Exercises IV (answers): organic micropollutant treatment III

Applied wastewater engineering

Exercise 1: Two stage activated carbon treatment

A wastewater treatment plant (pretreatment, primary clarifiers, biological tanks, secondary clarifiers) is currently constructing PAC contact reactors and sand filters to retain the PAC. The community mandates you to compute the PAC dose (mg PAC/L) based on two different scenarios of operation. In order to answer the questions you performed adsorption tests with their secondary clarified wastewater (Figure 1). You decided to compute the PAC dose based on a benzotriazole concentration in the raw wasterwater of 30 µg/L and a removal yield of 90 %.

The two scenarios are:

- PAC is only used in the PAC treatment unit (PAC contactors and sand filters)
- PAC is introduced into the PAC treatment unit and then recycled into the biological tank

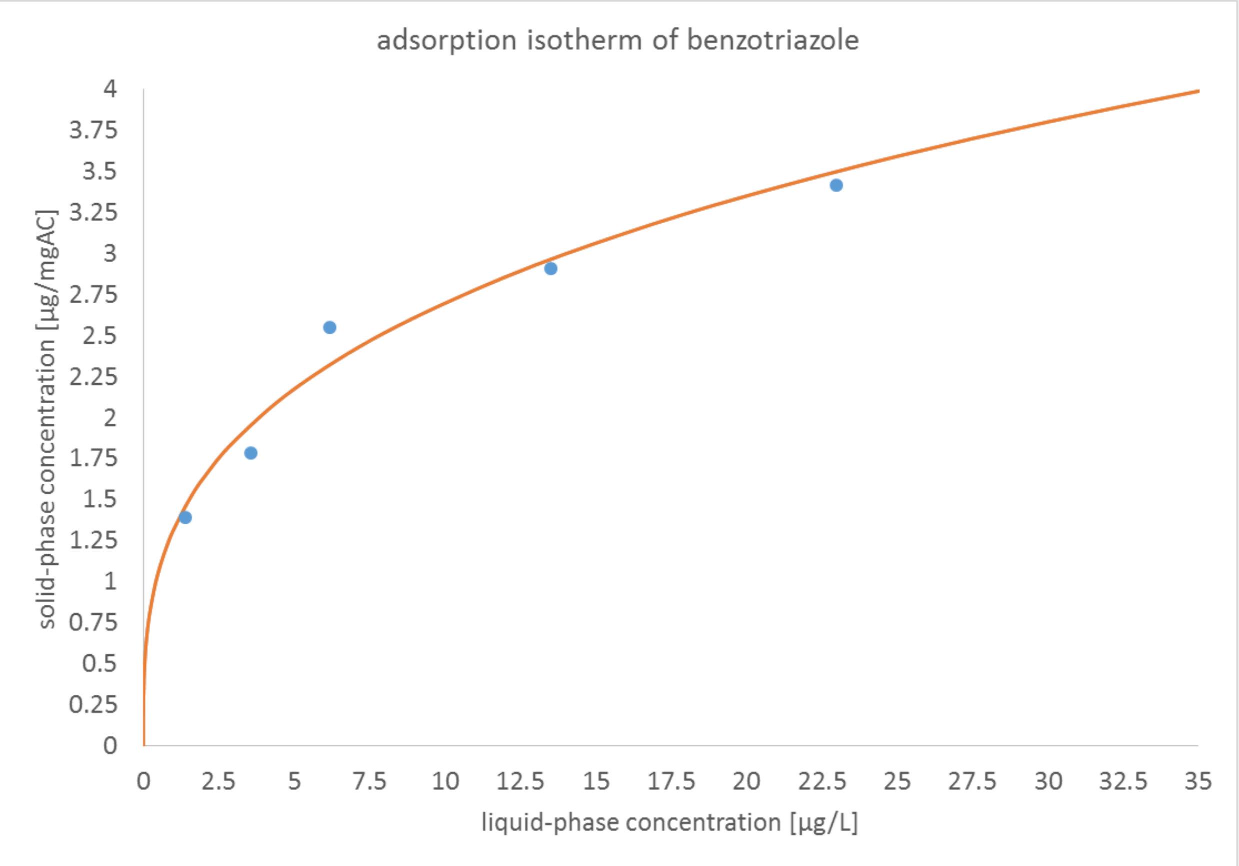

Figure 1: Adsorption isotherm of benzotriazole (data from: Super-fine powdered activated carbon (SPAC) for efficient removal of micropollutants from wastewater treatment plant effluent, Bonvin, F. et al., Water Research 2016).

a) Draw a scheme for scenario 1 and compute the PAC dose (mg PAC/L).

