Removal of TBA from Water

A Major Qualifying Project Report:

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By

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Christopher McCann

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Approved:

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Professor Robert W. Thompson

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Associate Professor Nikolaos K. Kazantzis

Abstract

In thisproject t-butyl alcohol was removed from water through the use of adsorption. Three different adsorbents (ZSM-5, HiSiv 3000, and Activated Carbon) were used to determine which one was the most efficient for removing TBA from water when present in low concentrations (approximately 10ppm TBA in water.) Through the use of 3cm tall beds, Activated Carbon as well as a mix of half ZSM-5 and half HiSiv 3000 were determined to be less efficient than the ZSM-5 and the HiSiv 3000. Through the use of 6cm and 9cm beds ZSM-5 was shown to have a greater adsorption capacity than the HiSiv 3000 in absorbing TBA from water when present in low concentrations.

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Introduction

T-butyl alcohol

Tert-butyl alcohol (TBA) is a clear, colorless liquid above 25ºC[1]. Health concerns for TBA include eye and skin irritation due to exposure, liver and kidney damage due to ingestion and central nervous effects due to inhalation[1]. TBA is found in the environment due to its use as a fuel oxygenate[2], it being a byproduct of MBTE blended fuels[2], and as the result of the breakdown of MBTE in water[3]. From these sources, TBA accumulates in water sources due to occurrences such as storage tank leaks, run-offs, and the use of gasoline in everyday life. Although TBA can have dangerous effects on animals in high concentrations, our focus is to remove it from drinking water.

TBA is miscible with water[4] and therefore difficult to remove. Biological degradation takes approximately 27 days[2] which is far too long because water systems and therefore the TBA is constantly moving and therefore would not stay in one place long enough for the process to go to completion. Due to TBA's low Henry's constant, air stripping and purge trapping are not good options[5].

Adsorption

Adsorption through a packed bed appeared to be the best option for removing TBA from water. In the process of adsorption, a solid adsorbent whose surface has a special affinity for the solute is used to remove the solute from a liquid or a gas[6]. For this experiment the solute (TBA) would be removed from a liquid (water) by the adsorbent (the zeolites.) Adsorption would also be favorable because the zeolites could be cleaned and reused and with the use of multiple beds, enough so that the regeneration periods were long enough, the process could be carried out continuously.

Choice of Zeolites

Initially there were 7 different zeolites considered for use Zeolite Beta, Zeolite Mordenite, MolSiv HiSiv 1000 (High Silica faujasite), MolSiv HiSiv 3000 (High Silica faujasite), Zeolite-Y 1, Zeolite-Y 2, and ZSM-5. Through the use of isotherms, it was earlier determined that the HiSiv 3000 and the ZSM-5 had the greatest adsorption

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[1] Material Safety Data Sheet, Tert-butanol, http://www.atmos.umd.edu/~russ/MSDS/tertbutanol.html
[2] Bradley, et al., Aerobic Mineralization of MTBE and TBA by stream bed sediment organisms, Environmental Scientific Technology (1999) pp 33, 1877-1879
[3] Fischer, A., Oehm, C., Selle, M., and Werner, P., Biotic and Abiotic Transformations of Methyl tertiary Butyl Ether (MTBE), Environmental Science & Pollution Res. (2005) pp. 12, 381-386
[4] Wade Jr., L.G., Organic Chemistry, 5th Edition, Prentice Hall, Pearson Education Inc. Upper Saddle River, NJ (2003) p. 412
[5] Hanson, J., Ackerman, C., Scow, K., Biodegradation of Methyl tert-Butyl Ether by a Bacterial Pure Culture, Applied and Environmental Microbiology (1999) pp. 4788-4792
[6] McCabe, Warren L., Smith, Julian C., Harriot, Peter, Unit Operations of Chemical Engineering, 7th Edition, McGraw-Hill Inc. New York, NY (2005) p. 522

capacity for the TBA[7]. Information for both the HiSiv 3000 and the ZSM-5 is shown in Table 1.

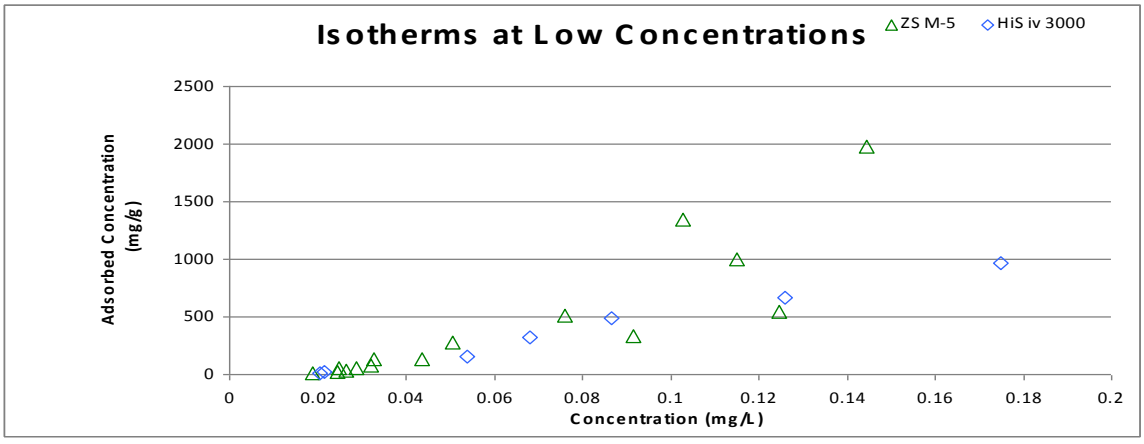
Table 1: HiSiv 3000 and ZSM-5 Information- provided by T. Butland

Sample name	SiO2 / Al2O3	Nature	Company Name	Lot #	Surface Area (m2/g)	Micropore Area (m2/g)	External Area (m2/g)	Fraction Micropore
HISIV 3000	< 10	Granular	UOP	2002001440	321.9	230.5	91.4	0.72
ZSM-5	280	Granular	Zeolyst	CBV28014	390.8	141.8	249	0.36

As shown in Table 1, both the HiSiv 3000 and the ZSM-5 are granular in nature. Although the ZSM-5 has only a slightly larger surface area than the HiSiv 3000 (390.8 m^2/g compared to 321.9m^2/g,) the distribution of the surface areas is very different for the two. The micropores account for only 36% of the surface area (with the other 64% accounted for by the external area) in the ZSM-5 while they account for 72% of the surface area in the HiSiv 3000. This could be a factor in the efficiencies of the zeolites because the external area has much easier access for the TBA and therefore it can be adsorbed more easily.

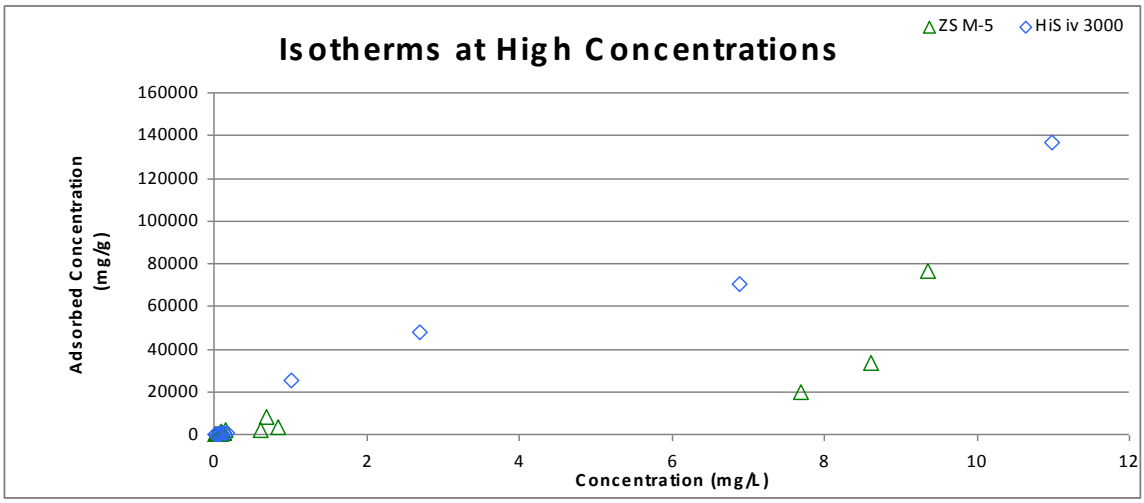
Adsorption isotherm data for both HiSiv 3000 and ZSM-5 was generated at low concentrations (less than 0.2 mg/L) and high concentrations (between 0.2 mg/L and 12mg/L.)This data was generated by Tricia Butland and is shown in Figures 1 and 2 respectively.

Figure 1: Isotherms at Low Concentrations- provided by T. Butland



[7] Butland, Tricia, TBA Work Done Summary, Worcester Polytechic Institute (2007), pp.2-3

Figure 2: Isotherms at High Concentrations- provided by T. Butland



As shown in Figure 1, it is hard to differentiate the HiSiv 3000 from the ZSM-5 at very low concentrations (less than 0.03mg/L) but as the concentration increases slightly (between 0.03mg/L and 0.18mg/L) it is easy to see that the ZSM-5 has a greater adsorption capacity than the HiSiv 3000 at low concentrations. From Figure 2 it is evident that at high concentrations (between 1mg/L and 12mg/L) the roles are reversed and the HiSiv 3000 has a greater adsorption capacity than the ZSM-5. For our experiment the feed concentration of approximately 10ppm TBA in water falls into the low concentration category the ZSM-5 was expected to outperform the HiSiv 3000.

Experimental Procedure

The Apparatus

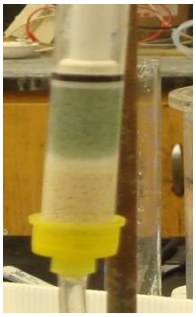
A large plastic bag that may be filled with up to 25L (maximum of 20L recommended) was used as the feed reservoir. Rubber tubing was used to transport the feed from the reservoir to the top of the adsorption column by use of a cylindrical pump. Downward flow of the feed is recommended because if fed from the bottom a high flow rate could cause the bed to become fluidized[6]. The adsorption column consisted of a glass cylinder with plastic joints on each end to attach to the tubing. A filter was placed between the glass cylinder and the plastic joint on the bottom of the column to allow the liquid product to pass through while keeping the zeolites in the column. Rubber tubing was attached to the bottom of the column to allow the product to flow into a large beaker when samples were not being taken.

Preparation of the column

The zeolites that were to be used initially came in a cylindrical shape that was too large for the purposes of this experiment so they were carefully ground into smaller particles. A predetermined amount of zeolite that would give the desired column height was placed into a ceramic baking dish. The zeolite was baked for a total of 12 hours in an oven, in a hood starting at 100ºC for 4 hours and then increasing to 200ºC for 4 hours and the 300ºC for the final 4 hours. The zeolites were heated to 300ºC to activate and clean them but the process was carried out gradually to avoid flashing any TBA that may have remained in the zeolites from a previous run. After the 12 hour period, the zeolites were removed from the oven and allowed to cool slightly so that they were easier to work with.

