

On the Uptake Mechanisms of Organics from Natural Water – Investigations with Strong and Weak Base Ion Exchangers and Their Corresponding Copolymers

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ABSTRACT

In laboratory column experiments, ion exchange resins and the corresponding non-functionalized copolymers were compared in order to investigate the uptake mechanisms of organics during the water demineralization process. To improve the detection limit, ^{14}C -labeled model substances (β -alanine, starch, synthetic humic acid type M42) were used. These compounds are supposed to represent the TOC fractions of neutrals/amphiphilics, polysaccharides and humics following the LC-OCD method. The uptake was investigated depending on the salinity and pH, the concentration of the organics, and the loading temperature. The main results are:

- At neutral pH, a near 100 % removal of β -alanine and starch by ion exchange and/or adsorption was observed, whereas humic acid was taken up by ion exchange to an extent of about 10 %.
- In acidic conditions, β -alanine and starch were completely removed up to the breakthrough point of the sulfate ions. These elute the organics. Humic acid will be removed owing to precipitation.
- The last mechanism allows the removal of humic acid by the copolymers too. These are inefficient in regard to the uptake of β -alanine and starch.
- The variation in the concentration of the organics as well as that in the loading temperature have only a subordinate influence on the uptake.

INTRODUCTION

Organics in the make-up water of power stations represent a potential corrosion risk because of their likely thermolytic decomposition and the volatility of the fission products into the gas phase of a steam/water cycle [1–5]. Therefore,

a total organic carbon (TOC) maximum of $200 \mu\text{g} \cdot \text{kg}^{-1}$ (VGB guidelines) and $100 \mu\text{g} \cdot \text{kg}^{-1}$ (EPRI guidelines) should not be exceeded. Under complicated raw water conditions, the classic demineralization process based on ion exchange is not sufficiently able to keep this limit. Biologically active activated carbon filters or reverse osmosis are alternatives [6,7]. However, this means a change in the demineralization plant concept and this is only worth it if the limit is considerably exceeded.

The other way – in cases of small overstepping – could be to improve the process within a given plant design without cost-intensive rebuilding. Thus, we have investigated the influence of the loading temperature on the uptake of organics [8]. Our results show that higher loading temperatures cause slightly later breakthrough points, and higher regenerating temperatures cause better regeneration factors, however, the uptake during the loading phase before the breakthrough point is not influenced by temperature; the equilibrium constant of the sorption system was found to be temperature-independent (the reaction enthalpy is about zero). As a conclusion, one can follow only the second option for changing the equilibrium constant, that is to change the uptake properties of the sorption system.

For this reason, non-functionalized ion exchange resins were included in the experiments to get a better understanding of the uptake mechanisms of the different fractions of organics. These non-functionalized resins have the same basic structure as the corresponding ion exchange resins, but they do not have the active groups, which determine the ion exchange properties. Thus, it is better to distinguish between ion exchange adsorption and "pure" adsorption. Therefore, these non-functionalized matrices are referred to as "copolymers."

β -alanine, starch and a synthetic humic acid were selected as model substances related to the fractions of neutrals/amphiphilics, polysaccharides and humics, following the liquid chromatography-organic carbon detection (LC-OCD) method according to Huber [9]. Next to the chromatographic nondetectable, hydrophobic organic carbon (HOC), these fractions of polysaccharides and neutrals/amphiphilics often show the lowest rate of removal from natural waters. The humics are indeed easily removable, but a special synthetic humic acid was included in the investigation to learn more about the uptake mechanism. Using the model substances instead of the mixture of a natural raw water, it should be easier to study the behavior of the different groups of organics. β -alanine was selected due to its simple composition in connection with the amphoteric properties of a zwitterion. Starch should be a well-defined polysaccharide.

All the model substances were labeled with ^{14}C atoms. This allows a better detection limit in relation to the classic TOC analysis. Further, possible organic leachables of the adsorbers do not influence the measurements.

EXPERIMENTAL DETAILS [10]

Adsorptives

Inactive starch and β -alanine were used in analytical grade quality (Merck). ^{14}C -labeled starch comes from BioTrend as uniform C-labeled product ($340 \text{ mCi} \cdot \text{mmol}^{-1}$), and ^{14}C -labeled β -alanine is a Sigma-Aldrich product ($49 \text{ mCi} \cdot \text{mmol}^{-1}$). The position of the ^{14}C atom (bold type) is shown in *Figure 1*.

The humic acid type M42 is a synthetic product developed and produced in the Forschungszentrum Rossendorf, Germany [11,12]. The synthesis starts with a mixture of glutamic acid, xylose and water, which is heated for 92 hours at 80°C under reflux and N_2 atmosphere. After cooling, the formed solid melanoidin fraction is separated

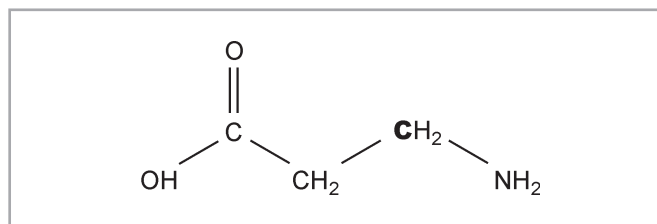


Figure 1: ^{14}C -labeled β -alanine.

from the liquid fraction by centrifugation. Then, the solid product is washed with ethanol and ether. The humic acid-like melanoidin fraction is extracted by stirring the solid product with NaOH under inert gas. The synthetic humic acid is precipitated from alkaline solution with HCl. Several steps of cleaning follow. Subsequently, the purified product is lyophilized. To obtain the ^{14}C labeling, uniform ^{14}C -labeled glutamic acid is used for synthesis.

