Delft University of Technology
Faculty of Civil Engineering and Geosciences
Subfaculty Civil Engineering
Section Sanitary Engineering

CT4471 Drinking water I - Technology

Date : 22 January 2007
Time : 9.00-12.00 h

There are 8 times 4 statements of equal weight. It not only necessary to answer the questions, but you should also **EXPLAIN** how you come to the answer. In all statements it is important to show insight in the influence of process parameters on the treatment step in consideration, in order to be able to optimise design and operation.

During the examination an A4 with own notes may **NOT** be used.

If there are uncertainties about the question, do not hesitate to ask the supervisor.

Motivate your answer and check if the answer is complete and practical.

Overview of questions

1. Introduction
2. Softening
3. Sedimentation
4. Filtration
5. Aeration
6. Membrane filtration
7. Adsorption
8. Coagulation/flocculation

General data

Table 1 – Atom mass of important elements in water chemistry.

Element	Atom mass	Element	Atom mass
H	1	S	32
C	12	Cl	35,5
N	14	K	39
O	16	Ca	40
F	19	Mn	55
Na	23	Fe	56
Mg	24	As	75
Al	27	Pb	207
P	31		

Table 2 - Dynamic and kinematic viscosity as function of temperature.

Temperature [°C]	Dynamic viscosity [10^{-3} Pa·s]	Kinematic viscosity [10^{-6} m^2/s]
0	1,79	1,79
5	1,52	1,52
10	1,31	1,31
15	1,15	1,15
20	1,01	1,01
25	0,90	0,90
30	0,80	0,80

Relevant formulas in water chemistry

bij T = 10°C

$CO_2 + 2H_2O$	<-->	$H_3O^+ + HCO_3^-$	$K_1 = 3{,}44\cdot10^{-7}$	$pK_1 = 6{,}46$
$HCO_3^- + H_2O$	<-->	$H_3O^+ + CO_3^{2-}$	$K_2 = 3{,}25\cdot10^{-11}$	$pK_2 = 10{,}48$
$CaCO_3 + CO_2 + H_2O$	<-->	$Ca^{2+} + 2HCO_3^-$	$K_a = 4{,}11\cdot10^{-5}$	

$NH_3 + H_2O$	<-->	$NH_4^+ + OH^-$
$NH_4^+ + 2O_2 + H_2O$	<-->	$NO_3^- + 2H_3O^+$
$CH_2O + O_2$	<-->	$CO_2 + H_2O$
$H_3O^+ + CaCO_3$	<-->	$Ca^{2+} + HCO_3^- + H_2O$
$5CH_2O + 4NO_3^-$	<-->	$2N_2 + 4HCO_3^- + CO_2 + 3H_2O$
FeS	<-->	$Fe^{2+} + S^{2-}$
$SO_4^{2-} + 2CH_2O$	<-->	$H_2S + 2HCO_3^-$
$S^{2-} + 2H_3O^+$	<-->	$H_2S + 2H_2O$
$2CH_2O$	<-->	$CH_4 + CO_2$
$NaOH + Ca^{2+} + HCO_3^-$	<-->	$CaCO_3 + Na^+ + H_2O$
$Ca(OH)_2 + Ca^{2+} + 2HCO_3^-$	<-->	$2CaCO_3 + 2H_2O$
$4Fe^{2+} + O_2 + 2H_2O + 8OH^-$	<-->	$4Fe^{3+} + 12OH^-$
$Fe^{3+} + 3OH^-$	<-->	$Fe(OH)_3$
$2Mn^{2+} + O_2 + 4OH^-$	<-->	$2MnO_2 + 2H_2O$

Table 3 - k_D-values for different gasses as function of temperature.

k_D	0°C	10°C	20°C
Nitrogen	0,023	0,019	0,016
Oxygen	0,049	0,039	0,033
Methane	0,055	0,043	0,034
Carbon dioxide	1,710	1,230	0,942
Hydrogen sulfide	4,690	3,650	2,870
Tetrachloroethene	-	3,380	1,880
Trichloroethene	-	4,100	2,390
Chloroform	-	9,620	5,070

Universal gas constant R = 8,3142 J/(K.mol)

