aerobic ponds can develop an odour; there is no harm in oversizing aerobic ponds
- the biggest risk lies in filter media clogging in both anaerobic tanks and constructed wetlands. However, the risk is more likely to come from inferior filter material, faulty structural details or incorrect wastewater data than from incorrect sizing

In general, moderate oversizing reduces the risk of unstable processes and inferior treatment results.

10.1.3 About the spreadsheets

The spreadsheets presented in this handbook are in Microsoft EXCEL; other suitable programmes may also be used.

There might be differences in the syntax of formulas, for example 3^2 (3 to the power of 2) may be written as =POWER(3;2) or =3^2, square root of 9 could be =SQRT(9) or =9^1/2, cubic root of 27 would be =power(27;1/3) or =27^1/3. Some programmes may accept only one of the alternatives.

The spreadsheets are based on data which is normally available to the planning engineer within the context of DEWATS. For example, while the measurement of BOD₅ and COD may be possible at the beginning of planning, it is unlikely that the BOD₅ will be regularly controlled later on. Therefore, calculations are based on COD or the results of BOD-based formulas have been set in relation to COD, and vice versa. In the following, the term BOD stands for BOD₅.

The formulas applied in the spreadsheets are based on curves from scientific publications, handbooks and the experience of BORDA and its partners. The formulas, therefore, define typical trends. For example, it is well-known that the removal efficiency of an anaerobic reactor increases when the COD/BOD ratio is narrow. Such curves have been simplified into a chain of straight lines to allow the reader to easily understand the formulas – and to adjust their values to local conditions if necessary. Although the amount of data on which some of these curves are based is sometimes too insignificant to be statistically relevant, the formulas have been applied successfully and adjusted on the basis of practical experience.

The formulas are simple. Besides basic arithmetical operations, they use only one logical function, namely the "IF"-function. For example:

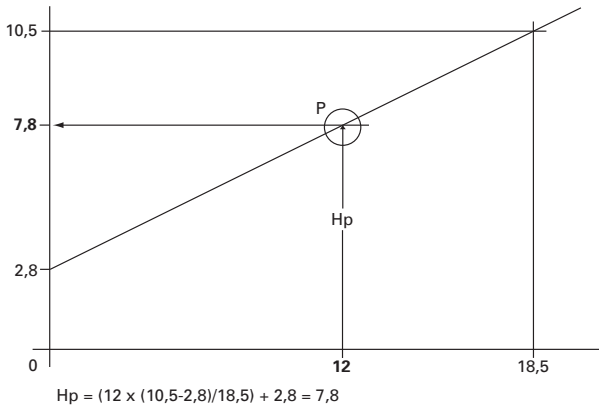
If temperature is less than 20°C; then hydraulic retention time is 20 days; if not, then it is 15 days in case the temperature is less than 25°C; otherwise (this means, if temperature is over 25°C) the HRT is 10 days.

10 Designing DEWATS

Assuming the temperature is stated in cell F5 of the spreadsheet, the formula for retention time will be written as: =IF(F5<20;20;IF(F5<25;15;10)).

The formulas have been kept simple, so that the user can make modifications, according to experience or superior knowledge. For example, if it has been found that, for a certain substrate, the HRT should be 25 days below 20°C, 23 days up to 25°C and 20 days above 25°C and, that for safety reasons, 10% longer retention time is added, then the formula should read:

```
= 110% * IF (F5 < 20; 25; IF (F5 < 25; 23; 20)).
```



Picture 10_1:
The graphical expression of the "rule of three" for solving proportions: if we know three numbers a, b, and c, and want to find d such that a/b = c/d, then d = cb/a.

Values between defined days or amounts may be calculated by using the famous "rule of three", of which there are plenty of examples in the following tables. The slope of a straight line is expressed in its tangent; the height of a certain point is found by multiplying the length with the ratio of the slope, i.e. total height divided by total length (Picture 10_1).

In case the reader is not familiar with working in EXCEL, it is better not to modify formulas but to manipulate the results by entering "modified" data. For example, if the values of spreadsheet results are generally lower or higher than the experienced in the field, dimensioning can be adjusted by entering lower or higher temperature values, or shorter or longer retention times. One could also multiply wastewater volumes or COD concentrations by a safety factor before starting the calculation. To avoid mishaps, all the spreadsheet cells should be locked, except the ones written in bold figures.

When the user prepares his or her own tables and copies the formulas below, the columns (A; B; C; D...) and the rows (1; 2; 3; 4; 5...) before the "equals" symbol of each formula, define which cell the formula should be written in. The names of cells and rows are shown on the entry mask of the monitor. In transferring formulas to the spreadsheet, the cell name before the "equals" symbol should not be copied; for example $E6=D5/E5$ should be written in cell E6 as $=D5/E5$.

The italic figures are either guiding figures to show usual values, or they indicate limits to be observed. The bold figures are those which have to be filled in by hand; the other figures are calculated. Columns which are labelled "given" contain data which reflects a given reality, for example, wastewater-flow volume or wastewater strength. Columns which are labelled "chosen" contain data which may be modified to optimise the design, for example, hydraulic retention time or desludging intervals. All other cells contain formulas and should be locked, in order to avoid deleting by accident formulas. Cells which are labelled "check" or "require" should be used to confirm whether the chosen and given values are realistic.

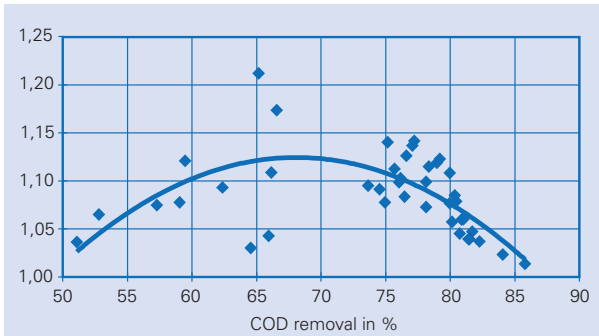
10.2 Technical spreadsheets – application

10.2.1 Assumed COD/BOD ratio

The COD/BOD ratio widens during biological treatment because the BOD reflects only that part of the oxygen demand which is reduced by biological treatment, while the COD represents total oxygen demand. The removed BOD, therefore, has a greater percentage-wise influence on the change of the BOD than on the COD. The COD/BOD ratio widens faster while biological degradation is incomplete, and slower when treatment efficiency reaches almost 100%.

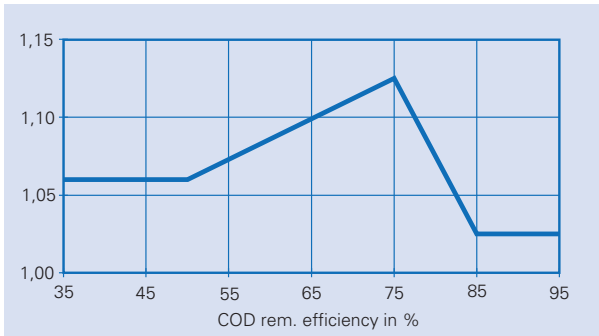
Picture 10_2:

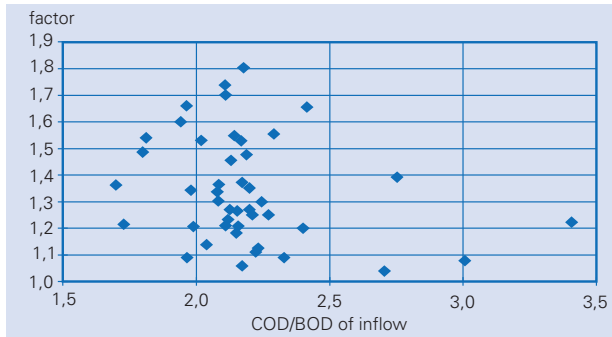
COD removal in relation to temperature in anaerobic reactors. Change of COD/BOD ratio during anaerobic treatment. The samples have been taken by SIITRAT from anaerobic filters, most of them serving schools in the suburbs of Delhi, India



Picture 10_3:

COD removal relative to wastewater strength in anaerobic filters. Simplified curve of Picture 10_2, which is used in the spreadsheet formulas





Picture 10_4: Illustration to spreadsheet for calculation of anaerobic filter dimensions. Changes of COD/BOD ratio during anaerobic treatment of domestic wastewater. The samples were taken by SIITRAT. The few sample points of high COD/BOD ratio (to the right of the graph) stem from a post-treatment plant and are not comparable to the majority of samples

10.2.2 Domestic wastewater quantity and quality

The following spreadsheet (see Table 24) helps to define domestic wastewater in terms of the number of people and the wastewater they discharge. BOD and water-consumption figures vary widely from place to place and, therefore, should be obtained for each site.

Formulas of spreadsheet “wastewater per capita”:

$$E5 = A5 \times C5 / 1000$$

$$F5 = A5 \times B5 / E5$$

$$G5 = D5 \times F5$$

	A	B	C	D	E	F	G
1	Wastewater production per capita						
2	user	BOD ₅ per user	water consump. per user	COD/BOD ₅ ratio	daily flow of wastewater	BOD ₅ concentr.	COD concentr.
3	given	given	given	given	calculated	calculated	approx.
4	number	g/day	litres/day	mg/l	m ³ /day	mg/l	mg/l
5	80	55	165	1.90	13.20	333	633
6	range =>	40 - 65	50 - 300				

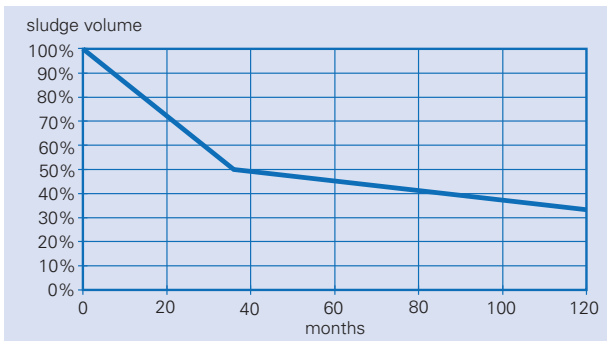
Table 24: Spreadsheet for calculation of quantity and quality of domestic-wastewater production

10 Designing DEWATS

10.2.3 Septic tank

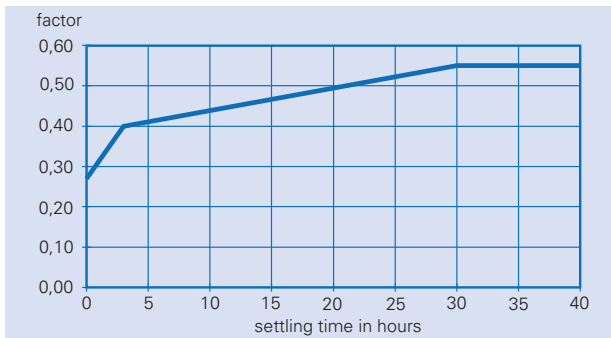
The size of septic tanks is standardised in most countries. In the case of DEWATS, however, the wastewater may not be the standard domestic wastewater. The spreadsheet (see Table 25) assists in the design of septic tanks. Flow volume, number of peak hours of flow and pollution load are the basic entries. "Chosen" parameters include the desludging interval and the HRT; the former is decisive for the digester volume for sludge storage, while the latter decides the volume of the liquid.

As sludge compacts with time, the formulas in the spreadsheets are based on the graph shown in Picture 10_5.

