Ion Exchange Conceptual Design for Treating Seven Technical Area Sumps with Elevated Levels of Copper and Zinc

by

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**ION EXCHANGE CONCEPTUAL DESIGN FOR TREATING SEVEN TECHNICAL
AREA SUMPS WITH ELEVATED LEVELS OF COPPER AND ZINC (U)**

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TO: M. S. Boerste, 773-43A

FROM: L. N. Oji and R. A. Hane, 773-43A

Author

Lawrence Oji *R. A. Hane* *12/15/98*

Lawrence Oji and R. A. Hane, Waste Processing Technology Date

Design Check

M. J. Barnes *12/15/98*

Barnes, Mark J. Date

Approvals/Review

B. T. Butcher *12/17/98*

B.T. Butcher, Level 4 Manager, Waste Processing Technology Date

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Keywords: Outfall
Sump water
IX Column

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SUMMARY

Recently a meeting was held to discuss technical support for developing a conceptual design and estimate for installing and operating an in-line ion exchange system to treat seven Technical Area sumps with elevated levels (high ppb - low ppm) of copper and potentially zinc (copper level is above the outfall limits). These sump waters are currently routed to the A01 outfall, which is permitted by the State of South Carolina. A study of potential treatment options and followup laboratory work done in the summer of 1997 by Larry Oji and John Hage identified two commercially available ion exchange resins, Duolite GT-73 and Chelex 100, for treating waters at these metals concentrations (Reference 1).

The Environmental Compliance Group in Technical Services Division requested WPT support for a conceptual design and estimate of this treatment option. They are also considering the option of re-routing these sumps to the sanitary sewer system.

The desired upper limit metal concentrations for the ion exchanged treated sump effluent are respectively, 0.022, 0.059, 0.005 and <0.0001 mg/L for copper, zinc, lead and mercury. The above identified ion exchange resins (Duolite GT-73 and Chelex 100) are expected to meet these desired metal concentration goals for the sump effluents. At a maximum pumping rate of 50 gpm (189.3 L/min.) for each sump pump, a Chelex 100 column resin would need to be changed after processing approximately 616,000 liters (163,000 gallons) of sump water (Table 2). The Duolite GT-73 will need to be changed after processing about 155,000 liters (41,000 gallons) of water.

These two ion exchange columns, in series, will require a pre-filter unit up stream to remove debris and particulate matter. The depth of the resins inside each column is expected to be greater than 0.6 Meters (2 feet).

The retail cost for Chelex 100 is \$0.49 per gram (Reference 2). Duolite GT-73 is in widespread use at SRS and is thus available for use in this application. A price for Duolite GT-73 has not been obtained for this report.

DESIGN APPROACH AND CALCULATIONS

The attached design calculations are based on two ion exchange columns in series (the first column is Chelex 100 and the second column is Duolite GT-73). These two resins have, in earlier studies, been identified as the most promising ion exchange materials for removing copper/zinc and mercury ions from the A01 outfall (Reference 1). The Chelex 100 column would remove primarily copper and zinc from the sump water. The GT-73 column would remove mercury and lead, and depending on the oxidation state of lead in the water both resins are expected to remove lead (water pH = 6.5-7.5).

The average concentration of copper, zinc, mercury and lead (respectively, 0.997, 0.154, 0.001 and 0.003 mg/L) used in the calculation of resin bed volume requirements are based on information provided by M. Boerste (Attachment A). The average concentrations of the principal competing ions (calcium, magnesium, and iron) are respectively, 0.434, 0.073 and 0.089 mg/L (Attachment A: Table 3 and e-mail from M. Boerste).

Because copper ions are preferentially removed by Chelex 100 over zinc ions, the determination of 50% breakthrough for column operations and resin cartridge replacement intervals are based on copper batch distribution constants (K_d and column $K_d(1)$), where the column K_d , λ , is equal to the product of the batch distribution constant and the bulk density (ρ) of the ion exchange material ($\lambda = K_d \cdot \rho$). This parameter represents the theoretical number of bed volumes that can be processed. Batch distribution constants for the ions, as measured in the laboratory (Reference 1), are summarized in Table 1.

