Appendix E

Filtra Systems
StiR Pilot Study Report

FILTRA SYSTEMS - STiR

PILOT STUDY REPORT

Prepared by Nic Korte

Nic Korte Consulting, Grand Junction, CO

For

Honeywell FM&T LLC

Kansas City, Missouri

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1. INTRODUCTION

The United States Department of Energy Kansas City Plant is considering the Filtra Systems STiR as a component of a replacement groundwater treatment system to be procured in the future. To that end, a pilot unit was brought to the site and a series of tests were performed. The Filtra Systems STiR removes suspended solids and oil, thereby conditioning the water for final treatment for dissolved, volatile organic contaminants.

The unit was shipped to the site by the vendor and installed by KCP personnel. Influent to the STiR was piped in before the flow entered the existing groundwater treatment system trainAfter being conditioned by the STiR, the water was routed back through the existing treatment system as usual. Thus, there was no interruption or change with respect to final treatment.

The pilot test continued from May 24, 2011 to June 30, 2011. The following week, a separate test was conducted to evaluate the filtration media for its applicability for PCB removal. In general, the testing period was the regular 8-hour shift with testing performed Monday through Friday.

SITE BACKGROUND

Groundwater at the KCP is being treated for chlorinated organic compounds. The nominal concentration of these contaminants was expected to be approximately 1,670 µg/L DCE (1,2-dichloroethene), 1,820 µg/L TCE (trichloroethene), and 98 µg/L vinyl chloride. Somewhat lower concentrations were encountered during the test with 1,2-DCE being on the order of 730 µg/L, TCE 11 µg/L, and vinyl chloride 60 µg/L. PCBs, although present in some locations in the KCP groundwater, are effectively treated by microfiltration and carbon adsorption and were, therefore, not present in the influent to the Filtra Systems pilot unit.

Contaminated groundwater at the KCP presents a difficult treatment problem for three principal reasons:

1. The groundwater is reducing (anoxic) -- in contrast to water-supply aquifers which are oxidizing. Reducing groundwater may contain significant dissolved iron and manganese

which precipitate on contact with air. At the KCP, certain locations in the shallow aquifer contain tens of ppm of dissolved iron and manganese. The KCP aquifer also contains naturally-occurring, dissolved arsenic in quantities exceeding the drinking water standard set by the US Environmental Protection Agency (EPA).

2. Groundwater such as the KCP shallow aquifer supports growth of a variety of bacteria, particularly as air is supplied. Hence, clogging with precipitates and bacterial growth are problematic and may cause more difficulty than removal of the principal contaminants.
3. The aquifer is in a clayey formation as opposed to water-supply aquifers which are typically sandy. Thus, there are generally more dissolved salts, including chloride, which can cause corrosion as well as higher concentrations of suspended solids (clays) that also can cause clogging.

An additional issue for the KCP treatment system is the sporadic presence of a small amount of oil from one pumping well (273) and a small amount of poly-chlorinated biphenyls (PCBs) from another (276). As noted above, these are effectively treated at present but, overall, the present pre-treatment system is cumbersome and subject to high maintenance. The purpose of this pilot test was to evaluate the Filtra Systems STiR as a means of addressing points 1, 2 and 3 above, while simultaneously removing any oil and potential PCBs. The effluent from the STiR would then be subjected to further treatment for the VOCs.

2. NATURE OF TECHNOLOGY

Filtra Systems provides an automatic backwashable media filter called the Filtra Systems STiR. Conventional technologies (sand, anthracite and carbon media filters/beds) do not completely fluidize the media during backwash and are presumed more susceptible to fouling. Appendix A contains a brief overview of the technology as provided by the vendor.

Two key differences between the STiR Filter and traditional Multi-Media Filters are:

1. The STiR Filter uses walnut shell media that is featured as having removal capability for both solids and oil and grease. According to the manufacturer, walnut shells, purchased from a specific source in Missouri, have an optimum modulus of elasticity for this application. They are hard and solid enough to provide a stable and long-lasting surface

yet are soft and supple enough to provide a sufficiently tortuous flow-path for trapping suspended solids.

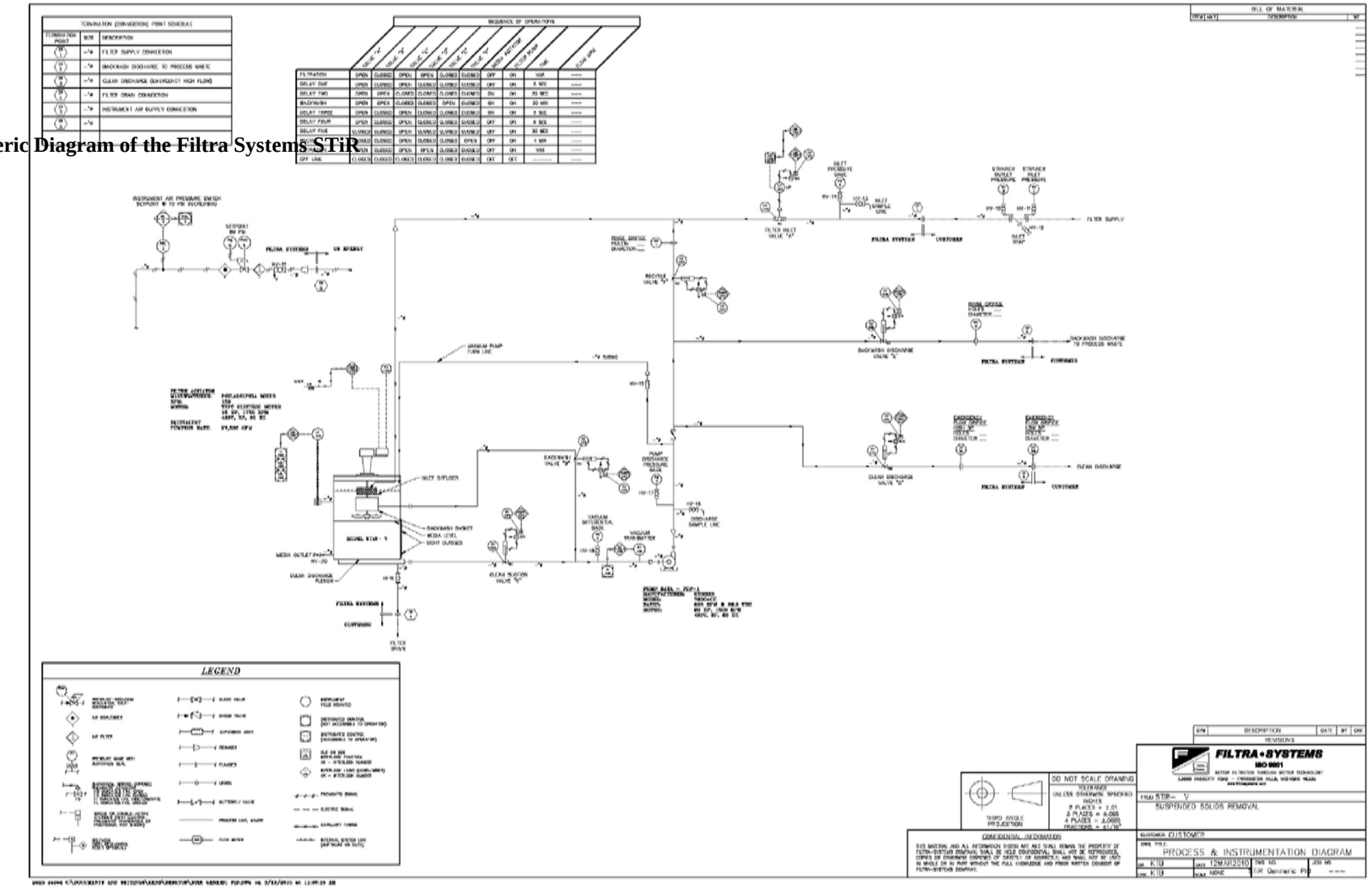
The specific gravity of the walnut shells is approximately 1.4 g/cc as compared to water's 1 g/cc and sand's 2.5 g/cc. Thus, the walnut shells sink to the bottom when the STiR unit is in the "clean" mode, that is, when untreated water is being pumped through the tank. During backwash, however, the walnut shell media is easily fluidized because of the low specific gravity. In contrast, sand, at 2.5 g/cc is very difficult to fluidize and clean effectively. The mesh size of the media is 12-20 (passes through 12 mesh but is retained on a 20 mesh screen)—small enough to provide a good support and effective filtration.