Table 1 shows some characteristics of the humic acids used in this work in comparison to natural acids from the literature.

	Elemental Composition [%]					Content [%]	
	C	H	N	S	O	Ash	Moisture
M42 (M145) [12]	56.1±0.3	4.1±0.1	4.4±0.1	0	26.8±0.3	0.11	8.4
Natural humics [13]	50–60	4–6	2–6	0–2	30–35	n. d.	n. d.

	Functional Groups [meq · g ⁻¹]		
	COOH	PEC	Phenolic/Acidic OH Groups
M42 (M145) [12]	3.76±0.09	3.51±0.07	2.0±0.2
^{14}C M42 (M180A)	3.76±0.02	3.34±0.18	n. d.
Natural humics [14]	1.5–5.7	n. d.	2.1–5.7

Table 1: Properties of the synthetic humic acid type M42 compared to natural products.

PEC proton exchange capacity
M145, M180A internal designations
n. d. not determined

Expected TOC fraction	β -Alanine	Starch	Humic acid M42
	Neutrals/Amphiphilics	Polysaccharides	Humics
LC-OCD analysis	92 % Neutrals/ Amphiphilics 6 % POC	85 % Polysaccharides 8 % Building Blocks 5 % Neutrals/ Amphiphilics	58 % Polysaccharides 16 % Building Blocks 10 % Neutrals/ Amphiphilics 15 % POC

Table 2: LC-OCD analysis of the model substances.

POC particular organic carbon

All model substances were checked with the LC-OCD method (*Table 2*).

β -alanine could be almost completely classified as neutrals/amphiphilics. As expected, starch is mainly identified as polysaccharide. In addition, small parts of building blocks and neutrals/amphiphilics were found. Contrary to expectations, most of the synthetic humic acid was identified as polysaccharide. Also, building blocks, neutrals/amphiphilics and particular organic carbon (POC) were found. A possible explanation for this unexpected result can be the fact that the LC-OCD method's basis of the arrangement of the organics into the different groups is size-exclusion chromatography. Accordingly, the synthetic substance, chemically identified as humic acid, does not necessarily act like a humic acid in LC-OCD analysis.

Adsorbers

A weak and a strong base ion exchanger (WBA and SBA, respectively) and the corresponding non-functionalized copolymers from Rohm and Haas Company were used as adsorbers. IRA96RF and IRA900RFCI are often applied as anion exchangers in demineralization plants of power stations. *Table 3* contains some relevant properties.

Procedures

All experiments were carried out as dynamic experiments in temperature-controlled laboratory columns with a constant flow rate of 20 BV per h (bed volumes per hour) and 5 ml resin volume.

The following parameters were changed:

- the salinity (adjusted with 96–98 % H_2SO_4 ; 0 $\text{mg} \cdot \text{kg}^{-1}$ SO_4 , 400 $\text{mg} \cdot \text{kg}^{-1}$ SO_4 (related to pH = 2.5) and 800 $\text{mg} \cdot \text{kg}^{-1}$ SO_4 (related to pH = 2.3)),

- the concentration of the related organic compounds (0.5 $\text{mg} \cdot \text{kg}^{-1}$, 2.5 $\text{mg} \cdot \text{kg}^{-1}$ and 10 $\text{mg} \cdot \text{kg}^{-1}$). 2.5 $\text{mg} \cdot \text{kg}^{-1}$ total organic carbon (TOC) relates to 5.62 $\text{mg} \cdot \text{kg}^{-1}$ inactive starch, 6.18 $\text{mg} \cdot \text{kg}^{-1}$ inactive β -alanine and 3.57 $\text{mg} \cdot \text{kg}^{-1}$ inactive humic acid type M42, plus the corresponding active compound, and
- the loading temperature (20 °C, 30 °C and 40 °C).

The solutions were labeled with an activity of 30 kBq/l (starch and β -alanine) and 20 $\text{kBq} \cdot \text{L}^{-1}$ (humic acid type M42). This gives a relation of 0.01 between the active and inactive concentration in the case of starch and β -alanine and a relation of 0.2 for the humic acid.

The concentration of the inactive organic compounds was measured with LC-OCD analysis or with TOC analysis (combustion method). Liquid scintillation counting (LSC) was used for the radioactive organics. For this, 1 ml of the relevant test solution was mixed with 5 ml of a scintillation cocktail (Ultima Gold, Perkin Elmer) and measured with a LS Counter of Beckmann LS6000LL. The detection limit is 0.2 Bq/ml [16] and the relative error due to the activity measurements was determined as 0.5 %. Sulfate ions were determined with ion chromatography. The overall error of a measure point including the errors of inactive dosages, throughput and resin volume was 2.5 %.

RESULTS

In the following figures the y-axis contains the column's output concentration divided by the input concentration and the x-axis refers to the throughput in bed volumes (BV).

