CTB3365x – Introduction to Water Treatment

W6a – Thickening

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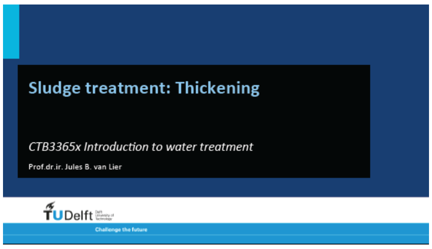
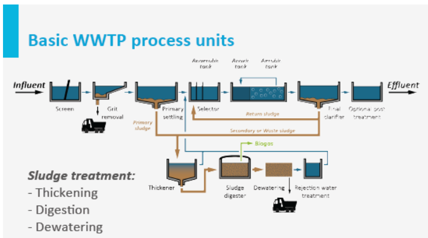
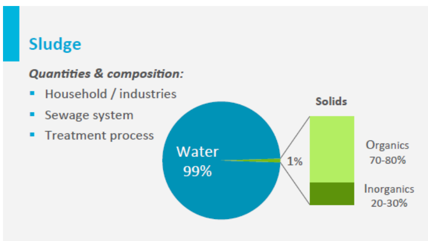


During the biological treatment of domestic sewage, excess sludge is being produced that originates from either, the incoming suspended solids, or from the growing biomass.
Can we discharge this sludge or does it need further treatment?
In the coming 3 lectures, we will discuss why and how the non-stabilized excess sludge is being processed in conventional activated sludge treatment systems.
We will have a look to the composition of the sludge and will learn why proper sludge – water separation is so important for the final disposal of the sludge.

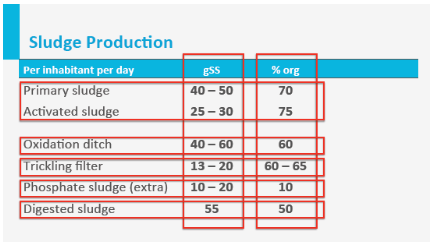


Let's have another look to the basic process units of the sewage treatment plant.
Where the excess sludge is being produced?
In the primary clarifier, non-stabilized sewage sludge is settled and thus separated from the main water stream.
In the secondary clarifier, settling of secondary sludge takes place, which consists of newly grown bacterial mass and other organics.
Bacterial mass is recycled to the aeration tank to increase the bioconversion capacity, but the excess sludge is directed to the sludge treatment units.
Sludge treatment generally consists of thickening, biological stabilization by anaerobic digestion, and advanced separation of the water from the sludge, also called dewatering.
What is "sludge?



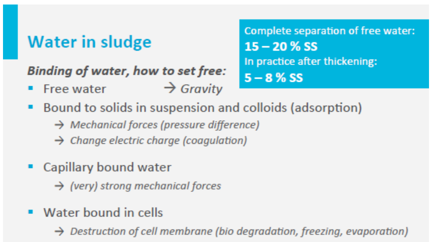
Sludge is non-defined, and the sludge characteristics differ per location and in time.
The exact quantities and composition of the sludge depend on the type of sewage treated.
Does the sewage comes from purely households, or, are also industries discharging to the sewer system?
What area is actually served by the sewer system and does it collect only sewage or also rainwater.
Also the type of sewage treatment plant will impact the excess sludge characteristics.
Extended aeration tanks will produces less sludge, which is more stabilized, than STPs equipped with both primary and

secondary clarification.
If both types of clarifiers are present, we can roughly differentiate between primary sludge and secondary sludge.
Both types of sludge largely consist of water.
In fact, with only 1% of solids in the original sludge stream, we are in fact dealing with polluted water.
On average, the 1% sludge solids consists of about 70-80% organic matter and 20-30% of inorganic residues or ash fraction, but values deviating from these averages certainly appear.