2. Backwash: The STiR Filter uses a mechanical mixer inside the vessel that agitates the entire filter during the backwash cycle. The mechanical agitation results in more efficient backwash operations than in traditional stationary media filters. The vendor claims that because the STiR media is fluidized, ~100% of trapped particulates are removed resulting in the following benefits:

- Smallest backwash volume of any competing technology.
- Media regeneration for the life of the product (20 years).
- Consistently high removal efficiency; year-after-year.
- Ease of handling upset conditions (e.g. unexpectedly high loading of solids or oils).

A diagram of the system is shown in Figure 1 and a photo in Figure 2. This unit is a STiR-7V. The walnut shells have a density of shells is 45 lbs/ft^3 with a total volume of 19 ft^3 and total mass of 836 lbs.

Figure 1. Generic Diagram of the Filtra Systems STiR



A photo of the pilot system employed at the KCP is shown in Figure 2.

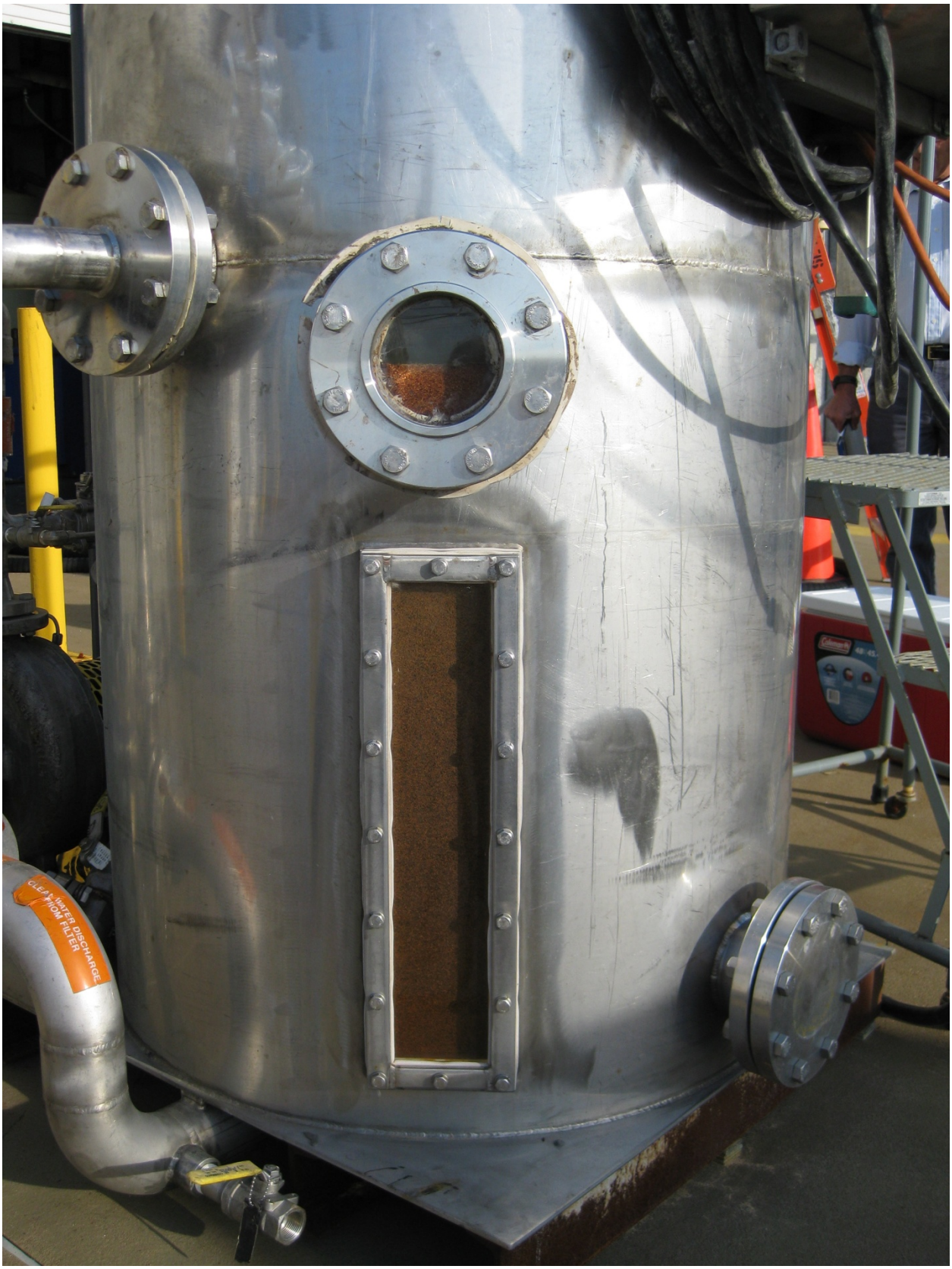


Figure 2. Photo of STiR pilot system.

According to the manufacturer, under normal operating conditions, the STiR filter is expected to remove 95% to 99% of suspended solids and 90% to 99% of insoluble hydrocarbons. The vendor representative stated that the STiR would reduce the total suspended solids (40-200 mg/L) at the KCP to 5 mg/L or less and remove all detectable PCBs and oil.

3. OPERATIONAL EVALUATION

Site Visit

A site visit was conducted by the author of this report on May 25 and 26. The unit was in full operation during this period. The flow rate was approximately 30 gpm. (Daily operational data are on file with the KCP CH2MHill-OMI water treatment group, supervised by Bob Hughes.)

Initially, acidified flow was treated. Acidification is required for the KCP's current UV/hydrogen peroxide treatment unit in order to prevent iron and manganese from precipitating. Acidification is not desired because it adds cost and complexity to treatment and presents an additional worker safety issue. Hence, a desired quality of a replacement treatment system would be one in which acidification was unnecessary.

Treatment appeared complete both visually, because of the clarity of the effluent (Figure 3), and quantitatively based on on-site measurements of TSS (total suspended solids) as performed by the vendor representative, Joe Haligowski.

Figure 3. Visual comparison of influent and effluent.

Because of the initial success, the acidification step was halted. pH rose from approximately 2.5 to near-neutral. TSS in the influent also increased by as much as a factor of 3 or more, from <20 mg/L to >50 mg/L. Again, based on the clarity of the effluent and the on-site measurements, treatment appeared sufficient without acidification of the influent wastewater.

An initial concern with the STiR system was whether volatile organic compounds (VOCs) would be inadvertently removed. Fugitive VOC emissions from the treatment tank could yield both industrial hygiene and air permitting issues. Inspection of the operation, however, led to a belief that off-gassing would not be a problem. As shown in Figure 4, the top of the tank quickly becomes coated with a film and a small amount of the walnut shell material. Although not shown by a still picture, the surface is also quiescent . Hence, escape of volatiles during

operation was not expected—a supposition supported by analytical results (see section 8) which showed no removal.

Figure 4. View through the top hatch of the STiR unit. Photo taken during normal operation.

One set of samples, during the first week, was collected after the tank had sat idle overnight. These data also showed no loss of VOCs.

Loss of VOCs during backwash was also evaluated. The backwash operation involves fluidizing the walnut shell bed. This operation, typically requiring approximately 15 minutes, is the only time the bed is stirred significantly. Based on measurements with a PID during the backwash cycle VOCs were not volatilized.

Backwash

Backwash of the system typically is performed based on an increase in pressure differential measured as pressure differential across the bed? It also becomes possible to see removed solids in the viewing port (Figure 5)—this build-up can also signal the need for backwash. During the KCP pilot test, there were no significant increases in pressure throughout the filtration cycle. According to the manufacturer: "Typically, the vacuum gage, which monitors the pressure on the clean side of the walnut shell media would change from + 2psi (clean) to –12 psi Hg (dirty), over the course of 24 to 48 hours." In the KCP case, the vendor recommends backwashing based on a 24-hour timer, in lieu of the vacuum transmitter (Appendix B). The vendor further recommended "operating the recirculation cycle for 3 minutes at 25% above the fixed filtration rate, then operating in recirculation mode, at the desired filtration rate for 10 minutes, prior to going back online."

