THIS QUESTION PAPER MUST BE HANDED-IN TO THE INVIGILATOR AT THE END OF THE EXAMINATION

CRANFIELD UNIVERSITY

Examination

SCHOOL OF ENERGY, ENVIRONMENT AND AGRIFOOD
WATER AND WASTWATER ENGINEERING
MSc / PgD / PgC

CHEMICAL PROCESSES

Friday 5 February 2016: 14.00 – 16.30

Open Notes

INSTRUCTIONS TO CANDIDATES:

Attempt **all** questions in Section A.

Attempt **one question only** from Section B.

Start each answer on a separate page.

Candidates are allowed a non-programmable calculator, 1 x A4 file of material, personal notes, and one book (Metcalf & Eddy: Wastewater Engineering).

SECTION A (COMPULSORY)
Question A-1 – Compulsory

1. Coagulant demand:

Powdered activated carbon (PAC) is being used for natural organic matter (NOM) removal from a moorland source water at a drinking water treatment works (WTW). The PAC is used before coagulation to provide enhanced NOM removal at a WTW providing 50 million litres of water per day.

Coagulation will be used to reduce the remaining Dissolved Organic Carbon (DOC) in the water from 7 mg/L to 1.5 mg/L and will also remove the PAC from the water. If the DOC has a coagulant demand of 1.3 mg of Fe^{3+} per mg of DOC and the PAC exerts a coagulant demand of 0.03 ng of Fe per particle of PAC, what is the required coagulant dose in mg/L of Fe?

Assume PAC particles are spherical. The volume of a sphere is given by: $4/3\ \pi r^3$.

The PAC dose applied is 20 mg/L.

The PAC density is 280 kg/m^3.

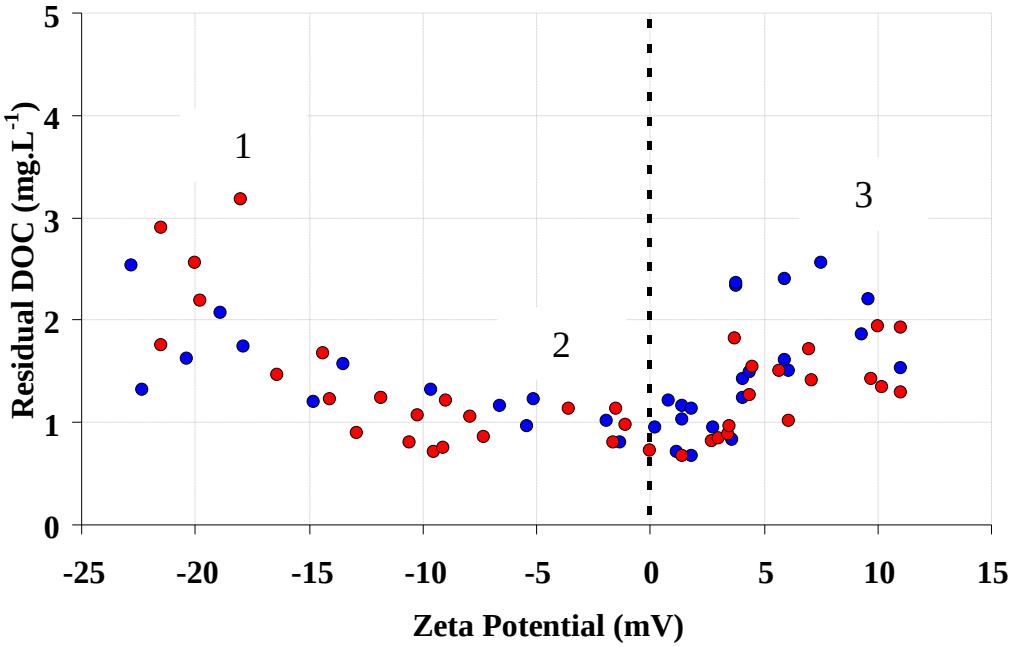
The particle size of the PAC is 12 µm.

[10 marks]

Question A-1 – Compulsory (continued)

2. Jar Testing:

A series of coagulation jar test experiments were carried out on an upland water source. After the coagulated sample had settled, the zeta potential of the clarified water was measured along with the residual dissolved organic carbon (DOC) in the water. The data was plotted on a graph and the following was produced:



(a) What is the purpose of carrying out jar tests and how do we use the information obtained?