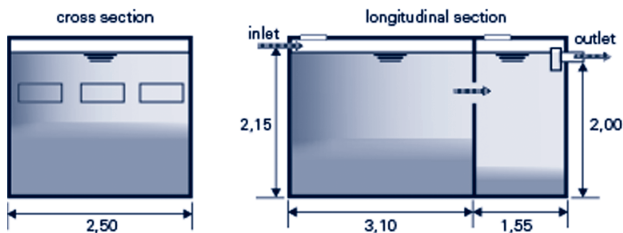


Picture 10_5:
Reduction of sludge
volume during
storage

COD-removal rates in settlers and septic tanks depend on the amount of settleable solids, their COD content and the intensity of inoculation with fresh inflow. The contact between fresh incoming substrate and active sludge in Imhoff tanks is nearly zero, while in sedimentation ponds with a deep inlet, it is intensive. This fact has been taken into consideration by dividing the parameter “settleable SS per COD” by an experience factor of between 0.50 and 0.60. The general tendency is shown in the graph Picture 10_6.



Picture 10_6:
COD removal
in settlers



Picture 10_7:
Illustration to
spreadsheet for
calculation of septic
tank dimensions

10 Designing DEWATS

Formulas of spreadsheet "septic tank"

	A	B	C	D	E	F	G	H	I	J	
1	General spreadsheet for septic tank, input and treatment data										
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD ₅ inflow	HRT inside tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD ₅ outflow	
3	given	given	calcul.	given	given	chosen	given	calcul.	calcul.	calcul.	
4	m ³ /day	h	m ³ /h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l	
5	13.0	12	1.08	633	333	18	0.42	35%	411	209	
6	COD/BOD ₅ ->				1.90	12 - 24 h	0.35 - 0.45 domestic		BOD rem. ->	1.06	
7	dimensions of septic tank										
8	desludging interval	inner width of septic tank	min. water depth at outlet point	inner length of first chamber		length of second chamber		volume incl. sludge	actual volume of septic tank	biogas 70% CH ₄ 50% dissolved	
9	chosen	chosen	chosen	requir.	chosen	requir.	chosen	requir.	check	calcul.	
10	months	m	m	m	m	m	m	m ³	m ³	m ³ /d	
11	12	2.50	2.00	3.13	3.10	1.56	1.55	23.46	23.25	0.72	
12	sludge l/g BOD rem.							0.0042			

Table 25:

Spreadsheet for calculating septic tank dimensions

$$C5=A5/B5$$

$$H5 = G5 / 0.6 \times IF (F5 < 1; F5 \times 0.3; IF (F5 < 3; (F51) \times 0.1/2 + 0.3; IF (F5 < 30; (F5 - 3) \times 0.15/27 + 0.4; 0.55)))$$

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

$$I5 = (1 - H5) \times D5$$

$$J5 = (1 - H5 \times J6) \times E5$$

$$E6 = D5 / E5$$

$$J6 = IF (H5 < 0.5; 1.06; IF (H5 < 0.75; (H5 - 0.5) \times 0.065 / 0.25 + 1.06; IF (H5 < 0.85; 1.125 - (H5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula relates to Picture 10_3.

$$D11 = 2/3 \times H11 / B11 / C11$$

$$F11 = D11 / 2$$

$$H11 = IF (H12 \times (E5 - J5) / 1000 \times A11 \times 30 \times A5 + C5 \times F5 < 2 \times A5 \times F5 / 24; 2 \times A5 \times F5 / 24; H12 \times (E5 - J5) / 1000 \times A11 \times 30 \times A5 + C5 \times F5) + 0.2 \times B11 \times E11$$

The formula takes into account that sludge volume is less than half the total volume.

$$I11 = (E11 + G11) \times C11 \times B11$$

$$J11 = (D5 - I5) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

350 l methane are produced from each kg COD removed.

$$H12 = 0.005 \times IF (A11 < 36; 1 - A11 \times 0.014; IF (A11 < 120; 0.5 - (A11 - 36) \times 0.002; 1/3))$$

The formula relates to [Picture 10_5](#).

10.2.4 Fully mixed digester

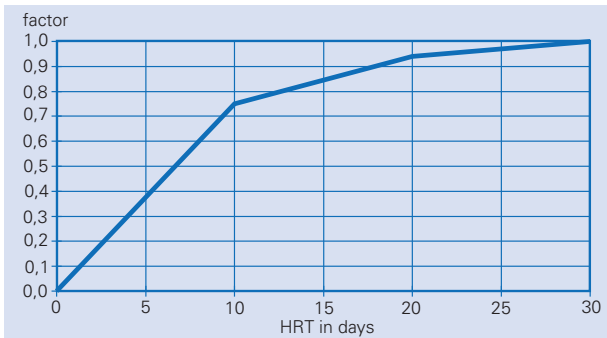
Within a fully mixed digester, or biogas plant, as it is commonly known in rural households in India, cattle dung is thoroughly mixed with water. Even as effluent, the substrate is very viscous; very little sludge settles and, as a result, no sludge must be removed for many years. The same type of rural biogas plant in China receives a substrate which is a mixture of human excreta, pig dung and water – however, less homogeneous by far than in India. Other wastewater, for example from slaughter-houses, may have different properties again. It is difficult, therefore, to calculate dimensions for the many different kinds of “strong” wastewater, for which biogas treatment might be suitable. The following spreadsheet should be used with certain reservations and – formulas may need to be adapted to local conditions.

10 Designing DEWATS

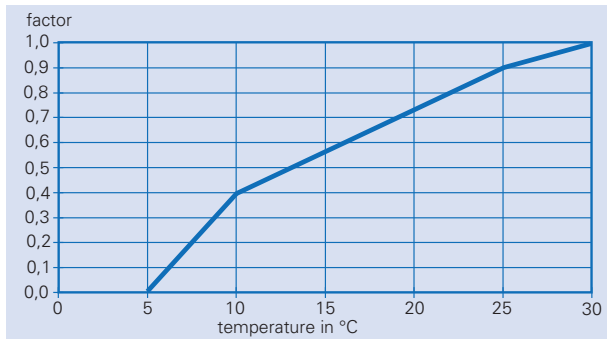
The spreadsheet does reveal, however, the influencing factors.

The formulas are based on the following assumptions:

- solids which settle within one day of benchmark testing represent 95% of all settleable solids
- there is a mixing effect inside the digester because of the relatively high gas production, which prevents sludge from settling. Any additional sludge will only make up for the loss in volume by compression. Thus, the accumulating sludge volume is equal to the amount calculated from the one day of benchmark testing
- all settleable and non-settleable solids will digest within hydraulic retention times typical for sludge reactors
- 95% of their BOD is removed after 25 days and 30°C; this is equivalent to 400l of biogas produced from 1kg of organic dry matter



Picture 10_8:
Gas production of fixed-dome biogas plants in relation to HRT



Picture 10_9:
Gas production of fixed-dome biogas plants in relation to temperature

Formulas of spreadsheet “fully mixed digester”

$$D5 = B5 \times C5$$

$$I5 = \text{IF}(F5 < 10; F5 \times 0.75 / 10; \text{IF}(F5 < 20; (F5 - 10) \times 0.19 / 10 + 0.75; (F5 - 20) \times 0.06 / 10 + 0.94))$$

The formula relates to Picture 10_8.

$$J5 = \text{IF}(G5 < 5; 0; \text{IF}(G5 < 10; (G5 - 5) \times 0.4 / 5;$$

$$\text{IF}(G5 < 25; (G5 - 10) \times 0.5 / 15 + 0.4; (G5 - 25) \times 0.1 / 5 + 0.9))$$

The formula relates to Picture 10_9.

$$K5 = H5 \times I5 \times J5 \times A5 \times D5$$

$$B11 = 1.1 \times ((1000 \times K5 \times L5 / A11 / 0.35) / (0.95 \times I5 \times J5)) \times (1 - 0.95 \times I5 \times J5) / A5$$

The formula determines the influent COD and calculates the COD removal by assuming a production of 350 l methane per kg COD removed; the additional 10% represent the inorganic COD, which is not removed.

$$D11 = 30 \times C11 \times A5 \times E5 / 1000$$

$$E11 = F5 \times A5$$

$$F11 = D11 + E11$$

$$H11 = K5 \times G11$$

$$L11 = 2 \times \text{SQRT}((H11 / J11 - (K11 / 2) \times (K11 / 2) \times \text{PI}()) / \text{PI}())$$

The mathematical expression is:

$$2 \times \sqrt{\frac{\left(\frac{H11}{J11} - \left(\frac{K11}{2}\right)^2 \times \pi\right)}{\pi}}$$

$$D17 = A17 - B17 / 2$$

$$E17 = H11 / (D17 \times D17 \times \text{PI}())$$

10 Designing DEWATS

The mathematical expression is:

$$H11 / (D17^2 \times \pi)$$

$$F17 = (F11 - \text{POWER}(A7 - B17 - C17; 2) \times \text{PI}() \times E17) / (A17 \times A17 \times \text{PI}()) + E17$$

The mathematical expression is:

$$F11 = \frac{(A17 - B17 - C17)^2 \times \pi \times E17}{A17 \times \pi} + E17$$

$$G17 = E17 + 0.15$$

$$H17 = F17 + 0.15$$

$$I17 = 3.14 \times I11 \times I11 \times (K17 - I11 / 3)$$

$$J17 = 0.02 + \text{POWER}((F11 + H11/2 + I17) / 4.19; 1/3)$$

The theoretical digester volume is taken as the volume below the zero line plus half the gas storage; 0.02m are added for plaster.

The mathematical expression is:

$$0.02 + \sqrt[3]{\frac{(F11 + H11/2 + I17)}{4.19}}; 4.19 \text{ is } 4/3\pi$$

$$L17 = 4.19 \times (K17 - 0.02) \times (K17 - 0.02) \times (K17 - 0.02) - I17 - H11 / 2$$

$$B23 = \text{PI}() \times (I11 + A23) \times (I11 + A23) \times (K17 - (I11 + A23) / 3)$$

The volume above the lowest slurry level is found by trial and error; π is expressed as PI().

$$C23 = I17 + H11$$

$$D23 = A23 + J11$$

$$E23 = 3.14 \times I11 \times I11 \times (G23 - I11/3)$$

$$F23 = 0.02 + \text{POWER}((F11 + H11/2 + E23) / 2.09; 1/3)$$

The mathematical expression is:

$$0.02 + \sqrt[3]{\frac{(F11 + H11/2 + E23)}{2.09}} ; 2.09 \text{ is } 2/3\pi$$

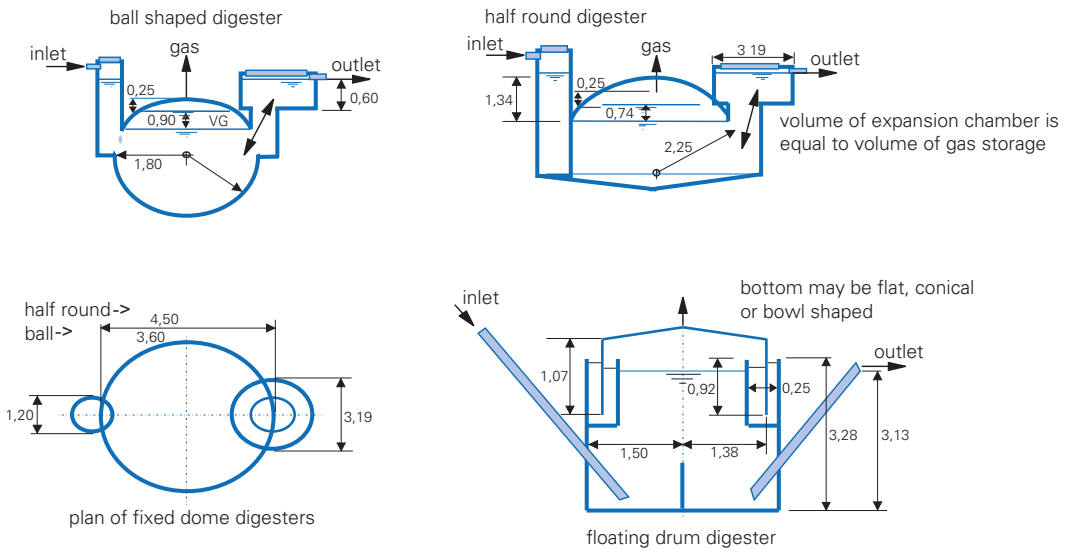
$$H23 = 2.09 \times (G23 - 0.02) \times (G23 - 0.02) \times (G23 - 0.02) - E23 - H11 / 2$$

$$J23 = \text{PI}() \times (I23 + I11) \times (I23 + I11) \times (G23 - (I23 + I11) / 3)$$

