**PART A**

**Written examination in Drinking Water Engineering 10 January 2018, at 08:30-13:30**

Course BOM075, Chalmers

Teacher: Thomas Pettersson, ext. 2127

The written examination consists of totally 50 credits (25 credits on Part A and 25 credits on Part B)

To pass the examination a minimum of 10 credits per part is required.

**Part A consists of 5 theory questions, *no aid allowed*** *(Suggested time spent on Part A is ~60-90 min)*

**Part B consists of 3 problems, where optional (pocket) calculator ("valfri miniräknare") and course literature (see list) are allowed, but not solved problems ("lösta exempel")**

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***Short and precise answers recommended!***

1. When quantifying the health risks for drinking water consumers the pathogen concentrations in the raw water are important to estimate. Which pathogen types are common in the drinking water context? Which pathogen sources are important and how can the concentrations be estimated/calculated (in a surface water source)? (5p)

2. The World Health Organisation (WHO) promotes drinking water utilities to implement Water safety plans (WSP) to ensure safe and healthy water provision to the consumers. One argument from WHO is that "*End-product testing is not sufficient to guarantee safe drinking water to consumers*". Describe the main components in WSP and how an implementation of WSP better can guarantee a safe drinking water supply. (5p)

3. At a small waterworks, treating surface water, the process consists of rapid gravity media filtration followed by nanofiltration and disinfection using free chlorine. Although the treatment train is considered an excellent barrier, the following problems are identified:
   - The membrane transmembrane pressure increases rapidly, which necessitates frequent membrane cleaning and high energy costs.
   - Heterotrophic plate counts are sometimes high in the drinking water at the tap.
   - During summer season, the consumers complain about the taste and odor of the water.

   As a consultant, you are called in to:
   1) Explain possible reason to each of the three (3) problems
   2) Come up with a process solution that will solve the identified problems. (5p)

4. When drinking water is very turbid, it is difficult to measure its absorbance accurately. Explain this statement, specifically identifying what type of measurement error occurs in turbid water and the reason why it occurs. Also suggest a potential solution, i.e. how to get accurate absorbance measurements from turbid drinking waters. (5p)

5. The distribution network is susceptible to events that can lead to contamination of the drinking water. If the drinking water is contaminated, this can pose an increased health risk for the consumers. Mention at least two (2) possible effects that consumers can experience if contaminated water is delivered to their taps. State three (3) ways in which you can handle the microbial risks to prevent contamination of the drinking water in your system. (5p)

**PART B**
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To pass the examination minimum 10 credits per part is required.

**Part B consists of 3 problems**
***where* optional (pocket) calculator ("valfri miniräknare") and the course literature (see list) are allowed to use for Part B, but not solved problems ("lösta exempel")**

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1. Professor Peng has invented a new chemical coagulant that she claims will dramatically improve drinking water treatment for Swedish surface waters. The new coagulant is marketed under the brand name Penglux®. Its precise chemical formula is a company secret, although according to Professor Peng, the balanced chemical reaction for coagulation using Penglux® is as follows:

   Penglux® (aq) + $3H_2CO_3$ (aq) + $6H_2O$ (l) $\rightleftharpoons$ Pengluxene (s) + $2HCO_3^-$ (aq)

   A drinking water treatment plant is considering whether to switch its coagulant from aluminium sulfate ($Al_2(SO_4)_3 \cdot 18H_2O$, Molecular weight = 666 g/mol, 55 cents per kg) to Penglux® (Molecular weight = 1029 g/mol, 79 cents per kg).

Refer to the data and equations below, then answer the following questions:
(i) Calculate the initial concentration of carbonic acid in the untreated raw water, assuming that the raw water quality is as shown in Table 1.
(ii) Write the equation for determining the pH of the water after adding only Penglux and no other chemicals. What will happen to pH after adding Penglux?
(iii) Calculate the pH of the water after adding 50 mg/L of Alum and 1 mM of NaOH.
(iv) Jar tests produce the data in Figure 1.
   a) Explain the shape of each curve.
   b) Summarise the advantages and disadvantages of the two coagulants.
   c) Are there any other data would you want to be able to examine before deciding which coagulant to use? Explain.
(v) Following coagulation using Penglux, the drinking water quality was measured (Table 2).

Identify any specific risks associated with distributing this finished water.