Table 4 – Composition of air in atmosphere ($T = 10°C$, $p = 1 \cdot 10^5$ Pa)

Gas	Volume percentage [%]
Nitrogen	78,1
Oxygen	20,95
Carbon dioxide	0,003
Argon	0,93
Rest gasses	0,0002

Relevant formulae

$$c = \frac{p}{R \cdot T} \cdot MW$$

$$\frac{dc}{dt} = k_2 \cdot (c_s - c)$$

$$RQ = \frac{Q_l}{Q_w}$$

$$K = \frac{c_e - c_0}{c_s - c_0}$$

$$K_1 = 1 - \exp(-k_2 \cdot t)$$

$$K_2 = \frac{1}{1 + \frac{1}{k_2 \cdot t}}$$

$$K_3 = \frac{1 - \exp\left(-k_2 \cdot t \cdot \left(1 + \frac{k_D}{RQ}\right)\right)}{1 + \frac{k_D}{RQ}}$$

$$K_4 = \frac{1 - \exp\left(-k_2 \cdot t \cdot \left(1 - \frac{k_D}{RQ}\right)\right)}{1 - \frac{k_D}{RQ} \cdot \exp\left(-k_2 \cdot t \cdot \left(1 - \frac{k_D}{RQ}\right)\right)}$$

$$K_5 = \frac{1}{1 + \frac{1}{k_2 \cdot t} + \frac{k_D}{RQ}}$$

$$K = 1-(1-k)^n$$

$$I_0 = \frac{H_0}{L} = 180 \cdot \frac{\nu}{g} \cdot \frac{(1 - p_0)^2}{p_0^3} \cdot \frac{v}{d^2}$$

$$H = 130 \cdot \frac{\nu^{0.8}}{g} \cdot \frac{(1 - p_e)^{1.8}}{p_e^3} \cdot \frac{v^{1.2}}{d^{1.8}} \cdot L_e$$

$$H_{max} = (1 - p) \cdot L \cdot \frac{\rho_f - \rho_w}{\rho_w}$$

$$q_{max} = \frac{x}{m} = K \cdot c_s^n$$

$$\frac{c_0}{c_e} = 1 + \exp\left(k_2 \cdot EBCT \cdot \left(1 - \frac{BV \cdot c_0}{q \cdot \rho}\right)\right)$$

$$BV = \frac{Q \cdot T}{V} = \frac{T}{EBCT}$$

$$J = \frac{Q}{A_{mem}} = \frac{K_w \cdot (TMD - \Delta\pi)}{\nu}$$

$$TMD = \frac{P_f + P_c}{2} - P_p = P_f - \frac{\Delta P_{hydr}}{2} - P_p$$

$$\pi = \sum \frac{R \cdot T \cdot c_i \cdot z_i}{MW_i}$$

$$\gamma = \frac{Q_p}{Q_f}$$

$$Ret = 1 - \frac{c_p}{c_f}$$

$$\beta = \exp\left(\frac{J \cdot \delta}{D_i}\right)$$

$$G = \sqrt{\frac{P}{\mu \cdot V}}$$

$$P = \rho \cdot g \cdot Q \cdot \Delta H$$

$$s_0 = \frac{Q}{B \cdot L}$$

$$r = (1 - p_0) + \frac{1}{s_0} \cdot \int_0^{p_0} s\,dp$$

$$Re = \frac{v_0 \cdot R}{\nu}$$

$$Fr = \frac{v_0^2}{g \cdot R}$$

$$R = \frac{B \cdot H}{B + 2 \cdot H}$$

$$\tau = \frac{\lambda}{8} \cdot \rho_w \cdot v_s^2$$

1. Introduction

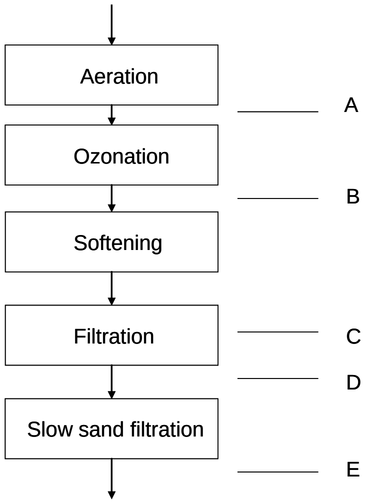
1.1. Which of the following characteristics can be given to dune infiltration (more answers can be possible)

a. Removal of pathogenic micro-organisms
b. Removal of organic micro-pollutants
c. Removal of iron and manganese
d. Removal of ammonia
e. Peak leveling of salt concentrations
f. Storage of water
g. Aeration of water