Resin	IRA96RF	Copolymer of IRA96RF	IRA900RFCI	Copolymer of IRA900RFCI
Type	weak base anion exchanger	IRA96RF matrix without functional groups	strong base anion exchanger	IRA900RFCI matrix without functional groups
Structure	macroporous	macroporous	macroporous	macroporous
Size	630 μm – 830 μm	630 μm – 830 μm	650 μm – 820 μm	650 μm – 820 μm
Matrix	styrene-DVB	styrene-DVB	styrene-DVB	styrene-DVB
Functional groups	ternary amine	none	quaternary amine	none
TVC (OH^-/Cl^-)	1.25 $\text{meq} \cdot \text{mL}^{-1}$	–	1.0 $\text{meq} \cdot \text{mL}^{-1}$	–
Surface (BET)*	31.5 $\text{m}^2 \cdot \text{g}^{-1}$	5.31 $\text{m}^2 \cdot \text{g}^{-1}$	16.4 $\text{m}^2 \cdot \text{g}^{-1}$	8.84 $\text{m}^2 \cdot \text{g}^{-1}$

Table 3: Characterization of the adsorbers [15].

TVC total volume capacity

* analyzed at the Forschungszentrum Rossendorf

DVB divinylbenzene

BET Brunauer, Emmett and Teller method

SBA Copolymer as Adsorber

Figure 2 shows the uptake of the three substances by the corresponding copolymer of the strong base anion exchanger depending on the sulfate concentration.

Obviously, β -alanine could not be removed from the solution at any sulfate concentration, neither in neutral (0 mg \cdot kg⁻¹ SO₄) nor in acidic (400 mg \cdot kg⁻¹ SO₄) conditions. β -alanine has an isoelectric point (IEP) of 6.9. Thus,

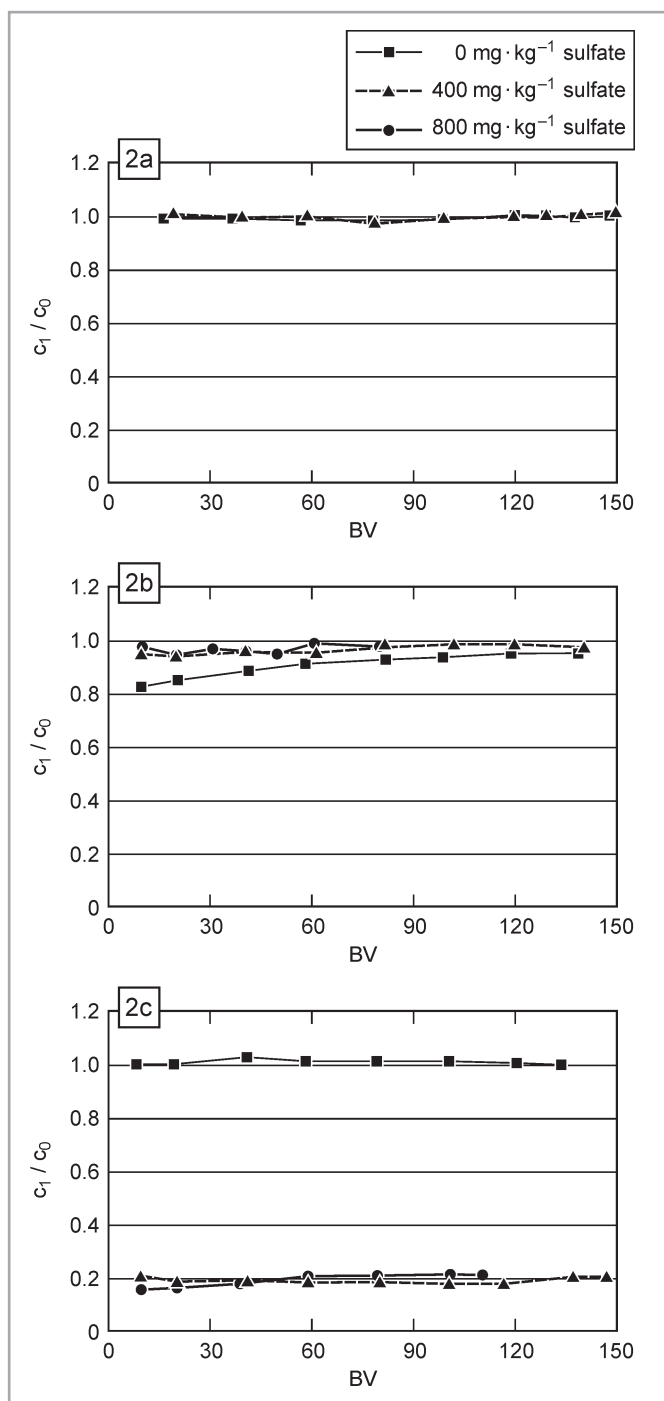


Figure 2: Uptake of β -alanine (2a), starch (2b) and humic acid (2c) by the corresponding copolymer of a SBA at different sulfate concentrations.

BV bed volumina

20 °C; 20 BV per hour; 2.5 mg \cdot kg⁻¹ TOC

it is electrically neutral in relation to the surroundings, but β -alanine has a positive and a negative charge inside (zwitterion). However, possible weak van der Waals forces are not strong enough to take up the β -alanine molecules.