Based on a nominal total capacity of 0.7 meq/mL for Chelex 100 resin and a maximum pumping rate of 50 gpm (189.3 L/min.) for each sump pump, a Chelex 100 column resin would need to be changed after processing 616,000 liters (163,000 gallons) of sump water (Table 2). The Duolite GT-73 will need to be changed after processing about 155,000 liters (41,000 gallons) of water.

Neither column is a mixed bed. It is advisable to install a pre-filter upstream of the Chelex 100 column to trap particulates. The Duolite GT-73 column is to be installed downstream of the Chelex 100 column. The pre-filter and two ion exchange columns are to be installed in series. They should be installed in a vertical or horizontal configuration and should not be installed at an angle greater than 15 degrees from the vertical or horizontal, respectively, to prevent channeling effect in the resin bed. It is advisable to provide a reservoir between the sump and the columns to maintain constant moisture content in the resin beds. Because the calculations were done conservatively, this is not, however, required. A water drip arrangement to keep the beds moist between pumpings is another alternative, but again is not required. The depth of resin in each column should be greater than 0.61 L (2 feet)^A. For other column dimensions see resin bed volumes (BV) as summarized in Table 2.

The spent resin should not be regenerated because of the remote possibility of resins trapping and concentrating traces of radionuclides. The resin beds are not composed of F-listed or hazardous chemicals. However, because they may be concentrating RCRA metals (Hg, Pb) they likely will require disposal as mixed-Low Level Waste.

^A Industrial standard.

Design Calculations

Chelex 100 resin capacity to remove copper and zinc ions, from each sump water reservoir in the presence of Ca, Mg, and Fe as competing ions.

A) Concentration of important sump water ions^B: [Cu] = 0.997 mg/L; target ion
[Zn] = 0.154 mg/L, target ion

[Ca] = 0.434 mg/L; competing ion
[Mg] = 0.073 mg/L; competing ion
[Fe] = 0.089 mg/L; competing ion
Sump water pH = near neutral (6.5-7.5)

B) Chelex 100 data:

- Moisture content = 71-76%
- Wet mesh range = 100-200 spherical
- Nominal total capacity = 0.7 meq/mL resin bed; 2.9 meq/dry bed
- Bulk density = 0.65 g/mL

C) Total weight of metal ions in a typical sump pump output volume per 24 hrs. (cycle)^C.

Maximum flow rate = 50 gpm

Maximum volume of water processed by each sump pump per cycle = 50 gallons/min * 60 min/hr. * 24 hours/cycle * 3.785 Liters/gallon = 272,500 Liters/cycle.

- Total concentration of metal ions = 1.747 mg/L
- Average mole. wt. of relevant metal ions ($\sum^n$ gram formula wt.)/n = average molecular wt. = 40.971 g/mole (an approximation)
- Total wt of metal ions = (1.747 mg/L) * 272,500 L/cycle = 476.06 g/cycle

D) Weight of total metal to equivalence (average equivalent is 11/5 = 2.2)

- (Total wt of metal ions)/(Average mo. wt.)/2eq/gmw =
476.06 (g/cycle)/(40.971 (gmw))/(2.2eq/gmw) = 5.282 eq/cycle

E) Daily needed capacity

- Calculated capacity/ Chelex 100 wet capacity =
5.282 eq/cycle/ 0.0007 eq/mL = 7,545.05 mL
≈ 7.545 Liters of Chelex 100 = One Bed Volume (BV)

F) Weight of Chelex 100

- capacity volume ((liters/cycle)*(Chelex 100 density)) =
7.545 Liters * 0.65kg/Liter = 4.904 kg (10.79 lbs).

At an average of 14.21 gallons per minute processing rate the volume of resin (BV) would equal 2.144 Liters of Chelex 100 or 1.395 Kg (3.07 lbs).

