

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

**CRANFIELD UNIVERSITY**

**Examination**

**SCHOOL OF WATER, ENERGY AND ENVIRONMENT  
WATER AND WASTEWATER ENGINEERING**

**CHEMICAL PROCESSES**

**Thursday 2 February 2017: 09.00 - 11.30 (2hrs 30mins)**

**Open Note and Open Book**

**INSTRUCTIONS TO CANDIDATES:**

Candidates should attempt **ALL** questions in **SECTION A** and **ONE question only** from **SECTION B**. Start each new 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).

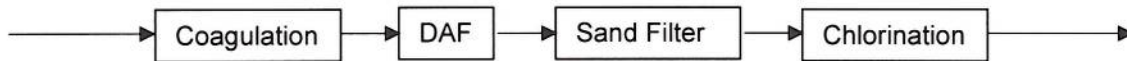
**EXAM MATERIALS:**

This paper is provided with **NO** additional materials.

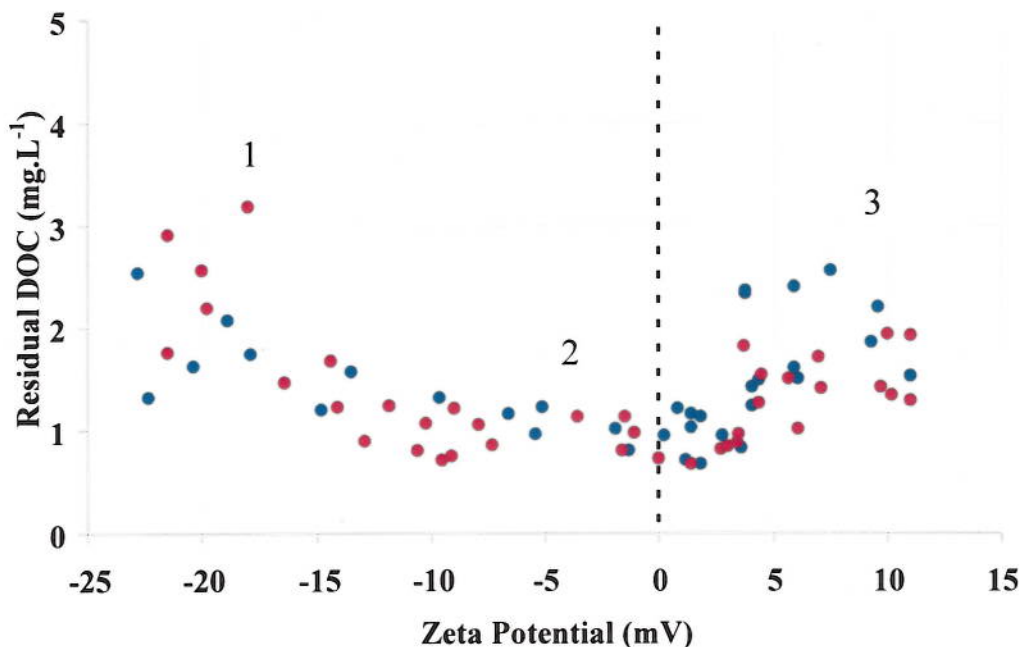
## Section A Compulsory

### Question A-1

You are a Process Engineer working for Northern Water. You are responsible for the operation of a water treatment works (WTW) which uses coagulation as the main treatment process for removal of organics. The process diagram is shown below.



A seasonal change has increased the organic loading in the raw (influent) water and you have had to carry out a series of jar tests to determine the optimal conditions for treatment. 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) Explain how this data might have been generated in the laboratory using the jar tester.

[9 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]

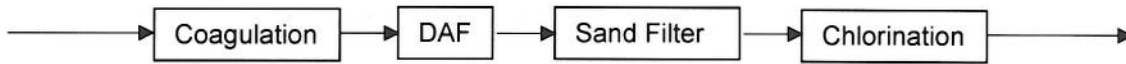
(d) What are the limitations of performing experiments on a jar tester?

[5 marks]

[Total 25 marks]

### Question A-2

Once coagulation has been optimised to reduce DOC as much as possible, the flocs are separated, the water is filtered and then disinfected. At this works chlorine is the disinfectant of choice as shown in the process diagram below.



(a) Describe how chlorine disinfects water

**[2 marks]**

(b) Which water parameters do you have to consider to achieve the optimum chlorination and what water quality tests would you consider?

**[4 marks]**

Disinfection byproducts (DBPs) are formed when the disinfectant applied reacts with the natural organic matter and bromide present in the water after treatment.

(c) Describe the impact of pH, temperature and bromide concentration on the DBPs trihalomethanes and haloacetic acids. Describe one method for abatement of DBPs.

**[5 marks]**

The regulator would like to set a drinking water standard for trichloroacetic acid. Tests carried out have shown that the lowest dose causing any effect is 60 mg/kg/day. A safety factor of 1000 is recommended.