(8p)

Table 1: Raw water chemistry

| | |
|---|---|
| $[HCO_3^-]$ | 1.5 mM |
| pH | 6.4 |
| $[Ca^{2+}]$ | 140 mg/L |

Table 2: Finished water chemistry

| | |
|---|---|
| $[HCO_3^-]$ | 3.5 mM |
| pH | 8.7 |
| $[Ca^{2+}]$ | 90 mg/L |

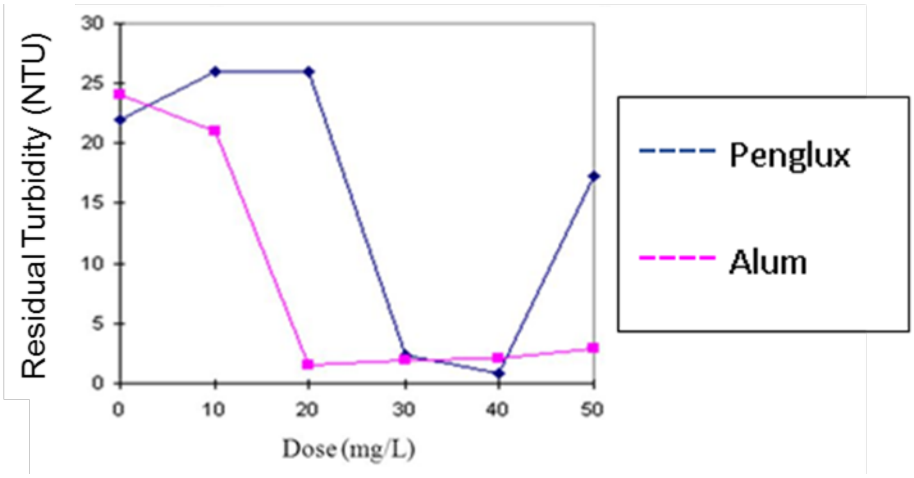



Figure 1: Results of coagulation jar tests using Alum and Penglux.

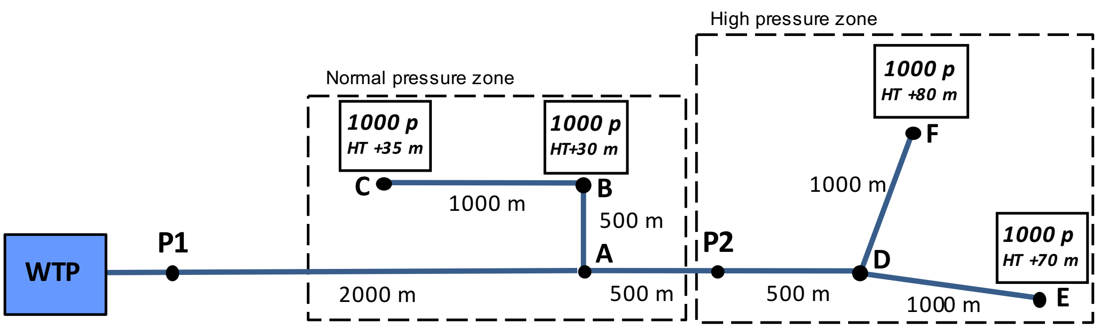
**Equilibrium equations**

| | | | | |
|---|---|---|---|---|
| 1. | $H_2CO_3 + H_2O$ | $\rightleftharpoons HCO_3^-$ | $+ H_3O^+$ | $pK_{a1} = 6.4$ |
| 2. | $HCO_3^- + H_2O$ | $\rightleftharpoons CO_3^{2-}$ | $+ H_3O^+$ | $pK_{a2} = 10.3$ |
| 3. | $2H_2O$ | $\rightleftharpoons OH^- + H_3O^+$ | | $pK_w = 14$ |
| 4. | $Al_2(SO_4)_3{\cdot}18H_2O$ | $\Rightarrow 2Al^{3+}$ | $+ 3SO_4^{2-} + 18H_2O$ | K is very large |
| 5. | $Al^{3+} + 3\,HCO_3^-$ | $\rightleftharpoons Al(OH)_3$ | $+ 3H_2CO_3$ | K is very large |
| 6. | $H_2SO_4 + 2\,HCO_3^-$ | $\rightleftharpoons 2H_2CO_3$ | $+ SO_4^{2-}$ | K is very large |
| 7. | $NaOH + H_2CO_3$ | $\rightleftharpoons Na^+ + HCO_3^- + H_2O$ | | K is very large |

2. In a small and hilly town drinking water is supplied to the 4000 consumers, living in apartments, from a local drinking water treatment plant (WTP). Since the distribution network was installed early 1940's it now needs to be renewed. The town consists of two pressure zones, one normal and one high pressure zone, see figure below. Between the pressure zones a pumping station (P2) raise the pressure for the 2000 consumers in the high pressure zone.