Figure 5. Solids build-up (brown/gray film) visible after several hours of treatment.

When untreated water or backwash samples were permitted to settle exposed to ambient air and atmospheric pressure, a brown/gray amorphous precipitate was soon evident. As supported by the inorganic analyses (see section 8); this precipitate is believed to be amorphous oxides of iron.

4. DISCUSSIONS WITH SITE PERSONNEL

A meeting was held with the onsite operating staff on October 12, 2011. In addition, several individual conversations were held with the same personnel. There was universal approval of the unit. Comments were received such as, "I would buy one," or "I will never use another sand filter if I can help it."

The only negative comments were about handling the large volume of backwash. However, two suggestions for handling it were provided:

1) Use a geotextile in a roll-off unit. Let the backwash "weep" out and be sent to tank 3b and recycled again through the treatment unit. While this remains a viable alternative (see appendix B for vendors and references for similar approaches), KCP personnel attempted to filter the backwash through a 25µ filter but little was collected. The on-site TSS measurements employed 5 µ filters suggesting such might be needed for "weeping" the backwash through a geotextile. Such a small pore size could lead to clogging problems.
2) Use a large cone tank with multiple decant ports. Decant the water for recycle to tank 3b and have the cone tank contents cleaned out and disposed of as necessary.

All site personnel seemed to like and have an interest in the unit and remarked on the ease of use and that the clarity of the effluent was better than the effluent from their present pre-treatment system.

5. SYSTEMS AUDIT

Training for KCP personnel (CH_2MHill-OMI) was provided by the Filtra-Systems engineer. This training continued throughout the time the engineer was onsite. The OMI technician with

primary responsibility for subsequent operation was queried and he regarded the training as sufficient.

The Filtra-Systems engineer performed TSS analyses on site. The performance of this test was observed on two occasions and the tests were performed according to the vendor's procedure which had been submitted prior to the pilot test. A check on these tests was provided by reviewing samples submitted to Pace Analytical Inc. (Section 8).

Samples for laboratory analysis were collected both by KCP personnel and personnel from Pace Laboratory. Sampling was performed according to established protocols. Samplers were aware of the need to prevent air pockets in the sample vials. It was observed that samples were carefully obtained in order to eliminate any headspace.

6. METHODS FOR EVALUATION OF CONTAMINANT REMOVAL

The laboratory and field water analyses were used to evaluate the following operational issues:
1. Removal of solids-target was 95-99% removal.
2. Removal of insoluble hydrocarbons (oil and grease) -target was 99% removal.
3. Distribution of VOCs during the operation. That is, was there significant inadvertent removal of volatile hydrocarbons? Specifically, are significant amounts captured in the backwash or in the particulates?
4. Oxygen addition—The oxygen status after treatment with the STiR is relevant to the choice of follow-on VOC treatment. Samples were measured on-site by personnel from Pace Analytical Inc., the analytical support laboratory for this project.

<u>Sampling and Analysis</u>—Samples for analysis were collected according to the following plan:

1. VOCs were sampled and measured every time the system was backwashed. Backwash was originally planned at a maximum of twice/day. Instead, backwash was performed weekly. It should be noted that the system was run only during the eight-hour day-shift. During continuous operation, backwash would be required daily.

2. A maximum of two samples/day were collected of the influent and effluent. Analyses included VOCs, oil and grease and suspended solids (TSS). One to two samples each week were analyzed for a full suite of inorganic analytes: Ca, Mg, Fe, Mn, Cl, SO_4, Na, and K. As the test progressed; the decision was made to increase sampling of iron because it appeared to be the principal source of suspended solids as judged by observing precipitation in the effluent and previous laboratory analyses.
3. Total Suspended Solids and oil and grease removal were monitored according to the procedure in Appendix C while the Filtra Systems operator was on site. Otherwise, samples for these analytes were collected by on-site personnel and the measurements were made at Pace, Inc. Lenexa, KS.
4. During the test, the walnut shells turned black. In order to evaluate the reason for the color change, samples were collected and submitted to Midwest Laboratories Inc., of Omaha, Nebraska for the analysis of iron and sulfur-reducing bacteria (SRB).
5. Sampling for some of the off-site laboratory analyses and all of the microbial analyses was performed by Pace Analytical Inc, Lenexa, KS. Pace personnel also provided courier service for the samples collected by on-site personnel.
6. Samples for off-site analyses were also collected by KCP personnel under the direction of Bob Hughes of CH_2MHill-OMI. However, all sample custody forms and sample bottles were provided by Pace Analytical Inc., Lenexa, KS.
7. The influent and effluent were analyzed for dissolved oxygen content using a YSI DO meter during the first week of testing. The DO measurement was performed on site by Pace personnel.

7. RESULTS

Removal of Total Suspended Solids

Target removal was 95-99%. During 25 days of operation, removal was frequently 100% with no suspended solids being detected in the effluent (Figure 6). Two explanations are offered for when 100% removal was not achieved.

Upset Conditions Test—On June 15, an “upset conditions” test was run. Tank 3b was stirred such that a very heavy load of suspended solids was added to the influent. (Tank 3b is a holding

tank for influent groundwater. Hence, over time, several inches of sediment accumulate at the bottom of the tank.) Approximately, 2200 mg/L of TSS was sent to the STiR—nearly two orders of magnitude more than in normal operation. Within approximately 15 minutes, effluent from the STiR was dark. Just before the "upset conditions," there was approximately 42 mg/L TSS in the influent with 2-3 mg/L in the effluent. In this instance, the effluent measured 379 mg/L—although this may not have been the maximum. There was some difficulty backwashing after the "upset." City water was used to backwash for 1 hr and 20 minutes—about five times the usual period. After the extensive backwash, however, the unit operated normally.

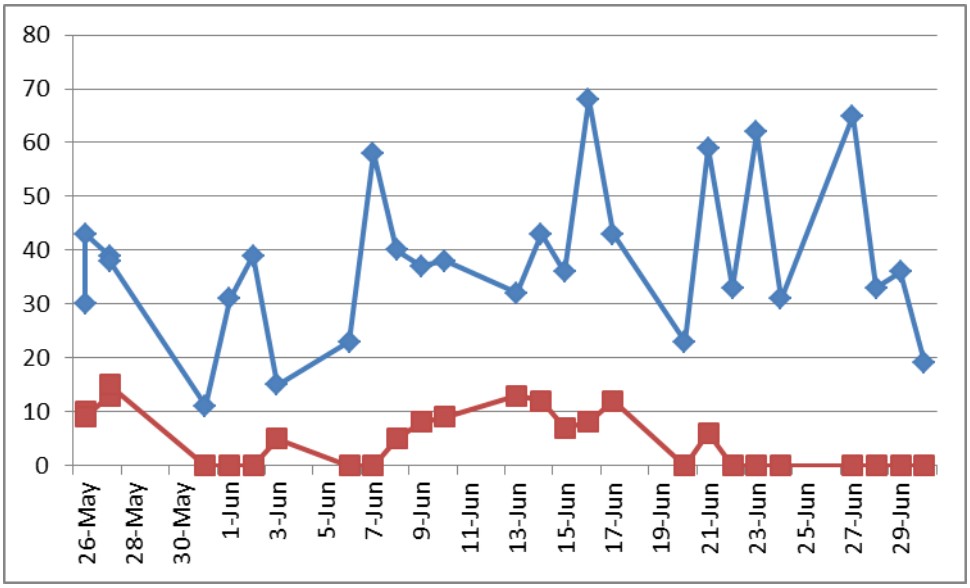


Figure 6. Daily treatment of Total Suspended Solids (TSS) in mg/L versus time. (Influent concentrations in blue, effluent in red.)

Sample Preservation for TSS—The second explanation for higher TSS in the effluent is that Pace Analytical Inc. performed their TSS analyses, in some cases, a day or more following collection. As data presented later in this section indicate, most of the suspended solids appeared to result from precipitation of iron. This iron is originally dissolved and precipitates with time and air exposure. Hence, TSS measurements for unpreserved samples increase with time as dissolved iron precipitates because of contact with air and light. This was verified by requesting Pace to collect two influent samples—one unpreserved and one acidified on June 8. Data showed an increase with time in the unacidified sample. Samples were always initially clear when collected by Pace, but being unacidified, the dissolved iron precipitated post-collection and

before being analyzed. Iron precipitation was also verified visually as samples became noticeably discolored post-collection. Thus, field analyses by the Filtra Systems representative always showed no detectable TSS and samples from Pace recorded a few mg/L on a few occasions.