^B Divalent and trivalent competing ions with concentrations greater than 0.001 mg/L.

^C Typical industrial length of service run (between resin regeneration) for automated ion exchange facility is 8 hours.

Duolite GT-73 capacity to remove mercury, copper and zinc ions from each sump water reservoir in the presence of Ca, Mg, and Fe as competing ions.

The first IX column (Chelex 100) will primarily remove copper and zinc from the sump water. The second IX column (GT-73) will remove the other ions of importance (mercury and lead). Competing ions (calcium, magnesium and iron) are expected to play a major role in the efficiency of both columns. Calculations have taken these into account.

A) Concentration of important sump water ions

[Hg] = 0.001 mg/L; target ion

[pb] = 0.003 mg/L; target ion

[Ca] = 0.434 mg/L; competing ion

[Mg] = 0.073 mg/L; competing ion

[Fe] = 0.089 mg/L; competing ion

B) GT-73 data:

- Nominal total capacity = 0.7 meq/mL resin bed

- Bulk density = 0.69 g/mL

-

C) Total weight of metal ions in sump pump water per 24 hrs (cycle)^C

- Maximum volume of sump pump water processed per cycle = **272,500 Liters/cycle.**

- Total concentration of metal ion = 0.6 mg/L

- Average mole. wt. of relevant metal ions (Σ^n gram formula wt.)/n = average molecular wt. = 105.60 g/mole (an approximation)

- Total wt of metal ions = (0.6mg/L)* 272,500 Liters/cycle = 163.5 g/cycle.

D) Weight of total metal to equivalence (average equivalent is 10/5 = 2)

- (Total wt of metal ions)/(Average mo. wt.)/2eq/gmw =

(163.5 (g/cycle))/(105.60 (gmw))/(2eq/gmw) = 0.774 eq/cycle

E) Daily needed capacity

- Calculated capacity/ GT-73 wet capacity =

0.774 eq/cycle/ 0.0007 eq/mL = 1105.93 mL

1.106 liters of GT-73) = One Bed Volume (BV)

F) Weight of GT-73

- capacity volume ((liters/cycle)*(GT-73 density)) =

1.106 Liters/cycle*0.69kg/Liter = 0.763 kg of GT-73 (1.678 lbs).

At an average of 14.21 gallons per minute processing rate the volume of resin (BV) would equal 0.314 Liters of Duolite GT-73 or 0.217 Kg (0.477 lbs).

Resin Type	Cu	Zn	Ca	Mg	Fe	Hg	Pb
Chelex -100	81,600	65,800	1.35E 07	2.55E 07	12,600	Not determined	Not determined
Duolite GT-73	53,000	6,500	1.45E 04	560	1,600	Resin designed primarily for Hg removal. ^D	Not determined, but known to be removed by this resin.

Table 1. Average batch distribution constants (K_d) for target ion and competing ions (ml/g) (Reference 1)

Resin Type	Resin BV for Columns in series: Sump flow rate of 14.21 gpm	Resin BV for Column in series: Sump flow rate of 50 gpm	Maximum volume processed Before 50% breakthrough for Cu, Zn and Hg. ($\lambda = K_d \rho$)BV
Chelex 100	2.144 L (3.07 lbs)	7.545 L (10.79 lbs)	615,672 L (copper) 496,461 L (zinc)
Duolite GT-73	0.314 L (0.45 lbs)	1.106 L (1.58 lbs)	154,840 L (mercury)

Table 2. Summary of bed volume (BV) and maximum processed volumes based on copper, zinc and mercury K_d values

References

- (1) L N. Oji and J. P. Hage, " Copper removal from A-01 Outfall by ion-exchange (U)" WSRC-RP-97-767. September 18, 1997.
- (2) Bio-Rad bulletin # 1224, Bio-Rad, Chemical Division, 2200 Wright Avenue, Richmond, Ca. 94804 (415-234-4130 or 1-800-4-BioRad).