[4 marks]

(b) What is zeta potential?

[2 marks]

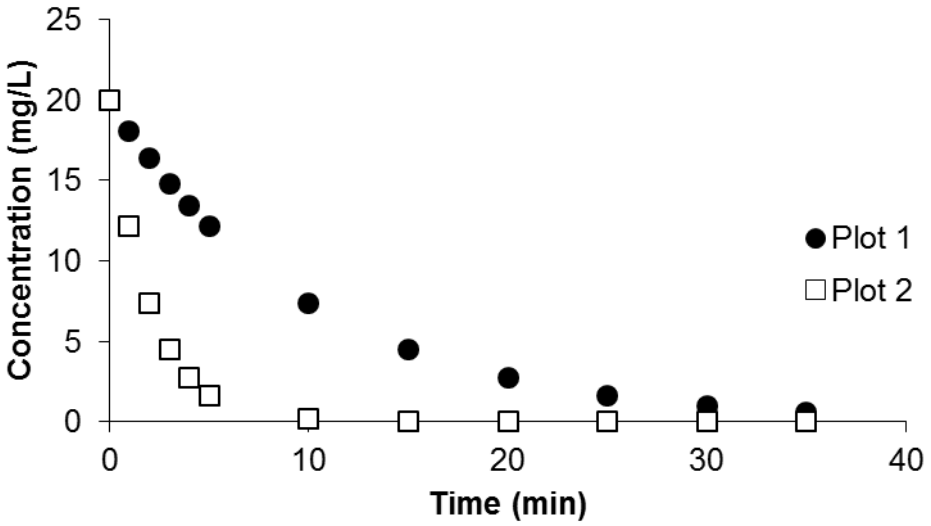
(c) Explain what is happening in regions 1, 2 and 3 on the figure in terms of the zeta potential and its impact on DOC removal.

[9 marks]

[Total 25 marks]

Question A-2 – Compulsory

1. The figure below shows results of the degradation of methylene blue dye using UV/H_2O_2 with two different lamps. One of them emits light at 254 nm and the other one at 300 nm. Considering the data answer the following questions:



(a) What is the order of the reaction?

[1 mark]

(b) What is the time required to remove 95% of the dye, if the degradation kinetic constant, k, for plot 1 and plot 2 are 0.1 min^{-1} and 0.5 min^{-1}, respectively? Calculate using the reaction rate equation.

[5 marks]

(c) Identify from the graph which plot shows the result of using the lamp at 254 nm and which one of using the lamp at 300 nm? Give one reason why.

[3 marks]

(d) During the degradation of the dye with the AOP treatment there is discoloration of the water (from blue to transparent). Give a reason why this happens.

[3 marks]

Question A-2 – Compulsory (continued)

2. A treatment works operator is carrying out a set of jar tests to optimise organics removal for the purpose of reducing trihalomethane (THM) and haloacetic acid (HAA) formation potential (FP). After the jar tests the following measurements are made: DOC, Ultraviolet Absorbance (UV), THM-FP, HA-FP and zeta potential. The results are shown in the table below.

Jar	DOC (mg/L)	UV (m^{-1})	Zeta Potential (mV)	THM-FP (µg/L)	HAA-FP (µg/L)
1	3.3	12	-18	150	100
2	1.8	7	-14	135	95
3	1.1	5	-10	100	90
4	1.0	3	-5	80	60
5	0.8	2	0	85	65
6	1.2	4	5	115	85

(a) Which conditions (jar) show the optimal dose in terms of:
   (i) DOC removal
   (ii) THM/HAA minimisation

[2 marks]

(b) Explain why optimal removal of DOC and minimisation of THM/HAA may not occur under the same conditions.