At an acidic pH, β -alanine will be positively charged outwards, but the copolymer has no ionic or polar functionality, so that an uptake could not be obtained.

Like β -alanine, starch shows practically no uptake in acidic conditions. On the other hand, a small removal of about 10 % is obtained at neutral pH. That means, in contrast to the amphoteric β -alanine, starch shows weak van der Waals interaction to the copolymer, probably based on the polarity of the hydroxyl groups and/or of the ring-acetalic oxygen of the starch molecule. The hydroxyl groups themselves dissociate only to a small extent (pK = 13.3 for wheat starch under alkaline conditions [17]). This is nearly in the range of methanol (pK = 15.5) and ethanol (pK = 16) [18]. Another explanation could be size-exclusion of that small part of starch. The molecular weight of starch can be up to 100 kDa. Further investigations are necessary to decide this.

The humic acid produces a subtly differentiated picture. In neutral conditions no uptake takes place. Unlike starch, the polar phenolic and carboxylic groups of the humic acid do not lead to a small uptake. However, in acidic conditions, about 80 % of the humic acid is removed. Figure 3 gives the explanation.

It is obvious that more and more precipitation takes place with progressive throughput and a filter layer is formed by precipitated humic acid molecules. The phenomenon of humic acid precipitation at pH values lower than approximately pH 3.5 is principally known and used for the operational definition of fulvic and humic acids. It plays an important role in the separation of humic and fulvic acids from natural waters [19, 20]. About 20 % of the humic acid can pass the filter (Figure 2). This result could be caused by a smaller molecular size and/or a higher solubility of the non-retained humic acid fraction because of functional and structural differences compared to the precipitated fraction.

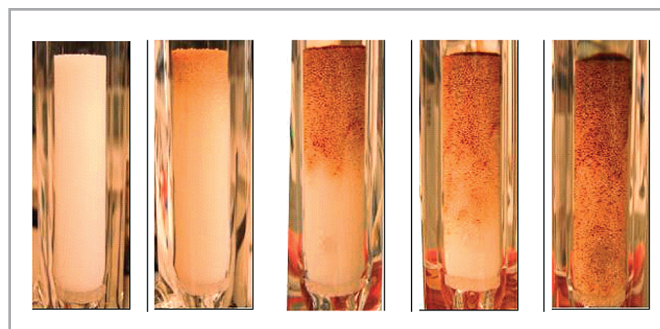


Figure 3: Progressive precipitation of humic acid at the copolymer of SBA depending on throughput (400 mg \cdot kg⁻¹ SO₄²⁻; 10 mg \cdot kg⁻¹ TOC as humic acid type M42).

SBA as Adsorber

Figure 4 gives an overview of the uptake of the three model substances by the corresponding strong base ion exchanger, which has quaternary amine groups as exchangeable active places.

In the absence of sulfate, the pH is in the neutral range ($\text{pH} \approx 6.5$). In contrast to the copolymer, β -alanine is nearly completely removed from the solution. Ion exchange or adsorption are possible uptake mechanisms. β -alanine as a molecule with dipolar ion character