The volume above the lowest slurry level is found by trial and error; π is expressed as PI().

$$K23 = E23 + H11$$

$$L23 = I23 + J11$$



Picture 10_10:
Illustration to
spreadsheet for
calculation of
fully mixed digester
dimensions

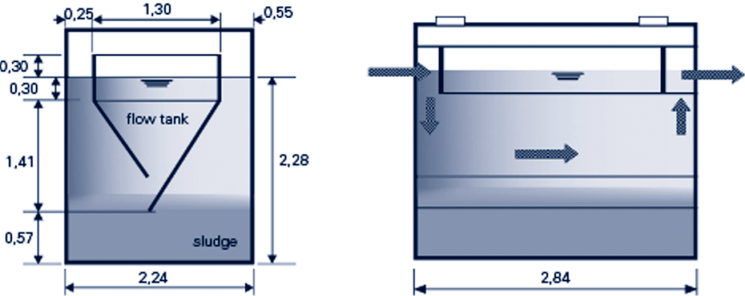
10 Designing DEWATS

A	B	C	D	E	F	G	H	I	J	K	L	
1 General spreadsheet for biogas plants, input and gas-production data												
2	daily flow	TS (DM) content	org. DM/ total DM	org. DM content	solids settleable within one day	HRT	lowest digester temperature	ideal biogas product at 30°C	gas production factors		total gas product	methane content
3	given	given	assumed	calcul.	tested	chosen	given	given	calcul. acc. to graphs		calcul.	assumed
4	m ³ /d	%	ratio	%	ml/l	d	°C	l/kg org DM	f-HRT	f-temp	m ³ /d	ratio
5	0.60	6.0	67%	4.0	20	25	25	400	0.97	0.90	8.42	70%
6								200 - 450				
7	values for all digester shapes								for all fixed-dome plants			
8	non-dissolv. methane prod.	approx. effluent COD	de-sludging interval	sludge volume	liquid volume	total digester volume	gas storage capacity	gas holder volume VG	free distance above slurry zero line	outlet above zero	diameter of left shaft	diameter of expans. chamber
9	assumed	calcul.	chosen	calcul.	calcul.	calcul.	given	calcul.	chosen	chosen	chosen	calcul.
10	ratio	mg/l	months	m ³	m ³	m ³	ratio	m ³	m	m	m	m
11	80%	7,943	12	4.32	15.0	19.3	65%	5.5	0.25	0.60	1.20	3.19
12										minimum 0.60 m		
13	cylindrical floating-drum plant								ball-shaped digester			
14	radius of digester	width of water ring	wall thickness of water ring	radius of gas holder	theor. height of gas holder	theor. depths of digester	actual height of gas holder	actual depth of digester	volume of empty space above zero line	radius ball shape	actual digester radius (ball)	actual net volume of digester
14	chosen	chosen	chosen	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	requir.	chosen	check
16	m	m	m	m	m	m	m	m	m ³	m	m	m ³
17	1.50	0.25	0.12	1.38	0.92	3.13	1.07	3.28	0.34	1.77	1.80	20.56
18												
19	ball shaped digester				half-ball shaped digester							
20	lowest slurry level below zero line (fill in trial until "calcul." match "target")			gas pressure ball shaped	volume of empty space above zero line	radius half round shape	actual digester radius (half round)	actual net volume of digester	lowest slurry level below zero line (fill in trial until "calcul." match "target")			gas pressure half-ball
21	trial!!	calcul.	target	calcul.	calcul.	requir.	chosen	check	trial!!	calcul.	target	calcul.
22	m	m ³	m ³	m w.c.	m ³	m	m	m ³	m	m ³	m ³	m w.c.
23	0.90	5.89	5.81	1.50	0.43	2.23	2.25	20.01	0.74	5.91	5.90	1.34
24	1,50 max.				1.50 max.							

Table 26: Spreadsheet for calculating fully mixed digester dimensions

10.2.5 Imhoff tank

The general treatment properties in the Imhoff tank are comparable to those in any other settler. Since wastewater does not come into direct contact with active sludge, BOD removal from the liquid is almost zero; however, as sedimentation is greater than in other settlers, the COD or BOD removal within these units is comparable. This fact is reflected in the factor 0.50 of cell H5.



Picture 10_11: Illustration to spreadsheet for calculation of Imhoff Tank dimensions

10 Designing DEWATS

Flow volume, number of peak hours of flow and pollution load are the basic entries for calculation. "Chosen" parameters are the same as those for the septic tank – HRT and desludging intervals.

Formulas of spreadsheet "Imhoff tank"

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for Imhoff tank, input and treatment data									
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD ₅ inflow	HRT inside flow tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD ₅ outflow
3	given	given	calcul.	given	given	chosen	given	calcul.	calcul.	calcul.
4	m ³ /day	h	m ³ /h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l
5	25.0	12	2,08	633	333	1.50	0.42	27%	460	237
6	COD/BOD ₅ ->				1.90	domestic 0.35 - 0.45		BODrem. ->		1.06
7	dimensions of Imhoff tank									
8	desludging interval	flow tank volume	sludge volume	inner width of flow tank	space be-side flow tank	total inner width of Imhoff tank	inner length of Imhoff tank	sludge height	total depth at outlet	biogas 70% CH ₄ 50% dissolved
9	chosen	calcul.	calcul.	chosen	chosen	calcul.	calcul.	calcul.	calcul.	calcul.
10	months	m ³	m ³	m	m	m	m	m	m	m ³ /d
11	12	3.13	3.61	1.30	0.55	2.24	2.82	0.57	2.28	1.08
12	sludge l/g BODrem.		0.0042							

Table 27:
Spreadsheet for calculating Imhoff tank dimensions

$$C5 = A5/B5$$

$$H5 = G5 / 0.5 \times \text{IF} (F5 < 1; F5 \times 0.3; \text{IF} (F5 < 3; (F5 - 1) \times 0.1 / 2 + 0.3 ;$$

$$\text{IF} (F5 < 30; (F5 - 3) \times 0.15 / 27 + 0.4; 0.55)))$$

The formula relates to 10_6. The number 0.5 is a correction factor based on practical experience.

$$I5 = (1 - H5) \times D5$$

$$J5 = (1 - H5 \times J6) \times E5$$

$$E6 = D5 / E5$$

$$J6 = \text{IF} (H5 < 0.5; 1.06; \text{IF} (H5 < 0.75; (H5 - 0.5) \times 0.065 / 0.25 + 1.06; \\ \text{IF} (H5 < 0.85; 1.125 - (H5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula relates to Picture 10_3.

$$B11 = C5 \times F5$$

$$C11 = A5 \times 30 \times A11 \times C12 \times (E5 - J5) / 1000$$

$$F11 = D11 + E11 + 0.25 + 2 \times 0.07$$

All formulas for dimensions relate to the geometry of the Imhoff tank, as shown in Picture 10_11.

$$G11 = B11 / (0.3 \times D11 + (D11 \times D11 \times 0.85 / 2))$$

$$H11 = C11 / F11 / G11$$

$$I11 = H11 + 0.85 \times D11 + 0.3 + 0.3$$

$$J11 = (D5 - I5) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

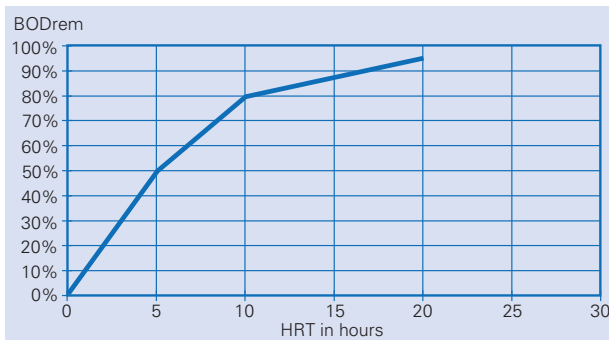
350 l methane are produced from each kg COD removed.

$$C12 = 0.005 \times \text{IF} (A11 < 36; 1 - A11 \times 0.014; \text{IF} (A11 < 120; 0.5 - (A11 - 36) \times 0.002; 1/3))$$

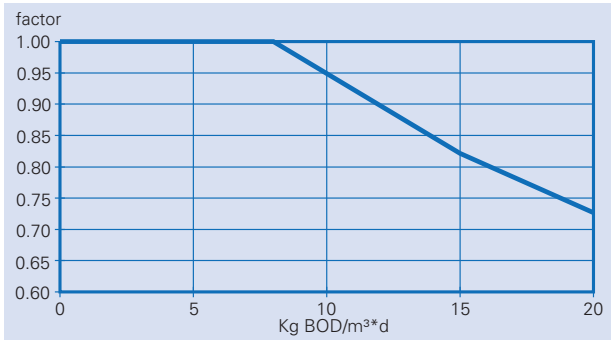
The formula relates to Picture 10_5.

10.2.6 Anaerobic baffled reactor

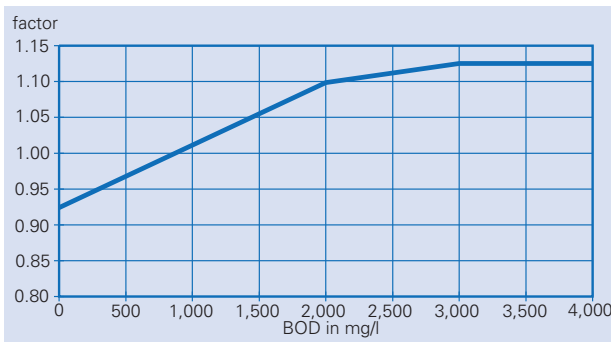
Volume of flow, number of peak hours of flow and pollution load are the basic entries for calculation. "Chosen" parameters for designing a baffled reactor are the HRT, desludging intervals and the up-flow velocity (cell I17). Due to the interrelation between these factors, the HRT cannot be reduced by changing the dimensions of the up-flow chambers because the up-flow velocity will thereby be increased. To achieve the desired effluent quality, it is better to add another chamber than to enlarge their volumes because treatment efficiency increases with the number of chambers (see formula of cell J17). However, practical experience has shown that treatment efficiency does not increase with more than six chambers. Calculation is based on the curve (Picture 10_12) showing BOD removal for a BOD of 900mg/l at 25°C. Factors are applied to adapt the calculation to waste-water strength (Picture 10_14) and temperature (Picture 10_17). An additional curve is used to prevent organic overloading (Picture 10_13).