When the zeolites have adequately cooled, they were carefully poured into the cylinder so that there were no large gaps in between the zeolites and that the top was close to level. A small wad of glass wool was placed into the cylinder, pushed down above the zeolites, and made as level as possible. Water was poured into the column to help pack the zeolites and wool down and allowed to drip out the bottom of the column. If another zeolite was also to be used in the same column, the process was then repeated with that column. If the zeolites and glass wool did not reach a certain height in the column (approximately 5 inches, to allow the tubing device to be placed directly above the wool) glass beads were added to the column until the appropriate height was achieved. Once that height was achieved, the tubing device was lowered into the column and pushed down until it was directly above the top layer in the column. The device was then locked into place so that the feed was pumped directly above the top layer of particles and evenly dispersed among them. Figure 3 displays a picture of one of the prepared columns.

Figure 3: A prepared column- provided by T. Butland



Preparation of the Feed

For all runs of the experiment the desired feed concentration was approximately 10 ppm (parts-per million) TBA in water. 2 liters of pure water was measured using a Florence flask and poured into a clean empty 20L Poland Springs jug. Another 2 liters of pure water was measured out and the correct amount of water was removed (10µL per liter of total desired volume) using a 200µL pipette. Using the same 200µL pipette, the correct amount of TBA (equal to the same amount of water that was removed) was added to the pure water in the Poland Springs jug. The remaining amount of pure water in the

Florence flask was then also poured into the Poland Springs jug. Pure water was then added 2 liters at a time using the Florence flask until the desired volume was finally attained. The Poland Springs container was kept sealed with a cork stopper whenever liquid was not being added to prevent any possible evaporation.
The Poland Springs jug was then carried from the Kaven Hall water treatment lab over to the lab in Goddard Hall where the experiment was to take place. Using a cylindrical pump, the feed was then pumped from the Poland Springs jug into the feed reservoir. Parafilm was used to make a seal over the Poland Springs jug while pumping the liquid. The seal was not perfect so some air entered the feed reservoir and their was a small chance of evaporation from the jug although pumping usually took approximately 90 minutes so the feed was exposed to the air for no longer than that.

Carrying out the experiment

The feed was pumped at approximately 10.4mL/min through the column and collected in a large glass beaker when samples were not being taken. Samples were taken at predetermined times depending on the conditions of the column and the goal of the run. Initially the samples were collected in 40mL vials and later transferred to the 18mL gas chromatography vials. It was later determined to be more efficient to collect the samples directly into the 18mL gas chromatography vials. The vials were attached to a cap with a hole in it with the rubber tubing carrying the product running through it to prevent possible evaporation. The vials were filled, capped and placed into the refrigerator for storage until they could be run through the gas chromatographer. When the experiment was to be carried out for longer than approximately 30 hours, it was necessary to refill the feed reservoir. Gas chromatography vials were filled with each new batch of the feed as well as a sample from the feed reservoir at the conclusion of the experiment so that the actual feed concentrations would be known.

Determination of the Composition of the Samples

Using a 10mL pipette and a 200μL pipette approximately 17.9mL of a sample was placed in a gas chromatography vial. 0.1mL of Isopropyl Alcohol was also added to each vial to be used as an internal standard. All of the samples were capped and then loaded into the automated gas chromatographer located in the Kaven Hall water treatment lab. First a water sample was run through the system to prepare the fiber and system and then up to 32 samples were analyzed one after another with each run taking approximately 50 minutes. When all the loaded samples had been run through the chromatographer, the results were printed so that they could be analyzed.

Attaining the calibration Curve for the Gas Chromatography Fiber

Each Gas Chromatography fiber lasted approximately 100 samples before needing to be replaced. Every fiber is different so a calibration curve had to be generated for each. Samples were prepared containing 18mL of 0, 0.1, 1, 2, and 10 ppm TBA in water using a 10mL pipette and a 200μL pipette. Each sample was then run through the Gas Chromatographer and the results were printed. The area of the peaks at a retention time of

approximately 4.7 minutes (the peaks representing TBA) was then plotted against the known concentrations of the prepared samples in Microsoft Excel. A line of best fit was drawn through the resulting points and the equation of the line was determined. All of the calibration curves are shown in Appendix I.

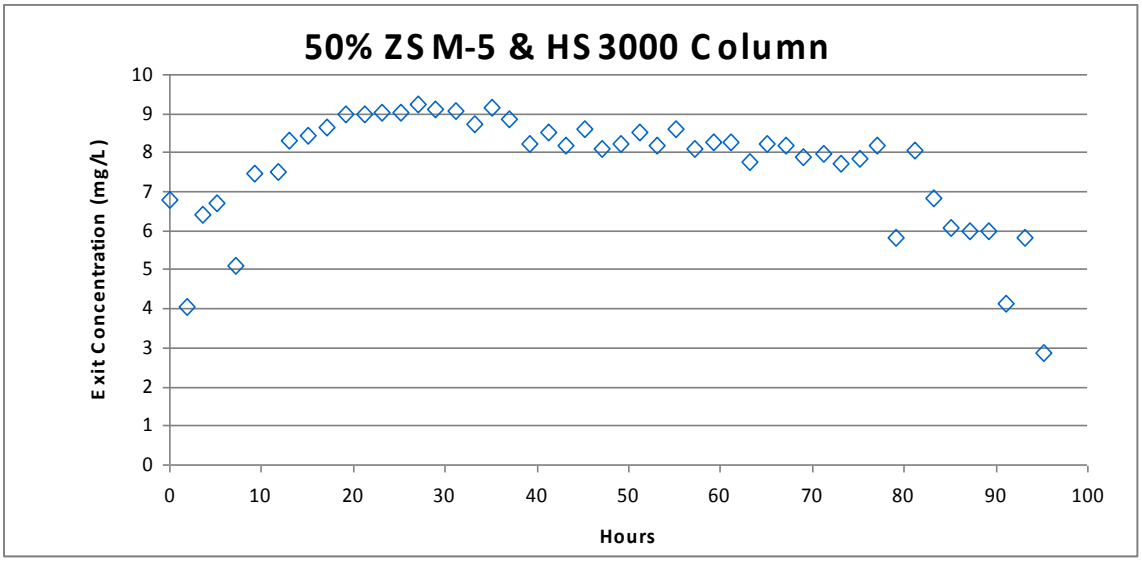
Results and Discussion

Trial 1- 50%, ZSM-5

The first set of runs was carried out using two columns, one with ZSM-5 only and the other containing half ZSM-5 and half HiSiv 3000. The beds each had a height of approximately 3cm. The runs were conducted for 96 hours with the feed flowing at a rate 10.4mL/min. The concentration of the feed was approximately 10ppm TBA in water and had to be replaced 3 times over the 4 day period. Samples were taken once approximately every two hours yielding 49 samples for each column. The samples were then run through the gas chromatographer and the breakthrough curves were attained through the use of Microsoft Excel.

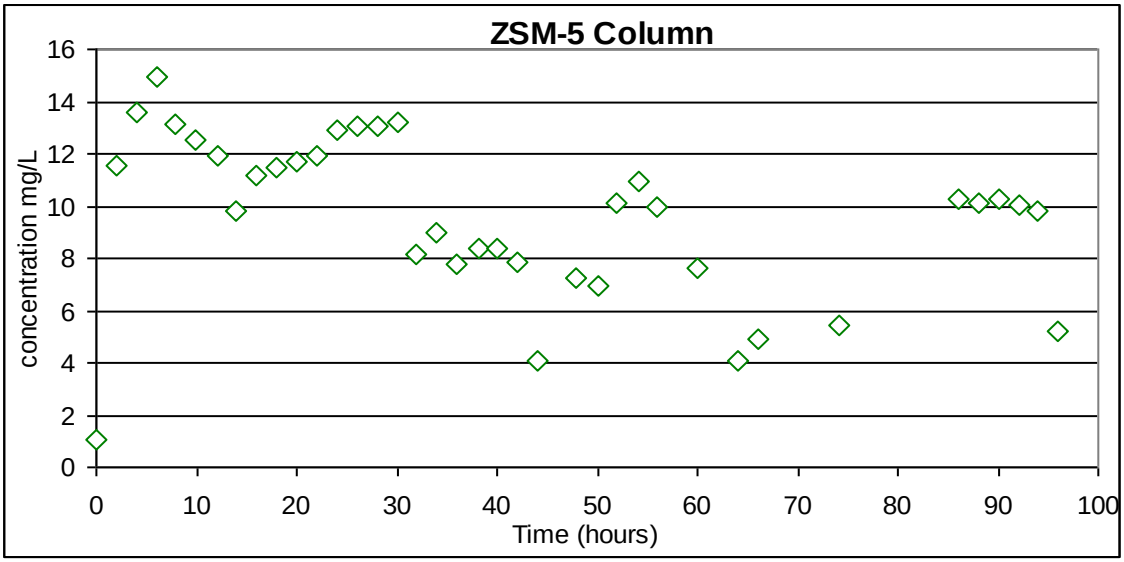
The GC data for the 50% column produced a somewhat reasonable curve as shown in Figure 4. The first 40 samples from the column, with a few exceptions, seem to follow the expected pattern of slowly rising creating an asymptote to the feed concentration. The exit concentration seems to reach its peak 18 hours into the experiment and level off meaning that the zeolites are fully saturated at that point. After approximately 36 hours, the exit concentration began to decrease but since the zeolites were fully saturated, this is due to the changing of the feed concentration rather than adsorption. After 80 hours, the data began to behave erratically, most likely due to some type of malfunction such as a contamination of the samples, or a lack of headspace in the GC vials.

Figure 4: Trial 1- 50% ZSM-5 & HiSiv 3000 Column, 3cm Bed- provided by T. Butland



The GC data for the ZSM-5 column behaved very erratically as shown in Figure 5. Although the concentration appeared to start low and increase, it did so too quickly. In the GC graphs, rather than the nice sharp peaks that are expected at the retention time of TBA, there were large smooth bumps, several peaks in series, or simply no peaks at all. In most of these graphs, the peak for the internal standard (Isopropyl Alcohol) did not appear which indicates that there was a problem with the GC results. Although the exact source of error was unable to be determined, it was most likely due to a possible lack of head space in the GC vials.