   Your task is to re-design the pipes in the distribution network providing a minimum velocity of at least 0.6 m/s (at design flow). You should also design the two pumps, at the WTP (P1, located ±0 m) and the pumping station (P2, located at +40 m) at the high pressure zone. Note that you only need to design the system (pipes and pumps) <u>during design flow</u>.

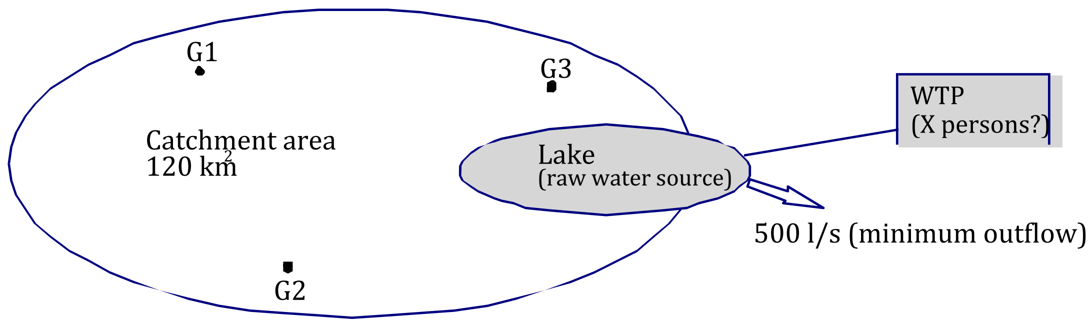
   The highest taps (HT) locations are showed in the figure below. (9p)



3. In a catchment (120 $km^2$) a lake is suggested to be used as a raw water source for a nearby city (see figure below). Precipitation measurements are provided from three rain gauges in the catchment area (all three equally important). Precipitation and evaporation data is presented in the table below.

How many drinking water consumers can be provided from this lake during a "dry year" (1 every 100 years) if the specific water demand is 200 l/pd (litres per person and day) and the minimum natural outflow from the lake should be at least 500 l/s?

| | Rain gauge 1 | Rain gauge 2 | Rain gauge 3 |
|---|---|---|---|
| $P_{normal\ year}$ (mm/year) | 850 | 900 | 890 |
| $\sigma_n$ (mm/year) | 25% of mean P | | |
| $E_{dry\ years}$ (mm/year) | 180 | | |




(8p)

SOLUTIONS DWE, Written examination 2018-01-10

# Problem 1

(i) Calculate the initial concentration of carbonic acid in the untreated raw water, assuming that the raw water quality is as shown in Table 1.

*Answer: 93 µg/L or 1.5mM.*

(ii) Write the equation for determining the pH of the water after adding only Penglux and no other chemicals. What will happen to pH after adding Penglux?

*Assume [P]=[Penglux]*

$$pH = -\log\left(10^{-6.4}\left\{\frac{[H_2CO_3] - 3[P]}{[HCO_3^-] + 2[P]}\right\}\right)$$

*Adding P will consume acidity leading to increased pH.*

(iii) Calculate the pH of the water after adding 50 mg/L of Alum and 1 mM of NaOH.

$[Al^{3+}]=2*[Alum]=2*50*10^{-3}/666=1.5*10^{-4}$ mol/L=0.15 mM

$$[H^+] = K_{a1}\frac{[H_2CO_3] + 3[Al^{3+}] - [NaOH]}{[HCO_3^-] - 3[Al^{3+}] + [NaOH]}$$

$$[H^+] = 10^{-6.4}\frac{[1.5] + 3[.15] - [1]}{[1.5] - 3[.15] + [1]} = 10^{-6.4}(0.95/2.05) = 1.84*10^{-7}$$

$$pH = 6.7$$

(iv) Jar tests produce the data in Figure 1.

i. Explain the shape of each curve.
ii. Summarise the advantages and disadvantages of the two coagulants.
iii. Are there any other data would you want to be able to examine before deciding which coagulant to use? Explain.

*Answer should identify optimal dose ranges for the two coagulants. Advantages/disadvantages should mention difference in cost and ranges of optimal dose, and (presumed) cost of any additional chemicals needed to achieve correct conditions for distribution. It would be useful to look at other data indicative of NOM content, to confirm the turbidity data, and if using PengLux for the first time, it would also be worth examining microbial data and data for potential trace contaminants, e.g. Metals.*

(v) Following coagulation using Penglux, the drinking water quality was measured (Table 2). Identify any specific risks associated with distributing this finished water.

