PART A

Written examination in Drinking Water Engineering 17 March 2021, 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 and Part B consists of 3 problems.

Any calculator ("valfri miniräknare"), course literature and solved problems ("lösta exempel") are allowed for both parts.

Short and precise answers recommended!

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1. Health risk assessment in drinking water supply systems can be performed using either microbial barrier analysis (MBA) or quantitative microbial risk assessment (QMRA) methods.
   - Describe the difference in input data for the two methods. *(1p)*
   - Describe how the acceptable risks are defined for the two methods. *(1p)*
   - Describe how the assessment results can be compared to each other for the two methods. *(3p)*

   (5p)

2. Natural organic matter (NOM) is present in all surface water. At waterworks, NOM is removed by various treatment methods. Why do we need to remove NOM in drinking water treatment? Give 3 reasons with explanations of each. **(6p)**

3. Rapid granular media filters need to be backwashed at regular intervals to maintain good removal of particles. After backwashing, the larger filter grains will accumulate at the bottom of the filter bed and the smaller grains will end up at the top of the bed. This leads to poor utilisation of the filter bed.
   - How do you as an operator know when it is time to backwash a filter?
   - Describe two solutions to the problem of uneven size distribution in granular media filtration after backwashing.
   - Describe how granular media filtration can be operated without any need for backwashing.

   (4p)

4. The drinking water distribution network pipes can be susceptible to intrusion events that can contaminate the drinking water being supplied to consumers. For an intrusion event to occur, there needs to be three conditions happening simultaneously: a trigger for the event, a source of the contamination, and a pathway for the contamination to enter the system. Describe how an intrusion event can cause contamination of the drinking water; what is the trigger, the source, and the pathway. **(5p)**

5. Reservoirs in the distribution network can be susceptible to both hydraulic and physical breaches/intrusions that can cause a degradation of the water quality, and in some cases, contamination of the drinking water. Give one (1) example of loss of hydraulic integrity and one (1) example of loss of physical integrity in reservoirs that can lead to a contamination event.

   (5p)

PART B
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Part B consists of 3 problems,
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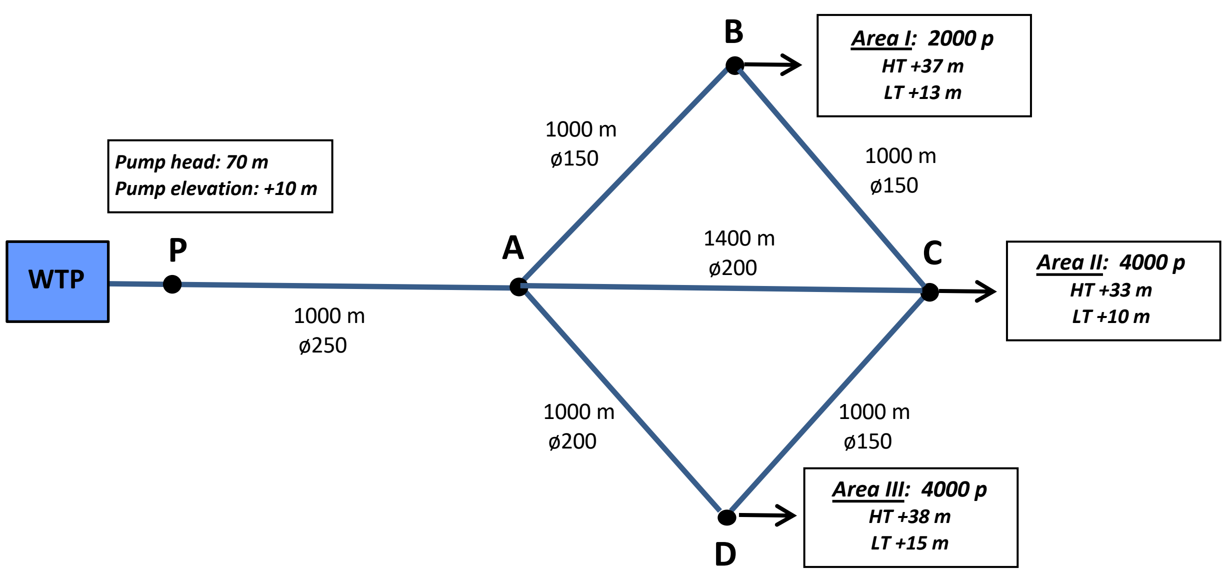
1. In a small town, *Watertown*, with 10 000 inhabitants the drinking water distribution network has a layout as shown in the figure below (six pipes: P-A, A-B, A-C, A-D, B-C and C-D). The pump (P) provides 70 m head at design flow and is installed at +10 m at the water treatment plant (WTP). Highest (HT) and lowest (LT) tap locations are also indicated in the figure below. People in the three housing areas are living in detached houses.