[3 marks]

(c) Describe how the formation potential tests are carried out

[8 marks]

[Total 25 marks]

SECTION B

Attempt <u>one question only</u> from Section B (B-1 <u>or</u> B-2)

Question B-1

Precipitation application in water and wastewater treatment

1. Explain the terms 'lime softening process', 'iron flocs' and 'common ion effect'.

[6 marks]

2. An industrial plant has to treat a waste stream which contains calcium (Ca), magnesium (Mg) and a number of heavy metals including cadmium (Cd), lead (Pb) and manganese (Mn). The heavy metals can be removed by adjusting the pH. The heavy metals are present at concentrations of approximately 0.002 M, and the magnesium and calcium concentrations are both 0.005 M. The relevant unbalanced reactions and solubility products for these metals are:

$Ca(OH)_{2\,(s)} \leftrightarrow Ca^{2+}_{(aq)} + OH^-_{(aq)}$	$K_{sp} = 1.3x10^{-6}$
$Cd(OH)_{2\,(s)} \leftrightarrow Cd^{2+}_{(aq)} + OH^-_{(aq)}$	$K_{sp} = 5.9x10^{-15}$
$Mg(OH)_{2\,(s)} \leftrightarrow Mg^{2+}_{(aq)} + OH^-_{(aq)}$	$K_{sp} = 8.9x10^{-12}$
$Mn(OH)_{2\,(s)} \leftrightarrow Mn^{2+}_{(aq)} + OH^-_{(aq)}$	$K_{sp} = 1.9x10^{-13}$
$Pb(OH)_{2\,(s)} \leftrightarrow Pb^{2+}_{(aq)} + OH^-_{(aq)}$	$K_{sp} = 1.2x10^{-15}$

M (Cd) = 112.4 g/mol
M (Pb) = 207.2 g/mol
M (Mn) = 54.9 g/mol
M (Ca) = 40.1 g/mol
M (Mg) = 24.3 g/mol

Answer the following:

(a) Within what pH range would all the heavy-metal pollutants from the industrial waste stream be precipitated, but not magnesium and calcium?

[13 marks]

(b) What is the residual concentration of calcium (in mg/l) in the waste stream if the pH is raised to 13?

[4 marks]

(c) Which chemicals (name two) could you use to correct the waste stream pH (if it were currently acidic)?

[2 marks]

Question B-1

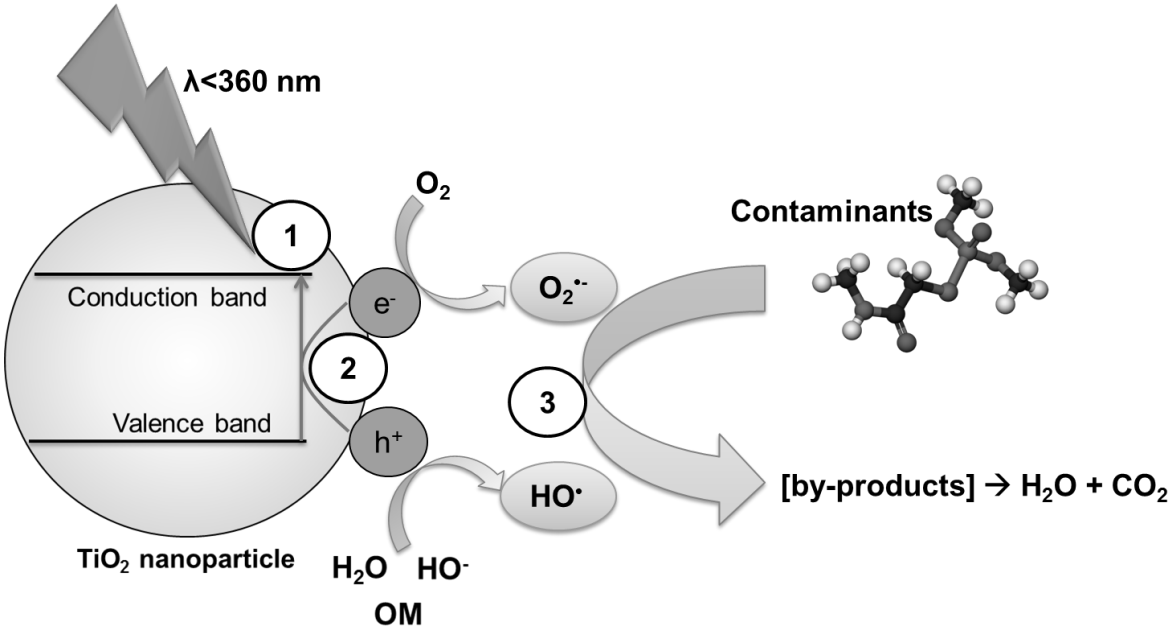
Oxidation and advanced oxidation processes

3. (a) How does the advanced oxidation process UV/H_2O_2 generate highly oxidising radicals to degrade contaminants in water?