Picture 10_12:
BOD removal in
relation to HRT in
baffled reactors



Picture 10_13:
BOD removal
affected by organic
overloading baffled
reactors



Picture 10_14:
BOD removal in
baffled reactors in
relation to waste-
water strength

10 Designing DEWATS

	A	B	C	D	E	F	G	H	I	J	K	
1	General spreadsheet for ABR with integrated settler											
2	daily waste-water flow	time of most waste-water flow	max. peak flow per hour	COD inflow	BOD ₅ inflow	COD/BOD ratio	settleable SS / COD ratio	lowest digester temperature	de-sludging interval	HRT in settler (no settler HRT=0)	COD removal rate in settler	
3	avg.	given	max.	given	given	calcul.	given	given	chosen	chosen	calcul.	
4	m ³ /day	h	m ³ /h	mg/l	mg/l	ratio	mg/l	°C	months	h	%	
5	25	12	2.08	633	333	1.90	0.42	25	18	1.50	23%	
6			COD/BOD ₅ >				0.35–0.45			1.5 h		
7	treatment data											
8	BOD ₅ removal rate in settler	inflow into baffled reactor		COD/BOD ₅ ratio after settler	factors to calculate COD removal rate of anaerobic filter			COD rem. 25°, COD 1500	theor. rem. rate acc. to factors	COD rem. rate baffle only	COD out	
9	calcul.	COD	BOD ₅	calcul.	calculated according to graphs				calcul.	calcul.	calcul.	
10	%	mg/l	mg/l	mg/l	f-overload	f-strenght	f-temp	f-HRT %	%	%	mg/l	
11	24%	489	253	1.94	1.00	0.91	1.00	87	79%	81%	94	
12	1.06	<- COD/ BOD removal factor						COD/BOD removal factor >-			1.025	
13	dimensions of settler								ABR			
14	total COD removal rate	total BOD ₅ removal rate	BOD ₅ out	inner masonry measurements chosen acc. to required volume		sludge accum. rate	length of settler	length of settler	max. upflow velocity	number of upflow chambers	depth 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	85%	87%	42	2.00	1.50	0.0037	2.39	2.40	1.8	5	1.50	
18									1.4–2.0m/h			
19	dimensions of ABR							status and gp				
20	length of chambers should not exceed half depth		area of single upflow chamber	width of chambers		actual upflow velocity	width of downflow shaft	actual volume of baffled reactor	actual total HRT	org. load (BOD ₅)	biogas (ass: CH ₄ 70%; 50% dissolved)	
21	calcul.	chosen	calcul.	calcul.	chosen	calcul.	chosen	calcul.	calcul.	calcul.	calcul.	
22	m	m	m ²	m	m	m/h	m	m ³	h	kg/m ³ *d	m ³ /d	
23	0.75	0.75	1.16	1.54	2.00	1.39	0.25	15.00	14	1.63	3.37	
24								HRT reduced by 5% for sludge				

TIP: If removal rate is insufficient; increase number of upflow chambers to keep upflow velocity low.

Table 28
Spreadsheet for the calculation of anaerobic baffled reactor dimensions

Formulas of spreadsheet "ABR"

$$C5 = A5 / B5$$

$$F5 = D5 / E5$$

$$K5 = G5 / 0.6 \times \text{IF} (J5 < 1; J5 \times 0.3; \text{IF} (J5 < 3; (J5 - 1) \times 0.1/2 + 0.3; \text{IF} (J5 < 30; (J5 - 3) \times 0.15 / 27 + 0.4; 0.55)))$$

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

$$A11 = K5 \times A12$$

$$B11 = D5 \times (1 - K5)$$

$$C11 = E5 \times (1 - A11)$$

$$D11 = B11 / C11$$

$$E11 = \text{IF} (J23 < 8; 1; \text{IF} (J23 < 15; 1 - (J23 - 8) \times 0.18 / 7; 0.82 - (J23 - 15) \times 0.9 / 5))$$

The formula relates to Picture 10_13.

$$F11 = \text{IF} (B11 < 2000; B11 \times 0.17 / 2000 + 0.87; \text{IF} (B11 < 3000; (B11 - 2000) \times 0.02 / 1000 + 1.04; 1.06))$$

The formula relates to Picture 10_14.

$$G11 = \text{IF} (H5 < 20; (H5 - 10) \times 0.39 / 20 + 0.47; \text{IF} (H5 < 25; (H5 - 20) \times 0.14 / 5 + 0.86; \text{IF} (H5 < 30; (H5 - 25) \times 0.08 / 5 + 1; 1.1)))$$

The formula relates to Picture 10_17.

$$H11 = \text{IF} (I23 < 5; I23 \times 0.51 / 5; \text{IF} (I23 < 10; (I23 - 5) \times 0.31 / 5 + 0.51; \text{IF} (I23 < 20; (I23 - 10) \times 0.13 / 10 + 0.82; 0.95)))$$

$$I11 = E11 \times F11 \times G11 \times H11$$

The formula relates to Picture 10_12.

$$J11 = \text{IF} (J17 < 7; E11 \times F11 \times G11 \times H11 \times (J17 \times 0.04 + 0.82); E11 \times F11 \times G11 \times H11 \times 0.98)$$

The formula considers improved treatment by increasing the number of chambers and limiting the treatment efficiency to 98%.

$$K11 = (1 - J11) \times B11$$

$$A12 = \text{IF} (K5 < 0.5; 1.06; \text{IF} (K5 < 0.75; (K5 - 0.5) \times 0.065 / 0.25 + 1.06; \text{IF} (K5 < 0.85; 1.125 - (K5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula relates to Picture 10_3.

10 Designing DEWATS

$$K12 = \text{IF}(A17 < 0.5; 1.06; \text{IF}(A17 < 0.75; (A17 - 0.5) \times 0.065 / 0.25 + 1.06; \text{IF}(A17 < 0.85; 1.125 - (A17 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula relates to Picture 10_3.

$$A17 = 1 - K11 / D5$$

$$B17 = A17 \times K12$$

$$C17 = (1 - B17) \times E5$$

$$F17 = 0.005 \times \text{IF}(I5 < 36; 1 - I5 \times 0.014; \text{IF}(I5 < 120; 0.5 - (I5 - 36) \times 0.002; 1/3))$$

The formula relates to Picture 10_5.

$$G17 = \text{IF}(A11 > 0; \text{IF}(F17 \times (E5 - C11) / 1000 \times 30 \times I5 \times A5 + J5 \times C5 < 2 \times J5 \times C5; 2 \times J5 \times C5; F17 \times (E5 - C11) / 1000 \times 30 \times I5 \times A5 + J5 \times C5); 0) / D17 / E17$$

The formula considers that sludge volume is less than half of the total volume; a settler may be omitted.

$$A23 = K17 \times 0.5$$

$$C23 = C5 / I17$$

$$D23 = C23 / B23$$

$$F23 = C5 / B23 / E23$$

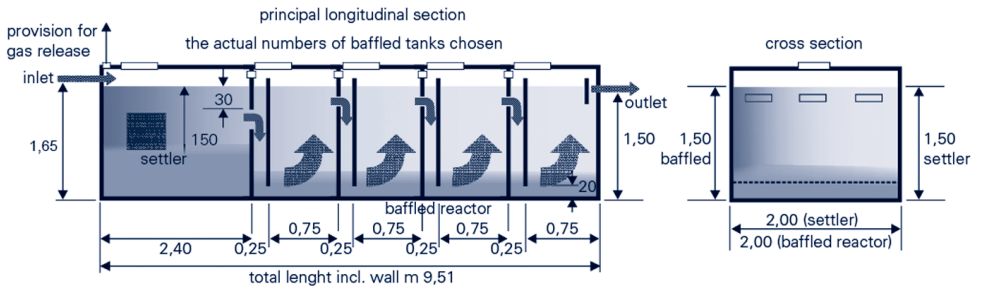
$$H23 = (G23 + B23) \times J17 \times K17 \times E23$$

$$I23 = H23 / (A5 / 24) / 105\%$$

$$J23 = B11 \times C5 \times 24 / H23 / 1000$$

$$K23 = (D5 - K11) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

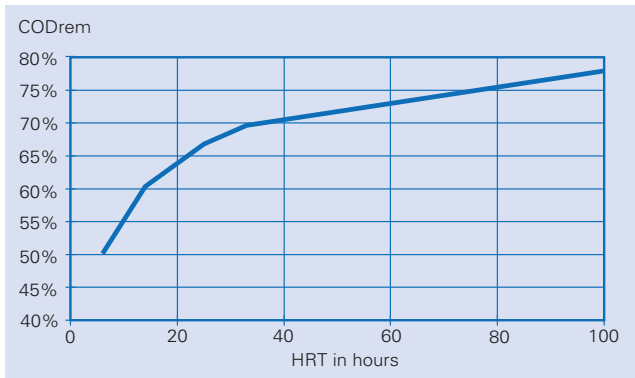
350l methane are produced from each kg COD removed.



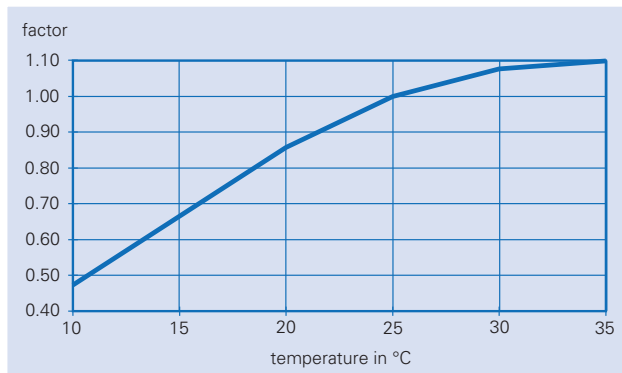
Picture 10_15
Illustration
spreadsheet
calculation of
ABR dimensions

10.2.7 Anaerobic filter

Volume of flow and pollution load are the basic entries for calculation. The “chosen” parameters for the anaerobic filter are the hydraulic retention time and desludging intervals. The calculation of performance is based on a curve, which describes the relation between hydraulic retention time and percentage of COD removal. The curve (Picture 10_16) is based on a COD of 1500mg/l at 25°C. The values are then multiplied by factors reflecting temperature (Picture 10_17), wastewater strength (Picture 10_18) and specific-filter surface (Picture 10_19).



Picture 10_16:
COD removal in
relation to HRT in
anaerobic filters

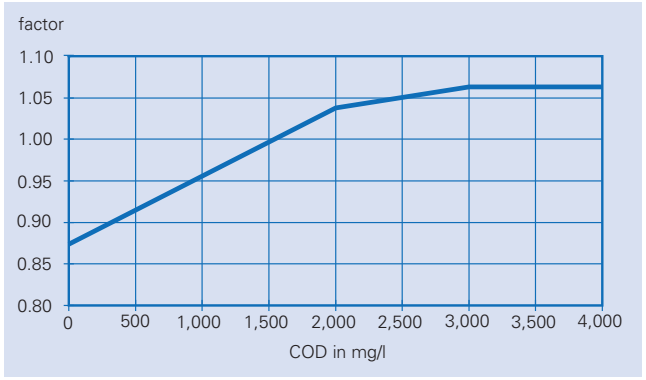


Picture 10_17:
COD removal in
relation to tempe-
rature in anaerobic
reactors

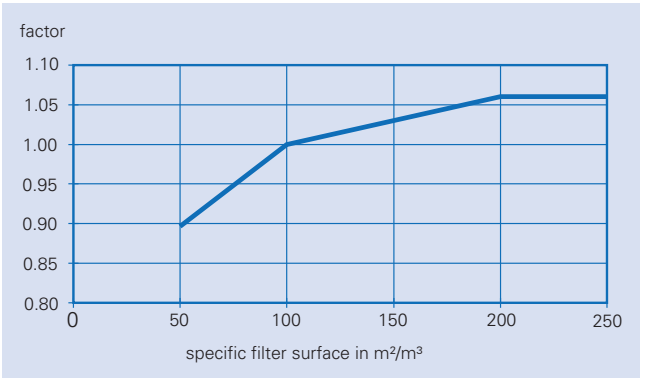
10 Designing DEWATS

The void space of the filter medium influences the digester volume required to provide sufficient hydraulic retention time. Gravel has approximately 35% void space, while specially manufactured plastic pieces may have over 90%. When filter height is increased together with total water depth, the impact of increased depth on HRT is less with gravel than with plastic pieces. While filter height remains the same, the distance from filter bottom to digester floor must be increased.