It is important to note that significant dissolved iron passed through the STiR only when the influent was acidified. Acidification retards the oxidation/precipitation of iron. Once the KCP influent was not acidified, no dissolved iron was expected to pass through the STiR because the iron would be oxidized and, thus, present in a form that should be collected by the walnut shell media. This was verified by the results from the last seven days of operation when TSS was not detected in the effluent by Pace.

Removal of Iron

As noted previously, the groundwater at the KCP contains significant dissolved iron. In general, except under highly-acid conditions, iron can only remain dissolved under reducing (anoxic) conditions. Thus, because oxygen exposure occurs when reducing groundwater is pumped to the surface, amorphous oxides of iron precipitate. These are often problematic because they can be difficult to filter and can form coatings on other substances. Additionally, bacterial activity is involved in iron precipitation and agglomerations can corrode other metals and clog piping.

Figure 7 shows iron removal with the STiR. Except during the “upset conditions” test, iron removal was >90% (Table 1). Because iron is probably the cause of essentially all of the Total Suspended Solids remaining after tank 3b, iron removal is very important to the KCP. Following the test, the vendor suggested the addition of conditioning chemicals as a means of further improving iron removal (Appendix B).

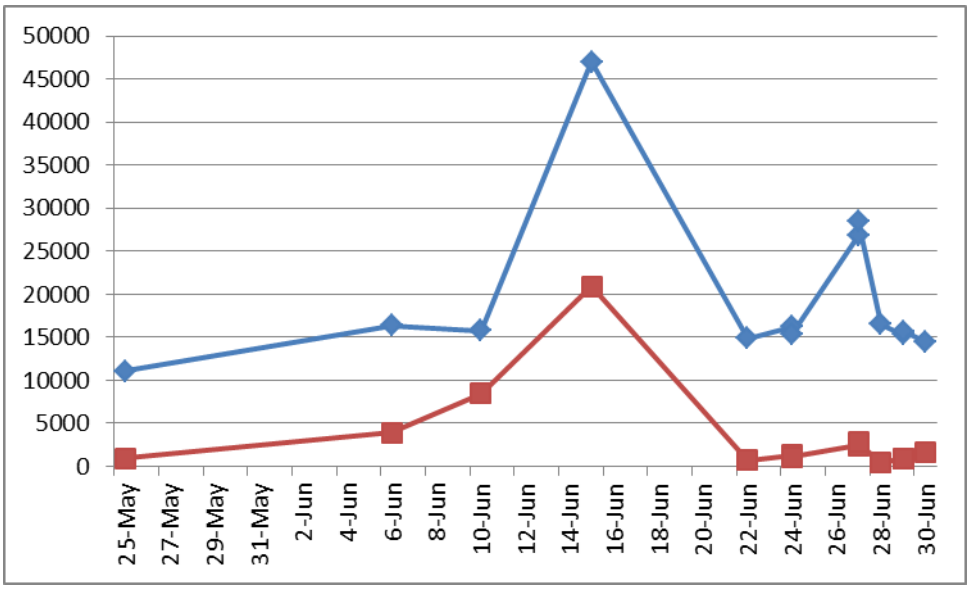


Figure 7. Daily treatment of Fe in mg/L versus time. (Influent concentrations in blue, effluent in red.)

Table 1. Iron removal from unacidified water by the STiR unit.

Date	22-June	24-June	27-June	28-June	29-June	30-June
influent	14900	16200	26800	16500	15300	14500
effluent	748	1340	2390	438	924	1580
% Removal	95%	92%	91%	97%	94%	89%

<u>Removal of Other Inorganics</u>

The other inorganics, Ca, Mg, Mn, K, Na, alkalinity, chloride and sulfate, as shown in Table 2 were not removed in the STiR. Manganese can precipitate in a like manner to iron but redox conditions of this test apparently were not sufficiently oxidizing. The other analytes all form very soluble salts and removal was not expected or desired.

In summary, the most desirable outcome with respect to measurements of inorganics was removal of iron and no effect on other analytes—precisely the observed effect.

Table 2. Influent and effluent concentrations of Mg, Mn, Na, and K

	influent Mg	effluent Mg	influent Mn	effluent Mn	influent Na	effluent Na	K influent	K effluent
25-May	16600	16400	3290	3200	71600	70300	2370	2330
6-Jun	16000	16000	3380	3300	72600	72200	2080	2070
10-Jun	16400	17200	3320	3420	75700	79400	2450	2560
15-Jun	15500	15700	4860	4830	70000	71700	3010	3120
22-Jun	17300	17800	3580	3610	74700	77100	2060	2130
24-Jun	18800	19000	4170	4130	88800	90000	2420	2470
27-Jun	14200	14400	3500	3430	70200	71400	1860	1900
29-Jun	17200	16700	3780	3600	76600	74600	2200	2120

Removal of VOCs

Groundwater treatment is performed at the KCP because of high concentrations of volatile organic compounds (VOCs), principally 1,2-dichloroethene (DCE), trichloroethene (TCE), and vinyl chloride. The STiR system has been proposed as a pre-treatment unit. Hence, losses of VOCs would be problematic for two reasons. If the VOCs were trapped inside the STiR unit or absorbed by walnut shells air permitting issues might arise . A second problem could be loss of fugitive emissions causing a potential exposure issue for workers in the area.

Initially, Pace was requested to perform field measurements of dissolved oxygen. The measurements were made of the influent and effluent with a YSI-DO meter. Because samples were collected in open containers, there was significant drift. All measurements, however, appeared to stabilize near 4 mg/L. Most importantly, however, there was no evidence that DO was changed by passage of the water through the STiR. These data indicate, therefore, that loss of volatile organics because of air entrained by mixing or stirring should not occur.

Similarly, VOC samples collected during backwash showed that the concentration of the principal contaminants did not change significantly. Values were within 5 to 10% of the influent indicating that there was no loss of VOCs despite the greater agitation that occurs with the backwash cycle.

Figure 8, shows VOC variability during passage through the STiR unit. On 11 of 25 samples, VOCs appeared to increase while passing through the STiR but the difference in influent and

effluent were always within 10% which suggests the differences were within experimental error. Taken together, all of the data, indicate there are no losses of VOCs within the STiR unit.

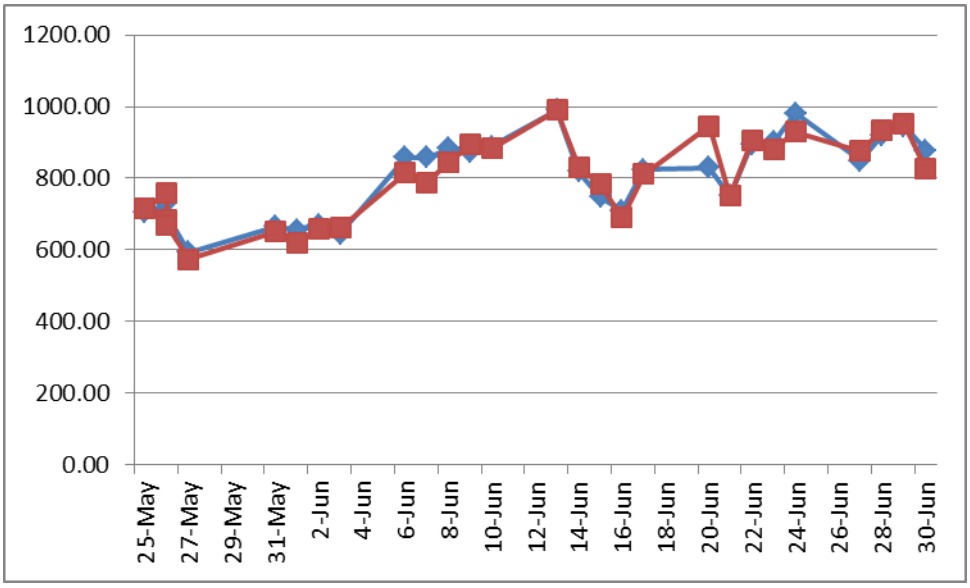


Figure 8. Effect of STiR treatment on VOC concentrations (mg/L). (Influent concentrations in blue, effluent in red.)