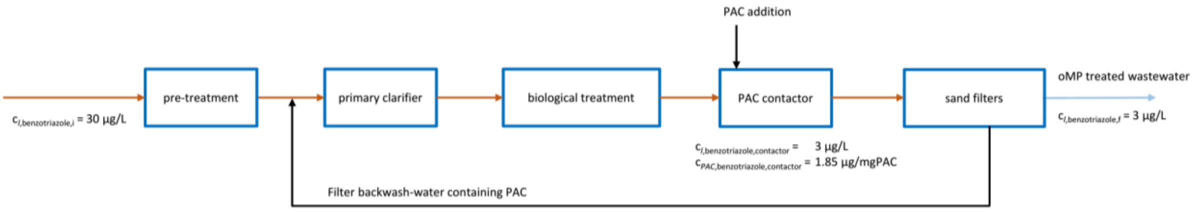

Figure 2: Scheme for scenario 1.

$$dose_{PAC} = \frac{Removal\ of\ benzotriazole_{contactor}}{c_{PAC,benzotriazole,contactor}} = \frac{c_{l,benzotriazole,i} - c_{l,benzotriazole,f}}{c_{PAC,benzotriazole,contactor}}$$
$$= \frac{30\mu g/L - 3\mu g/L}{1.85\mu g/mgPAC} = \frac{27\mu g/L}{1.85\mu g/mgPAC} = 15\ mgPAC/L$$

The required PAC dose is 15 mg PAC/L if PAC is wasted when sand filters are backwashed.

b) Draw a scheme for scenario 2 and compute the PAC consumption (conduct an iterative approach to find the result).

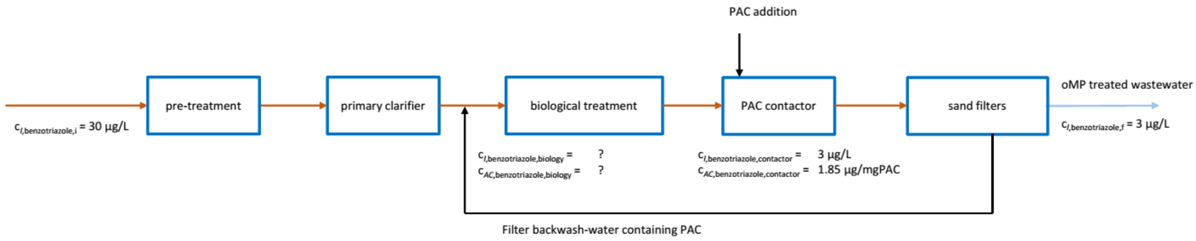

Figure 3: Scheme for scenario 2.

The PAC dose can be computed in two ways:

$$dose_{PAC,contactor} = \frac{Removal\ of\ benzotriazole_{contactor}}{c_{AC,benzotriazole,contactor}}$$
$$= \frac{c_{l,benzotriazole,biology} - c_{l,benzotriazole,f}}{c_{PAC,benzotriazole,contactor}} = \frac{x\mu g/L - 3\mu g/L}{1.85\mu g/mgPAC}$$

$$dose_{PAC,biology} = \frac{Removal\ of\ benzotriazole_{total}}{c_{AC,benzotriazole,biology}} = \frac{c_{l,benzotriazole,i} - c_{l,benzotriazole,f}}{c_{PAC,benzotriazole,biology}}$$
$$= \frac{30\mu g/L - 3\mu g/L}{y\mu g/mgPAC} = \frac{27\mu g/L}{y\mu g/mgPAC}$$

The PAC dose based on the biology can also be computed in a second way:

$$dose_{PAC,biology-2} = \frac{Removal\ of\ benzotriazole_{biology}}{c_{AC,benzotriazole,biology} - c_{AC,benzotriazole,contactor}} = \frac{30\mu g/L - x\mu g/L}{y\mu g/mgPAC - 1.85\mu g/mgPAC}$$

Both equations (or the three equations if we include the second equation based on the concentrations in the biology) should be equal as there is only one addition of PAC. By itineration, we find the following result:

Parameter	unit	comp.1	comp.2	comp.3	comp.4	comp.5	comp.6	comp.7
$c_{l,benzotriazole,biology}$ (x)	µg/L	25	20	19	18	17	15	10
$c_{PAC,benzotriazole,biology}$ (y)	µg//mgPAC	3.60	3.35	3.30	3.25	3.20	2.70	2.15
$dose_{PAC,contactor}$	mgPAC/L	11.9	9.2	8.6	8.1	7.6	6.5	3.8
$dose_{PAC,biology}$	mgPAC/L	7.5	8.1	8.2	8.3	8.4	8.9	10.0
$dose_{PAC,biology-2}$	mgPAC/L	2.9	6.7	7.6	8.3	8.6	9.6	12.5

Computation 4 gives nearly the same dose required in both cases. Therefore, only about 8.3 mg PAC/L is required if this mode of operation is chosen. Hence, if the PAC is recycled into the biology, the PAC dose required to achieve the same final yield reduced tremendously. However, we neglected that the PAC is less effective in the biological tank due to higher COD concentrations. Hence, the real gain in PAC dosage will be lower than estimated here.

c) Do you expect that scenario 2 will work better or worse in reality than computed in b).

This question is difficult to be answered without any additional experiments because we do not really have the adsorption isotherm in the water of the biological tank:

The COD concentration is higher in the untreated water (entry of biological tank), hence the adsorption capacity will be lower.

In contrast, there might be biodegradation of benzotriazole which increases the removal capacity.

Exercise 2*: Activated carbon use*

a) What are the advantages of granular activated carbon in a filter bed as compared to powdered activated carbon?

- *No storage of granular activated carbon is required. Hence, the risks of an explosion of powdered activated carbon can be avoided.*
- *The filling of a granulated activated carbon filter is relatively tedious. However, once in place, the operation is rather straightforward. On the other hand, the use of powdered activated*

carbon requires the constant dosage and operation of the wetting process for the addition of powdered activated carbon.

- *Granulated carbon is itself a filter and no additional filter system has to be operated. In contrast, the use of powdered activated carbon requires a system to remove it again from the wastewater (coagulation (and flocculation process) followed by a sedimentation process or a filtration process).*
- *Granular activated carbon can be regenerated which is not possible with powdered activated carbon*

b) How can the consumption of powdered activated carbon (PAC) be reduced?

- *An efficient biological treatment system beforehand in the treatment train (low COD content)*
- *The choice of an activated carbon product that has a high adsorption efficiency (preliminary tests in the laboratory)*
- *A long retention time of the activated carbon in the system to increase the saturation rate of the activated carbon*
- *The recirculation of the activated carbon into the biological tank if possible*
- *(The choice of the adequate indicator substances)*

Exercise 3: Efficiency of adsorption on powdered activated carbon (added directly into biological tank)

Based on Figure 4 answer the following two questions:

a) What percentage of clarithromycin and candesartan is removed by a 20 mg/L of PAC dosage excluding the biological removal? Which compound is more difficult to remove with the activated carbon employed in the trials?

Only PAC removal for clarithromycin (in percent):

$$\frac{(fraction_{clarithromycin,after\ CAP\ treatment} - fraction_{clarithromycin,after\ biological\ treatment})}{(1 - fraction_{clarithromycin,after\ biological\ treatment})} \cdot 100\% = \frac{0.96 - 0.58}{1.00 - 0.58} \cdot 100\% = \mathbf{90}\%$$

Only PAC removal for candesartan (in percent):

$$\frac{(fraction_{candesartan,after\ CAP\ treatment} - fraction_{candesartan,after\ biological\ treatment})}{(1 - fraction_{candesartan,after\ biological\ treatment})} \cdot 100\% = \frac{0.41 - 0.00}{1.00 - 0.00} \cdot 100\% = \mathbf{41}\%$$

Hence, even though at a first glance it might look as candesartan is equally well removed as clarithromycin, clarithromycin is much more efficiently removed by PAC used in these trials (90 %) than candesartan (41 %). The removal of the first percent is much easier to achieve than the last few percent.

b) Is diclofenac or benzotriazol more efficiently removed by 10 mg/L PAC dosage (excluding biological removal)?