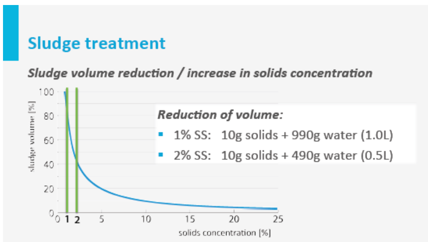
Per inhabitant per day	gSS	% org
Primary sludge	40 – 50	70
Activated sludge	25 – 30	75
Oxidation ditch	40 – 60	60
Trickling filter	13 – 20	60 – 65
Phosphate sludge (extra)	10 – 20	10
Digested sludge	55	50

How much sludge is produced during treatment?
As indicated, sludge production is directly linked to the treatment system applied.
This table presents average sludge production values in grams suspended solids per inhabitant per day.
The second column shows the percentage of organic matter in the produced sludge.
High loaded activated sludge systems equipped with both primary and secondary clarifiers, produce most sludge with a high fraction of organic matter.
A high organic fraction means that the sludge is non-stabilized, and requires putrefaction or stabilization prior to disposal.
The sludge produced in oxidation ditches is less and more stabilized.
Low loaded trickling filters produce the lowest amount of sludge, which is also more stabilized.
When chemical phosphate removal is applied, an additional stream is generated, which merely consists of inorganic phosphate precipitates like iron-phosphates.
Sludge stabilization is generally achieved in sludge digestion systems in which part of the organic matter is converted to biogas.
Therefore, digested sludge has a lower organic fraction.
For your information, the total excess sludge mass coming from all sewage treatment plants in The Netherlands is about 350.000 tons of dry solids per year.
Realizing that in the Netherlands sludge disposal costs about 400-500 euro per ton, means that sludge treatment is considered of crucial importance in the economics of a sewage treatment plant.
Highest volume reduction in sludge treatment is obtained by separating the water from the sludge particles.
To what extent can we dewater the sludge?
How water and sludge particles are interacting?

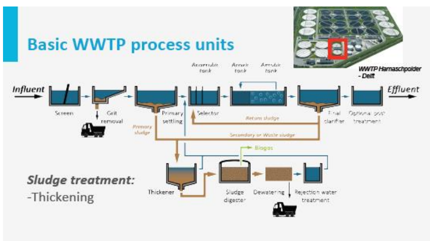


What technologies do we need to apply to separate the water from the sludge?
The largest water fraction is the so-called free water, which is not bound to the particles.
By simply settling, making use of gravity forces, we can separate the free water from the sludge.

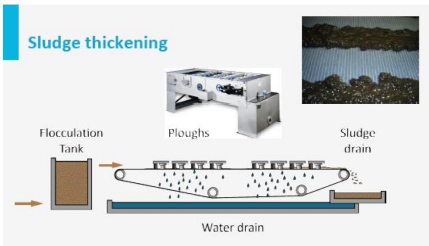
If we would be able to completely separate the free water from the solids, we would be able to concentrate the sludge to 15-20% dry solids.
However, in practice, gravity thickening results in sludge streams of only 5-8% of dry solids.
Next to the free water, water is also chemically bound or adsorbed to the suspended solids, and to the colloids.
The basis of this adsorption is the surface charge of the solids and the dipole of the water molecules.
In order to set free the adsorbed water, large mechanical forces are required by e.g. pressure differences.
Alternatively, the electric charge of the particles can be changed, for instance by coagulation processes.
Additionally, water is capillary bound in the interstices of the particles.
This very firm binding can only be disrupted by applying very strong mechanical forces, or drying.
And finally, water is an important part of the biological cells.
The intracellular water is only set free after destructing the cellular membranes by, for example, freeze drying, bio-degradation, evaporation, etc.
The water content of a concentrated sludge stream is determined by the electrostatic forces between the organic solids and the water.
The higher the organic solids content the higher the water fraction.
Therefore, in most large sewage treatment plants, a high degree of organic solids destruction is pursued.



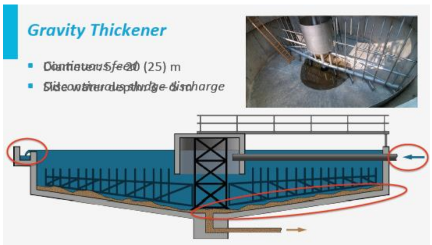
Excess sludge volume reduction leads to less transport costs and thus to lower operational exploitation costs of the treatment plant.
What volume reduction is achieved by increasing the solids content from 1 to 2% during thickening?
1L of sludge with 1% solids consists of 990 g water and 10 g sludge.
After thickening the liquid consists of the same 10 g sludge, so the amount of water is 490 g.
So, during thickening, an increase from 1% to 2% of solids, results in a volume reduction of 50%!



Let's have a closer look to the thickener.
A thickener is small unit, which is generally situated between the clarifiers and the digester with the objective to concentrate the sludge streams.



Thickeners are based either on gravity compression or on mechanical compression by drum sieves, centrifuges, sieve belts, etc.