   The task for you, as drinking water engineer, is to investigate how the system operates at design flow (for 10 000 people). Normal pressure requirements at the consumers and velocity requirements in the pipes should be fulfilled during design flow (and all other times). Check if these requirements are fulfilled? **(9p)**

2. The water engineers in *Watertown* fears that pipe A-D (ø200) may break, since there have been many repairs on this pipe last years. The second task for you as drinking water engineer is to investigate how the system operates when pipe A-D is broken (closed). Check how the velocity and pressure requirements will be fulfilled during these new circumstances.
   (9p)



3. A drinking water treatment plant treats surface water by coagulation, sedimentation and disinfection before sending it out to distribution. It uses $FeCl_3$ as a coagulant (molar mass = 162.2 g/mol), which speciates as shown in Figure 1. Incoming raw water properties are shown in Table 1. Additional chemicals that are available to use during treatment are listed along with their molar mass in Table 2.

   i. Calculate total alkalinity (mM) in the raw water. *(1p)*

   ii. State an optimal pH for coagulation, assuming that the optimal coagulant dose is 40 mg/L. What additional chemicals should be used for coagulation? Explain your choices. *(1.5p)*

   iii. Calculate the amounts (mg/L) of all chemicals needed during coagulation. *(2p)*

   iv. Calculate total alkalinity (mM) after adding the coagulant at the optimal dose. *(2p)*

   v. Following coagulation, what further chemical treatment is needed before distribution? Explain your reasoning, also specify chemicals needed and calculate required doses. *(1.5p)*

(8p)

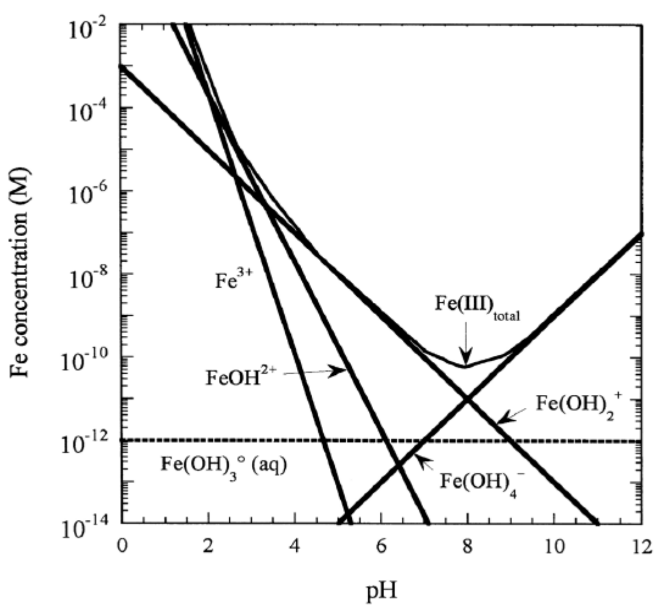


Fig. 1: Iron III speciation in water as a function of pH

Table 1. Raw water properties

Colour (mg Pt/l)	48
Turbidity (FNU)	6
pH	5.6
HCO_3^- (mg/l)	50
Ca^{2+} (mg/l)	95

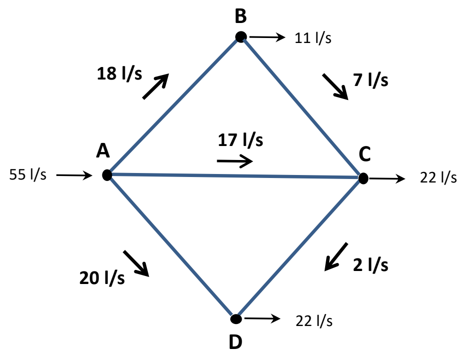
Table 2. Molar mass for selected chemicals, in g/mol.