To further evaluate potential losses of VOCs and exposure to workers, the air inside the unit was tested with a photo-ionization detector (PID) on June 22 (email from J. Baker, Honeywell FM&T to N. Korte). The air was measured in the headspace at the top of the STiR unit and near the outside of the unit. Measurements were obtained both pre-backwash and during backwash (when the tank is undergoing maximum agitation). All working zone readings were ND (nothing detected) for all samples. The PID was placed inside the unit during normal operation. Once again, results were ND. During the backwash cycle, the PID was again inserted inside the unit. There were three fleeting detects of 0.3, 0.2, 0.6 ppm but when inserted further inside five minutes later, the reading was ND. In summary, there is no evidence that VOCs are removed by the STiR unit.

Microbiological Analyses

The walnut shell media turned black within the first two weeks of operation prompting concern regarding its longevity. The black color is consistent with iron and sulfur precipitates that have

occurred within wells and piping at the KCP. The vendor was unconcerned noting that it is present in about 10% of their applications (~100 applications) (J. Haligowski, personal communication with N. Korte, 6/17/11). The vendor stated “in all cases the color change has no effect on media life and media performance.” The vendor further stated that bacteria cannot build up within the STiR because of the daily backwash in which the walnut shell media serve as a "soft abrasive” and scrub the tank.

In order to evaluate the type and quantity of bacteria, samples of walnut shell media were collected and submitted for microbiological analyses (Table 3). The data in Table 3 demonstrate that sulfur-reducing bacteria (SRBs) are present in the influent water and within the walnut shell media in the STiR tank. The detection limit in many laboratories is only 100 cfu/100ml and further internet search suggested that values below 1000 cfu/100ml are not significant. As noted above, the agitation of the media during backwash is expected to prevent any bacteria build-up.

There are, however, potential maintenance issues associated with the bacteria. There is a screen which retains the walnut shell media at the bottom of the STiR tank. Bacteria build-up has occurred on the underside of this screen at other sites. Some customers have to clean this screen with citric acid every few months. In such cases, there is an approximate four-hour shut-down and cleaning process required. The tank has to be drained and the screen rinsed with citric acid. The citric acid is remains in the tank for an hour at which point it is drained and the tank is permitted to dry for approximately another hour. At this point, the tank is filled up with fluid and a double-backwash cycle is performed. The most frequent cleaning requirement of this sort known to the vendor is every four months (J. Haligowski, personal communication with N. Korte, June 17, 2011). It is noted, however, that the need for the citric acid wash is signaled by a significant differential pressure across this screen—something not observed in the test at the KCP where pressures stayed low.

Table 3. Iron bacteria and sulfur-reducing bacteria on the walnut shell media and treatment system influent and STiR tank effluent (cfu/100ml)

Walnut Shell Media	**Virgin**	**Top of STiR Tank**	**Middle of STiR Tank**
Iron Bacteria	ND	ND	ND
Sulfur Reducing Bacteria	<10	180	150
Treatment Water	**STiR Influent**	**STiR Effluent**	--
Iron Bacteria	ND	ND	Not applicable
Sulfur Reducing Bacteria	90	70	Not applicable

Removal of PCBs

PCBs are found within the pumped groundwater in well 276. PCBs are typically not detected in the influent to the treatment system because of microfiltration and carbon adsorption performed on the well's effluent.

The amount of pre-treatment is a matter of cost and complication to the KCP. Thus, if the STiR could be shown to remove PCBs it would eliminate the microfiltration and carbon adsorption presently used as part of pre-treatment. This potential simplification would make the implementation of the STiR system more desirable. It is noted that the STiR has been used specifically for removal of PCBs and suspended solids (Appendix D). In some instances, the vendor has used addition of a small amount (~ 0.5 mg/L) of a high molecular weight Castor or Mineral oil to the water stream to ensure PCB removal. PCBs are hydrophobic and will quickly partition in the oil as the waste stream passes through the STiR. The walnut shell media then removes all of the oil which is removed during backwash. Several installations have found this sufficiently effective that granulated activated carbon was deemed unnecessary for final polishing of a PCB-laden waste stream. This process is an option for the KCP should more assurance be needed that PCBs will, in fact, be removed in the STiR.

Because there were no detectable PCBs in the untreated influent at the time of the STiR pilot test, a second experiment was devised to examine the capacity of the walnut shells for PCB removal. The test employed a polyester 100 micron sock filter filled with walnut shell media.

Sock Filter PCB Experimental Details

Mass, Density, Void Volume- The sock was 32 inches long with a diameter of 7.25 inches. Thus, the volume was 1320 in^3 or 0.764 ft^3. Assuming the packed density of the sock filter is the same as the full-scale unit (Walnut shell density = 45 lbs/ft^3. Test unit volume = 19 $ft^{3.}$ Media mass in test unit = 836 lbs.), there were approximately 33 lbs (~15 kg) of walnut shells in the sock filter. (Note: 1ft^3 = 28316.8 ml and 1 lb = 454g or 45 lbs = 20411g. Density = 0.72 g/ml.)

The vendor provided a void volume for the STiR tank of approximately 58%. Thus, the void volume of the sock filter would be 766 in^3 or 12552 ml (~12.5 L). With an average influent concentration of 130 µg/L of PCB-1242 in the influent, the amount of PCBs in the water within the sock filter would be ~1625 µg.

Volume Pumped-The walnut shell sock filter tests were conducted July 7th and 8th, 2011. Seven hours of flow occurred each day at a flow rate of 1.5 gpm. Thus, a total of 1,260 gallons (4769 liters) from well 276 were pushed through the sock with the effluent piped directly back into the well's existing microfiltration and carbon adsorption pretreatment system. . With the average PCB influent concentration of 130 µg/L, the total amount of PCBs passing through the column was 619,970 µg.

Samples Collected—Four sets of influent/effluent water samples were collected—in the morning and afternoon on both July 7 and 8. After removing the sock filter, the following series of samples of walnut media were analyzed: (1) virgin media, (2) two samples of media from within the STiR Pilot Unit, (3) walnut shells from near the sock filter influent—labeled as "dirtiest," and (4) walnut shells from the sock filter effluent side—labeled as "cleanest."

Results/Data Interpretation Issues—Data for the water samples are shown in Table 3.

Table 3. Analytical Results (µg/L) for the PCB Sock Filter Test.

	1,2 DCE	TCE	VC	1,1-DCA	1,1-DCE	Oil& grease	PCB-1242	PCE	Ca	Fe	Mg	Mn
Influent July 7, AM	5660	22000	<360	nd	23.9	ND	159	420	153000	15600	21100	6020
Effluent July 7, AM	5450	19300		nd	20.5	nd	77	374	140000	12900	20200	5390
% Removal							52%			18%		
Influent July 7, PM	6770	26900	364	0.74	24.9	nd	99.9	547	144000	14300	19300	5510
Effluent July 7, PM	5270	19800	<360	nd	20.7		76.5	382	146000	14500	20300	5720
Effluent July 7, PM (Dup)	5450	20300	304	nd	nd	nd	80.9	477	141000	13100	20400	5420
% Removal							24/19%					
Influent July 8,AM	6280	27500	392	nd	nd	nd	101	559	164000	16100	21500	5880
Effluent July8, AM	5450	23400	284	nd	nd	nd	78.3	426	161000	15800	21100	5750
% Removal							23%					
Influent July 8, PM	6650	29100	437	nd	nd	nd	163	601	159000	15800	22700	6170
Effluent July 8, PM	5310	25700	326	nd	nd	nd	93.5	431	160000	16000	21000	5700
Effluent July 8, PM (Dup)	6220	26800	428	nd	nd	nd	141	510	158000	15100	21600	6150
% Removal							43/14%					

Interpreting the data from this test is confounded by a number of issues which either could not be evaluated in such a brief experiment or that are common to all column tests. These include:

- How much does the influent concentration fluctuate? This issue may be relevant because several of the volatile organic contaminants and inorganics that were not

removed during the full-scale pilot test changed ~20% or so influent-to-effluent during this experiment. Thus, the PCB content of the influent also may have varied. Indeed, solely based on the influent measurements, 1,2-DCE varied from 5660 to 6770 µg/L (~17% variation) and PCB-1242 varied from 99.9 to 163 µg/L (~39% variation).