1.2. Softening is normally place before aeration (true or false)

1.3. Indicate the possible locations (see figure) of activated carbon filtration in a drinking water treatment plant (more answers can be possible)

a. A
b. B
c. C
d. D
e. E



1.4. The purpose of slow sand filtration in the Netherlands is mainly for the removal of (more answers can be possible)

a. Turbidity
b. Calcium
c. Pathogenic micro-organisms
d. Snails
e. Sand particles
f. Assimilable organic carbon (AOC)
g. Organic micro-pollutants

2. Softening

2.1. Raw water has the following characteristics: Total hardness of 2.5 mmol/l; Sodium concentration of 2.5 mmol/l and a Hydrogen carbonate concentration of 2.5 mmol/l. Indicate the best chemical to use, when the hardness has to be reduced to 1.5 mmol/l (multiple choice: one answer is valid).

a. caustic soda
b. lime
c. Hydrogen chloride
d. Potassium permanganate
e. Soda

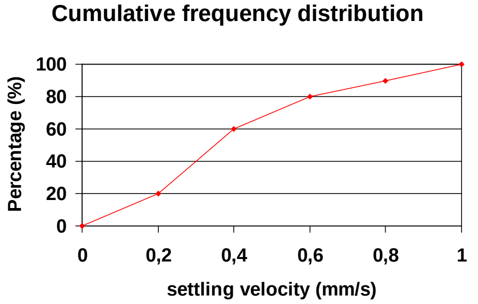
2.2. Assume influent water with a calcium concentration of 2.25 mmol/l, a pH of 7, a temperature of 10 ^{o}C and a Hydrogen carbonate concentration of 4 mmol/l. Then the needed dosing of caustic soda for reducing the concentration of calcium to 1.25 mmol/l is… mmol/l.

2.3. The total hardness of a water is 2.5 mmol/l of which 1.5 mmol/l is contributed to calcium. Then the by pass ratio to be applied to reduce the total hardness has to 1.5 mmol/l is ….

2.4. The temperature of the water is 10 ^{0}C, the flow velocity through the pellet softening reactor is 70 m/h, the density of the pellets is 2700 kg/m3 and the pressure drop over the bottom 50 cm of the filter is 40 cm, then the porosity of the fluidised pellet bed is … and the pellet diameter is .. mm (fill in the blanks).

3. Sedimentation

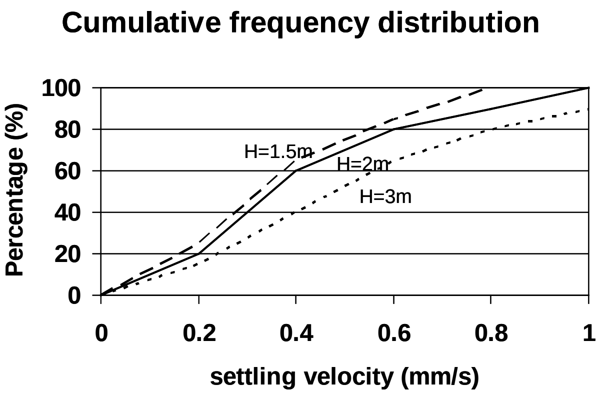
3.1. The cumulative frequency distribution of settling velocities of suspended solids is given in figure x. Assuming a surface loading of 0.4 mm/s, then the removal of discrete settling in a horizontal flow tank is …%



3.2. The removal efficiency by discrete settling in a horizontal flow tank will be improved by:

a. Placing vertical baffle in the tank
b. Placing a "false" floor in the tank
c. Increasing the depth of the tank
d. Increasing the width of the tank
e. Increasing the flow through the tank
f. Increase of temperature of the water

3.3. Based on the following graph it can be concluded that flocculent settling occurs in a horizontal flow tank (true or false).