$FeCl_3$	162.2
HCl	36.5
H_2SO_4	98.1
NaOH	40.0
Na_2CO_3	106.0
$Ca(OH)_2$	74.1
Ca^{2+}	40.1

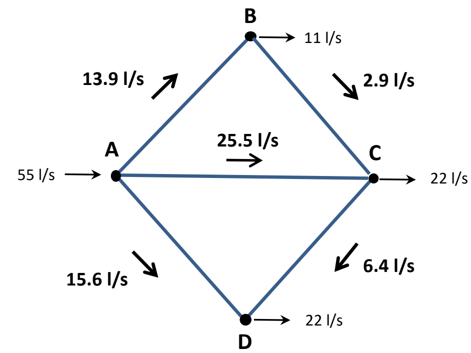
Solution: Problem 1

Watertown's 10 000 inhabitants, in detached houses, has a maximum demand of 55 l/s. To calculate the flow distribution in the grid system, keeping the continuity conditions, Watertown's maximum demand (55 l/s) needs to be divided proportional to the number of inhabitants in each housing area. Housing area I (at node B) has 2000 persons connected, i.e. 20% of Watertown's population and the demand at node B is then $0.2 \cdot 55 = 11$ l/s. For area II (node C) and area III (node D) the demand is then 40% each, i.e. $0.4 \cdot 55 = 22$ l/s each. Friction loss in pipe P-A: $h_{f\,P\text{-}A} = 1.8 \cdot 1000 \cdot 0.055^2 = 5.45$ m and the velocity 1.12 m/s.

The first guess of the flow distribution in the grid system (fulfilling $\Sigma q=0$ in each node), before the first iteration using Hardy Cross method is carried out, is presented in the figure below:



Initial guess:



Final flow:

The iterations to find the final flow distribution in the grid system, with two loops, are then carried out, in the table below. The final flow is presented in the figure above.

LOOP 1				Iteration:	1					2				
pipe	D (mm)	m	L	C=mL	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)
A-B	150	27	1000	27000	**0,0180**	1,02	8,748	486,0	-0,00471	**0,01329**	0,75	4,768	358,8	-0,00091
B-C	150	27	1000	27000	**0,0070**	0,40	1,323	189,0	-0,00471	**0,00229**	0,13	0,141	61,8	-0,00091
A-C	200	5,9	1400	8260	**-0,0170**	0,54	-2,387	140,4	-0,00471	**-0,02150**	0,68	-3,817	177,6	-0,00091
							7,684	815,4	***-4,712***	Σ		1,0926	598,1	***-0,913***
									Δq (l/s)					***Δq (l/s)***
				Max flow (m³/s):	0,018			Δq /max flow:	**26%**	0,021				**4,25%**
LOOP 2					1					2				
pipe	D (mm)	m	L	C=mL	Q(m3/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)
A-C	200	5,9	1400	8260	**0,0170**	0,54	2,387	140,4	-0,00022	**0,02150**	0,68	3,817	177,6	-0,00216
C-D	150	27	1000	27000	**0,0020**	0,11	0,108	54,0	-0,00022	**0,00178**	0,10	0,086	48,2	-0,00216
A-D	200	5,9	1000	5900	**-0,0200**	0,64	-2,360	118,0	-0,00022	**-0,02022**	0,64	-2,411	119,3	-0,00216
					Σ		0,135	312,4	***-0,216***	Σ		1,4911	345,0	***-2,161***
									Δq (l/s)					***Δq (l/s)***
				Max flow (m³/s):	0,02			Δq /max flow:	**1%**	0,021				**10,05%**

