Troubled Waters: Removing Estrogen from Our Water Supply

Luke Dery
The Massachusetts Academy of Math and Science

Abstract

Estrogen contamination from products such as birth control and estrogen therapy has led to possible health concerns when consumed from drinking water sources. It is unhealthy for the human body, animals, and the environment, causing feminization in humans and the birth of more females. In order to make the removal of estrogen more practical, multiple filtration methods where tested to determine which method was the most efficient and practical to use. From gathered research, graphitized carbon was hypothesized to be the most efficient and practical method of estrogen removal from water. It is both inexpensive and made of fine material. After three rounds of experimentation with the filters, GCB (Graphitized Carbon Black) was found to be the most effective filtration material for estrogen removal. Although it was not more effective than some of the filter that are specially designed to purify water (the Oasis products), it was the most effective and practical material that was used, removing 98-100 percent of the estrogen compounds on each of the tests. Therefore, GCB was found to be the most efficient and practical filtration material overall.

Introduction

Over the past decade, a new contaminant has found its way into water supplies around the world: pharmaceutical products that contain estrogen. Estrogen comes from multiple sources, both natural and synthetic-made. It has been found to have negative effects on males and females alike when it is consumed daily in public drinking water. Not much has been done to stop this problem. Most water treatment plants have not implemented any processes to remove estrogen, and little research has been done to find the best way to solve the problem. The goal of this research project is to test practical estrogen purification methods to find the most efficient one and to then apply it to a device that can be used to purify water at a home level.

Literature Review

Estrogen and Pharmaceutical Contaminants

Estrogen is a group of chemically similar hormones that are needed for development of female characteristics and reproduction. In reality, estrogen is produced by both men and women, but it is difficult for scientists to detect its role in the male body (“Estrogen refers to a group of hormones,” 2010).

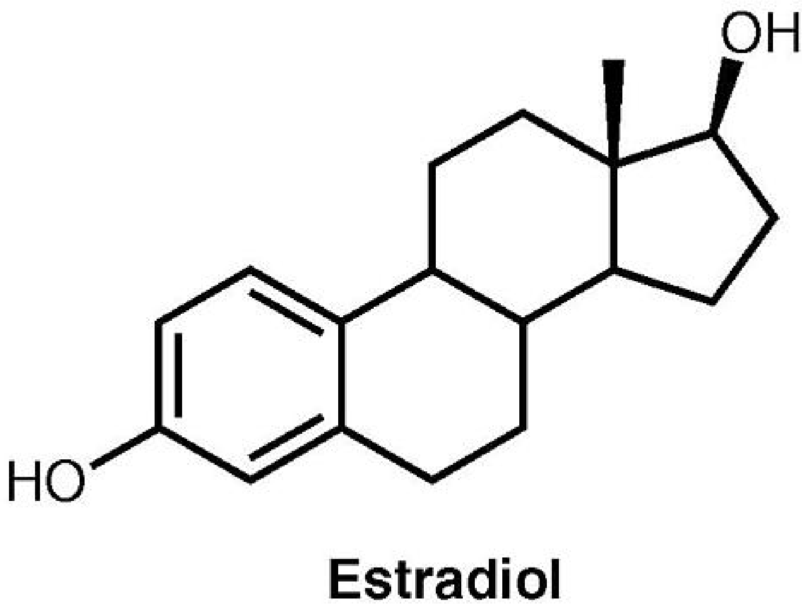

Figure 1. Estradiol. This figure shows the structural formula of the chemical compound estradiol (retrieved from "Activella tablets," 2007). Estradiol is a natural form of estrogen that is produced in the bodies of humans and other organisms ("Estrogen refers to a group of hormones," 2010).

Hormones in general are chemical substances in all organisms. They carry information and instructions to and from different groups of cells. In humans, hormones are active in mostly every part of the body. They control our bodily growth and development, our metabolism, tissue function, sexual function, reproduction, the way we use food, our bodies' reactions, and our moods. Therefore, hormones are crucial to the body's health ("Estrogen refers to a group of hormones," 2010).

Birth control pills control hormone levels in women. They prevent ovulation in the female body. The estrogen in birth control pills can also be used to relieve menstrual pain and control the menstrual cycle of a woman. Also, there is a chance that birth control can reduce the possibility of developing ovarian, uterine, and colorectal cancer in women. Estrogen supplements can also be used in other health ways. It can be used to treat delayed puberty and hot flashes and to speed up female hormone production ("Estrogen refers to a group of hormones," 2010).