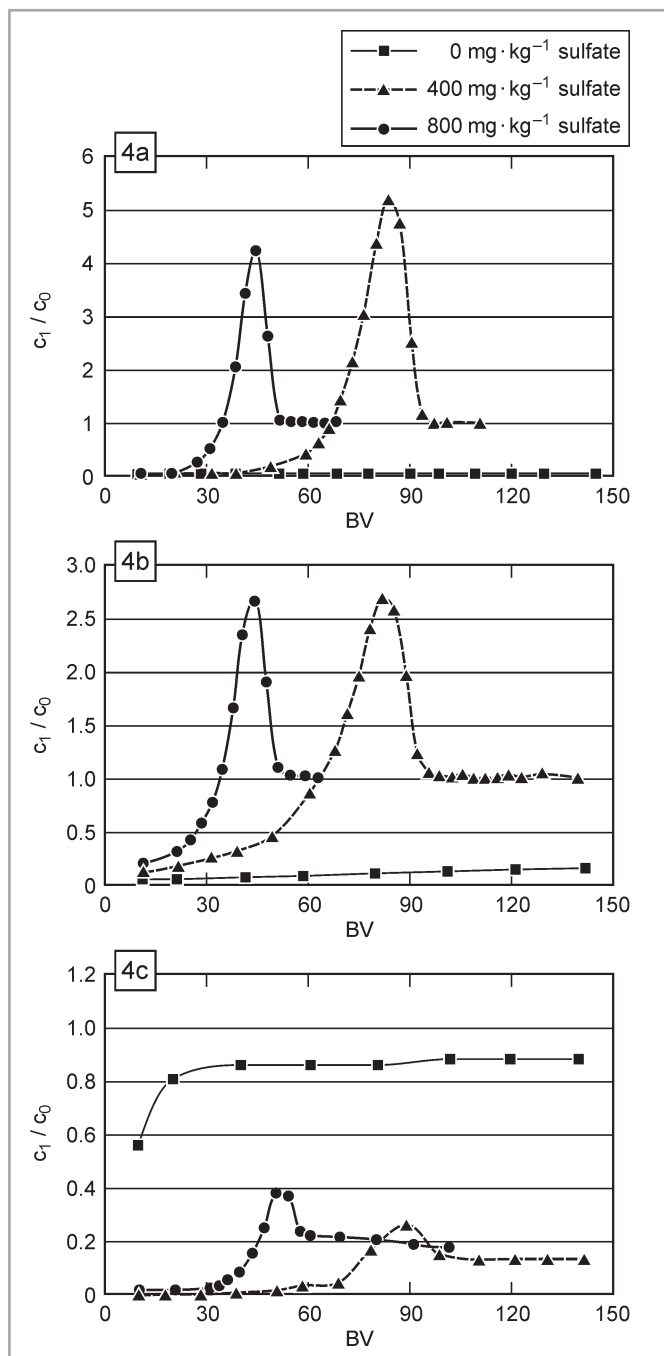


Figure 4: Uptake of β -alanine (4a), starch (4b) and humic acid (4c) by a strong base ion exchanger at different sulfate concentrations. 20 °C; 20 BV per hour; 2.5 mg · kg⁻¹ TOC

($\text{pH}_{\text{IEP}} = 6.9$) could be removed by both mechanisms. In order to decide this, the pH was measured in the eluate after the SBA (OH^- form), which was treated with a neutral salt-free solution of 200 mg · kg⁻¹ β -alanine. We found a $\text{pH} > 9$, which indicates ion exchange as a mechanism.

Starch was removed up to 85–90 %, probably based on adsorption. However, a 200 mg · kg⁻¹ salt-free solution of starch led to a slightly basic pH of about 8.5 in the eluate after SBA, so that ion exchange could not be excluded.

The uptake of humic acid in neutral conditions, where its carboxyl groups are completely deprotonated, amounts to 10 to 15 %. Thus, ion exchange could be possible in spite of the untypical "breakthrough" curve with a breakthrough of constant 85–90 %, if the distribution coefficient of the humic acid is in the lower range.

In the presence of sulfate (acidic conditions), β -alanine and starch were completely removed as long as the capacity of the resin was not exhausted by the sulfate ions. The sulfate ion has a much stronger affinity to the resin than β -alanine or starch, so that β -alanine and starch are eluted. In consequence, higher sulfate concentrations lead to an earlier breakthrough of the organics.

At acidic pH, the humic acid is at first completely eliminated, too. Then, a small breakthrough with a typical elution peak takes place, indicating the displacement of the humic acid by sulfate. After this, about 80 % of the humic acid is removed by precipitation – the same result as with the copolymer. The 10–15 % of the humic compound which is removed by ion exchange has "its own" breakthrough point at 85 BV (400 mg · kg⁻¹ SO_4) and 40 BV (800 mg · kg⁻¹ SO_4). From the potentiometric titration data that were used for the determination of the PEC values of humic acid type M42 (cf. Table 1), the pK_a values for the humic acid were derived. These values amount to 4.64 for the unlabeled humic acid type M42 (M145) and 4.86 for the ¹⁴C-labeled humic acid type M42 (M180A). At pH 3.5, about 30 % of the humic acid carboxylic groups are deprotonated.

The different heights of the elution peaks indicate different affinities of the adsorptives in regard to the SBA.

Comparison between SBA and WBA

Figure 5 contains the uptake of the three model substances by the strong and weak base anion exchangers and the corresponding copolymers in acidic conditions.

β -alanine could not be removed by both copolymers, whereas starch was eliminated by the copolymers to an extent of about 5 % (SBA) and 25 % (WBA). Steric effects might be the reason for this difference. This can also be the explanation for the 95 % removal of humic acid by the WBA-copolymer in comparison to only 80 % for the SBA-copolymer.

Comparing the strong base with the weak base resin, the breakthrough point moves to higher throughputs. The reason is the 25 % higher total volume capacity of the weak base exchanger (see Table 3). A second difference is the sharper exchange front at the strong base resin. The stronger affinity of the quaternary amines to the organic compounds in comparison to the tertiary groups of the WBA should be responsible for this.