LOOP 1	3					4					5					Correct answer			
pipe	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	Q(l/s)	v (m/s)	hf
A-B	**0,01238**	0,70	4,135	334,1	-0,00074	**0,01163**	0,66	3,654	314,081	-0,00026	**0,01137**	0,64	3,491	307,016	-0,00012	**0,01137**	11,4	0,64	3,49
B-C	**0,00138**	0,08	0,051	37,1	-0,00074	**0,00063**	0,04	0,011	17,081	-0,00026	**0,00037**	0,02	0,004	10,016	-0,00012	**0,00037**	0,4	0,02	0,00
A-C	**-0,02025**	0,64	-3,386	167,2	-0,00074	**-0,02030**	0,65	-3,403	167,665	-0,00026	**-0,02021**	0,64	-3,374	166,938	-0,00012	**-0,02030**	-20,3	0,65	3,40
	Σ		0,80	538,5	***-0,7424***	Σ		0,26	498,83	***-0,262***	Σ		0,12	483,97	***-0,125***				
					Δq (l/s)					***Δq (l/s)***					***Δq (l/s)***				
	0,020				**3,667%**	0,020				**1,289%**	0,020				**0,618%**				
LOOP 2	3					4					5					Correct answer			
pipe	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	Q(l/s)	v (m/s)	hf
A-C	**0,02025**	0,64	3,386	167,2	-0,00069	**0,02030**	0,65	3,403	167,665	-0,00035	**0,02021**	0,64	3,374	166,938	-0,00012	**0,02030**	20,3	0,65	3,40
C-D	**-0,00038**	0,02	-0,004	10,2	-0,00069	**-0,00107**	0,06	-0,031	28,862	-0,00035	**-0,00142**	0,08	-0,054	38,303	-0,00012	**-0,00119**	-1,2	0,07	0,04
A-D	**-0,02238**	0,71	-2,954	132,0	-0,00069	**-0,02307**	0,73	-3,140	136,107	-0,00035	**-0,02342**	0,75	-3,236	138,170	-0,00012	**-0,02319**	-23,2	0,74	3,17
	Σ		0,43	309,5	***-0,6916***	Σ		0,23	332,63	***-0,350***	Σ		0,08	343,41	***-0,122***				
					Δq (l/s)					***Δq (l/s)***					***Δq (l/s)***				
	0,022				**3,091%**	0,023				**1,516%**	0,023				**0,521%**				

Next step is to check the excess pressure in the highest taps during the maximum demand period within the three housing areas, where $P_{excess} = P_{pump} - H_s - \Sigma hf$. ($H_s = HT - H_{pump}$)

Area I (P-A-B): $P_{excess} = 70 - (37 - 10) - (5.45 + 3.49) = 34.06$ m (>20 m, **Ok**)

Area II (P-A-C): $P_{excess} = 70 - (33 - 10) - (5.45 + 3.40) = 38.15$ m (>20 m, **Ok**)

Area III (P-A-D): $P_{excess} = 70 - (38 - 10) - (5.45 + 3.17) = 33.38$ m (>20 m, **Ok**)

The excess pressure is Ok (>20 m) in all areas' highest taps. During night the highest excess pressure will occur when no friction loss reduces the pressure. But since the lowest tap is located at the same level as the pump (+10 m) and the pump only provides 70 m head the highest pressure in the lowest tap will never exceed 70 m, which is Ok.

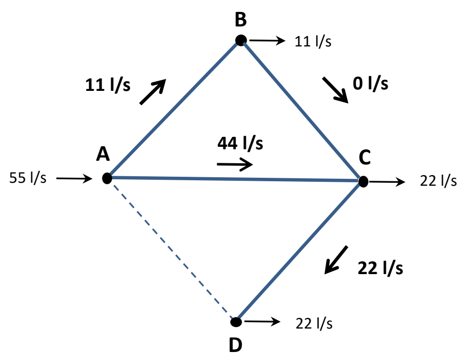
The velocity is larger than 0.6 m/s in pipes P-A, A-B, A-C and A-D at design flow, but too low (<0.6 m/s) in pipes B-C and C-D why these two need to be flushed regularly.

Answer: Final flow distribution in figure above, and excess pressure is Ok, $20 < P_{excess} \leq 70$ m. Pipes B-C and C-D need to be flushed regularly since velocity <0.6 m/s.