In a Women's Health Initiative study in 2002, 27,347 women from the ages of fifty to 79 where given estrogenic therapies for health issues. However, this study found no conclusive benefits or ailments caused by the estrogen. The National Cancer Institute found a decrease of hormone-dependent cancers in women in 2003. A later study found that the cause of the decrease was because most women stopped taking estrogen after the results of a government study in 2002 that labeled hormones as cancer inducing medications. This study found that some cancers require an abundance of estrogen grow, so the added estrogen supplements provided the hormone levels necessary for cancers to grow and develop. Overall, hormones treatments for women are effective, but have dangerous side effects ("Estrogen refers to a group of hormones," 2010). A study by Shane Synder in 1996 showed that factory and farm runoffs are not the problem; the source of the chemicals is from pharmaceuticals, personal care products, and hormones that the people of the area flush down the toilet ("Prozac in the Water," 2006).

Estrogen can then be transferred to large bodies of water through sewage. Water treatment removes sewage and trash, but it leaves estrogen and other chemicals in the water. Estrogen can also get into groundwater through. As estrogen gets into the water in rivers and lakes, it also attaches itself to sediments and soils. Those sediments are transferred through water from one water supply to another, and therefore so is the estrogen (Labadie, 2007).

The U.S.A. has 53,000 drinking water systems which require billions of dollars annually to repair, upgrade, and expand wastewater treatment plants. However, not many facilities deal with other chemical substances that pass through treatment unaffected ("Prozac in the Water," 2006).

As far as how to carefully dispose of pharmaceuticals, the government is providing some regions with methods of safely doing so, rather than simply flushing them down the toilet. Three years ago, Maine encouraged a mailing system for people to dispose of medication. Chicago has also experimented with mass drug return programs. Washington State has gone through with a program that allows people to drop off medications at drug stores ("Prozac in the Water," 2006).

In September 2007, the Artic Monitoring and Assessment Program in Norway found that two times as many girls as boys were being born in areas of Greenland, Canada, and Russia, and the regions around the Artic area had similar reports. Tests on women's blood in these areas found high levels of human hormone mimickers. This information led people to believe that these artificial hormones led to the changing sex of unborn babies. These reports are not only limited to the Artic area. This article reports that it is true across the globe. A 2007 study by the U.S. National Institute of Environmental Health Sciences done in Japan found that in that year there were 250,000 fewer boys than expected based on the yearly ratio. Scientists are not completely sure of what the cause is, but most signs point to estrogen mimickers and endocrine disruptors that contaminate our water supply. These estrogens disrupt the synthesis, secretion, binding, and actions of natural hormones. These synthetic estrogens all affect human reproduction, development, and behavior, and decrease fertility. These facts are evidence that estrogens are a likely cause of a high female birth ratio and the feminization of males ("Pink Water," 2010).

Estrogen finds its way into our water supply in many ways. Chemicals from plastic are a source of estrogen in the water. Bisphenol A, or BPA, is a type of endocrine disruptor, and is largely used in plastics. Plastic does not biodegrade; instead it photo degrades, meaning it breaks down under sunlight. In this photo degradation process, the plastic releases estrogen mimickers from the BPA that can seep into the water supply. When water is cleaned publicly by means of chlorination (a common purification method), the chlorine combines with these estrogenic mimickers, forming estrogen mimicking organic chlorides ("Pink Water," 2010).

An AP investigation also found that prescription drugs are very present in our water supply. These include estrogen birth control pills and hormone replacement therapy medication. Most of this medication is either flushed down the toilet manually, or excreted through human waste, mainly urine. These drugs are not getting removed from the water by treatment plants ("Pink Water," 2010).

Testing for Estrogen in Water

Testing for estrogen in water is lengthy, and is an expensive process. Although little testing has been done, research and interest in estrogen testing and removal has grown in the past decade. Gas chromatography-mass spectrometry, gas chromatography-tendem mass spectrometry, and liquid chromatography-tandem mass spectrometry when used on three potent steroidal estrogens in water. These methods also work with for testing larger freshwater sources for estrogen. Out of the three methods, gas chromatography-mass spectrometry was found to be the best method to analyze estrogen levels in fresh water (D.P. Grover, 2009).

A research team from the Associated Press tested sediments from a freshwater source and an estuary source. They found that estrogen levels in shallow groundwater were approximately 28.8 parts per billion. The shallow groundwater measurement was taken from 10-18 centimeters below the ground. This was much greater than the 3.3 parts per billion measurement in surface sediment. This test showed the danger of estrogen pollution in our groundwater, and documented the high concentration it has in our groundwater (Labadie, 2007).

The Associated Press released a study that they performed in March 2008 that reported finds of estrogen among more than 50 other prescription drugs in the water that goes to 41 million people. The AP also said that these drugs have been found in the water supplies of 24 major metropolitan areas such as Detroit, Louisville, Southern California, and Northern New Jersey. Now, these levels of the pharmaceutical contaminants are safe according to drinking water guidelines, but studies show that mutations and sexual changes can still occur in animals even at low levels ("Pink Water," 2010).