- What was the analytical variation? One of the effluent duplicates measured by Pace Laboratory Inc., had values for PCBs of 93/141 µg/L meaning PCB removal was either 43% or 14%. (Unless the difference is explained by variation in the influent or there was a sampling problem.) Reviewing the data, however, suggests the 14% is likely to be correct, because removal percentage appeared to be declining with time.
- How does contact time vary between use in the STiR and in the sock? Contact time is greater in the STiR both because of the size of the unit and because the bed is fluidized guaranteeing maximum interaction between the media and the wastewater (see vendor comments below). Channeling or bypass flow is very common in any packed media and is difficult to quantify without multiple tests. Thus, what appears at first glance as poor efficiency in the sock filter--may actually be easily sufficient in the STiR. An example is Fe. Fe removal in the STiR was typically 90% or greater--only failing that during the "upset" conditions test. Fe removal in the sock filter was 10% or less.
- How does iron accumulation in the sock filter affect the removal of PCBs? Although iron removal was low, it was occurring and may have blocked sorption sites and prevented PCB removal or caused additional channeling within the column. The data suggest that channeling occurred because the removal percentage for PCBs declined significantly with time while the apparent capacity of the walnut shells (as evidenced by the data for the “clean” versus “dirty” shells), was far from exhausted.
- How does lack of a backwash cycle affect the performance of the walnut shells? The vendor claims that the highly-efficient backwash cycle in the STiR constantly renews the walnut shell media (Appendix A). In conjunction with the previous

point, the lack of a backwash cycle may be the principal reason that PCB sorption declined over time.

A further discussion of the differences between the sock filter test and the typical STiR system was provided by the vendor who commented on the difference in the scale of the tests as follows:

> "The major differences/interferences from this scale differential are 1) wall effects (area/circumference ratio), and 2) freeboard residence time (for oil or PCB removal).
> WHAT IS THE SAME:
> The media depth (about 3 feet), and the flux rate (flow/area) (about 5.5 gpm/ft2). Both units share these characteristics.
> WHAT IS DIFFERENT:
> A) WALL EFFECTS (Area/Circumference):
> Due to the geometry of the systems, the difference in Area/Circumference is 2.33 times higher for the Bag [sock filter] housing. This means that the opportunity to flow along the wall [channeling] is substantially greater in the bag filter.
> Another customer has completed some column tests when evaluating suspended solids and the best results of the column were:
> Column: 60% (primary evaluation)
> STIR -7V: 98% (once arrived and installed, one week after column tests….I believe this is due to the surface area to circumference ratio, and visual solids that build around the perimeter of the column. [These are circumstances analogous to the iron removal at the KCP; ~10% with the sock filter and 90% with the STiR.]
>
> B) FREEBOARD RESIDENCE TIME:
> The filter works as a coalescer with oil and solids. By having a large freeboard residence time we obtain the benefit of gravity difference of the oils (lighter than water), and as the PCB's would sit at the top of the water level in the well, they will do the same thing in the STiR Filter. That is of course until we backwash, whereby they will be stirred up and removed. [This may not be true for PCBs sorbed to particulates, but is true for PCBs that are dissolved or within oil]
>
> The difference in this case is 5.25 minutes in the STiR and 0.63 minutes in the bag—a factor of 8.3."

To summarize, the vendor has noted that wall effects and residence times are very much different between the two tests and has provided some supporting calculations that show the sock filter would be less efficient than the STiR.

Data from the walnut shell media analyses are shown in Table 4.

Table 4. PCBs (µg/kg), VOCs (µg/kg), and inorganics (mg/kg) on walnut shell media.

	Virgin[1]	STiR Tank[2] (1)	STiR Tank (2)	Sock Filter[3] Dirtiest	Sock Filter Cleanest
PCB1242	0	24.8	150	609000	977
Calcium	562	1120	1720	1250	1130
Iron	0	3930	5320	442	305
Magnesium	137	43	70.1	93.8	87.8
Manganese	4.6	48.7	64.4	44.3	39.2
oil&grease	6900	0	0	1060	711
1,2-DCE	0	312	286	84.9	3080
TCE	0	14.6	11.9	3970	62200
PCE	0	0	0	81.8	4880

[1]The virgin shell data are based on dry shells; the other shells were wet from use.

[2]Two samples were collected from the STiR tank.

[3]The sampler visually collected a sample of the most and least discolored shells in the sock filter following the test.

The following observations can be made from these data:

- Virgin shells are low in leachable ions. The oil and grease is believed to be natural oils that are quickly removed during initial use.
- The "used" shells from the STiR tank show there is some accumulation of inorganics as well as the organic contaminants.
- The sock filter data show that the walnut shells have a very large capacity for retaining PCBs, however, these data are difficult to interpret for the reasons described above, including the fact that the total mass added is not accurately known. Similarly, the mass on the shells versus mass in the remaining interstitial water is also unknown.
- A further complicating factor is the unknown kinetics of the sorption reaction. The flow through the system may have been sufficiently fast that there was not time for the PCBs to sorb completely. Typically, tests to determine sorption capacity are performed with a series of shaker flasks so that various sorption times can be compared.

Specifically, at 60,900 µg/kg, the amount of PCBs on the dirtiest walnut shells, the sock filter had the ability to sorb 15 kg x 60,900 µg/kg or 913,500 µg or approximately one and one-half the amount (619,970) added. The cleanest of the sock filter shells had only sorbed 15 kg x 97 µg/kg or 14,655 µg or approximately 1/4th as much as the dirty shells. As noted above, however, any calculation of sorption capacity is confounded because the shells were analyzed wet and it is

unknown what amount of PCBs were on the shells versus in the water. Nevertheless, also as noted above, there can only be approximately 1625 µg of PCBs in the water in the entire column. Consequently, the majority of the PCBs were on the shells indicating a large capacity for PCB removal.

The decline in performance over time is probably a result of channeling or clogging of sorption sites by iron. PCB removal is expected to be highly efficient so long as the shells are backwashed sufficiently.

8. MEDIA CAPACITY AND BACKWASH VOLUMES

According to the vendor (personal communication, Joe Haligowski, Filtra Systems with N. Korte, phone consultation December 12, 2011), the general holding capacity of the media is approximately 1 1b of suspended solids and 0.5 lbs of oil and grease per ft^3. The pilot unit had 800 lbs or ~17 ft^3 of media. Thus, the media could hold 25 lbs of contaminants, assuming 2/3 were solids and 1/3 oil. Assuming 35 gpm and 20-40 mg/L solids, which were the nominal values for the KCP test; it would require at least 36-40 hours before the bed capacity would be depleted. (At 20 mg/L, the filter would be removing 3.27 kg/day or 7.2 lbs, while at 40 mg/L the filter would remove ~ 14lbs/day.)

Based on the testing at the KCP, backwash volumes are expected to be as follows (Appendix B):

1. A Model STiR-12V will backwash once per day, with a backwash volume of 1200 gallons (80 gpm for 15 minutes).
2. Solids volume, as measured during the pilot test, will be 5 to 10% of the daily backwash volume (60 to 120 gallons per day, of iron solids, per day)

9. POWER CONSUMPTION

A portable power meter is available at the KCP. This unit was connected to the STiR to measure power usage on three days. The usage averaged approximately 6kwh/h.

Electricity costs for the facility are approximately 5.2 cents/kwh (per email from Joe Baker, KCP on 5/5/10). Thus, operational costs are approximately 7.50/day or $2733/year.

10. COST EVALUATION

A 2005 test (CH_2MHill 2005) of the Filter Systems STiR, was estimated to have a $200,000 capital cost and $6,900 worth of annual operating costs for media replacement and related labor every three years, power supplied during the backwash cycle and periodic maintenance-related labor and parts replacement.

The vendor estimates the recommended unit would cost the KCP $208,389.00 and that most customers assume an installation cost of ~ 15 and 20% of the capital equipment cost (Appendix B).

Further evaluation is required to determine equipment and labor costs associated with handling the backwash and solids removal. The section entitled "Backwash Handling," in Appendix B provides discussion and references that augment the brief comments on this subject previously presented at the end of Section 4.