(d) What is the safe dose for humans and what is the safe concentration in drinking water in µg/L? It is assumed that an adult weighs 70 kg, drinks 2 L of water per day and 50% of exposure to trichloroacetic acid comes from drinking water.

Safe concentration = (safe dose × body weight × %exposure from drinking water) ÷ consumption

**[5 marks]**

The formation of regulated disinfection byproducts such as trihalomethanes are often maximised during chlorination and alternative disinfectants are often considered to reduce their formation. Two such alternatives are chloramines and chlorine dioxide.

- (e) How is chloramine typically added to water before pumping it into the distribution system? Please briefly describe the procedure starting from use of chlorine for primary disinfection. How is the disinfectant level adjusted to the desired concentration?

**[2 marks]**

- (f) Chlorine dioxide ( $\text{ClO}_2$ ) can under certain conditions be more 'efficient' in killing microorganisms than chlorine although  $\text{ClO}_2$  has a higher Ct value. How can this apparent discrepancy be explained?

**[2 marks]**

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, UV, THM-FP, HA-FP and zeta potential. The results are shown in the table below.

Jar	DOC (mg/L)	UV ( $\text{m}^{-1}$ )	Zeta Potential (mV)	THM-FP ( $\mu\text{g/L}$ )	HAA-FP ( $\mu\text{g/L}$ )
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

- (g) Which conditions (jar) show the optimal dose in terms of:

- (i) DOC removal
- (ii) THM/HAA minimisation

**[2 marks]**

- (h) Why might these be different?

**[3 marks]**



## Section B Water and Wastewater Treatment

### Question B-1

Now that coagulation is optimised the WTW described in Section A is performing well. However, news has come in from the testing laboratory that they are detecting the pesticide Diuron in the raw and treated water at levels greater than the  $0.1 \mu\text{g/L}$  limit set by the regulator. Your boss has asked you to consider the following technologies for the removal of Diuron:

1. Granular activated carbon (GAC)
2. Advanced Oxidation Process (AOP)

- (a) What physico-chemical properties would you want to know about Diuron to help understand whether it may be removed by activated carbon adsorption?

**[11 marks]**

- (b) Describe what experimental tests you might carry out to help you assess whether activated carbon adsorption would be able to treat 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?

**[9 marks]**

- (c) Calculate the time to remove 99% of Diuron using UV/H<sub>2</sub>O<sub>2</sub>: if the pseudo-first order kinetic constant is  $0.3 \text{ min}^{-1}$

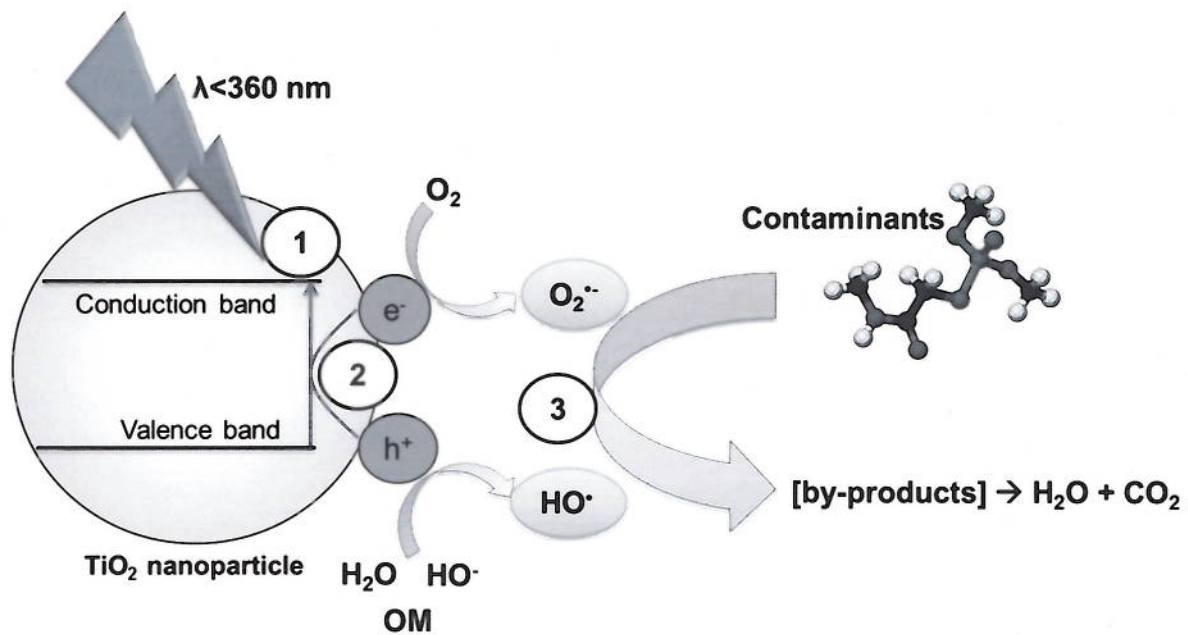
**[5 marks]**

- (d) How does the advanced oxidation process UV/H<sub>2</sub>O<sub>2</sub> generate highly oxidising radicals to degrade contaminants in water?