Figure 5: Trial 1- ZSM-5 Column, 3cm Bed

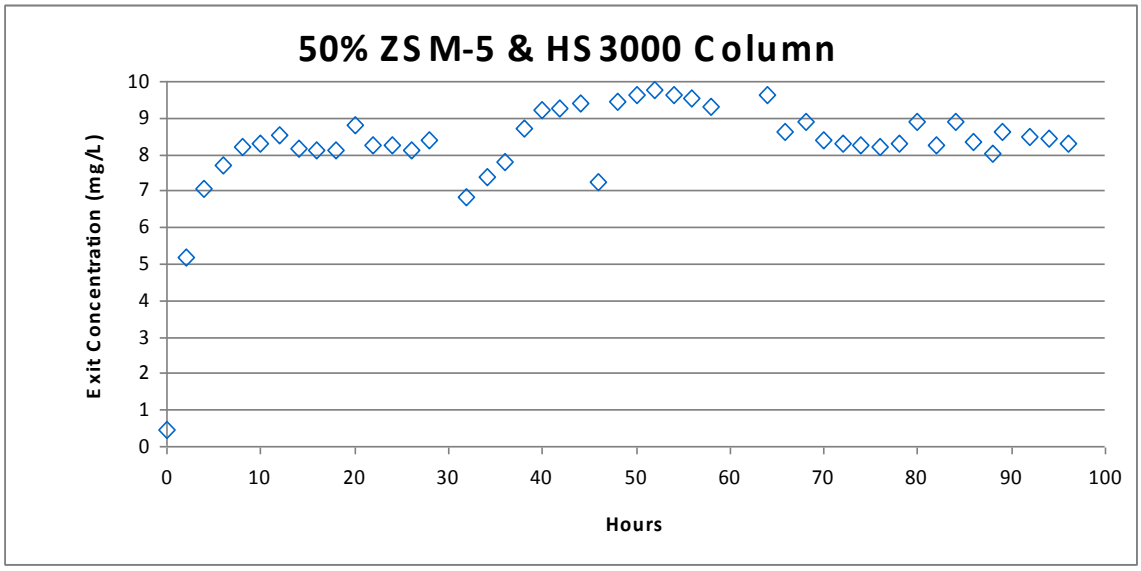


Trial 2- 50%, ZSM-5

The second set of runs was also carried out using two columns, one with ZSM-5 only and the other containing half ZSM-5 and half HiSiv 3000. All of the initial conditions were the same as in the first set of runs. The same zeolites used in the first set of runs were used again after being baked for a 12 hour period with the last 4 hours at 300 degrees Celsius. This was done to try and correct the error that had been made in the first set of runs and attain usable data.

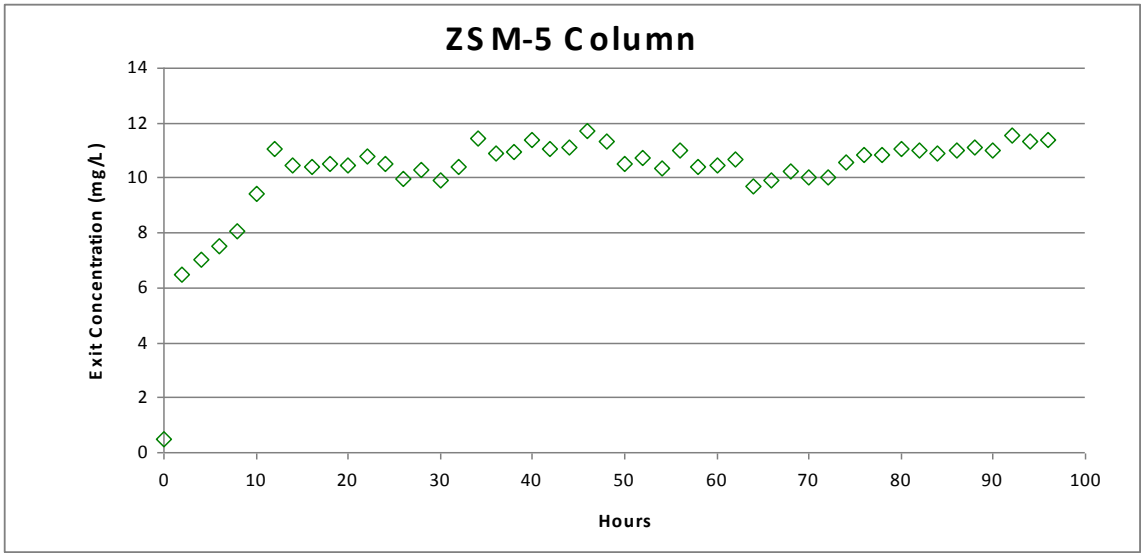
The GC data for the second run of the 50% column produced similar results to those of the first run but the later samples were no longer erratic as shown in Figure 6. The zeolites again appeared to be completely saturated with TBA approximately 16 hours into the experiment. There are slight fluctuations around hours 30 and 60 in the graph but again these are most likely due to the changing of the feed concentration and the use of different GC fibers and have nothing to do with the adsorption.

Figure 6: Trial 2- 50% ZSM-5 & HiSiv 3000 Column, 3cm Bed-provided by T. Butland



The GC data for the second run of the ZSM-5 produced much more acceptable results than the first run as shown in Figure 7. The exit concentration started out low and then increased until the zeolites appeared to be completely saturated with TBA, approximately 16 hours into the experiment. As was the case for the 50% column, there were slight fluctuations in the graph around 30 and 60 hours into the experiment due to a change in the feed concentration.

Figure 7: Trial 2- ZSM-5 Column, 3cm Bed

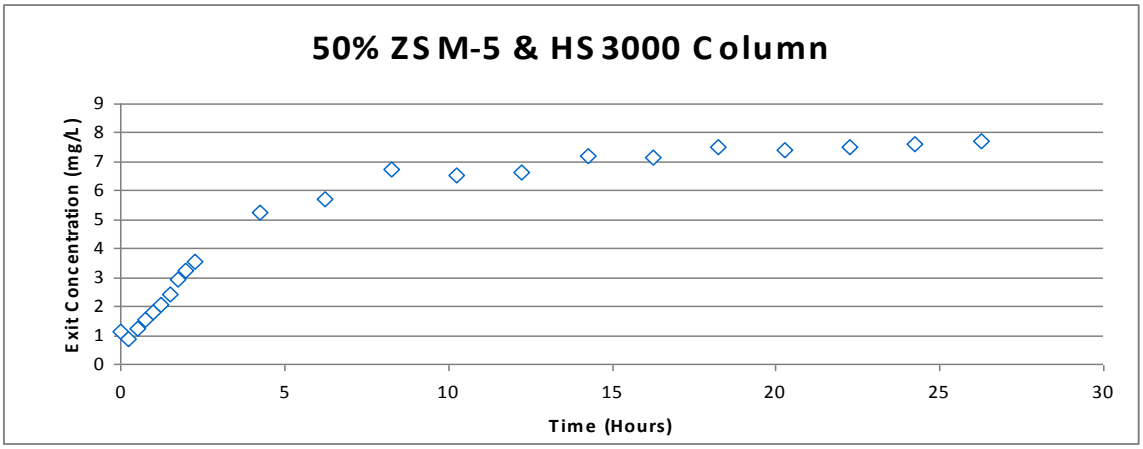


Trial 3- 50%, ZSM-5

The third set of runs was also carried out using two columns, one with ZSM-5 only and the other with half ZSM-5 and half HiSiv 3000. The beds again had heights of 3 cm but there were other changes made to try to reduce the sources for error and also attain more accurate results. The first major change that was made was cutting down the experiment time to 30 hours as opposed to 96 hours. This was done because in the first two trials, the zeolites had been completely saturated by approximately 16 hours into the experiment so the last 80 hours were not necessary. 30 hours was a convenient time period in that it gave extra time in case saturation took longer than 16 hours but it still only required one batch of feed. Another change was that all of the rubber tubing in the system was shortened so that the stream spent as little time as possible going through the system. To gain a more accurate curve in the initial stages, a sample was taken once every 15 minutes for the first 2 hours which meant there were 24 samples total for each column. The last major change was that samples were collected directly into the 18mL GC vials rather than the 40mL vials to simplify the transferring process as well as reduce the time range that the sample was collected over. The feed still had a concentration of approximately 10ppm TBA in water and was being pumped at a rate of 10.4mL/min.

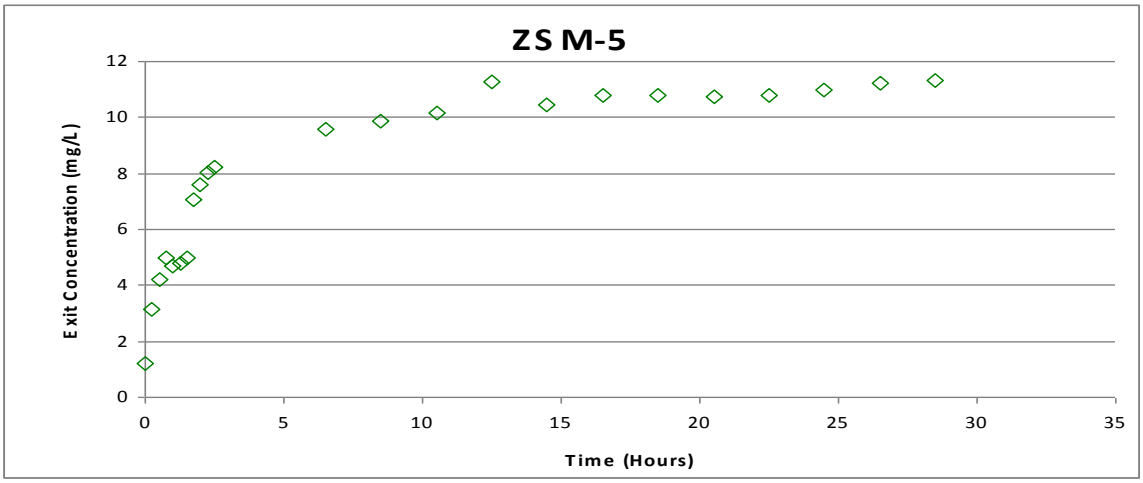
The GC data for the 50% column produced similar results to the first two runs but the addition of the extra samples in the first 2 hours gave a much more detailed look at the early stages of the experiment as shown in Figure 8. The feed concentration was later found to be approximately 7ppm TBA in Water rather than the expected 10ppm TBA in water which explains why the curve never approached 10 ppm. As was the case in the earlier runs, the zeolites were completely saturated at approximately 16 hours into the experiment. The extra samples taken in the first two hours showed the change in exit concentration over time had a near constant increase in the early stages before starting to behave asymptotically. This is most likely due to the availability of surface area on the zeolites for the TBA to be adsorbed. Initially all of the zeolite's surface area was available for adsorption but as time went on there was less surface area available so it was harder for the TBA to come into contact with the available area.

Figure 8: Trial 3- 50% ZSM-5 & HiSiv 3000 Column, 3cm Bed- provided by T. Butland (Feed App. 7-8 ppm TBA in water)



The GC data for the ZSM-5 column gave similar results to that of the 2nd run but again because of the extra samples in the first 2 hours there was a more detailed look at the early stages of the experiment as shown in Figure 9. The zeolites appeared to be fully saturated approximately 16 hours into the experiment. The early data points were much more erratic than those for the 50% column but still showed that the exit concentration was going up gradually and not jumping up immediately. Due to technical difficulties, the sample taken at 4.5 hours was not usable so there is a void in the graph from 2.5 hours to 6.5 hours. Although it is unknown why, the concentration of the feed at the end of the run was found to be greater than at the beginning of the running which explains why the concentration continued to rise after the zeolites were completely saturated.