*Compare Table 2 with data for Chemical precipitation lecture 2, page 10. These values are a little high in terms of hardness, but still within the acceptable range.*

## Problem 2

a) Determine the flows (demand) in the pipes for the four housing areas (apartments) and select standard pipe sizes based on v>0.6 m/s at design flow. Demand, pipe diameter and friction losses are calculated and summarized in the table: ($h_f = mLq^2$)

| Section | Total users | Maximum demand (l/s) | Standard pipe diameter (mm) | m-value | Pipe length (m) | Friction loss. $h_f$ (m) |
|---|---|---|---|---|---|---|
| P1-A | 4000 | 38 | 250 | 1.8 | 2000 | 5,20 |
| A-B | 2000 | 24 | 200 | 5.9 | 500 | 1,70 |
| B-C | 1000 | 15 | 150 | 27 | 1000 | 6,08 |
| A-D | 2000 | 24 | 200 | 5.9 | 1000 | 3,40 |
| D-E | 1000 | 15 | 150 | 27 | 1000 | 6,08 |
| D-F | 1000 | 15 | 150 | 27 | 1000 | 6,08 |

b) Check the pressure needed in the <u>highest taps</u> (HT) in the normal pressure zone, during design flow conditions, for the housing areas B and C. Pump P1 need to provide:

$H_{P1} = H_s + \sum h_f + p_{excess,HT}$ ➔

Area B (P1-A-B): $H_{P1} = (30 - 0) + 5.20 + 1.70 + 20 = 56.90$ m

Area C (P1-A-B-C): $H_{P1} = (35 - 0) + 5.20 + 1.70 + 6.08 + 20 = 67.97$ m

Pump P1 needs to give 67.97 m pressure and 38 l/s.

Check the pressure needed in the high-pressure zone for housing areas E and F. In point P2 (in the middle between points A and D) the excess pressure from pump P1 is:

$p_{excess,P2} = H_{P1} - H_s - \sum h_f = 67.97 - (40 - 0) - 5.20 - 3.40/2 = 21.08$ m

Pump P2 need to provide:

$H_{P2} = H_s + \sum h_f + p_{excess,HT} - p_{excess,P2}$ ➔

Area E (P2-D-E): $H_{P2} = (70 - 40) + 3.40/2 + 6.08 + 20 - 21.08 = 36.70$ m

Area F (P2-D-F): $H_{P2} = (80 - 40) + 3.40/2 + 6.08 + 20 - 21.08 = 46.70$ m

Pump P2 needs to give 46.7 m pressure and 24 l/s.

**<u>Answer</u>**: a) The pipe sizes should be sized as in the table (above)

b) The two pumps need to provide: P1 – 68 m and 38 l/s, P2 – 47 m and 24 l/s.

## Problem 3

The average annual rain depth is
$P_{mean}$ = (850+900+890)/3 = 880 mm/year

A dry year occurring once in 100 years corresponds to a probability of exceedance of 99%, thus
$K_{100}$ = - 2.33, from which we calculate the rain depth as:

$P_{100} = P_{mean} - K_{100}\,\sigma_n$, where $\sigma_n$ = 25% of $P_{mean}$

$P_{100}$ = 880 – 2.33*0.25*880 = 367.4 mm/year

The net rain depth after the evaporation is withdrawn is

$R_{100} = P_{100} - E$ = 367.4 – 180 = 187.4 mm/year

Assume 100% of the net rain depth results in surface runoff. The runoff supply to the lake is then:

$q_{100} = A \cdot R_{100} = 120 \cdot 10^6 \cdot 0.1874$ = 22 488 000 $m^3$/year = 713.1 l/s

The natural outflow from the lake during a dry year should be: $Q_{outflow}$ = 500 l/s, why the water supply to the city during a dry year can provide $Q_{DW} = q_{100} - Q_{outflow}$ = 713.1 - 500 = 213.1 l/s.
$Q_{DW}$ = 213.1 l/s is equal to 213*3600*24 = 18 410 959 l/d.
The specific water demand in the population was 200 l/pd.

This means that 18 410 959 l/d / 200 l/pd = 92 055 persons can be supplied with drinking water.

**Answer**: During a dry year (1 every 100 years) the lake can provide around 92 000 persons with drinking water.