Gravitational thickeners are most commonly applied, and are based on the hindered flocculent settling principle, as discussed during the primary clarification lecture.
Gravitational thickeners are usually constructed as round tanks with a sloping or flat bottom, according to the same principle as a settling tank.
The thickener is equipped with a slowly rotating agitator; the round vertical rods serve to very lightly agitate and to mix, so that accumulating gasses can escape and do not disturb the thickening process.
In general at the surface, the floating scum is held back by a scum baffle and is removed through a discharge drain.
Implemented diameters for thickeners vary from 5 to 20 - 25 m; the sidewater depth amounts to minimum 3 m and for practical reasons maximum 5 m.
Similar to a primary clarifier, the gravity thickener is fed from the top and the thickened sludge accumulates at the bottom.
The clarified liquid leaves the thickener at the topside and is sent back to the head works of the treatment plant.
A gravity thickener is generally continuously fed.
Sludge concentrations coming from primary clarifiers are between 1-2%, whereas from secondary clarifiers these are less than 1%.
The discharge takes place discontinuously throughout the day.

Sludge thickening – characteristics of sludge

type of sludge		Max. conc. of SS (%)
primary sludge	- organic > 65 %	5 – 7
	- organic < 65 %	7 – 12
	- digested	8 – 14
activated sludge	- fresh	3 – 5
	- digested	6 – 9
	- after thermal conditioning	10 – 15
primary + activated sludge	- aerobically stabilised	3 – 5
	- SVI > 100 mL/g	4 – 6
	- SVI < 100 mL/g	6 – 11
primary + humic sludge		7 – 10
primary + industrial sludge		10 – 30

The achievable concentration of suspended solids after thickening depends on the organic fraction of the sludge.
This table shows, for instance, the impact of digestion on the achievable solids content of both thickened primary sludge and secondary sludge.
The general observation is that the highest dry solids concentration can be achieved with stabilized sludge, that is characterized by a low organic matter content, and a low sludge volume index.

Sludge thickening – Sludge Loading Rate

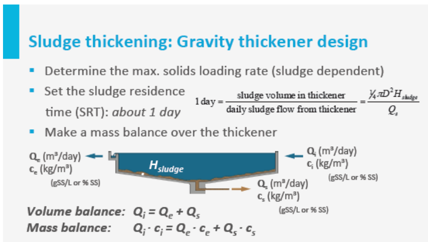
Solids loading rate:

$$v_{ds} = \frac{Q_s \cdot X_{sl}}{A}$$

type of sludge	Max. SLR (kg SS/(m².d)
Primary sludge	100 – 150
Activated sludge	20 – 30
Primary + Activated sludge	30 – 50
Digested sludge	30 – 50
Oxidation ditch sludge	30

v_{ds} = solids loading rate (kg SS/(m^2.d)
Q_s = sludge flow rate (m^3/d)
X_{sl} = sludge concentration (kg/m^3)
A = surface of thickener (m^2)

In terms of designing, the nature and quality of the sludge must be taken into account.
The most important variables are, the suspended solids load, expressed as Vds in the formula, and the sludge retention time.
Qs stands for the sludge flow rate, Xsl is the sludge concentration, and A is the surface of the thickener.
The applicable maximum solids loading rate largely depends on the nature of the solids as indicated in the table.



The design of a gravity sludge thickener is determined by the maximum solids loading rate.
In addition, the solids residence time or SRT is an important design criterion of the gravity thickener.
The SRT is defined by the volume of sludge layer divided by the flow rate of the thickened sludge.
In general the SRT is set to about 1 day and is a compromise between the achievable extent of sludge settling and the prevention of putrefaction of the accumulated sludge.
Sludge putrefaction inside the thickener may lead to acidification, mal odor, and sludge flotation owing to gas production.
At an SRT of about 1 day, proper sludge thickening is achieved whereas odor development is prevented.
When the tank diameter is known as well as the thickened sludge flow, the sludge height in the thickener can be calculated.
Missing design values can then be obtained by making a volume balance and a mass balance over the thickener.
Note that the influent mass always equals the effluent mass + the mass in the thickened sludge.
The sludge mass is now thickened to an SS content of up to 8%.
Now it is time to destruct some organic matter, so we lose some sludge mass and can more easily further de-water the sludge.

Let's talk about sludge digestion in the next presentation.