Figure 9: Trial 3- ZSM-5 Column, 3cm Bed

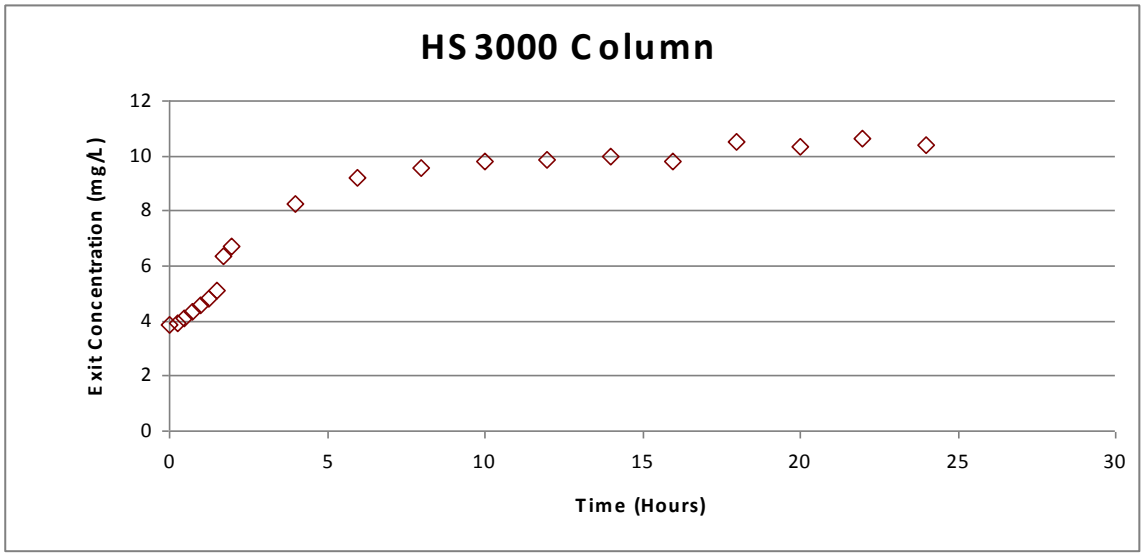


Trial 4- HiSiv 3000, Activated Carbon

The fourth set of runs was also carried out using two columns but this time one contained HiSiv 3000 and the other contained Activated Carbon. The beds again had heights of 3cm and were run at all of the same conditions as trial 3. New zeolites were used for this process but they were still baked to guarantee that they were clean as well as activated. These runs were done at these conditions so that a comparison could easily be made between the HiSiv 3000, the Activated Carbon, the 50%, and the ZSM-5 columns.

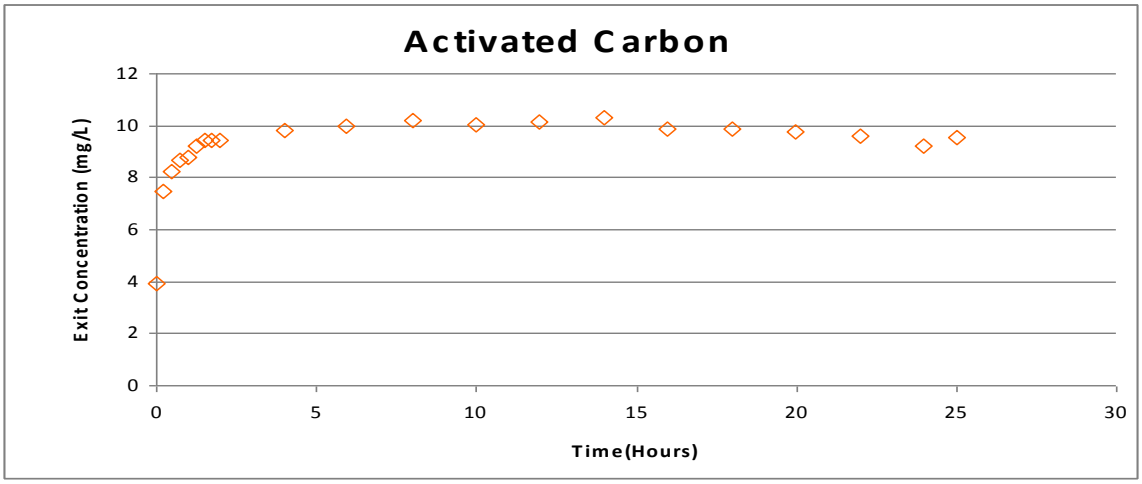
The GC data for the HiSiv 3000 column was expected to be similar to that of the ZSM-5 and is, as shown in Figure 10. Unlike the ZSM-5 and 50% columns, the HiSiv 3000 appears to reach saturation at only 12 hours into the experiment. The initial exit concentration is already approximately 4ppm TBA in Water which is about 4 times greater than the ZSM-5 or the 50% column. Although the exit concentration seems to increase more gradually than it did in the other columns, because of its high initial exit concentration, the zeolites are completely saturated with TBA much earlier. The HiSiv 3000 column does not appear to be as efficient as the ZSM-5 or 50% columns.

Figure 10: Trial 4- HiSiv 3000 Column, 3cm Bed



The GC data for the Activated Carbon was expected to produce a graph similar to that of the other zeolites but reach complete saturation earlier and it did as shown in Figure 11. The Activated Carbon appeared to reach complete saturation approximately 8 hours into the experiment which was much earlier than the other zeolites. The initial exit concentration for the Activated Carbon column was similar to that of the HiSiv 3000 column (approximately 4ppm) but it increased much more rapidly. Due to the high initial exit concentration as well as the rapid increase, the Activated Carbon was much less efficient than the HiSiv 3000, the ZSM-5, and the 50% columns.

Figure 11: Trial 4- Activated Carbon Column, 3cm Bed- provided by T. Butland



All 3cm columns

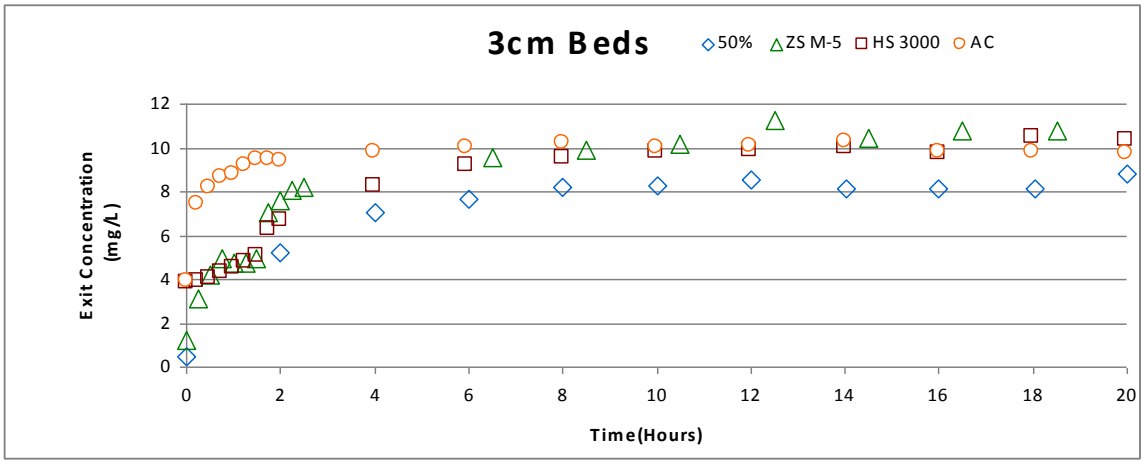
To make comparisons easier, the data for all 4 beds were placed on the same graph as shown in Figure 12. When observing the curves it is important to remember that the feed concentration was slightly different for all of the columns. The graph only shows the first 20 hours of the experiments, the zeolites were all completely saturated by that point, in order to give a better idea of the curve.

When looking at the graph it is very easy to see that the Activated Carbon greatly underperformed the other zeolites as was expected. The Activated Carbon not only had the highest initial exit concentration but also had the fastest increasing exit concentration. The amount of TBA that the Activated Carbon adsorbs was much less than the other zeolites. Therefore it was decided that there was no need to continue testing Activated Carbon columns.

The 50% column's performance seemed to be very similar to that of the ZSM-5 and HiSiv 3000. It follows a very similar pattern and was completely saturated around the same time as the other columns. The hope in running the 50% column was to give a column that was much more efficient than either the ZSM-5 or the HiSiv 3000 columns. The 50% column did not give much better results and also took more work to make so it was determined that there was no need to continue testing the 50% columns.

The ZSM-5 and HiSiv3000 columns produced similar results. The exit concentrations for both columns increased gradually and took reasonable amounts of time to reach complete saturation. The only major difference between the two columns was that the initial exit concentration for the HiSiv 3000 (approximately 4 ppm) was almost 4 times the initial exit concentration for the ZSM-5. To get a better comparison between the HiSiv 3000 and ZSM-5 columns it was decided that both zeolites should be tried again but with bed heights of 6cm rather than 3cm.

Figure 12: Comparison of All 3cm Beds

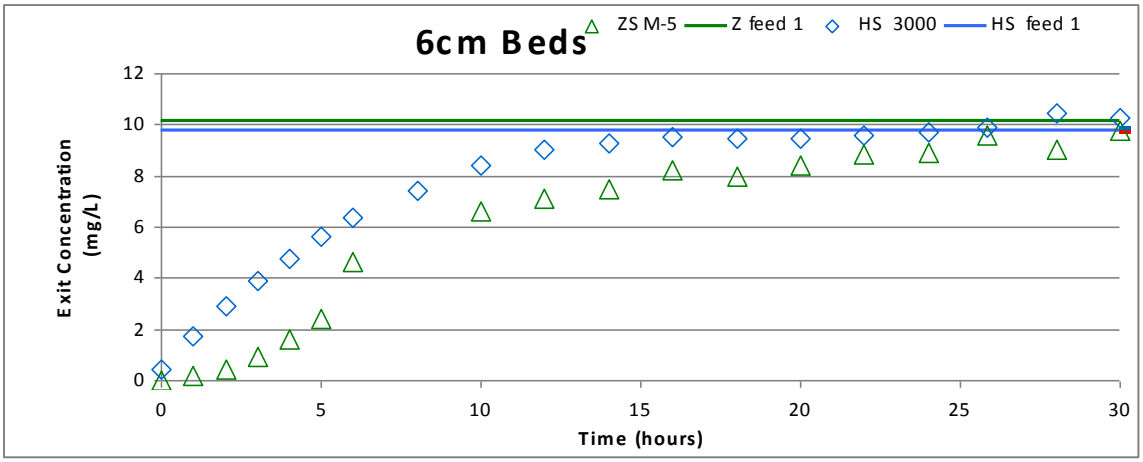


Trial 5- HiSiv 3000, ZSM-5

The fifth set of runs was again carried out using two columns, one containing HiSiv 3000 and the other containing ZSM-5. As previously stated, the bed heights were both 6cm for this set of runs. Doubling the bed heights meant that the adsorption process took approximately twice as long so the runs were carried out for 48 hours to allow for complete saturation. Rather than taking a sample every 15 minutes for the first 2 hours, a sample was taken once every hour for the first 6 hours. All of the other conditions were the same as in trials 3 and 4 except the feed had to be replaced once.

When graphing the GC data for the ZSM-5 and the HiSiv 3000 together (as shown in Figure 13) it was clear that the ZSM-5 outperformed the HiSiv 3000. The initial exit concentration of the HiSiv 3000 column was slightly greater than that of the ZSM-5 column. The exit concentration of the HiSiv 3000 column increased more rapidly than the ZSM-5 and therefore reached complete saturation in approximately 24 hours compared to the ZSM-5 column's approximate 30 hours.