11. SUMMARY

The full-scale pilot test of the STiR filter at the KCP demonstrated the following:

1. Removal of suspended solids achieved essentially 100% from unacidified influent. Treating VOCs subsequent to passage of water through the STiR would be possible without the currently used acidification step.
2. Iron removal was approximately 90%. The vendor suggested a chemical additive which he believes will improve removal to near 100%.
3. VOCs are not removed nor entrained in air during STiR operation.
4. Inorganics, other than iron, are not removed by the STiR.
5. The unit operated at the desired KCP flow rate for the duration of the test. When "upset conditions" (a very high sediment load) were applied to the unit, it was overwhelmed by such a high load. On the other hand, after backwash, the unit's efficiency returned to its previous condition.
6. Plant personnel found the unit easy to operate and reacted favorably to the idea of purchase.

7. PCB sorption capacity of the walnut shells is quite high. Although not tested in this experiment, PCB removal with the full-scale backwashable system is expected to be complete.
8. Additional cost analysis is required to determine expenses associated with handling the backwash and associated solids disposal.

In summary, the Filtra Systems Pilot Test demonstrated that the unit is a viable replacement for the entire pre-treatment approach, including acidification, now used for KCP groundwater treatment. Based on vendor experience and plant operator observations, the unit is easy to automate and would provide a long-term solution to groundwater conditioning prior to removal/destruction of the VOCs.

A formal cost estimate was not requested, but based on previous data, capital costs will be in the vicinity of $200,000 and annual operating costs on the order of $7000. These costs, of course, are subject to the degree of redundancy and quantity of "fail-safe" operation that is deemed necessary.

REFERENCES:

CH_2MHill, 2005.Technical Memorandum, Summary of Wyckoff Bypass Test Results.

APPENDIX A

PROCESS DESCRIPTION PROVIDED BY THE VENDOR

BACKGROUND:

The Filtra Systems Deep Bed filter is the next generation of automatic backwashable media bed filter, which has overcome the limitations of conventional sand and anthracite filtration. This new product builds upon Filtra Systems patented fluidization technology and years of experience in difficult water treatment applications.

The key to the successful performance of any deep bed granular medium filter lies in the efficiency of the backwash procedure. The media must be fully cleaned after each backwash cycle if long-term performance is to be maintained. Problems arise when the backwash is incomplete. This can happen anytime sticky solid particulate or oil adhere to the media or high specific gravity solids get trapped in the media bed. The retained particles and oil have a tendency to cause the media particles to stick together, so small particles quickly become big lumps or 'mudballs'. These cause plugging of the bed, reduce filtration surface area and hence, make back-washing less efficient by allowing channeling of the backwash water. The end result is declining filtration performance, requiring the addition of chemicals in an attempt to aid the cleaning of the filter media and eventually complete removal of the filter media by manually removing the filter media from the vessel, and replacement with new media. The Deep Bed filter has overcome these limitations, by cleaning 100% of the filter media during every backwash cycle, by utilizing, our patented fluidization technology based upon the kinetic model of a CSTR.

HOW IT WORKS:

Filtration Principle:

The Deep Bed filter is a down flow media filter, capable or removing suspended solids and oil from water streams. The filtration principles employed are tortuous path, in conjunction with coalescence. As suspended solids enter the filtration tank from the inlet pipe at the top of the tank, they lose velocity and begin to travel downward through the media. As they attempt to pass through the small void space of the media bed, the fine particles lose velocity, and become trapped by the bed. Oil droplets follow the same path, however once the small oil droplets come into contact with previous captured oil, they then coalesce, forming larger pools of captured oil.

MEDIA CLEANING/REGENERATION PRINCIPLE:

Our walnut shells filter media is a by-product from the food processing industry, and are harvested yearly. Unlike medias that are produced via chemical process, or mined, the walnut shells are a renewable resource with an expected life of 30+years. Once water wetted, the shells exterior has 1) an affinity for coalescing oil, 2) a very high modulus of elasticity, which allows it to resist fracture, and 3) the perfect specific gravity such that it is just slightly heavier than water.

This specific gravity characteristic allows the shells to sink in a stagnant water tank, yet become easily fluidized, and homogenously mixed when agitated.

The mixer and filter media work in concert to not only provide friction between the media, which scrubs the contaminants from the surface of the media, but keeps the media suspended and completely fluidized (homogeneous slurry), thus giving it the opportunity to perform as CSTR, when backwashing.

MATHEMATICAL PROOF of the CSTR MODEL:

The kinetic model of a CSTR outlines the principles of perfect mixing. When trying to achieve a rapid concentration change, more correctly, diluting high concentration slurry, this mathematical model can be utilized to predict the dilution This means that if by mixing slurry homogenously, the dilution of said slurry is dependent on the concentration and volume of dilute.

NOTE: For the purposes of regenerating the media, the Deep Bed filter will remove the contaminants as quickly and efficiently as possible, with the smallest amount of dilution water possible. By sampling the backwash water at one minute intervals throughout the backwash cycle we are able to track the dilution of the filter and observe an exponentially decreasing curve is formed. At the point at which the slope of the curve nears 0, there is no benefit in continuing the backwash, as little contaminant remains in the filter. The Deep Bed filter backwash curve follows the dilution curve of a CSTR, which is the most efficient method to mix a bed, and therefore provides the most efficient use of the dilution water.

The R2 value when comparing the two functions is 0.9726. Figure 1 shows the theoretical performance of a perfectly mixed CSTR, and the performance observed by the Deep Bed Filter. Figures 2 and 3, illustrate water samples extracted at one minute intervals, highlighting the exponential decay of contaminants.

Figure 1. CSTR Backwash Curve

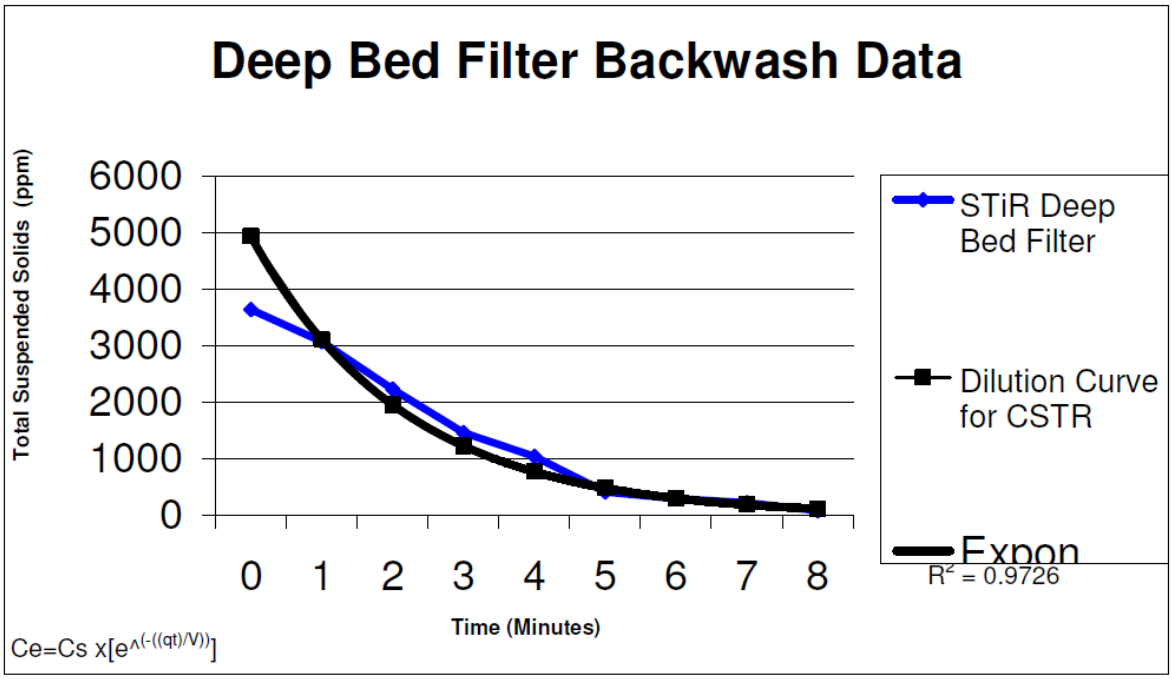


FIGURE 2. Backwash Samples at 0,2,4,6,8 minute intervals:

FIGURE 3. Backwash Samples (Oil and Solids) at 0,2,4,6,8 minute intervals:

APPENDIX B

ADDITIONAL SUGGESTIONS/OBSERVATIONS FROM THE VENDOR

Upon request of a final report, the vendor provided the following observations.