Picture 10_18:
COD removal relative to wastewater strength in anaerobic filters



Picture 10_19:
Spreadsheet for calculating anaerobic-filter dimensions



	A	B	C	D	E	F	G	H	I	J	K	L	
1	General spreadsheet for anaerobic filter (AF) with integrated septic tank (ST)												
2	daily waste water flow	time of most waste water flow	max. peak flow per hour	COD inflow	BOD ₅ inflow	SS _{settl./} COD ratio	lowest digester temperature	HRT in septic tank	de-sludging interval	COD-removal septic tank	BOD ₅ removal septic tank	BOD/ COD-removal factor	
3	given	given	calcul.	given	given	given	given	chosen	chosen	calcul.	calcul.	calcul.	
4	m ³ /day	h	m ³ /h	mg/l	mg/l	mg/l	°C	h	month	%	%	ratio	
5	25.0	12	2.08	633	333	0.42	25	2	36	25%	26%	1.06	
6	COD/BOD ₅ ->			1.90	0,35 - 0.45 (domestic)			2h			BOD _{rem} -> 1.06		
7	treatment data												
8	COD inflow in AF	BOD ₅ inflow into AF	specific surface of filter medium	voids in filter mass	HRT inside AF reactor	factors to calculate COD-removal rate of anaerobic filter				COD-removal rate (AF only)	COD outflow of AF	COD-removal rate of total system	
9	calcul.	calcul.	given	given	chosen	calculated according to graphs				calcul.	calcul.	calcul.	
10	mg/l	mg/l	m ² /m ³	%	h	f-temp	f-strength	f-surface	f-HRT	%	mg/l	%	
11	478	247	100	35%	30	1,00	0,91	1,00	69%	70	142	78%	
12			80 - 120	30 - 45	24 - 48 h								
13	dimensions of septic tank												
14	BOD/ COD removal factor	BOD ₅ rem. rate of total system	BOD ₅ outflow of AF	inner width of septic tank	min. water depth at inlet point	inner length of first chamber		length of second chamber		sludge accum.	volume incl. sludge	actual volume of septic tank	
15	calcul.	calcul.	calcul.	chosen	chosen	calcul.	chosen	calcul.	chosen	calcul.	requir.	calcul.	
16	ratio	%	mg/l	m	m	m	m	m	m	l/kg BOD	m ³	m ³	
17	1.10	85	49	1.75	2.25	1,69	1.70	0.85	0.85	0,00	10.00	10.04	
18	sludge l/g BODrem.												
19	dimension of an aerobic filter							bio gas production			check!		
20	volume of filter tanks	depth of filter tanks	length of each tank	number of filter tanks	width of filter tanks	space below perforated slabs	filter high (top 40cm below water-level)	out of septic tank	out of anaerobic filter	total	org. load on filter volume COD	max. up-flow velocity inside filter voids	
21	calcul.	chosen	calcul.	chosen	requir.	chosen	calcul.	assump.: 70% CH ₄ ; 50% dissolved			calcul.	calcul.	
22	m ³	m	m	No.	m	m	m	m ³ /d	m ³ /d	m ³ /d	kg/m ³ *d	m/h	
23	31.25	2.25	2.25	3	2.69	0.60	1.20	0.97	2.10	3.07	1.57	0.98	
24	max.!!											< 4.5	<2.0

Table 29:
Spreadsheet for calculating anaerobic-filter dimensions

Formulas of spreadsheet “anaerobic filter”

$$C5 = A5 / B5$$

$$J5 = F5 / 0.6 \times \text{IF} (H5 < 1; H5 \times 0.3; \text{IF} (H5 < 3; (H5 - 1) \times 0.1 / 2 + 0.3; \\ \text{IF}(H5 < 30; (H5 - 3) \times 0.15 / 27 + 0.4; 0.55)))$$

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

$$K5 = L5 \times J5$$

$$L5 = \text{IF} (J5 < 0.5; 1.06; \text{IF} (J5 < 0.75; (J5 - 0.5) \times 0.065 / 0.25 + 1.06; \\ \text{IF} (J5 < 0.85; 1.125 - (J5 - 0.75) \times 0.1/0.1; 1.025)))$$

The formula relates to Picture 10_3.

$$D6 = D5 / E5$$

$$A11 = D5 \times (1 - J5)$$

$$B11 = E5 \times (1 - K5)$$

$$F11 = \text{IF} (G5 < 20; (G5 - 10) \times 0.39 / 20 + 0.47; \text{IF}(G5 < 25; (G5 - 20) \times 0.14 / 5 + 0.86; \\ \text{IF} (G5 < 30; (G5 - 25) \times 0.08 / 5 + 1; 1.1)))$$

The formula relates to Picture 10_17.

$$G11 = \text{IF} (A11 < 2000; A11 \times 0.17 / 2000 + 0.87; \\ \text{IF} (A11 < 3000; (A11 - 2000) \times 0.02 / 1000 + 1.04; 1.06))$$

The formula relates to Picture 10_18.

$$H11 = \text{IF} (C11 < 100; (C11 - 50) \times 0.1 / 50 + 0.9; \text{IF} (C11 < 200; (C11 - 100) \times 0.06 / 100 + 1; 1.06))$$

The formula relates to Picture 10_19.

$$I11 = \text{IF} (E11 < 12; E11 \times 0.16 / 12 + 0.44; \text{IF} (E11 < 24; (E11 - 12) \times 0.07 / 12 + 0.6; \\ \text{IF} (E11 < 33; (E11 - 24) \times 0.03 / 9 + 0.67; \text{IF} (E11 < 100; (E11 - 33) \times 0.09 / 67 + 0.7; 0.78))))$$

The formula relates to Picture 10_16.

$J11 = \text{IF} (F11 \times G11 \times H11 \times I11 \times (1 + (D23 \times 0.04)) < 0.98; F11 \times G11 \times H11 \times I11 \times (1 + (D23 \times 0.04)); 0.98)$

The formula considers improved treatment by increasing the number of chambers and limiting the treatment efficiency to 98%.

$K11 = A11 \times (1 - J11)$

$L11 = (1 - K11 / D5)$

$A17 = \text{IF} (L11 < 0.5; 1.06 ; \text{IF} (L11 < 0.75; (L11 - 0.5) \times 0.065 / 0.25 + 1.06; \text{IF}(L11 < 0.85; 1.125 - (L11 - 0.75) \times 0.1 / 0.1; 1.025)))$

The formula relates to Picture 10_3.

$B17 = L11 \times A17$

$C17 = (1 - B17) \times E5$

$F17 = 2/3 \times K17 / D17 / E17$

$H17 = F17 / 2$

$J17 = 0.005 \times \text{IF} (I5 < 36; 1 - I5 \times 0.014; \text{IF} (I5 < 120; 0.5 - (I5 - 36) \times 0.002; 1/3))$

The formula relates to Picture 10_5.

$K17 = \text{IF} (\text{OR} (K5 > 0; J5 > 0); \text{IF}(J17 \times (E5 - B11) / 1000 \times I5 \times 30 \times A5 + H5 \times C5 < 2 \times H5 \times C5; 2 \times H5 \times C5; J17 \times (E5 - B11) / 1000 \times I5 \times 30 \times A5 + H5 \times C5); 0)$

The formula considers that the sludge volume is less than half of the total volume; a settler may be omitted.

10 Designing DEWATS

$$L17 = (G17 + I17) \times E17 \times D17$$

$$A23 = E11 \times A5 / 24$$

$$C23 = B23$$

$$E23 = A23 / D23 / ((B23 \times 0.25) + (C23 \times (B23 - G23 \times (1 - D11))))$$

$$G23 = B23 - F23 - 0.4 - 0.05$$

$$H23 = (D5 - A11) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

350l methane are produced from each kg COD removed.

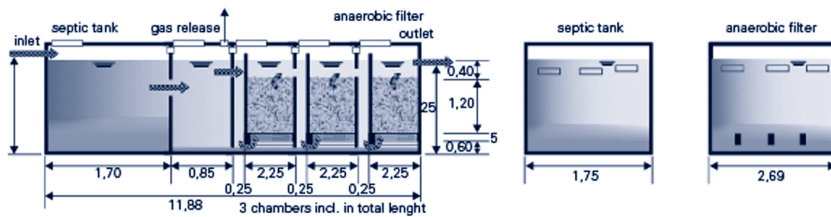
$$I23 = (A11 - K11) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

350l methane are produced from each kg COD removed.

$$J23 = \text{SUM} (H23 : I23)$$

$$K23 = A11 \times A5 / 1000 / (G23 \times E23 \times C23 \times D11 \times D23)$$

$$L23 = C5 / (E23 \times C23 \times D11)$$

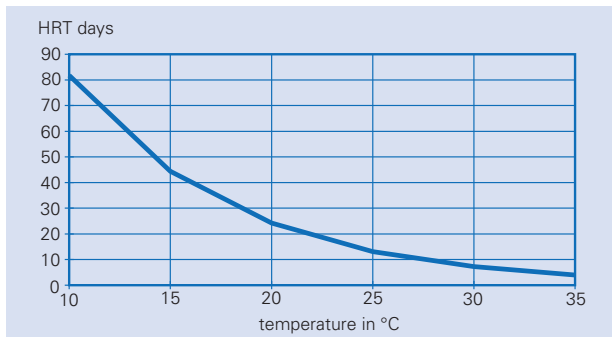


Picture 10_20:
Illustration to
spreadsheet for
calculating anaerobic-
filter

10.2.8 Horizontal gravel filter

Average flow and pollution load are the basic entries for calculation. The “chosen” parameter for the design of gravel filters is the desired effluent quality (BOD_{out}, cell E5). The hydraulic retention time and temperature have the greatest influence on treatment performance. The HRT depends on the desired BOD-removal rate (Picture 10_22); the curve is based on 25°C and 35% pore space. The pore space inside the filter defines the “real” HRT, also influenced by the type and number of plants chosen. Further influencing factors are close to 1.0; the information needed to define these factors probably not available at the site anyway.

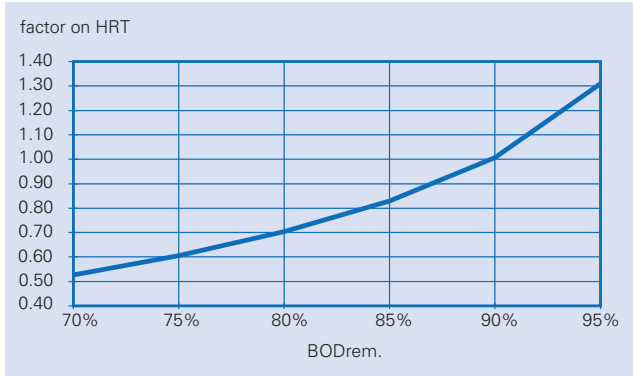
In practice, the limiting factors are the organic load and the hydraulic load. The limit for hydraulic loading is approximately 100l/m² or 0.1m, although this value can be much higher when using coarse-filter media with guaranteed conductivity. A horizontal filter should not receive more than 10g BOD/(m²×d) because oxygen supply via the surface is limited; this value is only half of the limit for aerobic ponds. This is because a gravel filter works more like a plug flow system; the organic load is much higher in the front section compared to the rear, while oxygen supply is also inferior in the lower part. As a result, the cross-sectional area at the inflow side is influenced by organic loading (cell E12).