^D Based on estimated mercury batch distribution constant (K_d) value of 140,000 ml/g.

ATTACHMENT A

Meeting minutes

Subject: Support to Environmental Compliance on Sump Water Treatment

Author: Tom Butcher at SRCCA13

Date: 10/9/98 11:23 AM

A meeting was held on Wednesday, 10/7, to discuss technical support for developing a conceptual design and estimate for installing and operating an in-line ion exchange system to treat seven Technical Area sumps with elevated levels (high ppb - low ppm) of copper, lead, mercury, zinc and iron. These sumps are currently routed to the A01 outfall which is permitted by the State. Copper level are above the outfall limits. A study of potential treatment options and followup labwork done in summer 1997 by John Hage and Larry Oji identified two commercially available ion exchange resins, Duolite GT-73 and Chelex 100, for treating waters at these metals concentrations. The Environmental Compliance Group in Technical Services Division is requesting WPT support for a conceptual design and estimate of this treatment option. They are also considering the option of re-routing these sumps to the sanitary sewer system. Those on distribution were in attendance. The following items were discussed and actions identified:

- Stan Harmon will be the point of contact for receiving all design input information. Stan is preparing a request to Bectel to do the conceptual design and estimate for both the treatment and sanitary sewer options.
- Mike Boerste is the lead on the overall effort and will provide treatment goals and other environmental considerations.
- Spent resin will be disposed and not regenerated. Treatment must not result in generation of hazardous secondary waste.
- Richard Hane will provide engineering input to Stan. Information needed for design includes: size of columns, flow rate requirements, configuration of beds, resin replacement requirements, disposal requirements, etc.
- Larry Oji will consult with Richard on chemistry requirements such as single or mixed bed IX, time to breakthrough at given metals concentrations, competitive ion effects, need for prefiltering, etc.
- All design input will be gathered and turned over to Stan Harmon two weeks from receipt of activity code
- Gordon Hayford will provide the activity code to WPT for this effort

Please contact me at x5-5810 if you have any questions.

E-Mail communications: Author: Michael Boerste at SRCCA07

The second round of sump data is in. Here are both sets for your use in development of the ion exchange treatment option.

Condensate Sump Location	Dates Sampled	[Copper] mg/L	[Iron] mg/L	[Lead] mg/L	[Zinc] mg/L	[Mercury] mg/L
773-A A-wing	8/10/98	0.443	0.086	0.011	0.045	<0.0001
773-A A-wing	10/2/98	0.147	0.166	<0.003	0.022	<0.0001
773-A C-wing W	8/10/98	1.07	<0.020	<0.003	0.062	0.0001
773-A C-wing W	10/2/98	0.386	0.058	<0.003	0.024	<0.0001
773-A C-wing SE	8/10/98	2.04	0.037	<0.003	0.093	0.0003
773-A C-wing SE	10/2/98	0.851	0.079	0.003	0.041	<0.0001
773-A B-wing SE	8/10/98	2.19	0.143	<0.003	0.138	0.0002
773-A B-wing SE	10/2/98	1.17	0.21	<0.003	0.131	<0.0001
773-A B-wing W	8/10/98	1.6	0.076	<0.003	0.077	<0.0001
773-A B-wing W	10/2/98	0.616	0.073	<0.003	0.1	<0.0001
773-A B-wing NE	8/10/98	1.52	0.134	<0.003	0.133	0.0001
773-A B-wing NE	10/2/98	1.43	0.029	<0.003	0.124	<0.0001
735-A A-Wing	8/10/98	0.254	0.077	0.032	0.092	<0.0001
735-A A-Wing	10/2/98	0.238	0.078	0.01	0.081	<0.0001
Average concentration		0.997	0.089	0.003	0.154	0.0001

Table 3. Metal concentrations in sump water.