VACUUM PRESSURE CHANGE:

Over the course of this test, we did not notice or witness a significant increase in vacuum pressure change throughout the filtration cycle. Typically, the vacuum gage, which monitors the pressure on the clean side of the walnut shell, media would change from + 2psi (clean) to –12" hg (dirty), over the course of 24 to 48 hours.

In this, purely solids (very little hydrocarbon) application, we would recommend backwashing based on 24-hour timer, in lieu of the vacuum transmitter.

FLUX RATE:

Through variation of the filter flux rate (flow rate/filter area) it was determined that the optimal filtration flux rate should be between 35 and 5.5 gpm/ft2. This assumes a condition in which there is no chemical addition and no addition of acid to the water stream.

RECIRCULATION CYCLE:

It was observed during the test that suspended solids are the primary constituent (little oil). We recommend operating the recirculation cycle for 3 minutes at 25% above the fixed filtration rate, then operating in recirculation mode, at the desired filtration rate for 10 minutes, prior to going back online.

This will improve the water quality immediately following a backwash.

Additional Considerations

FURTHER OPTIMIZATION:

We recommend the addition of 0.5 to 2 ppm of a coagulant or flocculent to improve the removal efficiency of the filtration unit from 90% to 98+%. The addition of the proper chemical will increase the mean particle size of the suspended solids, and also remove a portion of the filtration unit void space. I am extremely confident that a small amount of the proper chemical, added in the proper place, would allow the filter to increase the removal efficiency, build differential pressure (which would provide a more measurable operation, giving operators another trend-able data point) while not increasing the backwash frequency beyond once every 24 hours.

BACKWASH HANDLING:

KCP personnel mentioned experience with specific bags, but from my discussions, and the testing they completed with the bag filters (backwash), I believe they have a micron size in mind

that would allow good collection of the solids, while allowing the remaining liquid to wick out. The links below offers a few options for the plant personnel to consider for collection and removal of the iron fines.

http://www.usfabricsinc.com/products/us-400t-ecotube-dumpster-bag

http://www-packagingresearch-com.netsolads.com/dewatering.html

http://www.flotrend.com/rolloffcontainer.html

TECHNICAL RECOMMENDATIONS/DATA POINTS

- To process 25 to 60 gpm of non acidified waste water, Filtra Systems recommends implementing (1) model STiR 12V (2.1 to 5 gpm/ft2).
- For maximum filtration unit operation (removal efficiency, and backwash recovery), we recommend a clean water source for backwash. The excursions above 100 mg/l of inlet of waste water are just over the threshold for contaminant level for the inlet dilution fluid.
- A Model STiR-12V will backwash once per day, with a backwash volume of 1200 gallons (80 gpm for 15 minutes).
- Solids volume, as measured during the test, will be 5 to 10% of the daily backwash volume (60 to 120 gallons per day, of iron solids, per day)
-

INSTALLED DIMENSIONS: (as shown in product literature).

L- 7'-9"

W- 7'-3"

H- 9'-3"

SCOPE:

-304 SS vessel

-Cast Iron piping

-Cast Iron pump (stainless impeller)

-304 SS mixer, and screens

-Pneumatically operated automated valves

-Level control in the filter tank (via inlet control valve)

-Flow Control (25 to 60 gpm). (via flow meter and outlet control valve)

-Local PLC, for automated control

ESTIMATED CAPITAL COST $208,389.00 USD

INSTALLATION COST:

Since our equipment falls under the capital equipment category of "pre-piped and pre-wired" (fully assembled and run off in our shop, prior to shipment), most of our customers assume an installation cost between 15 and 20% of the capital equipment cost.

OPERATING COST:

The operating cost would be the electrical operating costs, clean water cost (should you decide to use clean water for backwash, as recommended by not necessary), and maintenance costs.

ENERGY:

(1) 5 hp motor – operating continuously.

(1) 7.5 hp motor – operating intermittently (30 minutes once per day)

WATER:

1200 gallons of clean water, once per day (as dilution water for backwash)

MAINTENANCE:

The unit is fully automated, and requires a minimal operator attention. We recommended the same maintenance cycle as you would use on any plant instrument, pump, valve or mixer. The media life is 20+ years. There are no continuous consumables, such as acid, filter elements (bags/cartridges), or carbon.

APPENDIX C

PROCEDURE FOR DETERMINATION OF OIL AND GREASE AND SUSPENDED SOLIDS

PROCEDURE: CONCENTRATION OF SUSPENDED SOLIDS & OIL

The following method is the procedure followed by Filtra Systems Company laboratory personnel to determine the concentration of suspended solids in water samples containing oil.

1. The following equipment is required:

   a. Millipore 47 mm stainless steel in-line filter holders, Millipore Hydrosol Vacuum funnel with vacuum flask and vacuum pump.
   b. Graduated Cylinder, 2,000 ml
   c. Hose to connect in-line filter holders to sampling ports
   d. Millipore filter membranes (0.45 & 5.0 micron)
      1. Handle filter swatches with forceps at all times.
   e. Forceps
   f. Squeeze bottle
   g. Drying oven
   h. Desiccator
   i. Analytical balance (0.0000 g accuracy)
   j. Distilled water
   k. Solvent (Tri-Chloroethylene, Xylenes, di-ethyl ether, etc.)

2. The pre-weighing of the membranes requires the following:

   a. Mark filters membranes with sample numbers.
   b. Dry the membranes in the oven for 20 minutes at 90 degrees Celsius.
   c. Place filters membranes in the desiccator for 20 minutes.

d. Weigh membranes with analytical balance and record weights.

3. The filtering procedure involves:

a. Place pre-weighed filter membranes in the in-line filter holders. Attach filter holders to inlet and outlet sampling ports.

b. Allow an aliquot of test sample to pass through filter membranes. Read and record the volume of liquid passed through, in the graduated cylinder (minimum 1 liter).

c. Remove membranes from in-line filter holders. Transfer membranes onto vacuum set up and rinse with distilled water, to remove any soluble salts.

d. Re-dry membranes in oven for 20 minutes at 90 degrees Celsius, place filter membranes in the desiccator for 20 minutes.

e. Re-weigh membranes and record weight.

f. Again, place the filter membrane in the filter holder; rinse the swatches with the selected solvent to remove any residual oil.

g. Re-dry swatches in oven, place filter swatches in the desiccator for 20 minutes and re-weigh test swatches for the third time.

4. Calculation of parts per million: ppm = mg / liter (mg solids / volume in liters

APPENDIX D

VENDOR PRODUCT BULLETIN DESCRIBING USE OF THE STiR FOR PCB REMOVAL FROM WASTEWATER

The following text is from a product bulletin provided by Filtra Systems Inc.

Data:

End User:	Aluminum Producer
Location:	Pacific Northwest, USA
Commissioned:	Summer, 2002
Units:	(3) model FDB-340P (340 ft^2/filter)
Flow Rate:	12,000 gpm (**17.3 Million gallons of water per day)**
Process:	PCB removal from non contact caster water with discharge to a fish bearing river.

Process Description:

A west coast aluminum producer uses the HDBF for to remove PCBs and suspended solids from non contact caster water, which comes from the ground water. The producer uses the ground water, which contains PCBs, for use as cooling water. The water does not come into contact with their process. To discharge the water to the river, it must meet EPA specified PCB levels for discharge into fish bearing streams. The Hydromation deep bed filter removes the PCBs to meet this discharge requirement and is the only removal system in the process

The standard EPA recommended equipment for this application is to use sand filtration followed by carbon columns. The end user pilot tested various pieces of equipment and it was determined that the HDBF could meet the removal requirement on a continuous basis, by itself, in a single step. This eliminated the need for granular activated carbon filters, which have a large operation cost associated to regeneration.

This installation was originally quoted with vertical vessel deep bed filters. Using the vertical vessel configuration, our competition quoted 9 filtration units. The horizontal filter vessel orientation allowed Filtra Systems Company to provide (3) model FDB-340P for the entire flow rate, which significantly reduced capital and installation costs.