Figure 13: Comparison of ZSM-5 & HiSiv 3000 6cm Beds- HiSiv 3000 data provided by T. Butland



To determine the amount of TBA per unit mass the zeolites adsorbed the following equation can be used:

$$T_{ad} = \frac{Q_f (A_f - A_c)}{m_z} \qquad \text{Equation 1}$$

Given that Q_f is the flow rate of the feed, A_f is the area under the feed line, A_c is the area under the curve, m_z is the mass of the zeolite, and T_{ad} is the amount of TBA adsorbed by the zeolite per unit mass. The flow rate of the feed and the mass of the zeolites are known. The areas under the feed line and under the curve can be found using integration. These values and the results of them being plugged into the equation can be found in Table 2.

Table 2: Comparison of Adsorption Capacities of ZSM-5 and HiSiv 3000 6cm Beds

Zeolite	A_f (L/(mg·h))	A_c (L/(mg·h))	A_f-A_c (L/(mg·h))	Q_f (L/hour)	m_z (g)	T_{ad} (mg TBA/g Zeolite)
ZSM-5	480	365	115	0.618	6.40	11.105
HiSiv 3000	470	435	35	0.618	6.83	3.167

As shown in Table 2, the area under the feed line was very similar for both the ZSM-5 and the HiSiv 3000 due to the fact that the feed concentrations were similar for the two columns. The main difference between the columns is that the area under the curve for the ZSM-5 column was much greater than the area under the curve for the HiSiv 3000 column. A large part of this difference stemmed from the fact that the HiSiv 3000 column reached saturation much earlier than the ZSM-5 which led to ZSM-5 adsorbing small amounts of TBA for a long time after the HiSiv 3000 had ended. The ZSM-5 adsorbed

over 3 times as much TBA per gram of zeolite as the HiSiv 3000 did thus proving to be much more efficient.

Although it was impossible to generate isotherm data for the exact feed concentrations that were used (as shown in Figure 1), the isotherms should have still given a good indication as to how much TBA would be adsorbed per unit mass of the zeolite. The isotherm data predicted that the ZSM-5 should have been capable of adsorbing approximately 10mg TBA per gram. The results showed that in the 6cm bed, the zeolites actually adsorbed more than the predicted amount of TBA (11.105mg TBA/g ZSM-5.) The isotherm data predicted that the HiSiv 3000 should adsorb approximately 5mg TBA per gram. The results showed that in the 6cm bed, the zeolites adsorbed less than the predicted amount (3.167mg TBA/g zeolite.)

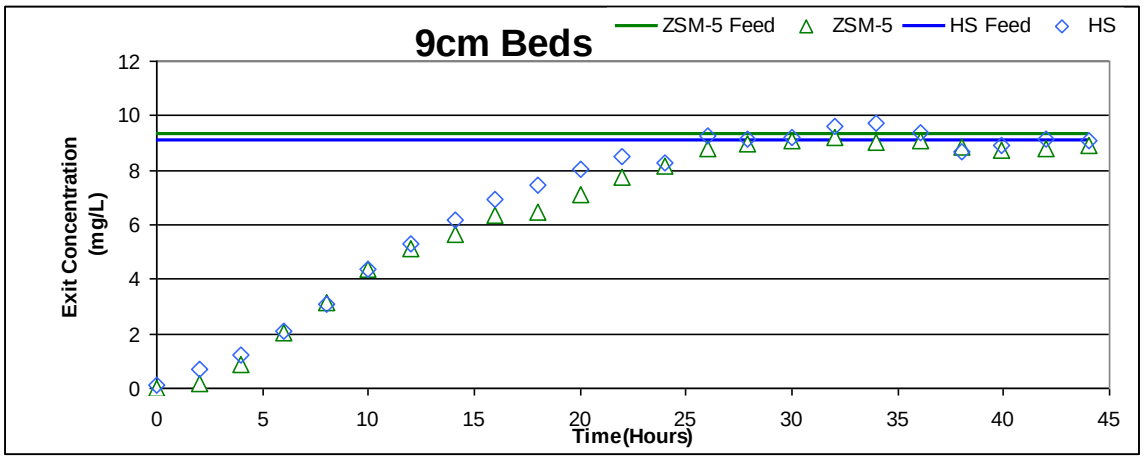
Trial 6- HiSiv 3000, ZSM-5

The sixth and final set of runs was again carried out using two columns, one containing HiSiv 3000 and the other containing ZSM-5. The bed heights were both increased to 9cm to give an even more detailed exit concentration profile. The experiment was planned to run for 60 hours but due to time constraints and the E-Pure water system going down, the experiment was only run for 44 hours (the feed was only replaced once and was not a full batch.) All of the other conditions were the same as in the previous 3 trials except new columns were required due to both of the original columns breaking.

Although the experiments were not able to be run for as long as desired it still appeared that the 44 hours was enough time for both columns to reach complete saturation as shown in Figure 14. As was the case with the 3cm and the 6cm beds, the HiSiv 3000 still reacheed complete saturation before the ZSM-5. This was expected because changing the height of the beds should not have changed the amount of TBA adsorbed per unit mass of zeolite. The initial exit concentration of the HiSiv 3000 column was slightly higher than that of the ZSM-5 column. The ZSM-5 still took much longer to reach complete saturation than the HiSiv 3000 did which allowed it to adsorb more TBA.

Looking at the graph it is also apparent that the 9cm bed does not simply take 3 times as long as the 3cm bed to become completely saturated for either the ZSM-5 or the HiSiv 3000. This could be due to the fact that the whole bed was exposed to the feed for the whole experiment although not always at the feed concentration. Therefore all of the zeolites' surface area was initially available for the adsorption and more of the TBA was adsorbed in the early stages (although this was somewhat hampered by the fact that all of the surface area was not exposed to the feed concentration.) Thus comparatively more of the zeolites' surface area is taken up in the early stages. This means that the rate of increase of the exit concentration varies with the bed height. This should also hold true for the 6cm beds but is more visible in the 9cm beds.

Figure 14: Trial 6, Comparison of ZSM-5 & HiSiv 3000, 9cm Beds- Data for HiSiv 3000 provided by T. Butland



Equation 1 could again be used to determine the amount of TBA per unit mass the zeolites adsorbed.

Table 3: Comparison of Adsorption Capacities of ZSM-5 and HiSiv 3000 9cm Beds

Zeolite	A_f (L/(mg·h))	A_c (L/(mg·h))	A_f-A_c (L/(mg·h))	Q_f (L/hour)	m_z (g)	T_{ad} (mg TBA/g Zeolite)
ZSM-5	446	284	162	0.618	10.02	9.992
HiSiv 3000	405	299	106	0.618	10.03	6.533

As shown in Table 3 the area under the feed line is slightly greater for the ZSM-5 column than for the HiSiv 3000 column. The area under the curve for the HiSiv 3000 is only slightly greater than for the ZSM-5 column which explains why difference between the amounts of TBA adsorbed per unit mass of zeolite is much smaller than it was for the 6cm beds. The amount of TBA adsorbed per unit mass of zeolite for the ZSM-5 is just over 1.5 times that of the HiSiv 3000 as compared to over 3 times for the 6cm beds. This ratio should not vary this much when nothing but the height of the bed has changed. Theoretically the ratio should be the approximately the same for the 9cm beds as it is for the 6cm beds. Even when allowing for the slight change in conditions, such as slightly different feed concentrations, the results should not vary this much. Although the results did not come out exactly as expected, it is still clear that the ZSM-5 outperforms the HiSiv 3000.

Again, although it was impossible to generate isotherm data for the exact feed concentrations that were used (as shown in Figure 1), the isotherms should have still given a good indication as to how much TBA would be adsorbed per unit mass of the zeolite. The isotherm data predicted that the ZSM-5 should have been capable of

adsorbing approximately 10mg TBA per gram. The results showed that in the 9cm bed, the zeolites adsorbed slightly less than the predicted amount of TBA (9.992mg TBA/g ZSM-5) as opposed to more in the 6cm bed. The isotherm data predicted that the HiSiv 3000 should adsorb approximately 5mg TBA per gram. The results showed that in the 9cm bed, the zeolites adsorbed more than the predicted amount (6.533mg TBA/g zeolite) as opposed to less in the 6cm bed.

Conclusions

ZSM-5 and HiSiv 3000 vs. Activated Carbon

As was shown in Figure 12, the ZSM-5 and HiSiv 3000 greatly outperformed the Activated Carbon. The Activated Carbon not only had a higher initial exit concentration than the other zeolites but it also reached complete saturation in a much shorter period of time. This comparison is important because Activated Carbon is used throughout the industry. The fact that both the ZSM-5 and HiSiv 3000 adsorbed more TBA than the Activated Carbon at low concentrations shows that the possibility of replacing Activated Carbon with one of the other zeolites might be worth exploring.

ZSM-5 vs. HiSiv 3000

Looking at Figures 13 and 14 it is clear that the ZSM-5 columns had a greater adsorption capacity than the HiSiv 3000 columns. For the 6cm beds, the ZSM-5 column adsorbed over 3 times the amount of TBA per unit mass of the zeolite as the HiSiv 3000 column did. For the 9cm beds, the ZSM-5 column adsorbed just over 1.5 times as much TBA per unit mass of the zeolite as the HiSiv 3000 column did. Therefore it is clear that the ZSM-5 is more efficient in adsorbing TBA from water in low concentrations than the HiSiv 3000 as expected.
The difference in the ratios of TBA adsorbed per unit mass of zeolite was not expected, as the height of the bed should have no effect on the amount of TBA adsorbed per unit mass of the zeolite. Both an increase in the amount of TBA adsorbed per unit mass of zeolite in the HiSiv column as well as a decrease in the amount of TBA adsorbed per unit mass of zeolite contributed to the smaller difference in the 9cm columns. The predicted factor from the isotherm data, shown in Figure 1, was approximately 2 which falls in between the two ratios that were attained in the experiment. There are many factors that could have contributed to this such as the packing of the beds, change in the feed concentration and other uncontrollable factors.

Performance of the 50% column

When looking at Figure 12 it does not appear that the 50% column outperformed the ZSM-5 and HiSiv 3000 columns. The 50% column may have slightly outperformed the other two columns but it was not a great enough difference to pursue further study of it. The 50% column required more time to assemble and was more difficult to maintain. It is also presumed that exactly 50% of each zeolite would not necessarily give the best results

of combining the two, but would require a different percentage for optimal adsorption. The effort required to pursue this ratio was not worth the slight gains in performance that might have existed over the ZSM-5 or the HiSiv 3000 columns.