**[3 marks]**

- (e) Use the diagram below to explain how UV/TiO<sub>2</sub> generates radicals in three steps (1-3 on the diagram)

**[8 marks]**



- (f) Using the schematic process diagram below, draw a new schematic incorporating the AOP and any other technology required.



[4 marks]

- (g) Consider both technologies and discuss the implementation of the technology including the operational considerations that will have to be made.

1. Granular activated carbon (GAC)
2. Advanced Oxidation Process (AOP)

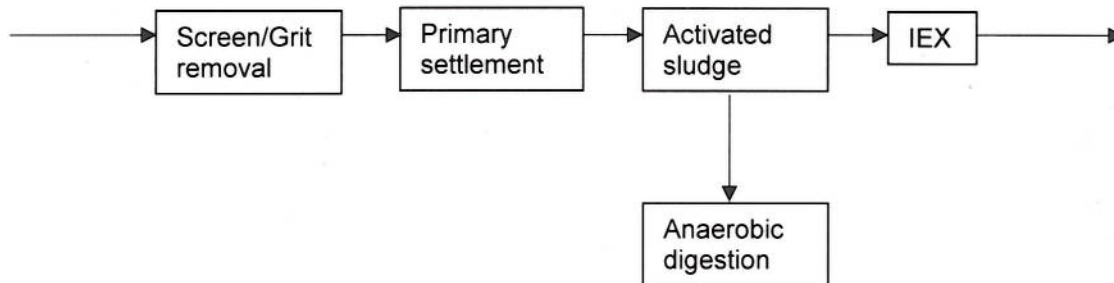
[7 marks]

[3 marks]

## Question B-2

As a Process Engineer at a Wastewater Treatment Works, you have been asked to help optimise treatment for removal of phosphorus and ammoniacal nitrogen. Currently there is no treatment to remove phosphorus and it is suggested that precipitation is implemented. There is an activated sludge plant and the effluent from this goes into an Ion Exchange Plant for removal of ammoniacal nitrogen (see process diagram). The existing levels and targets are as follows:

	Phosphorus (mg/L)
Existing level in Influent	16
Target level after Precipitation	1
	Ammoniacal Nitrogen (mg $\text{NH}_4^+\text{-N l}^{-1}$ )
Level exiting activated sludge process	40
Target level after Ion Exchange	10



### B-2-A Precipitation

- a) When using precipitation to remove phosphorus with ferric, advise whether ferric chloride is suitable.

[1 mark]

- b) Jar tests will have to be carried out to establish the Fe:P molar ratio required to remove the phosphorus, however in order to reduce the sludge levels, the sludge produced during this process should not exceed 0.15 kg per m<sup>3</sup> of wastewater. What is the maximum Fe:P ratio applicable in order to fulfil this condition? (MW (Fe) = 56g/mol, MW (P) = 31 g/mol, MW (H) = 1g/mol, MW(O) = 16 g/mol)

[20 marks]

- c) What are the two main reaction mechanisms involved in removal of phosphorus by  $\text{Fe}^{3+}$ ?

[2 marks]

- d) When would you choose  $\text{FeSO}_4$  over  $\text{FeCl}_3$  to remove phosphorus from wastewater?

[1 mark]

- e) Removal of phosphorus from wastewater by chemical precipitation will increase the levels of phosphate in the sludge. What could be a serious consequence of this increase?

[1 mark]

### **B-2-B Ion exchange**

Following treatment of a  $30000 \text{ m}^3 \text{ d}^{-1}$  wastewater flow in a carbonaceous activated sludge process, the effluent is characterised by an effluent ammonia concentration of  $40 \text{ mg NH}_4^+ \text{-N L}^{-1}$ .

- a) An ion-exchanger is sited on the effluent to remove the residual ammonia. The IEX material has the following characteristics: a total exchange capacity of  $0.8 \text{ Eq. L}^{-1}$ ; and, an optimum hydraulic loading of  $35 \text{ Bv/h}$ . Comment on the current design run time.

[10 marks]

- b) The site has a total nitrogen consent of  $10 \text{ mg N L}^{-1}$ . Using the optimum run time calculated above and assuming a 'zero leakage rate', estimate how much resin is now required?

[5 marks]

- c) An alternate method to managing the nitrogen load is to remove the ammoniacal nitrogen in the return liquors that are recycled to the head of works from the anaerobic digester. The return liquor flow is typically 2% of the main flow and constitutes around 30% of the total nitrogen load entering the activated sludge plant.

- d) Assuming that there is no nitrogen removal in the activated sludge plant, determine an appropriate IEX resin volume.

[7 marks]

- e) What kind of resin is suitable for this application?

[3 marks]

[Total 50 marks]