EPD anticipats (sic) any zinc limit will be above 200 mg/L, which is higher than all the sump values. Zinc removal should therefore be considered just a bonus. Please focus on Copper, Lead and Mercury. This may make GT-73 alone more attractive since it may last longer for the target ions, taking up less iron, zinc and water hardness metals (Ca/Mg), and it's already widely used on site. Please consider this as well as a mixed bed.

Reply Separator _____ Subject: Goals for Metals

Author: Michael Boerste at SRCCA07

Date: 10/7/98 4:06 PM

Copper and lead have outfall permit limits as follows. Mercury has a limit below detection so the mandated detection limit is listed. Zinc is only anticipated for a limit so I have provided a water quality standard as a very conservative first approximation. (Iron has no limit and is not anticipated to get one.) Please consider these as desired upper bounds for ion exchanged sump effluent.

Copper (Cu) 0.022 mg/L

Lead (Pb) 0.005 mg/L

Mercury (Hg) <0.0001 mg/L

Zinc (Zn) 0.059 mg/L

Metals in Condensate Sumps, mg/l

Sump Location	Date	Aluminum	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Nickel	Potassium	Silver	Sodium	Zinc	Mercury
[1] 773-A-A-wing	8/10/98	<0.050	0.553	<0.010	0.443	0.086	0.011	<0.050	<0.010	<0.200	<0.005	9.66*	0.045	<0.0001
[1] 773-A-A-wing	10/2/98	<0.050	0.472	<0.005	0.147	0.166	<0.003	0.183	<0.010	0.34	<0.005	12.2	0.022	<0.0001
[2] 773-A-C-wing W	8/10/98	<0.050	0.728	<0.010	1.07	<0.020	<0.003	<0.050	<0.010	<0.200	<0.005	3.49*	0.062	0.0001
[2] 773-A-C-wing W	10/2/98	<0.050	0.284	<0.005	0.386	0.058	<0.003	0.076	<0.010	0.232	<0.005	4.02	0.024	<0.0001
[3] 773-A-C-wing SE	8/10/98	<0.050	0.319	<0.010	2.04	0.037	<0.003	<0.050	<0.010	<0.200	<0.005	0.534*	0.093	0.0003
[3] 773-A-C-wing SE	10/2/98	<0.050	0.643	<0.005	0.851	0.079	0.003	<0.050	<0.010	<0.200	0.014	<0.100	0.041	<0.0001
[4] 773-A-B-wing SE	8/10/98	<0.050	<0.100	<0.010	2.19	0.143	<0.003	<0.050	<0.010	<0.200	<0.005	0.690*	0.138	0.0002
[4] 773-A-B-wing SE	10/2/98	<0.050	<0.100	<0.005	1.17	0.21	<0.003	<0.050	<0.010	0.318	<0.005	0.198	0.131	<0.0001
[5] 773-A-B-wing W	8/10/98	<0.050	0.455	<0.010	1.6	0.076	<0.003	<0.050	<0.010	<0.200	<0.005	0.612*	0.077	<0.0001
[5] 773-A-B-wing W	10/2/98	<0.050	1.16	<0.010	0.616	0.073	<0.003	0.082	<0.010	0.467	<0.005	0.18	0.1	<0.0001
[6] 773-A-B-wing NE	8/10/98	0.181	0.229	<0.010	1.52	0.134	<0.003	<0.050	<0.010	<0.200	<0.005	0.817*	0.133	0.0001
[6] 773-A-B-wing NE	10/2/98	0.142	0.159	<0.005	1.43	0.029	<0.003	<0.050	<0.010	<0.200	<0.005	<0.100	0.124	<0.0001
[7] 735-A-A-wing	8/10/98	<0.050	0.445	<0.010	0.254	0.077	0.032	<0.050	<0.010	10.6	<0.005	10.0*	0.092	<0.0001
[7] 735-A-A-wing	10/2/98	<0.050	0.622	<0.005	0.238	0.078	0.01	0.177	<0.010	17.4	<0.005	12.6	0.081	<0.0001

*QC out

Distribution:

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