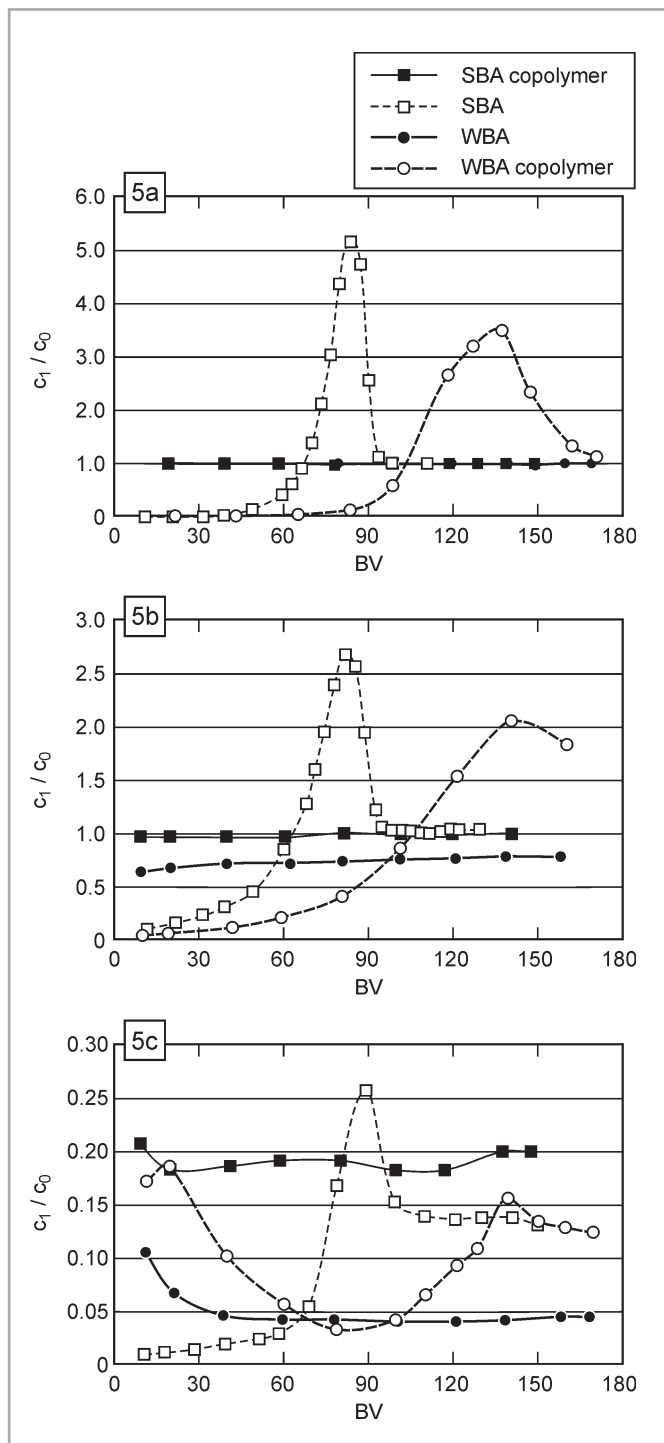


Figure 5: Uptake of β -alanine (5a), starch (5b) and humic acid (5c) by SBA, WBA and the corresponding copolymers.

20 °C; 20 BV per hour; $2.5 \text{ mg} \cdot \text{kg}^{-1}$ TOC

Influence of concentration

Figure 6 shows the breakthrough curves of the model substances at SBA and acidic pH depending on their concentrations.

In agreement with Figure 4, the breakthrough of the organics is observed at about 85 BV. The sulfate ions determine the organics' breakthrough in every case. The

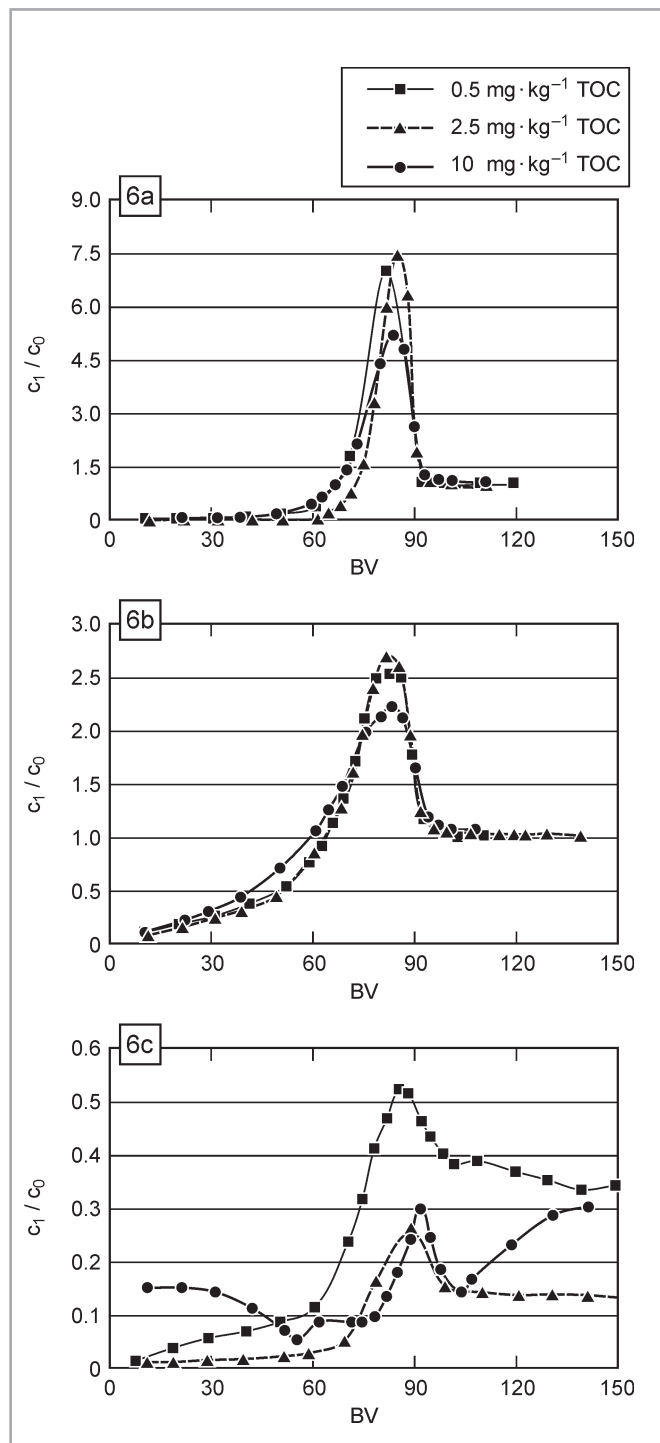


Figure 6: Uptake of β -alanine (6a), starch (6b) and humic acid (6c) by SBA at different TOC concentrations.