Picture 10_21:
HRT relative to temperature in gravel filters, based on 90% BOD-removal

10 Designing DEWATS

Picture 10_22:
Influence of desired
BOD removal rates
on HRT of gravel
filters, based on
35% pore space at
25°C



Formulas of spreadsheet “gravel filter”

$$D5 = B5 / C5$$

$$F5 = 1 - E5 / C5$$

$$G5 = F5 / G6$$

$$H5 = B5 \times (1 - G5)$$

$$J5 = \text{IF}(F5 < 0.4; (F5 \times 0.22) / 0.4); \text{IF}(F5 < 0.75; (F5 - 0.4) \times 31 / 35 + 0.22; \\ \text{IF}(F5 < 0.8; (F5 - 0.75) \times 9.5 / 5 + 0.605; \text{IF}(F5 < 0.85; (F5 - 0.8) \times 12.5 / 5 + 0.7; \\ \text{IF}(F5 < 0.9; (F5 - 0.85) \times 17.5 / 5 + 0.825; (F5 - 0.9) \times 30 / 5 + 1))))$$

The formula refers to Picture 10_22.

$$K5 = J5 \times \text{IF}(I5 < 15; 82 - (I5 - 10) \times 37 / 5; \text{IF}(I5 < 20; 45 - (I5 - 15) \times 31 / 5; \\ \text{IF}(I5 < 25; 24 - (I5 - 20) \times 11 / 5; \text{IF}(I5 < 30; 13 - (I5 - 25) \times 6 / 5; 7))))$$

The formula refers to Picture 10_21.

$$G6 = \text{IF}(F5 < 0.5; 1.06; \text{IF}(F5 < 0.75; (F5 - 0.5) \times 0.065 / 0.25 + 1.06; \\ \text{IF}(F5 < 0.85; 1.125 - (F5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula refers to Picture 10_3.

$$L6 = L5 / 86400$$

$$A11 = K5 \times 35\%$$

$$D11 = \text{IF} (A5 / L5 / B11 < A5 \times C5 / E12; A5 \times C5 / E12; A5 / L5 / B11)$$

The formula compares hydraulic load to maximum organic load in cell E12.

$$E11 = D11 / C11$$

$$F11 = \text{IF} (A5 \times C5 / L12 > A5 \times K5 / C11; A5 \times C5 / L12; A5 \times K5 / C11)$$

The formula compares permitted hydraulic load with organic load in cell L12.

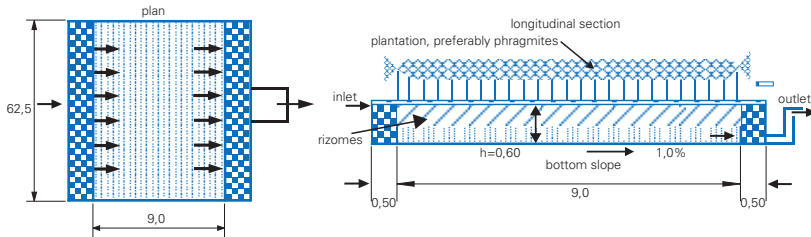
$$G11 = F11 / E11$$

$$J11 = H11 \times I11$$

$$K11 = A5 / J11$$

$$L11 = K11 \times C5$$

$$H12 = E11$$



Picture 10_23:
Illustration to
spreadsheet for
calculating
dimensions
horizontal gravel
filter

10 Designing DEWATS

	A	B	C	D	E	F	G	H	I	J	K	L	
1	General spreadsheet for planted gravel filter, input and treatment data												
2	average flow	COD in	BOD ₅ in	COD/BOD ratio	outflow BOD ₅	BOD ₅ removal rate	COD removal	COD out	min. annual Temp.	HRT factor acc. to k ₂₀ =0.3	HRT	hydraulic conduct. Ks	
3	given	given	given	calcul.	wanted	calcul.	calcul.	calcul.	given	calcul. via graph	calcul.	given	
4	m ³ /d	mg/l	mg/l	mg/l	mg/l	%	%	mg/l	°C		days	m/d	
5	26	410	215	1.91	30	86%	84	66	25	0.86	11.20	200	
6			COD/ BOD rem. factor via graph ->				1.025				Ks in m/s ->		2.31E-0.3
7	dimensions									results			
8	HRT in 35% pore space	bottom slope	depth of filter at inlet	cross section area	width of filter basin	surface area required	length of filter basin	chosen width	length chosen	actual surface area chosen	hydr. load on chosen surface	org. load on chosen surface	
9	calcul.	chosen	chosen	calcul.	calcul.	calcul.	calcul.	chosen	chosen	check!	calcul.	calcul.	
10	days	%	m	m ²	m	m ²	m	m	m	m ²	m/d	g/m ² BOD	
11	3.92	1.0%	0.60	37.27	62.1	559	9.0	62.5	9.0	563	0.046	9.9	
	^ information only		0.3 - 0.6 m	max. BOD ₅ 150 g/m ²			always -> 62.1		max. loads =>		0.100	10	

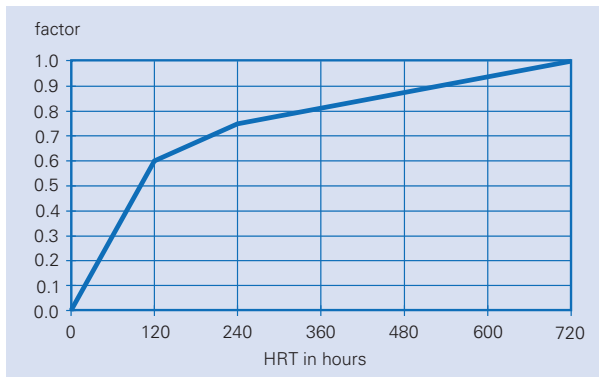
Table 30: Spreadsheet for calculating dimensions horizontal gravel filters

10.2.9 Anaerobic pond

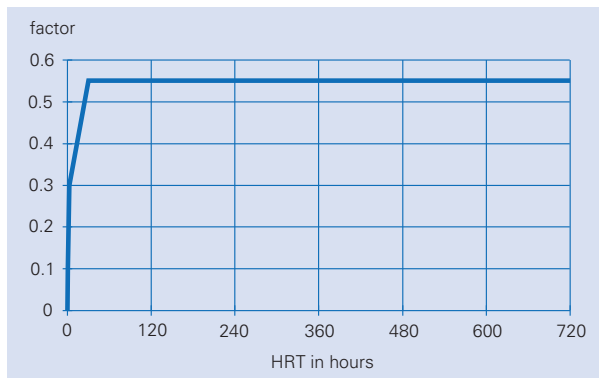
Anaerobic ponds should be built for sedimentation purposes only, as highly loaded ponds with very short retention times and heavy scum formation on the surface – or as relatively low-loaded ponds which are almost odourless because of neutral pH values. The spreadsheet may be used for all three categories. The hydraulic retention time is, therefore, the “chosen” parameter. Ponds with long retention times (low organic loading rates) may be divided into several ponds in series. For ponds with short retention times, the front section can be separated to support development of scum. The choice of HRT strongly influences the organic load of the effluent. Ambient temperature is important and an excessively high temperature should not be chosen for want of smaller ponds. It is assumed that temperature has no influence on COD removal at short retention times of less than 30 hours.

Cell G11 should be observed and compared with F11 when the pond is near residential houses.

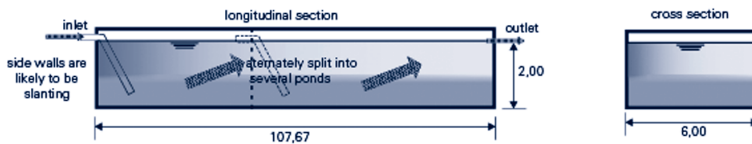
The biogas potential is also calculated to decide whether a closed anaerobic tank with biogas collection should be built instead.



Picture 10_24:
Influence of HRT on COD removal of non-settled solids in anaerobic ponds



Picture 10_25:
Influence of HRT on COD removal of settled solids in anaerobic ponds



Picture 10_26:
Illustration to spreadsheet for calculating dimensions of anaerobic ponds (figures of Table 31)

Formulas of spreadsheet “anaerobic and sedimentation pond”

$$D5 = B5 / C5$$

H5 = IF (E5 < 1; F5 / 0.6 × (0.3 × E5); IF (E5 < 3; F5 / 0.6 × (E5 - 1) × 0.1 / 2;
 IF (E5 < 30; F5 / 0.6 × ((E5 - 3) × 0.15 / 27 + 0.4);
 IF(E5 < 120; E5 × 0.5 × (1 - 0.55 × F5 / 0.6) / 120 + 0.55 × F5 / 0.6;
 IF (E5 < 240; (E5 - 120) × 0.25 × (1 - 0.55 × F5 / 0.6) / 120 + 0.5 × (1 - 0.55 × F5 / 0.6) + 0.55 × F5 / 0.6;
 IF (E5 < 480; (E5 - 240) × 0.19 × (1 - 0.55 × F5 / 0.6) / 240 + 0.55 × F5 / 0.6 + 0.75 × (10.55 × F5 / 0.6);
 (E5 - 480) × 0.06 × (1 - 0.55 × F5 / 0.6) / 240 + 0.55 × F5 / 0.6 + 0.94 × (1 - 0.55 × F5 / 0.6))))))

The formula refers to Picture 10_24 and Picture 10_25. Below 30 hours HRT, COD removal is influenced by settling properties (F5/0.6); longer retention times also influence non-settled solids.

I5 = IF (E5 < 30; 1; IF (G5 < 20; (G5 - 10) × 0.39 / 20 + 0.47;
 IF(G5 < 25; (G5 - 20) × 0.14 / 5 + 0.86; IF(G5 < 30; (G5 - 25) × 0.08 / 5 + 1; 1.1))))

The formula refers to Picture 10_17. COD removal by sedimentation (HRT <30 hours) is not influenced by temperature.

J5 = IF (E5 < 24; 1; IF (F17 = 1; 1; IF (F17 = 2; 1.08; IF (F17 = 3; 1.12; 1.13))))
 A11 = IF (H5 × I5 × J5 < 0.98; H5 × I5 × J5; 0.98)
 B11 = IF (A11 < 0.5; 1.06; IF (A11 < 0.75; (A11 - 0.5) × 0.065 / 0.25 + 1.06;
 IF (A11 < 0.85; 1.125 - (A11 - 0.75) × 0.1 / 0.1; 1.025))

The formula refers to Picture 10_3.

$$C11 = A11 / B11$$

$$D11 = B5 - (C11 \times B5)$$

$$E11 = C5 - (A11 \times C5)$$

$$F11 = A5 \times C5 / (A17 + J11)$$

$$G11 = 75\% \times \text{IF}(G5 < 10; 100; \text{IF}(G5 < 20; G5 \times 20 - 100; \text{IF}(G5 < 25; G5 \times 10 + 100; 350)))$$

The formula refers to the rule of thumb by Mara, reflected in Table 22.

$$I11 = 0.005 \times \text{IF}(H11 < 36; 1 - H11 \times 0.014; \text{IF}(H11 < 120; 0.5 - (H11 - 36) \times 0.002; 1/3))$$

The formula refers to Picture 10_5.

$$J11 = 30 \times A5 \times (C5 - E11) \times I11 \times H11 / 1000$$

$$A17 = A5 / 24 \times E5$$

$$C17 = (J11 + A17) / B17$$

$$E17 = C17 / D17$$

$$G17 = E17 / F17$$

$$J17 = A5 \times (B5 - D11) \times 0.35 / 1000 / H17 \times I17$$

The formula assumes 350l methane production per kg COD removed.