[3 marks]

(b) Use the diagram below to explain how UV/TiO_2 generates radicals in three steps (1-3 on the diagram)

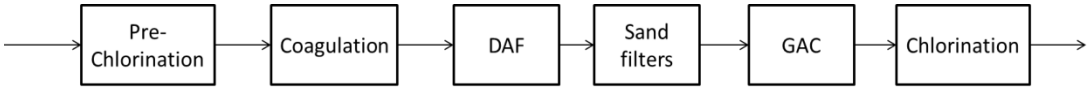
[8 marks]



Question B-1

Oxidation and advanced oxidation processes (continued)

4. A drinking water treatment works utilises the treatment steps shown in the flowsheet below. Recently, some analyses of the treated water have revealed the presence of pesticides above the regulated values. To solve this issue, the company has decided to install a UV/H_2O_2 plant.



(a) Select from the three options below (i, ii and iii) the appropriate flowsheet for the works after the UV/H_2O_2 [denoted AOP] plant has been installed.

[4 marks]

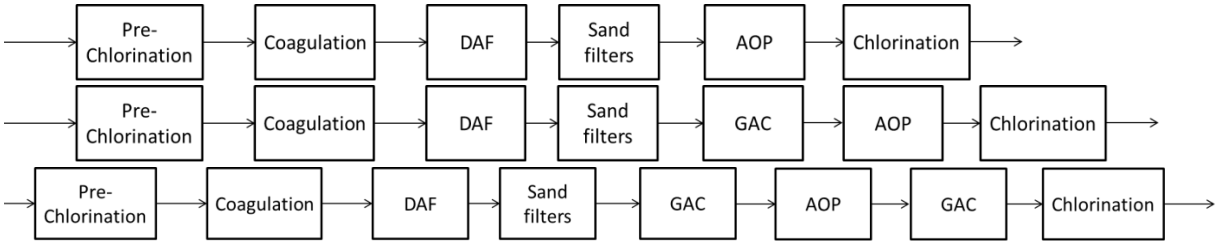
(b) Give reasons for your choice.

[10 marks]

i)

ii)

iii)



[Total for Question B-1 50 marks]

Question B-2

Ion Exchange

A fixed bed ion exchanger is to be considered for DOC removal at a potable water works with a throughflow of 1200 m^3 h^{-1}. The DOC of the water to be treated is 2.5 mg l^{-1} and has a charge of 1.8 meq $gDOC^{-1}$. The resin has a specific capacity for DOC of 0.8 eq l^{-1} and is to be operated for a recommended minimum of 8 h.

(a) Briefly describe the site parameters that should be considered before implementation to establish whether efficient operation can be expected if the unit is installed.

[5 marks]

(b) How much resin is required?

[4 marks]

(c) What is the hydraulic loading rate?

[2 marks]

(d) Comment on the likelihood of achieving complete separation (i.e. 100%) of the DOC.

[2 marks]

(e) Determine the new run time if a leakage rate of 0.3 mg l^{-1} is determined upon commissioning.

[4 marks]

(f) The resin is regenerated with 50 g NaCl l^{-1} in a sequence of: regeneration (7.5 Bv h^{-1}, for 20 minutes), slow rinse (2.5 Bv h^{-1}, for 20 minutes) and finally fast rinse (15 Bv h^{-1}, for 10 minutes). Rinse water is made up of treated water. What will be the DOC concentration in the waste regenerant (in g l^{-1})? What proportion of flow does the regenerant flow comprise? Explain whether this used brine would be suitable for subsequent regenerations.

[8 marks]

Question B-2

Adsorption

2,4-Dichlorophenoxyacetic acid (2,4-D) is a widely used herbicide that is found in some source waters used for drinking.

(g) What physico-chemical properties of this herbicide would you want to know to help understand whether it may be removed by activated carbon adsorption?

[11 marks]

(h) Describe what experimental tests you might carry out to help you assess whether activated carbon adsorption would be able to remove the herbicide from the water effectively. What information would you obtain from these experiments that would be useful for the design of a full-scale system and what are the limitations of the experimental approach taken?

[14 marks]

[Total for Question B-2 50 marks]