20 °C; 20 BV per hour; $400 \text{ mg} \cdot \text{kg}^{-1} \text{SO}_4^{2-}$

concentration of the organics has no influence on the breakthrough point. In addition, the heights of the peaks seem to be independent of the concentration. This means that the organics are removed from the solution following the Nernst law, which predicts concentration-independent distribution coefficients.

Influence of Temperature

Figure 7 shows the uptake of the model substances by the SBA resin at different loading temperatures.

Again, the overall picture of the breakthrough curves of the organics at acidic pH is determined by the sulfate uptake. A significant influence of the loading temperature on the center of the breakthrough curve could not be observed. The beginning of the breakthrough itself is delayed by higher temperatures, but only to a small degree (starch and humic acid). This is in agreement with earlier investigations [8].

SUMMARY AND OUTLOOK

The main results are:

- At neutral pH, a near 100 % removal of β -alanine and starch by ion exchange and adsorption was observed, whereas humic acid was taken up by ion exchange to an extent of about 10 %.
- In acidic conditions, β -alanine and starch were completely removed up to the breakthrough point of the sulfate ions. These elute the organics. Humic acid will be removed owing to precipitation.
- The last mechanism allows the removal of humic acid by the copolymers too. These are inefficient in regard to the uptake of β -alanine and starch.
- The variation in the concentration of the organics as well as that in the loading temperature have only a subordinate influence on the uptake.

Table 4 gives an overview of uptake mechanisms of several organics at the strong base anion exchanger and its corresponding copolymer. The same is principally valid for the weak base anion exchanger pair.

The following conclusions relating to the conditions of a power station can be drawn:

- All substances existing in an ionic form in an acidic environment will be removed to an extent of nearly 100 % before the breakthrough point of the salt ions. The last elute the minor bonded organics before their own breakthrough depending on the ion exchange capacity. However, the strong base ion exchanger, which follows the weak base one in a demineralization plant, should be able to take up the elution peak. Furthermore, the mixed bed filter acts as a safety filter. On the other hand, the mixed bed works under neutral conditions, so that neutral matter without inner charges can pass the filter.

- More attention should be dedicated to the non-polar fractions of TOC (POC and HOC, relating to the LC-OCD method).
- The possible precipitation of humics at the first anion exchange filter (WBA) needs excellent regenerating conditions to minimize loss of capacity as a consequence of blocking of the ion exchange groups, above all at the inner surface of the resin beads.
- Investigations on the size distribution of natural matter and its effect on the removal of organics may be a further field of research.

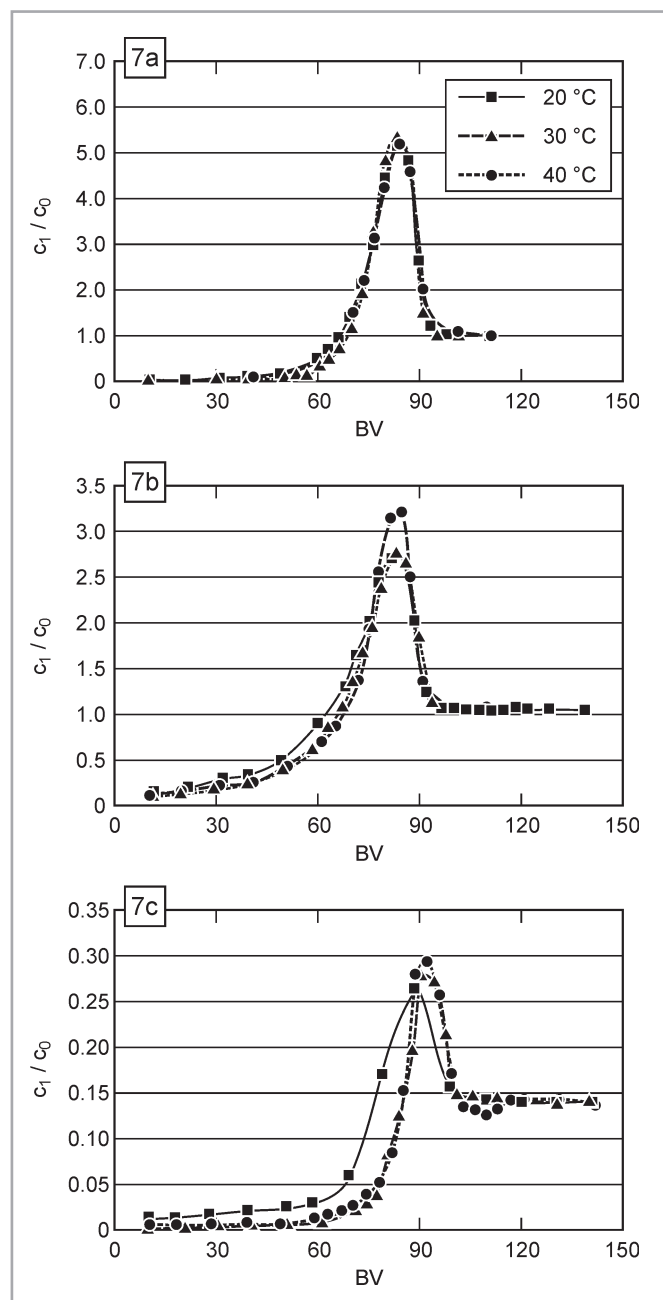


Figure 7: Uptake of β -alanine (7a), starch (7b) and humic acid (7c) by SBA at different temperatures. 20 BV per hour; $400 \text{ mg} \cdot \text{kg}^{-1} \text{ SO}_4^{2-}$; $2.5 \text{ mg} \cdot \text{kg}^{-1} \text{ TOC}$