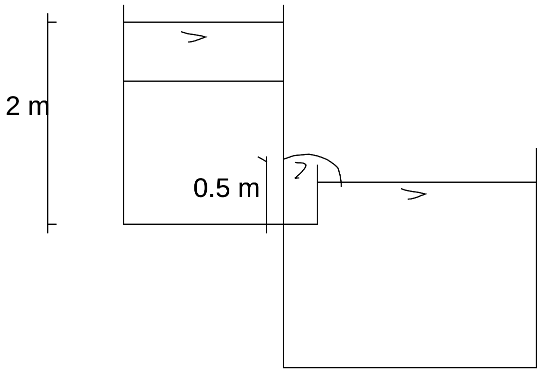


3.4. The flow in a horizontal flow tank treating a flow of 1000 m^3/h and a volume of (LxWxH) of 50x10x3 m^3 is turbulent and stable (true or false). Temperature is 10 ^oC.

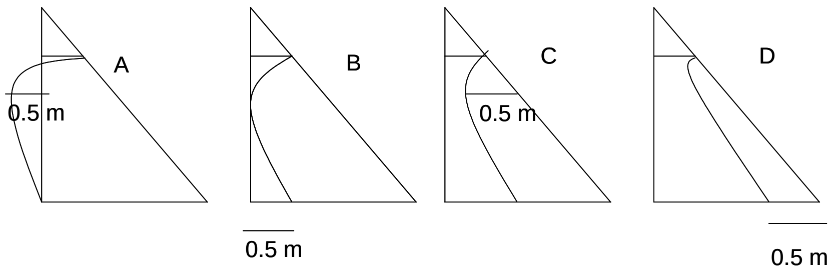
4. Filtration

4.1. Indicate which of the diagrams related to a maximally clogged rapid sand filter with the characteristics indicated in the figure is correct.

Rapid sand filter construction



Lindquist diagrams of clogged filters



a. A
b. B
c. C
d. D

4.2. A filterbed has a height of 1.5 m, a porosity of 40% and a grainsize of 1 mm. The water temperature is 10 ^{o}C and the water velocity through the filter is 20 m/h. Then the clean bed resistance is …m.

4.3. During back washing of the same filter of 4.2 and expansion of 30% has to be reached. Then the backwash velocity must be …. m/h.

4.4. The clean bed filtration coefficient of the filter of 4.2 is 0.8 m^{-1}. Then the removal efficiency of the clean bed is 70% (true or false).

5. Aeration and Gas Transfer

5.1. The effect of aeration and gas transfer systems is (more answers can be possible)

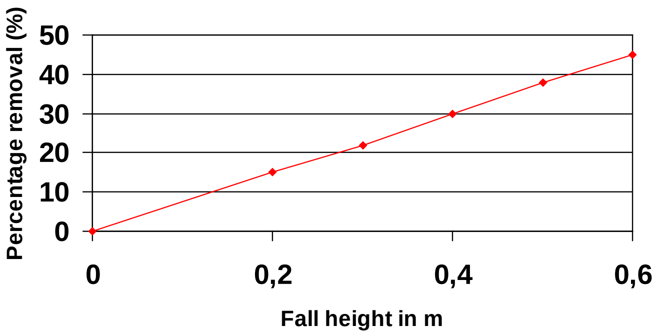
a. to remove volatile organic compounds
b. to remove gasses such as CO_2 and CH_4
c. to add oxygen
d. to decrease pH
e. to decrease electrical conductivity
f. to cool down the water

5.2. Compounds with a low K_D value are easily removed from the water (true or false)

5.3. The saturation concentration of oxygen in water decreases from … to …. When the water temperature increases from 10 ^{o}C to 20 ^{o}C.

5.4. The removal efficiency of methane by one cascade step is given in the figure (as function of fall height). The maximum construction height is 2 m. A cascade consisting of 3 steps of 0.6 m is more efficient than a cascade consisting of 6 steps of 0.3 m (true or false).