Only PAC removal for diclofenac (in percent):

$$\frac{(fraction_{diclofenac,after\ CAP\ treatment} - fraction_{diclofenac,after\ biological\ treatment})}{(1 - fraction_{diclofenac,after\ biological\ treatment})} \cdot 100\%$$
$$= \frac{0.57 - 0.03}{1.00 - 0.03} \cdot 100\% = \mathbf{56}\%$$

Only PAC removal for benzotriazole (in percent):

$$\frac{(fraction_{benzotriazole,after\ CAP\ treatment} - fraction_{benzotriazole,after\ biological\ treatment})}{(1 - fraction_{benzotriazole,after\ biological\ treatment})} \cdot 100\%$$
$$= \frac{0.82 - 0.33}{1.00 - 0.33} \cdot 100\% = \mathbf{73}\%$$

Even though benzotriazole is in group 2, it is more efficiently removed by PAC (73 %) than diclofenac (group 1; 56 %) during the trials at wastewater treatment plant Schönau.

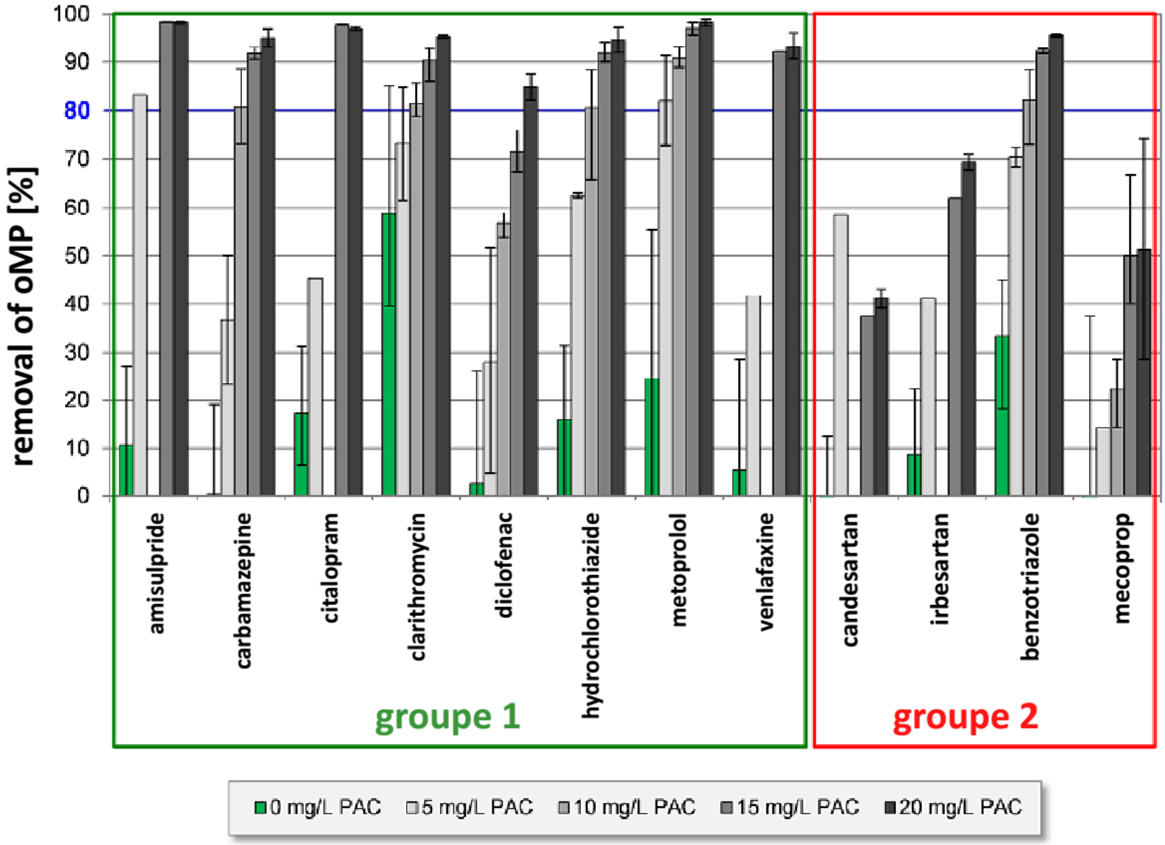

Figure 4: Trials conducted at the wastewater treatment Schönau in Cham (PAK im Belebtschlammbecken, Frank, K. et al., HSR and UMTEC 2015).