SBA Copolymer as Adsorber				
pH	Adsorber	Adsorptive	Uptake	Interpretation
	Copolymer	β -Alanine		
neutral	non-polar	neutral (+/-)	0 %	no interaction
acidic	non-polar	ionic	0 %	no interaction
	Copolymer	Starch		
neutral	unpolar	polar	10 %	adsorption
acidic	unpolar	polar	(5 %)	(adsorption)
	Copolymer	Humic acid		
neutral	unpolar	negatively charged	0 %	no interaction
acidic	unpolar	neutral (slightly ionic)	80 %	precipitation
Strong Base Anion Exchanger as Adsorber				
pH	Adsorber	Adsorptive	Uptake	Interpretation
	SBA	β -Alanine		
neutral	bipolar ionic	neutral (+/-)	100 %	ion exchange
acidic	bipolar ionic	ionic	100 % until BP	ion exchange
	SBA	Starch		
neutral	bipolar ionic	polar	90 %	adsorption (ion exchange)
acidic	bipolar ionic	polar	100 % until BP	adsorption (ion exchange)
	SBA	Humic acid		
neutral	bipolar ionic	negatively charged	10 % – 15 %	ion exchange
acidic	bipolar ionic	neutral (slightly ionic)	80 % / 20 %	precipitation/ion exchange

Table 4: Overview of uptake mechanisms of β -alanine, starch and humic acid at SBA and SBA-copolymer.

SBA strong base anion exchanger

BP breakthrough point

REFERENCES

- [1] *Organic Matter and Dissolved Carbon Dioxide in the Steam Water Circuit of Power Plant*, **2002**. VGB PowerTech Service GmbH, Essen, Germany, M 418 Le.
- [2] Bursik, A., Jensen, J. P., *PowerPlant Chemistry* **1999**, 1(3), 28.
- [3] Maughan, E. V., Gericke, G., Roscoe, G., *PowerPlant Chemistry* **2000**, 2(4), 219.
- [4] Lyons, J., Bane, J. E., *PowerPlant Chemistry* **2000**, 2(9), 535.
- [5] Svoboda, R., Denk, J., Maggi, C., *PowerPlant Chemistry* **2003**, 5(10), 581.
- [6] Schönfelder, T., Lutat, A., *Proc., Zittau Power Plant Chemistry Symposium TOC in Steam Water Cycles*, **2000** and *Scientific Reports of the University of Applied Sciences Zittau/Görlitz*, **2000**, 67,1821.
- [7] Schley, H., Markert, A., *Proc., Zittau Power Plant Chemistry Symposium Application of Ion Exchange and Membrane Techniques to Makeup Boiler Water Treatment in Power Plants*, **2004**, Paper #2.
- [8] Ender, V., Kettner, B., Schumann, T., Hajdamowicz, S., *PowerPlant Chemistry* **2006**, 8(2), 117.
- [9] Huber, S., Gluschke, M., *Ultrapure Water* **1998**, 3, 48.
- [10] Schumann, T., **2005**. University of Applied Sciences Zittau/Görlitz, Zittau, Germany, B.S. Thesis.
- [11] Pompe, S., Brachmann, A., Bubner, M., Geipel, G., Heise, K. H., Bernhard, G., Nitsche, H., *Radiochim. Acta* **1998**, 82, 89.
- [12] Sachs, S., Schmeide, K., Brendler, V., Krepelová, A., Mibus, J., Geipel, G., Heise, K. H., Bernhard, G., *Final Report, BMWA Project No. 02E9299, Rossendorf, FZR-399, Rossendorf*, **2004**. Stevenson, F. J., *Humus Chemistry*, **1994**. John Wiley & Sons, New York, NY, U.S.A., 2nd Edition.

- [14] Stevenson, F. J., *Humus Chemistry*, **1982**. John Wiley & Sons, New York, NY, U.S.A., 1st Edition. Rohm and Haas Ion Exchange Resins, **2006**.
<http://www.rohmhaas.com/ionexchange/amberlite.htm>
- [16] Dörschel, B., Schuricht, V., Steuer, J., *Praktische Strahlenschutzphysik*, **1992**. Spektrum Akademischer Verlag, Heidelberg, Germany.
- [17] Saric, S. P., Schofield, R. K., *Proc. of the Royal Society of London (A)*, **1946**, 185, 431.
- [18] Ballinger, P., Long, F. A., *J. Am. Chem. Soc.* **1960**, 82, 795.
- [19] Aouabed, A., Ben Aim, R., Hadj-Boussaad, D. E., *Environmental Technology* **2001**, 22(5), 597.
- [20] Choppin, G. R., *Radiochim. Acta* **1988**, 44/45, 23.

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