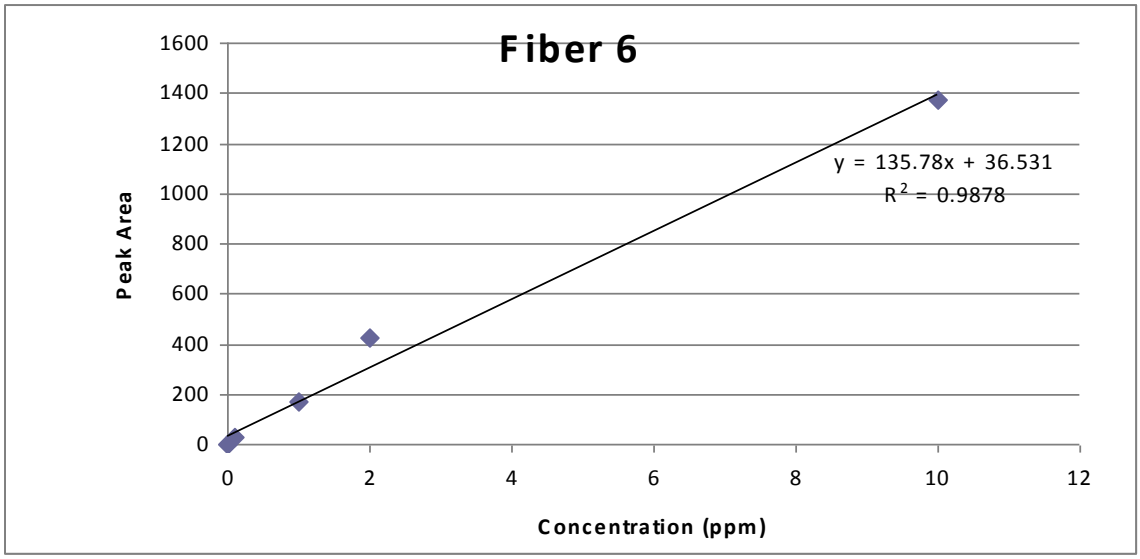
Effects on the Industry

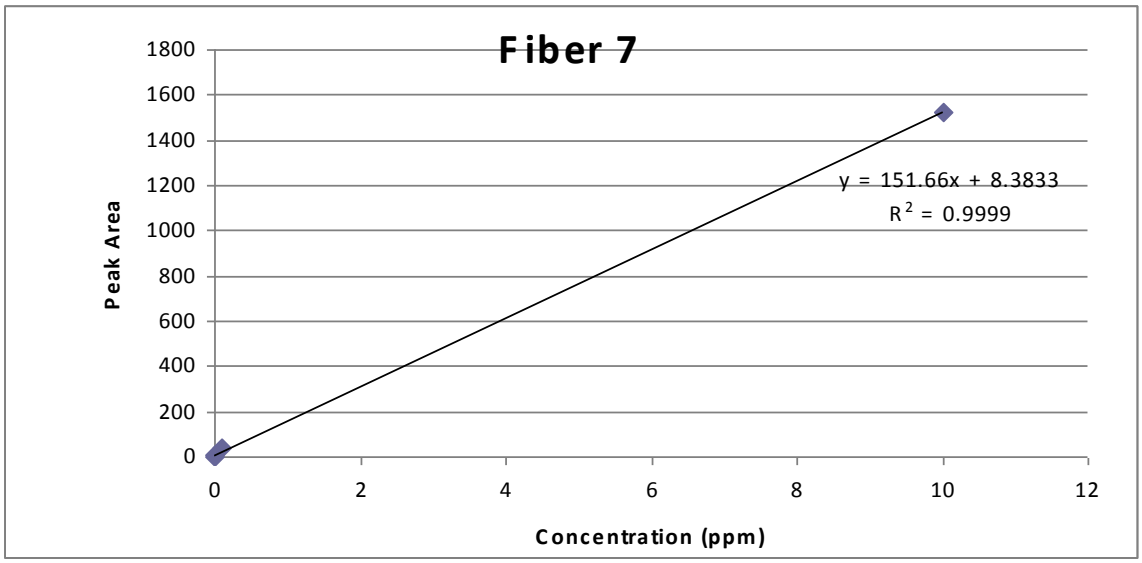
The main problem with trying to apply our experiment to real industrial use would be the lack of information available from the industry. TBA is not generally a threat for drinking water unless there is a large contamination of it and therefore water treatment plants are not always keeping track of its levels. TBA is usually only treated specifically if there is a known contamination of it.

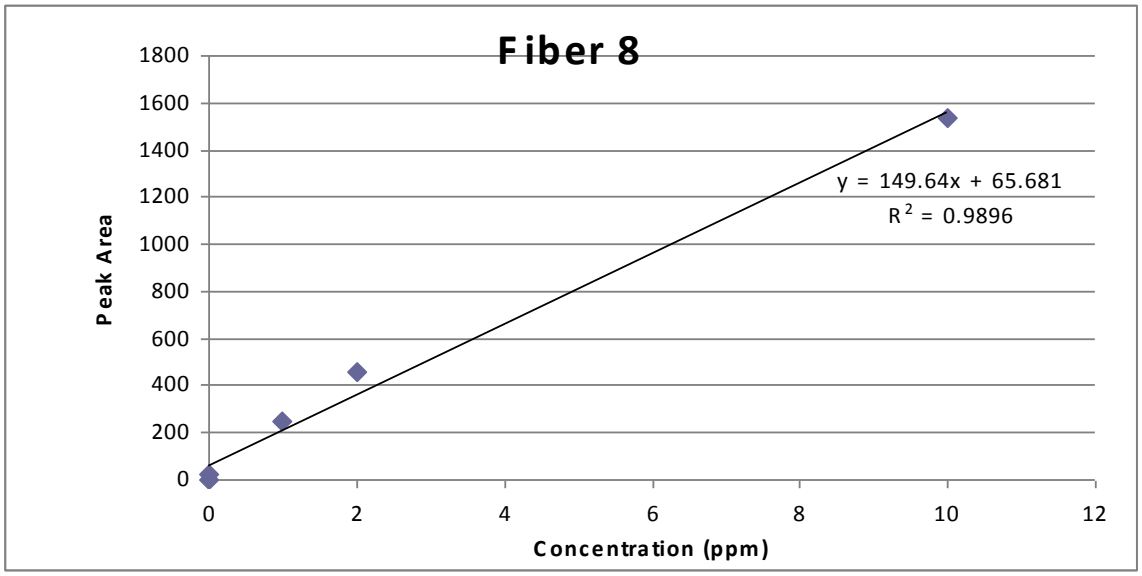
Another problem with trying to apply our experiment to real industrial use is that this project examined the total amount of TBA adsorbed by the zeolites. This included several instances where the exit concentration was just slightly under the feed concentration for a long period of time. Over this period of time, the amount of TBA being adsorbed kept adding up but in the industry this exit concentration would most likely be above regulations and therefore the product would be unusable. If one were to attempt to apply this experiment to the industry a more suitable way of analyzing the data might be to examine how long the exit concentration stayed under a certain standard rather than how long until the adsorbent was completely saturated.

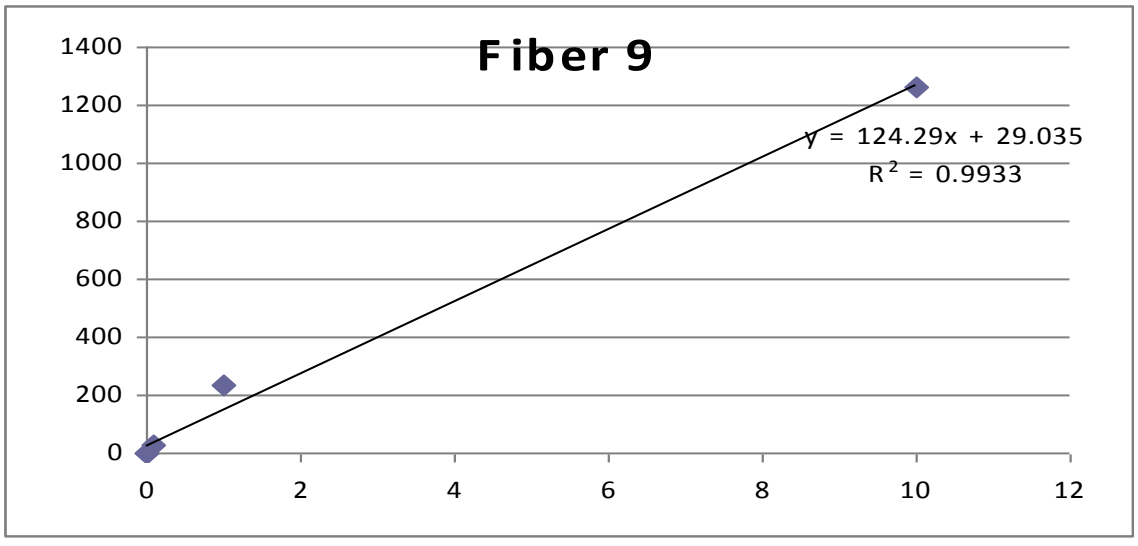
Appendix I

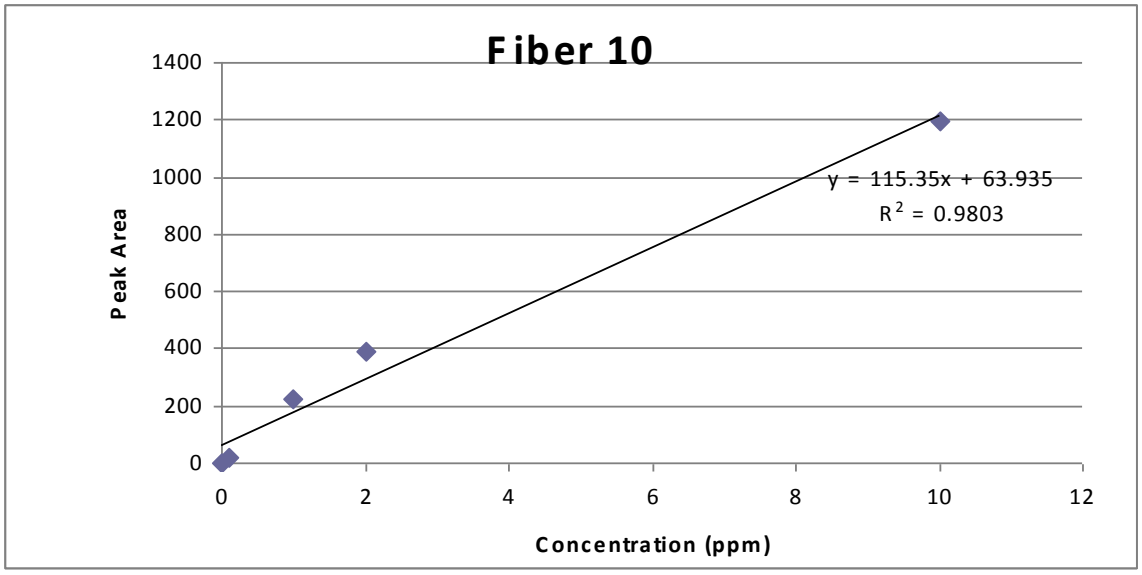
GC Fiber Curves

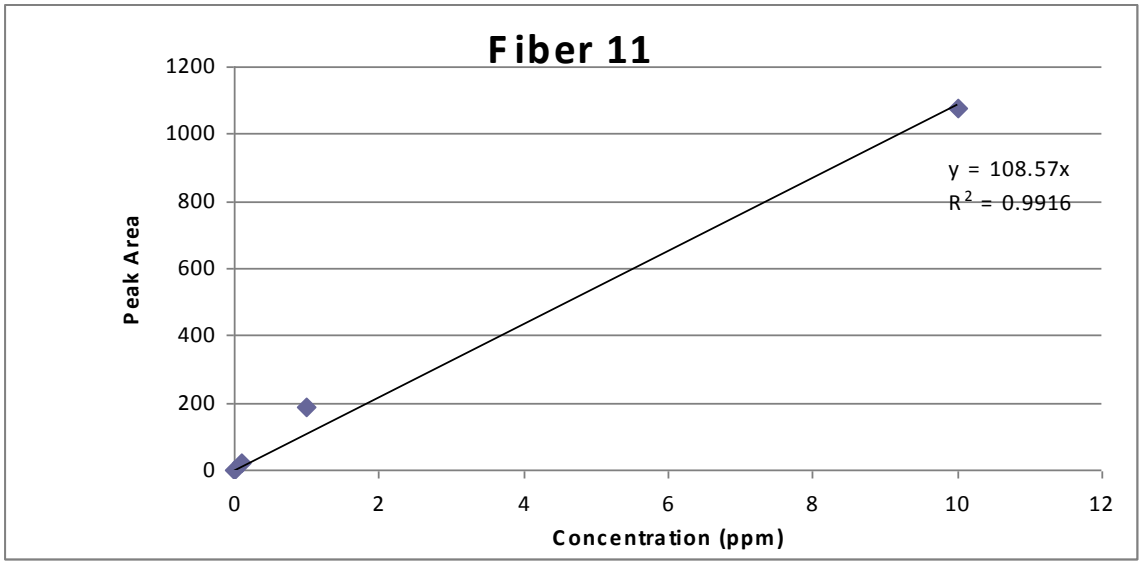





Fiber 8
Peak Area
Concentration (ppm)
y = 149.64x + 65.681
R 2 = 0.9896
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12