10 Designing DEWATS

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for anaerobic and sedimentation ponds									
2	daily flow	COD in	BOD ₅ in	COD/ BOD ₅	HRT	settleable SS/COD ratio	ambient temp. °C	BOD ₅ removal factors		
3	given	given	given	calcul.	chosen	given	given	calculated acc. to graphs		
4	m ³ /day	mg/l	mg/l	ratio	h	mg/l	°C	f-HRT	f-temp	f-number
5	260	2000	850	2.35	72	0.42	25	57%	100%	100 %
6	domestic -> 0.35 - 0.45									
7	treatment data									
8	BOD ₅ removal rate	BOD/COD removal	COD removal rate	COD out	BOD ₅ out	org. load BOD ₅ on total vol.	odourless limit of org. load	deslud- ging interval	sludge accum.	sludge volume
9	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	chosen	calcul.	calcul.
10	%	factor	%	mg/l	mg/l	g/m ³ *d	g/m ³ *d	months	l/g BOD	m ³
11	57	1.08	53	943	366	171	263	60	0.0023	512
12										
13	dimensions						biogas potential			
14	water volume	depth of pond	total area of pond	width of ponds	total length of pond	number of ponds	length of each pond if equal	methan content	non- dissolv. methane prod.	potential biogas product.
15	calcul.	chosen	required	chosen	calcul.	chosen	calcul.	assumed	assumed	calcul.
16	m ³	m	m ²	m	m	number	m	ratio	ratio	m ³ /d
17	780	2.0	646	6.00	107.67	1	107.67	70%	50%	68.67
18										

Table 31:

Spreadsheet for calculating dimensions for anaerobic sedimentation pond (with **short HRT**).

In the example, the pond is extremely long and narrow to facilitate the development of scum in the highly loaded front portion. A baffle wall in the front third supports the effect.

If the pond was squarer, there would be no highly loaded areas, but also no sealing-scum layer. Both options are possible.

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for anaerobic and sedimentation ponds									
2	daily flow	COD in	BOD ₅ in	COD/ BOD ₅	HRT	settleable SS/COD ratio	ambient temp. °C	BOD ₅ removal factors		
3	given	given	given	calcul.	chosen	given	given	calculated acc. to graphs		
4	m ³ /day	mg/l	mg/l	ratio	h	mg/l	°C	f-HRT	f-temp	f-number
5	260	2000	850	2.35	480	0.42	25	92%	100%	108 %
6	domestic -> 0.35 - 0.45									
7	treatment data									
8	BOD ₅ removal rate	BOD/COD removal	COD removal rate	COD out	BOD ₅ out	org. load BOD ₅ on total vol.	odourless limit of org. load	desludging interval	sludge accum.	sludge volume
9	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	chosen	calcul.	calcul.
10	%	factor	%	mg/l	mg/l	g/m ³ *d	g/m ³ *d	months	l/g BOD	m ³
11	98%	1.03	96	88	17	36	263	60	0.0023	881
12										
13	dimensions							biogas potential		
14	water volume	depth of pond	total area of pond	width of ponds	total length of pond	number of ponds	length of each pond if equal	methane content	non- dissolv. methane prod.	potential biogas product.
15	calcul.	chosen	required	chosen	calcul.	chosen	calcul.	assumed	assumed	calcul.
16	m ³	m	m ²	m	m	number	m	ratio	ratio	m ³ /d
17	5.200	2.5	2.432	20.00	212.62	2	60.81	70%	50%	124.29
18										

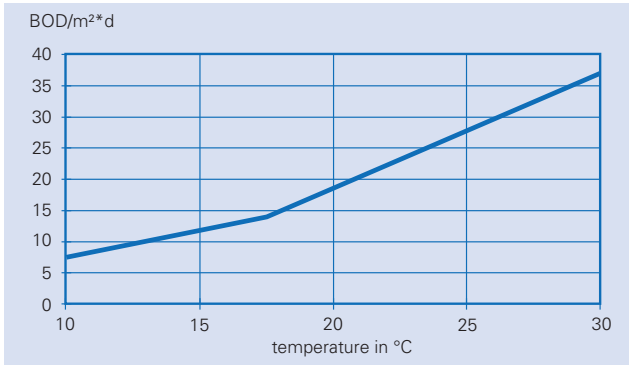
Table 32:
Spreadsheet is the same as Table 31,
but is used to calculate dimensions of
anaerobic-fermentation pond with long HRT

10.2.10 Aerobic pond

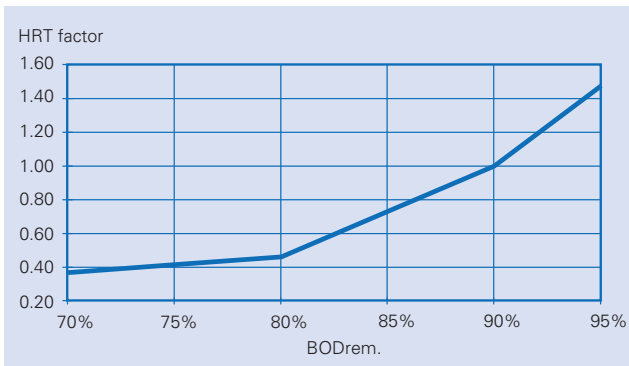
Volume of flow and pollution load are the basic entries for calculation. Key “chosen” parameter is the desired effluent quality (BOD_{out}, cell F5). The HRT required to achieve a certain BOD-removal rate depends on the temperature. The curve (Picture 10_29) shows this relationship for a 90% BOD-removal rate.

Picture 10_28 shows how HRT changes with altering treatment performance, defined as BOD-removal rate at 25°C.

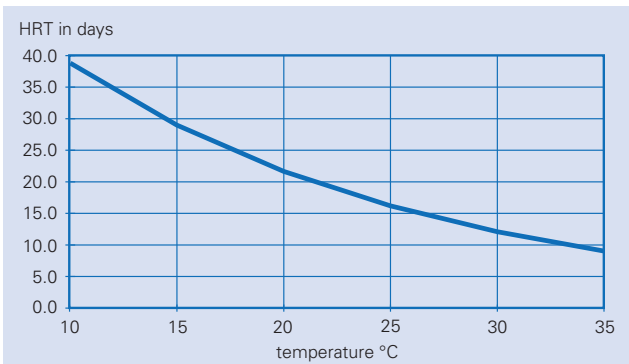
Sludge production may be high in aerobic ponds, due to dead algae sinking to the bottom. According to Suwarnarat 1.44g TS can be expected from 1g BOD₅. Assuming a 20% total-solids content in compressed bottom sludge and a 50% reduction of volume due to anaerobic stabilisation, almost 4mm of bottom sludge per gram BOD₅/m²×d organic load would accumulate during one year. At loading rates of 15g BOD₅/m²×d, approximately 6cm of sludge is expected per year. Since the surface area plays the major role for dimensioning, the sludge volume has been neglected in the calculation.



Picture 10_27:
Maximum organic load in relation to temperature for aerobic-facultative oxidation ponds; the influence of sunshine hours has been included



Picture 10_28
Influence of desired BOD removal on HRT in aerobic-facultative ponds, based on 25°C



Picture 10_29:
Influence of temperature on BOD removal in aerobic-facultative ponds, based on desired BOD removal of 90%

Formulas of spreadsheet for calculation of “aerobic pond”

$$D5 = B5 / C5$$

$$G5 = 1 - (F5 / C5)$$

$$H5 = G5 \times 1 / \text{IF} (G5 < 0.5; 1.06; \text{IF} (G5 < 0.75; (G5 - 0.5) \times 0.065 / 0.25 + 1.06; \text{IF} (G5 < 0.85; 1.125 - (G5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

The formula refers to [Picture 10_3](#).

$$I5 = B5 - H5 \times B5$$

$$J5 = \text{IF} (G5 < 0.8; (G5 - 0.7) \times 0.05 / 0.1 + 0.37; \text{IF} (G5 < 0.9; (G5 - 0.8) \times 0.54 / 0.1 + 0.46; (G5 - 0.9) \times 0.48 / 0.05 + 1))$$

The formula refers to [Picture 10_28](#).

$$K5 = J5 \times \text{IF} (E5 < 15; 39 - (E5 - 10) \times 10 / 5; \text{IF} (E5 < 20; 29 - (E5 - 15) \times 7 / 5; \text{IF} (E5 < 25; 22 - (E5 - 20) \times 6 / 5; \text{IF} (E5 < 30; 16 - (E5 - 25) \times 4 / 5; 12)))$$

The formula refers to [Picture 10_29](#).

$$A11 = 30 \times A5 \times (C5 - F5) \times A12 \times L5 / 1000$$

$$B11 = \text{IF} (E5 < 17; (E5 - 10) \times 7.5 / 7.5 + 7.5; (E5 - 17) \times 23 / 13 + 14)$$

The formula refers to [Picture 10_27](#).

$$C11 = A5 \times C5 / (F11 \times G11 \times H11)$$

$$E11 = \text{IF} (\text{IF} (F11 = 1; 1; \text{IF} (F11 = 2; 1 / 1.1; \text{IF} (F11 = 3; 1 / 1.14; 1 / 1.16))) \times (A11 + A5 \times K5) / D11 > C5 \times A5 / B11; \text{IF} (F11 = 1; 1; \text{IF} (F11 = 2; 1 / 1.1; \text{IF} (F11 = 3; 1 / 1; 14; 1/1.16))) \times (A11 + A5 \times K5) / D11; C5 \times A5 / B11)$$

The first part of the formula considers the influence of dividing the total pond area into several ponds. The second part compares permitted organic load with calculated HRT.

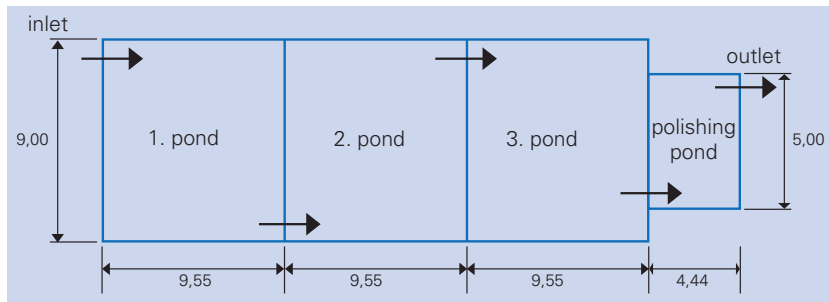
$$H11 = E11 / F11 / G11$$

$$I11 = A5 / D11$$

$$K11 = I11 / J11$$

$$L11 = I11 + F11 \times E11$$

$$A12 = 0.0075 \times \text{IF} (L5 < 36; 1 - L5 \times 0.014; \text{IF} (L5 < 120; 0.5 - (L5 - 36) \times 0.002; 1 / 3))$$



Picture 10_30: Illustration to spreadsheet for the calculation of dimensions of aerobic-facultative ponds

	A	B	C	D	E	F	G	H	I	J	K	L
1	General spreadsheet on aerobic-facultative ponds, input and treatment data											
2	daily flow	COD in	BOD ₅ in	COD/BOD ₅	min. water temp.	BOD ₅ out (wanted)	BOD removal	COD removal	COD out	BOD ₅ removal factor for HRT	HRT	de-sludging interval
3	given	given	calcul.	calcul.	given	chosen	calcul.	calcul.	calcul.	calcul.	calcul.	chosen
4	m ³ /d	mg/l	mg/l	mg/l	°C	mg/l	%	%	mg/l	%	days	months
5	20	500	170	2.94	20	30	82	78	108	0.59	12.9	12
6	0.05 - 1.0											
7	dimensions of aerobic-facultative ponds								polishing pond 1 day HRT			total
8	accum. sludge volume	permit org. load BOD ₅	actual org. load (BOD ₅)	depth of ponds	total pond area	number of main ponds	width of ponds	length of each ponds	area of polish pond	width of polish pond	length of polish pond	area of all ponds
9	calcul.	calcul.	calcul.	chosen	calcul.	chosen	chosen	calcul.	calcul.	chosen	calcul.	calcul.
10	m ³	g/m ² *d	g/m ² *d	m	m ²	No	m	m	m ²	m	m	m ²
11	6.3	19.3	13.2	0.9	258	3	9.00	9.55	22	5.00	4.44	796
12	0.00624	l/g BOD	0.9 - 1.2 m									