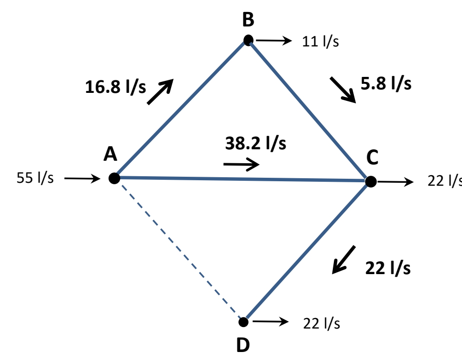
<u>Solution</u>: Problem 2

The demands from the three housing areas are still as in Problem 1, but when pipe A-D is broken only one loop (A-B-C-A) exists, and the water to Area I flows through pipe C-D only, with 22 l/s and v = 1.24 m/s. The friction loss for this pipe is then $h_{f\,C\text{-}D} = 27 \cdot 1000 \cdot 0.022^2 = 13.07$ m. For pipe P-A, the friction loss remains the same ($h_{f\,P\text{-}A} = 5.45$ m).

The flow distribution in the grid system (A-C-D-A) needs to be calculated and the initial guess, before the iteration with Hardy Cross method is carried out, is presented in the figure below:



<u>Initial guess</u>:



<u>Final flow</u>:

The iterations to find the final flow distribution in the grid system (one loop) are then carried out, in the table below. The final flow is presented in the figure above.

LOOP 1					1					2					3					4		
pipe	D (mm)	m	L	C=mL	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)	h/Q	ΔQ (m³/s)	Q(m³/s)	v (m/s)	h=C|Q|Q (m)
A-B	150	27	1000	27000	**0,011**	0,62	3,267	297,0	0,00733	**0,01833**	1,04	9,068	494,8	-0,00142	**0,01691**	0,96	7,717	456,5	-0,00006	**0,016848**	0,95	7,664
B-C	150	27	1000	27000	**1E-11**	0,00	0,000	0,0	0,00733	**0,00733**	0,41	1,449	197,8	-0,00142	**0,00591**	0,33	0,942	159,5	-0,00006	**0,005848**	0,33	0,923
A-C	200	5,9	1000	5900	**-0,044**	1,40	-11,422	259,6	0,00733	**-0,03667**	1,17	-7,935	216,4	-0,00142	**-0,03809**	1,21	-8,562	224,8	-0,00006	**-0,038152**	1,21	-8,588
					Σ		-8,155	556,6	***7,326***	Σ		2,5816	909,0	***-1,420***	Σ		0,10	840,7	***-0,0577***	Σ		0,00
									Δq (l/s)					***Δq (l/s)***					***Δq (l/s)***			
				Max flow (m³/s):	0,044			Δq /max flow:	**17%**	0,037				**3,87%**	0,038				**0,151%**	0,038		

Next step is to check the excess pressure in the highest taps during the maximum demand period within the three housing areas, where $P_{excess} = P_{pump} - H_s - \Sigma h_f$. ($H_s = HT - H_{pump}$)

Area I: $P_{excess} = 70 - (37 - 10) - (5.45 + 7.66) =$ 29.89 m (>20 m, **Ok**)
Area II: $P_{excess} = 70 - (33 - 10) - (5.45 + 8.59) =$ 32.97 m (>20 m, **Ok**)
Area III: $P_{excess} = 70 - (38 - 10) - (5.45 + 8.59 + 13.07) =$ 14.89 m (**<20 m, NOT OK!**)

The excess pressure is Ok (>20 m) in the highest taps in Area I and Area II, but not in Area III (since it is even lower than 15 m). As in the previous problem the highest excess pressure never exceeds 70 m in lowest taps here which is Ok, but therefore it is impossible to raise the pump head to avoid too low pressure in Area III.

The velocity is larger than 0.6 m/s in pipes P-A, A-B, A-C and A-D at design flow, but too low (<0.6 m/s) in pipe B-C (0.33 m/s) why this needs to be flushed regularly (during this period with closed pipe A-D).

Answer: <u>Final flow distribution in figure above, and excess pressure, >20 m in highest taps Ok in Area I and Area II, but not Ok in Area III (14.9 m). Pipe B-C need to be flushed regularly during this pipe break period (velocity <0.6 m/s).</u>

<u>Solution</u>: Problem 3

(Short solution)

i. Initial alkalinity 0.82 mM

ii. Choose pH=8, and NaOH is best base to keep hardness and alkalinity in correct range for treated water

iii. Answers 3-5 vary depending on choice of base, e.g.

Dose around 260 mg/L for NaOH (if Ka=6.5)

After adding coagulant, final alkalinity around 6 mM for NaOH

Regardless of coagulant, alkalinity is too high and aeration is recommended. 1.5