Fiber 9
y = 124.29x + 29.035
R 2 = 0.9933
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12


Fiber 10
1400
1200
1000
800
600
400
200
0
Peak Area
y = 115.35x + 63.935
R 2 = 0.9803
0
2
4
6
8
10
12
Concentration (ppm)


Fiber 11
1200
1000
800
600
400
200
0
Peak Area
y = 108.57x
R 2 = 0.9916
0
2
4
6
8
10
12
Concentration (ppm)

Appendix II

GC Data

Trial 1 ZSM-5 3cm

Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (μg/L)
0	1	180.76266	1.0622452	1062.245
1.97	2	1608.3762	11.576412	11576.41
4.017	3	1876.8798	13.553902	13553.9
6.017	4	2066.3307	14.94918	14949.18
7.97	5	1818.8997	13.126887	13126.89
9.983	6	1733.9862	12.501511	12501.51
12.07	7	1653.3378	11.907547	11907.55
14.03	8	1364.3474	9.7791752	9779.175
15.97	9	1550.0565	11.146896	11146.9
17.983	10	1598.3516	11.502582	11502.58
20.017	11	1623.0281	11.684321	11684.32
21.983	12	1659.8859	11.955773	11955.77
24	13	1787.0702	12.892467	12892.47
26	14	1806.6339	13.036551	13036.55
27.983	15	1808.2549	13.04849	13048.49
30.017	16	1828.1598	13.195086	13195.09
31.9	17	1147.027	8.178642	8178.642
34.017	18	1259.9044	9.0099674	9009.967
36.03	19	1092.905	7.7800409	7780.041
38.083	20	1175.749	8.3901754	8390.175
40.03	21	1172.2872	8.3646798	8364.68
42	22	1105.0477	7.8694702	7869.47
44.067	23	594.81216	4.1116597	4111.66
45.97	24	30.64942	-0.043317	-43.317
47.97	25	1022.2977	7.2600285	7260.029
50.017	26	976.04936	6.9194164	6919.416
51.95	27	1410.6228	10.119987	10119.99
54.083	28	1523.7788	10.953364	10953.36
55.97	29	1390.7201	9.9734064	9973.406
58.017	30		-0.529377	-529.377
60.03	31	1210.882	7.6126477	7612.648
62.05	32		-0.529377	-529.377
64.03	33	688.60492	4.1008332	4100.833
66	34	806.95117	4.8965988	4896.599
68	35		-0.529377	-529.377
69.983	36		-0.529377	-529.377
71.983	37		-0.529377	-529.377

74.05	38	888.06097	5.4419847	5441.985
76.03	39		-0.529377	-529.377
78.03	40		-0.529377	-529.377
80.017	41		-0.529377	-529.377
82.017	42		-0.529377	-529.377
84.067	43		-0.529377	-529.377
86.017	44	1606.6859	10.274051	10274.05
88	45	1588.1288	10.149272	10149.27
90	46	1602.0099	10.24261	10242.61
92.067	47	1572.5	10.044184	10044.18
93.97	48	1543.0386	9.8460837	9846.084
95.93	49	858.22382	5.2413584	5241.358

Trial 1 50% 3cm

Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	956.6242	6.776353	6776.353
1.85	2	587.8619	4.0604724	4060.472
3.55	3	906.1332	6.4044943	6404.494
5.217	4	949.5126	6.7239772	6723.977
7.183	5	729.1616	5.1011236	5101.124
9.17	6	1048.924	7.4561254	7456.125
11.85	7	1056.091	7.5089129	7508.913
13.07	8	1162.946	8.2958861	8295.886
15.15	9	1181.781	8.4345974	8434.597
17.183	10	1209.941	8.6419938	8641.994
19.117	11	1257.298	8.9907752	8990.775
21.2	12	1259.511	9.0070702	9007.07
23.1	13	1264.49	9.0437425	9043.743
25.117	14	1265.065	9.0479716	9047.972
27.13	15	1292.412	9.2493786	9249.379
28.93	16	1276.723	9.133837	9133.837
31.2	17	1270.016	9.0844389	9084.439
33.15	18	1221.365	8.7261287	8726.129
35.167	19	1277.817	9.1418878	9141.888
36.983	20	1240.11	8.8641882	8864.188
39.167	21	1155.893	8.2439383	8243.938
41.23	22	1192.552	8.5139243	8513.924
43.15	23	1145.742	8.1691812	8169.181
45.183	24	1206.345	8.6155093	8615.509
47.1	25	1134.388	8.0855571	8085.557
49.083	26	1161.136	8.2439383	8243.938
51.2	27	1158.295	8.5139243	8513.924

53.083	28	1092.067	8.1691812	8169.181
55.117	29	1151.235	8.6155093	8615.509
57.15	30	1148.848	8.0855571	8085.557
59.167	31	1108.111	8.2825526	8282.553
61.067	32	1117.532	8.2616304	8261.63
63.15	33	1085.489	7.7738678	7773.868
65.13	34	1100.963	8.2096295	8209.63
67.117	35	1149.124	8.1920508	8192.051
68.93	36	825.5897	7.8920292	7892.029
71.15	37	1132.501	7.9614154	7961.415
73.15	38	830.9169	7.7254209	7725.421
75.2	39	806.9533	7.83939	7839.39
77.13	40	1068.073	8.1940889	8194.089
79.117	41	1087.026	5.811303	5811.303
81.183	42	1051.643	8.0716634	8071.663
83.167	43	965.7457	6.8435317	6843.532
85.1	44	863.6213	6.0914004	6091.4
87.13	45	849.368	5.9864264	5986.426
89.2	46	848.4859	5.97993	5979.93
91.1	47	599.8923	4.149074	4149.074
93.13	48	826.623	5.8189129	5818.913
95.15	49	445.7412	2.8838055	2883.805

Trial 2	ZSM-5	3cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	154.91467	0.51227589	512.27589
2	2	1040.8818	6.46955917	6469.5592
4.03	3	1123.2488	7.0233982	7023.3982
6	4	1197.5844	7.52323393	7523.2339
8	5	1277.3239	8.05940593	8059.4059
10	6	1483.6491	9.4467459	9446.7459
12.0167	7	1726.8301	11.0819061	11081.906
14	8	1632.9471	10.450633	10450.633
16	9	1626.1028	10.4046112	10404.611
18.03	10	1641.7837	10.5100504	10510.05
20	11	1635.1041	10.4651367	10465.137
22	12	1682.9266	10.7866974	10786.697
24	13	1638.759	10.4897124	10489.712
26	14	1558.4016	9.94938549	9949.3855
28	15	1612.9716	10.3163163	10316.316
29.983	16	1553.3324	9.91529989	9915.2999
32	17	1621.1094	10.3901271	10390.127

34.067	18	1777.4579	11.4319643	11431.964
36	19	1698.5547	10.9061884	10906.188
38.0167	20	1702.0374	10.9293953	10929.395
40	21	1767.1439	11.3632366	11363.237
41.93	22	1720.2556	11.0507938	11050.794
44	23	1733.0366	11.1359607	11135.961
46	24	1820.8232	11.7209318	11720.932
48	25	1765.071	11.3494239	11349.424
50.0167	26	1635.6594	10.4870822	10487.082
52	27	1670.1497	10.7169098	10716.91
54	28	1615.506	10.3527886	10352.789
56	29	1715.3495	11.0181015	11018.101
58	30	1621.146	10.3903712	10390.371
60	31	1632.0159	10.4628032	10462.803
62	32	1664.2415	10.6775402	10677.54
64	33	1513.8243	9.67522716	9675.2272
65.95	34	1546.379	9.89215719	9892.1572
68.0167	35	1601.6924	10.2607409	10260.741
70.03	36	1565.7883	10.0214922	10021.492
72.03	37	1565.685	10.0208038	10020.804
74	38	1648.4496	10.5723101	10572.31
76.0167	39	1685.4027	10.818549	10818.549
78	40	1690.0784	10.8497059	10849.706
80.0167	41	1721.9157	11.0618555	11061.855
82	42	1710.689	10.9870457	10987.046
84	43	1694.2076	10.8772216	10877.222
86	44	1711.7112	10.9938574	10993.857
88	45	1725.8132	11.0878272	11087.827
89.983	46	1717.2972	11.0310804	11031.08
92	47	1793.4976	11.5388456	11538.846
94.03	48	1760.9463	11.3219384	11321.938
96	49	1766.8707	11.3614158	11361.416

Trial 2	50%	3cm		
Time		Peak		
(hrs)	Sample #	Areas	C (mg/L)	C (µg/L)
0	1	78.18242	0.460234	460.23421
2	2	796.3028	5.195302	5195.302
4	3	1078.34	7.054969	7054.9686
6	4	1175.073	7.692799	7692.7993
8	5	1250.785	8.192017	8192.0175
10	6	1265.5	8.289046	8289.0459
12	7	1304.465	8.545967	8545.9666
14.0167	8	1246.698	8.165072	8165.072