Table 33: Spreadsheet for calculating dimensions of aerobic-facultative ponds

10.3 Spreadsheets for costings

General background

This chapter helps the reader to produce his or her own tool for calculating annual DEWATS costs. Since economic calculations always incorporate the unknown future, they are never exact. However, it would be reckless to invest in DEWATS without prior economic evaluation. The spreadsheet helps one to calculate annual expenditure, including capital costs, operational costs and maintenance. Expected income from biogas or the sale of sludge for fertiliser may be deducted. To use the spreadsheet, the following data must be collected:

- planning costs, including transport to site and laboratory costs for initial wastewater analysis
- investment costs of buildings, site work and equipment
- assumed maintenance and operating costs
- rate of interest (minus inflation rate)
- wastewater data to calculate possible benefits – and to compare cost per amount of treated wastewater

Formulas of spreadsheet “annual costs of DEWATS”

$$D5 = \text{SUM} (A5 : C5)$$

$$I5 = \text{SUM} (D5 : H5)$$

$$J5 = \text{SUM} (G9 : K9) + E13 - J13$$

$$K5 = \text{SUM} (H9 : K9) + E13 - J13$$

$$F9 = 1 + E9$$

$$G9 = E5 \times E9$$

$$H9 = (F5 + D5) \times (\text{POWER} (F9; 20)) \times (F9 - 1) / (\text{POWER} (F9; 20) - 1)$$

This and the following formulas are financial standard operations; the mathematical expression is:

$$I9 = G5 \times (\text{POWER} (F9; 10)) \times (F9 - 1) / (\text{POWER} (F9; 10) - 1)$$

The mathematical expression is:

$$J9 = H5 \times (\text{POWER} (F9; 6)) \times (F9 - 1) / (\text{POWER} (F9; 6) - 1)$$

The mathematical expression is:

$$K9 = \text{SUM} (G9 : J9) + E13 - J13$$

$$E13 = A13 + B13 + C13 + D13$$

$$F13 = A9 \times (B9 - D9) \times 0.35 \times 0.5 / 0.7 / 1000$$

The formula assumes 350l produced biogas per kg COD removed.

$$H13 = F13 \times 70\% \times G13 \times 0.85 \times 360$$

$$J13 = H13 + I13$$

10 Designing DEWATS

1	Calculating of annual costs of DEWATS										
2	planning and site supervision cost				investment cost					total annual cost	
	A	B	C	D	E	F	G	H	I	J	K
3	salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost includ. overheads and acquisition	cost of plot incl. site preparation	main structures of 20 years' durability	secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)	total annual cost (including land)	total annual cost (excluding land)
4	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.
5	1,200	650	500	2,350	150,000	295,000	9,000	3,000	459,350	74,359	62,359
6	wastewater data				annual capital costs						
7	daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor $q=1+i$	on investment for land	on main structures of 20 years' lifetime (incl. planning fees)	on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs
8	m ³ /d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c./year	l.c./year	l.c./year	l.c./year
9	20	3,000	2	450	8%	1.08	12,000	30,286	1,341	649	37,179
10	operational cost					income from biogas and other sources					explanat.
11	cost of personal for operation, mainten. and repair	cost of material for operation, mainten. and repair	cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost	daily biogas production (70% CH ₄ , 50% dissolved)	price 1 litre of kerosene (1m ³ CH ₄ =0.85 l kerosene)	annual income from biogas p.a.	other annual income or savings (e.g. fertilizer, fees)	total income per annum	<i>l.c. = local currency; mg/l = g/m³</i>
12	l.c./year	l.c./year	l.c./year	l.c./year	l.c./year	m ³ /d	l.c./litre	l.c./year	l.c./year	l.c./year	
13	100	100	50	0	250	12.75	2.69	7,347	0	7,347	

Table 34: Spreadsheet for the economic calculation of DEWATS (based on annual costs).

Viability of using biogas

Whether using biogas is economically viable depends on the additional investments to facilitate storage, transport and utilisation of biogas – and, if these costs can be recovered by the income generated by biogas production within a reasonable time. The payback period is considered to be an adequate indicator of viability.

Formulas of spreadsheet “viability of biogas”

$$B4 = 6.5\% \times A4$$

For rough calculation, it is assumed that additional construction costs are 6.5% of original costs, which includes investment for making the reactor roof gas-tight, providing additional volume for gas storage, and for gas distribution and supply pipes.

$$D4 = 50\% \times C4$$

To guarantee permanent gas supply, additional care must be taken at the site; it is assumed that operational costs are 50% higher than without biogas use.

$$F4 = B4 / (E4 - D4)$$

Negative values show that costs will never be recovered.

	A	B	C	D	E	F
1	Economic viability of using biogas					
2	investment cost without use of biogas	additional constr. cost to facilitate use of biogas	operational cost without use of biogas	additional operational cost to use biogas	income from biogas	pay back period of additional cost
3	l.c.	l.c.	l.c./year	l.c./year	l.c./year	years
4	307,000	19,955	250	125	3,650	5.7

Table 35:
Spreadsheet for calculating the viability of necessary measures to facilitate biogas utilisation

10.4 Using spreadsheets without a computer

Not everybody uses a computer; some may not even have access to one. But, computer formulas may also be useful to those who usually work with a pocket calculator. The following explanations are presented for them. The calculation for the septic tank (see Table 36) is a good example:

A computer table is made up of cells. The location of each cell within the table is described by columns A.....X, AA...AX, etc. and rows 1.....>1000. Each cell within the table, therefore, has an exact address. For example, the first cell in the top left corner has the address A1 (column A, row 1). In the table below, cell J10 reads m^3/d and cell D5 reads 633. Cell I11 reads 23.25; this figure is the result of a formula hidden "under" it. On the computer, the formula appears in the headline every time one clicks on the cell. These formulas can also be applied without a computer, in connection with the various graphs. One must realise, however, that the computer writing differs from normal mathematical writing in some points: for example, $4/(3 \times 2)$ is written as = 4/3/2 on the computer, and $4 \times 2/3$ may be written either $4 * 2/3$ or $4/3 * 2$.

	A	B	C	D	E	F	G	H	I	J	
1	General spreadsheet for septic tank, input and treatment data										
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD ₅ inflow	HRT inside tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD ₅ outflow	
3	given	given	calcul.	given	given	chosen	given	calcul.	calcul.	calcul.	
4	m ³ /day	h	m ³ /h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l	
5	13.0	12	1.08	633	333	18	0.42	35	411	209	
6	COD/BOD ₅ ->				1.90	12 - 24	0.35 - 0.45 domestic		BOD rem. ->		1.06
7	dimensions of septic tank										
8	desludging interval	inner width of septic tank	min. water depth at outlet point	inner length of first chamber		length of second chamber		volume incl. sludge	actual volume of septic tank	biogas 70% CH ₄ 50% dissolved	
9	chosen	chosen	chosen	requir.	chosen	requir.	chosen	requir.	check	calcul.	
10	months	m	m	m	m	m	m	m ³	m ³	m ³ /d	
11	12	2.50	2.00	3.13	3.10	1.56	1.55	23.46	23.25	0.72	
12	sludge l/g BOD rem.							0.0042			

Table 36:
Sample spreadsheet used to help understand computer formulas

10 Designing DEWATS

Cell A5 and all other bold written figures contain information to be collected and do not comprise formulas. The cells with hidden formulas are these:

$$C5 = A5 / B5$$

Meaning: $13.0 \text{ [m}^3\text{/d]} / 12 \text{ [hours]} = 1.08 \text{ [m}^3\text{/hours]}$

$$H5 = G5 / 0.6 \times \text{IF} (F5 < 1; F5 \times 0.3; \text{IF} (F5 < 3; (F5 - 1) \times 0.1 / 2 + 0.3; \text{IF} (F5 < 30; (F5 - 3) \times 0.15 / 27 + 0.4; 0.55)))$$

Meaning: $(0.42 \text{ [mg/l]} / \text{mg/l}) / 0.6$ [a given factor found by experience] multiplied by the value taken from Picture 10_6 at 18 hours HRT (shown in cell F5).

The calculation is, therefore:

$$(0.42 / 0.6) \times 0.495 = 0.35 = 35\% \text{ (which is shown in cell H5)}$$

$$I5 = (1 - H5) \times D5 \\ (1 - 0.35) \times 633 = 411 \text{ (shown in cell I5)}$$

$$J5 = (1 - H5 \times J6) \times E5 \\ (1 - 0.35 \times 1.06) \times 333$$

$$E6 = D5 / E5 \\ 633 / 333 = 1.90$$

$$J6 = \text{IF} (H5 < 0.5; 1.06; \text{IF} (H5 < 0.75; (H5 - 0.5) \times 0.065 / 0.25 + 1.06; \text{IF} (H5 < 0.85; 1.125 - (H5 - 0.75) \times 0.1 / 0.1; 1.025)))$$

This formula refers to Picture 10_3. Since cell H5 (the removal rate) is 35%, the value of cell J6 is found in the graph and equals 1.06.

$$D11 = 2/3 \times H11 / B11 / C11$$

$$((2/3) \times 23.46) / (2.50 \times 2.00) = 3.13$$

$$F11 = D11 / 2$$

$$3.13 / 2 = 1.56$$

$$H11 = \text{IF}(H12 \times (E5 - J5) / 1000 \times A11 \times 30 \times A5 + C5 \times F5 < 2 \times A5 \times F5 / 24; 2 \times A5 \times F5 / 24; H12 \times (E5 - J5) / 1000 \times A11 \times 30 \times A5 + C5 \times F5) + 0.2 \times B11 \times E11$$

The formula refers via cell H12 to Picture 10_5; cell H12 must be calculated first. The formula H11 states that the total volume must be at least twice the sludge volume. One has to check whether the total volume must be calculated via the hydraulic retention time or via the double sludge volume.

The total volume equals the sludge volume, which is $0.0042 \times (333 - 209) \times 12 \times 30$ [days/month] $\times 13.0 / 1000$, plus the volume of water, which is $1.08 \times 18 = 21.88\text{m}^3$. This is compared to $2 \times 13.0 \times 18 / 24$ [hours/day], which equals 19.50m^3 . Since 21.88 is the larger of the two, it must be used. Finally, the volume of 20cm of scum must be added, which is $0.2 \times 2.50 \times 3.10 = 1.55$. The total volume is $21.88 + 1.55 = 23.43$ (the computer is slightly more exact and states 23.46m^3 in cell H11).

$$I11 = (E11 + G11) \times C11 \times B11$$

$$(3.10 + 1.55) \times 2.00 \times 2.50 = 23.25\text{m}^3$$

$$J11 = (D5 - I5) \times A5 \times 0.35 / 1000 / 0.7 \times 0.5$$

$$(633 - 411) \times 13.0 \times 0.35 \times 0.5 / (1000 \times 0.7) = 0.72\text{m}^3$$

$$H12 = 0.005 \times \text{IF}(A11 < 36; 1 - A11 \times 0.014; \text{IF}(A11 < 120; 0.5 - (A11 - 36) \times 0.002; 1/3))$$

The last formula refers to Picture 10_5. The desludging interval is 12 months (cell A11), which results in a value of approximately 80% in the graph; this figure is multiplied by the sludge-production figure of 0.005.

The calculation is, therefore:

$$0.8 \times 0.005 = 0.004 \text{ (the computer calculates } 0.0042\text{)}.$$