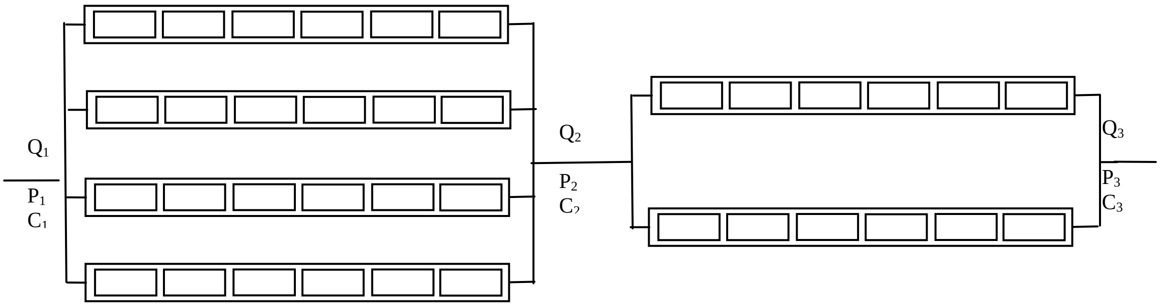
Methane removal as a function of fall height



6. Membrane filtration

The figure shows a RO-membrane filtration plant. Q is the flow, P the pressure and C the concentration of ions

6.1. In the installation …. membrane-elements, ……pressure vessels and …… stages are used



6.2. Which of the answers is correct?

a. Q1>Q2>Q3 and P1<P2<P3 and C1<C2<C3

b. Q1>Q2>Q3 and P1>P2>P3 and C1>C2>C3

c. Q1<Q2<Q3 and P1>P2>P3 and C1>C2>C3

d. Q1>Q2>Q3 and P1>P2>P3 and C1<C2<C3

6.3. Because of fouling the permeate production (not shown in the figure) is decreasing, but the cross flow velocity is not changed. What should an operator do to increase the permeate production and maintain the same cross flow velocity?

a. increase P1 and decrease P3

b. increase P1 and increase P3

c. maintain P1 and increase P3

d. increase P1 and maintain P3

6.4. Cross-flow velocity is very important in reverse osmosis, because it is important to for energy consumption to prevent scaling (true or false).

7. Activated carbon adsorption

7.1. Mention the three main water quality improvements with the application of activated carbon in drinking water treatment.

7.2. Which of the following statements are correct?

a. The investment costs are lower for Pseudo moving bed configuration compared with parallel columns

b. Regeneration costs are higher for Pseudo moving bed configuration compared with parallel columns

c. Activated carbon columns can never be backwashed

d. With activated carbon you can remove all the organic micro pollutants

7.3. The benefit of GAC above powdered activated carbon (PAC) is (more answers can be possible)

a. The adsorption capacity is higher
b. A column is better in dealing with peak concentrations of micropollutants
c. A column is always better than a batch process
d. After breakthrough GAC can be regenerated and PAC not

7.4. An activated carbon filter has the following properties: a round filter with a diameter of 5 m, a bed height of 3 meters a feed velocity of 12 m/h, a maximum loading of 0.1 kg of atrazin for the complete filter at a feed concentration of 2 microgram atrazin/l. Then the empty bed contact time (EBCT) is …. and the running time of a filter until breakthrough (steep front) is…..

8. Coagulation

8.1. During coagulation three mechanisms can be involved (Which of the statements are true):

a. adsorptive coagulation is suited for removing organic substances
b. precipitation coagulation is suited for removing turbidity
c. electrostatic coagulation is the main coagulation mechanism in drinking water treatment
d. precipitation coagulation is the same as sweep coagulation

8.2. A flow of 750 m^3/h water is fed to 2 units. The coagulant is dosed and mixed in a cascade with a fall height of 0,2 m. The shear during mixing(G_c) is in this situation(10 °C) 1500 sec^{-1}. The coagulation chamber has an overcapacity. If the flow is below 500 m^3/h only one unit is used. Then the shear rate during mixing at a flow of 500 m^3/h and a temperature of 10°C is …..

8.3. Mention three ways to anticipate to bad coagulation results at low temperatures during winter time.

a. Increase temperature
b. Increase coagulant dosing
c. Increase steering rate
d. Increase by-pass ratio
e. Increase flow
f. Increase dosing of coagulant aid
g. Increase settling time

8.4. In the Netherlands iron chloride is mostly used for coagulation because of its independency of pH (true or false).