16	9	1240.016	8.121012	8121.0121
18.0333	10	1239.348	8.116608	8116.6077
20	11	1340.665	8.78466	8784.6597
22	12	1262.793	8.271195	8271.1949
24	13	1257.278	8.234832	8234.8322
26	14	1242.334	8.136296	8136.2962
28	15	1280.701	8.389277	8389.277
30	16	14.8801		
31.9833	17	1045.933	6.841284	6841.2845
34.05	18	1167.621	7.363941	7363.9407
36	19	1229.383	7.77668	7776.6802
38.0167	20	1372.044	8.730039	8730.0392
40	21	1442.801	9.20289	9202.8895
41.85	22	1452.982	9.270926	9270.9264
44	23	1469.882	9.383861	9383.861
46	24	1149.381	7.242047	7242.0474
48	25	1476.892	9.430708	9430.7084
50.0167	26	1506.94	9.631511	9631.511
52	27	1525.09	9.752801	9752.8007
54	28	1507.995	9.63856	9638.56
56	29	1495.901	9.55774	9557.7402
58	30	1458.876	9.310312	9310.3121
60	31	1640.162	10.52179	10521.793
62	32	1636.657	10.49837	10498.368
64	33	1504.516	9.615313	9615.3133
65.95	34	1355.965	8.622591	8622.5906
68.0167	35	1393.929	8.876292	8876.2919
70.0167	36	1319.813	8.380997	8380.9967
72.0333	37	1310.518	8.318879	8318.8791
74	38	1302.817	8.267416	8267.4161
76	39	1294.266	8.210272	8210.2721
78	40	1305.42	8.284807	8284.8073
80.0167	41	1395.476	8.886628	8886.6276
82	42	1302.002	8.261971	8261.9709
84	43	1394.762	8.881859	8881.8587
86.0167	44	1315.663	8.353263	8353.2626
88	45	1267.52	8.031537	8031.5366
89.0333	46	1357.116	8.630282	8630.2815
92	47	1338.283	8.504424	8504.4245
94.03333	48	1325.814	8.4211	8421.0995
96	49	1310.829	8.320959	8320.9593

Trial 3 Time (hrs)	ZSM-5 Sample #	3cm Peak Areas	C (mg/L)	C (µg/L)
0	1	181.2432	1.224622	1224.622
0.25	2	420.3771	3.148621	3148.621
0.5	3	554.2546	4.225759	4225.759
0.75	4	647.6439	4.977141	4977.141
1	5	615.2991	4.716905	4716.905
1.25	6	621.8552	4.769653	4769.653
1.5	7	646.2452	4.965888	4965.888
1.75	8	906.3571	7.05867	7058.67
2	9	972.4215	7.590204	7590.204
2.25	10	1028.6	8.042198	8042.198
2.5	11	1050.836	8.221101	8221.101
4.5	12			
6.5	13	1218.175	9.567464	9567.464
8.5	14	1255.753	9.869804	9869.804
10.5	15	1293.11	10.17036	10170.36
12.5	16	1427.42	11.25098	11250.98
14.5	17	1328.085	10.45176	10451.76
16.5	18	1367.996	10.77288	10772.88
18.5	19	1369.862	10.78789	10787.89
20.5	20	1365.765	10.75493	10754.93
22.5	21	1370.91	10.79632	10796.32
24.5	22	1395.725	10.99598	10995.98
26.5	23	1422.321	11.20996	11209.96
28.5	24	1434.114	11.30485	11304.85

Trial 3 Time (hrs)	50% Sample #	3cm Peak Areas	C (mg/L)	C (µg/L)
0	1	167.23727	1.111934	1111.934
0.25	2	137.80658	0.875143	875.1435
0.5	3	182.74825	1.236731	1236.731
0.75	4	220.70218	1.542097	1542.097
1	5	253.27815	1.804193	1804.193
1.25	6	286.86148	2.074394	2074.394
1.5	7	330.51086	2.425584	2425.584
1.75	8	391.17645	2.913681	2913.681
2	9	429.67709	3.223446	3223.446
2.25	10	468.65659	3.537063	3537.063
4.25	11	682.23553	5.255455	5255.455
6.25	12	740.28375	5.722494	5722.494

8.25	13	866.43512	6.73747	6737.47
10.25	14	842.14227	6.542017	6542.017
12.25	15	856.69202	6.65908	6659.08
14.25	16	923.41779	7.195935	7195.935
16.25	17	918.7337	7.158248	7158.248
18.25	18	962.77264	7.512573	7512.573
20.25	19	951.29834	7.420254	7420.254
22.25	20	962.69269	7.511929	7511.929
24.25	21	976.31262	7.621511	7621.511
26.25	22	989.89606	7.730799	7730.799

Trial 4	HiSiv 3000	3cm		
Time		Peak		
(hrs)	Sample #	Areas	C (mg/L)	C (µg/L)
0	1	506.6026	3.837604	3837.604
0.2333	2	516.9363	3.927189	3927.189
0.48333	3	535.8306	4.090989	4090.989
0.73333	4	562.3568	4.320951	4320.951
0.983333	5	589.4835	4.55612	4556.12
1.2333	6	619.8209	4.819123	4819.123
1.48333	7	653.7136	5.112949	5112.949
1.73333	8	794.1998	6.330861	6330.861
1.98333	9	840.3065	6.730572	6730.572
3.98333	10	1016.183	8.255294	8255.294
5.9333	11	1125.242	9.200755	9200.755
7.98333	12	1166.793	9.560974	9560.974
9.98333	13	1195.892	9.813242	9813.242
11.98333	14	1202.825	9.873344	9873.344
13.98333	15	1218.295	10.00746	10007.46
15.98333	16	1191.756	9.777383	9777.383
17.96667	17	1274.438	10.49417	10494.17
19.98333	18	1258.321	10.35445	10354.45
21.98333	19	1289.476	10.62455	10624.55
23.98333	20	1265.215	10.41422	10414.22

Trial 4	AC	3cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	516.2446	3.921193	3921.193
0.2333	2	925.5575	7.469636	7469.636
0.48333	3	1011.009	8.210434	8210.434
0.73333	4	1065.94	8.686646	8686.646
0.983333	5	1079.122	8.800928	8800.928
1.2333	6	1128.866	9.23217	9232.17
1.48333	7	1154.958	9.458366	9458.366
1.73333	8	1155.188	9.460367	9460.367
1.98333	9	1152.611	9.438027	9438.027
3.98333	10	1198.368	9.834707	9834.707
5.9333	11	1217.694	10.00225	10002.25
7.98333	12	1241.159	10.20567	10205.67
9.98333	13	1223.797	10.05515	10055.15
11.98333	14	1232.479	10.13042	10130.42
13.98333	15	1255.625	10.33108	10331.08
15.98333	16	1201.754	9.864053	9864.053
17.96667	17	1201.254	9.859719	9859.719
19.98333	18	1189.712	9.759665	9759.665
21.98333	19	1168.496	9.575734	9575.734
23.98333	20	1130.331	9.244874	9244.874
25.9833	21	1162.802	9.526368	9526.368

Trial 5	ZSM-5	6cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	1.5677	0.01444	14.43953
1	2	20.60995	0.189831	189.831
2.033	3	44.36269	0.408609	408.6091
3	4	99.33439	0.914934	914.9341
4	5	176.4162	1.624907	1624.907
5	6	259.7901	2.392835	2392.835
6	7	505.4583	4.655599	4655.599
8	8			
10	9	721.1463	6.642224	6642.224
12	10	769.8633	7.09094	7090.94
14	11	813.5352	7.493186	7493.186
16	12	894.6852	8.24063	8240.63
18	13	863.5091	7.953478	7953.478
20	14	912.5385	8.40507	8405.07
22	15	957.1072	8.815577	8815.577
24	16	963.899	8.878134	8878.134
25.8333	17	1039.858	9.577767	9577.767

28	18	978.9721	9.016966	9016.966
30	19	1060.398	9.766952	9766.952
32	20	962.2923	8.863335	8863.335
34	21	982.0878	9.045665	9045.665
36	22	1077.022	9.920066	9920.066
38.0167	23	980.6896	9.032787	9032.787
40	24	1048.929	9.661316	9661.316
42	25	1047.008	9.643625	9643.625
44	26	951.5192	8.764108	8764.108
46	27	991.074	9.128433	9128.433
48	28	976.3144	8.992488	8992.488

Trial 5	HiSiv 3000	6cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	49.78833	0.458583	458.5828
1	2	188.79022	1.73888	1738.88
2.033	3	318.98535	2.938062	2938.062
3	4	421.01959	3.877863	3877.863
4	5	519.72607	4.787014	4787.014
5	6	608.56049	5.605236	5605.236
6	7	694.26263	6.394608	6394.608
8	8	806.49121	7.428306	7428.306
10	9	911.01758	8.391062	8391.062
12	10	981.01225	9.035758	9035.758
14	11	1008.6535	9.290352	9290.352
16	12	1031.0422	9.496567	9496.567
18	13	1030.2217	9.489009	9489.009
20	14	1028.061	9.469108	9469.108
22	15	1037.9594	9.560278	9560.278
24	16	1055.0405	9.717606	9717.606
25.8333	17	1073.4174	9.886869	9886.869
28	18	1131.7466	10.42412	10424.12
30	19	1112.0996	10.24316	10243.16
32	20	1137.7922	10.4798	10479.8
34	21	1144.2556	10.53934	10539.34
36	22	1132.5131	10.43118	10431.18
38.0167	23	1151.1116	10.60248	10602.48
40	24	1204.6085	11.09522	11095.22
42	25			
44	26	1220.5464	11.24202	11242.02
46	27	1110.12	10.22492	10224.92
48	28	1131.3301	10.42028	10420.28

Trial 6	ZSM-5	9cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	0.315676	0.004064	4.064219
2.016667	2	13.95681	0.179689	179.6891
4	3	69.72836	0.897728	897.7284
6	4	157.0898	2.022477	2022.477
8	5	242.5945	3.123319	3123.319
10	6	338.8908	4.363101	4363.101
12	7	398.0821	5.125169	5125.169
14.08333	8	437.9206	5.638075	5638.075
16	9	491.139	6.323244	6323.244
18	10	501.3291	6.454438	6454.438
20	11	552.8297	7.11749	7117.49
22	12	602.9421	7.76267	7762.67
24	13	635.2785	8.17899	8178.99
26	14	681.7376	8.777135	8777.135
27.91667	15	695.8741	8.959137	8959.137
30	16	704.8068	9.074142	9074.142
32	17	716.8784	9.22956	9229.56
34	18	700.4412	9.017936	9017.936
36.05	19	707.9317	9.114375	9114.375
38.01667	20	685.5344	8.826017	8826.017
39.91667	21	678.2301	8.731977	8731.977
42	22	683.1827	8.79574	8795.74
44	23	693.1577	8.924164	8924.164

Trial 6	HiSiv 3000	9cm		
Time (hrs)	Sample #	Peak Areas	C (mg/L)	C (µg/L)
0	1	11.14482	0.143486	143.4857
2.016667	2	52.88589	0.680887	680.8874
4	3	95.85744	1.234131	1234.131
6	4	162.95547	2.097995	2097.995
8	5	241.80112	3.113105	3113.105
10	6	337.14816	4.340665	4340.665
12	7	413.13226	5.318934	5318.934
14.08333	8	477.35928	6.145835	6145.835
16	9	536.54602	6.907843	6907.843
18	10	581.36658	7.484893	7484.893
20	11	623.72913	8.030296	8030.296
22	12	658.94641	8.483706	8483.706
24	13	641.53381	8.259525	8259.525

26	14	721.13953	9.284421	9284.421
27.91667	15	712.43439	9.172345	9172.345
30	16	715.01611	9.205584	9205.584
32	17	745.7381	9.601119	9601.119
34	18	754.41876	9.712879	9712.879
36.05	19	729.0589	9.38638	9386.38
38.01667	20	674.04333	8.678074	8678.074
39.91667	21	690.82623	8.894148	8894.148
42	22	708.21112	9.117972	9117.972
44	23	704.09033	9.064918	9064.918