Mr. Peter Philbrook, who is a chemist at the EPA lab in North Chelmsford, Massachusetts, described the method in which the scientists at his lab read the amount of estrogen in water samples. He has a device called the HP LC that takes in water samples and outputs data based on concentration levels of the samples. It is capable of detecting amounts of many chemicals, including estradiol, a natural estrogen, and ethynylestradiol, a synthetic estrogen commonly found in birth control pills. The device works by using chromatography to separate the water into the substances it includes (personal communication).

Water Purification of Estrogen

Recently, estrogen compound types such as nonylphenol, octylphenol, nonylphenol polyethoxylates, dihydrofolliculin, estrone, estriol, and ethynylestradiol have been found to be more prominent in treated public wastewater. Estrogen compounds can have many negative effects on those who drink it. Although it is not certain, estrogen has been tied to changing the endocrine function and harming the brain of both animals and human beings. There has been information that tells of an increase in hormone dependent cancers and a decrease in sperm quantity and quality in male humans. Many people have mentioned estrogen as the cause of these problems. Now, both humans and animals excrete natural estrogen every day, but estrogen pollution has also been linked to estrogen used for cancer treatment, hormonal imbalance, osteoporosis, and various other ailments. Most of this type of estrogenic pollution comes from farm runoffs and industrial sewage (Lin, 2008).

Many public water treatment plants can lower the concentration and remove some of the estrogen from water, but are not powerful enough to reduce estrogen to a safe concentration. Ozonation, UV radiation, membrane filtration, reverse osmosis, and activated carbon adsorption are methods suggested by the article to properly remove estrogen from water. These methods, however, are very expensive, so they are not commonly used in water treatment plants (Lin, 2008).

Surprisingly, bacteria may have estrogen removal capabilities. Bacteria have the ability to cleaning zinc, selenium, arsenic, and various other elements out of the water. Bacteria has been found to form mineral deposits on these elements from the water that it is in, therefore binding zinc and sulfate together in the water. Scientists hope to use this method to remove other pollutants from the water ("Cleaning Drinking Water with Bacteria," 2000).

Another method of purifying estrogen from water is being developed by Shane Synder. He is working with the American Water Works Association and the water systems of California on a large project to find water treatment method best removes common pharmaceuticals and endocrine disruptors from the water. Desert cities reported that they are recycling sewage effluent by using it to irrigate golf courses. Gully, a Los Angeles County researcher, has discussed another strategy that is intended to remove pharmaceutical contaminants out of the water. He says that we should let the polluted water go through layers of soil, which would act as a natural filter that could remove chemicals from the water. He has tested it and so far it has worked well at removing estrogen from the wastewater that California and Arizona possess ("Prozac in the Water," 2006).

Synder's research also found another possible treatment for chemicals in the water. He found that treating water with ozone or reverse osmosis can remove over seventy percent of pharmaceuticals and endocrine-disrupting contaminants (such as estrogen). However, the cost of this process on a large scale can be expensive ("Prozac in the Water," 2006).

Mr. Peter Philbrook spoke about purification methods for removing estrogen from water. He suggested that I experiment with filtering materials in order to create a more portable purification device. The power of the filter largely depends on the material used. If the material is fine and thicker, it is better at removing contaminants. However, any filter material can be upgraded in order to increase its effectiveness (personal communication).

Effects of Estrogen on People and Animals

Estrogen compounds can have many negative effects on those who consume the chemical. Although it is not certain, estrogen has been tied to changing the endocrine function and harming the physiological parts of both animals and humans. There has been information from hospitals and patient reports that tell of an increase in hormone dependent cancers and a decrease in sperm quantity and quality in male humans. Many people have mentioned estrogen as the cause of these problems (Lin, 2008).

In Canada Karen Kidd, an ecotoxicologist at the University of New Brunswick, performed some tests at a lake in north-west Ontario. She purposely polluted the lake with estrogen. In the lake she tested on, the algae, bacteria, and invertebrates seemed unbothered and unaffected by the estrogen she added to the lake. She added a consistent amount of estrogen at set time intervals. The chemistry of the estrogen was not similar enough to the organisms' biochemicals for them to notice the change. However, the smallest fish species in the lake, the fathead minnow, suffered a decline in population. The male minnows became feminized, which means that their production of sperm was delayed and they started producing eggs. Dr. Kidd tested for two years. In that time span, the fathead minnow population collapsed ("A poison pill; pollutant," 2008).

Other organisms in the lake were affected, but at different time intervals. This largely depended on the lifespan of the organism. For example, pearl dace outlive minnows by a few years, so they could survive longer before lack of male potency brought about their demise. There were fewer small organisms, larger organisms started to die out due to lack of food. However, when Dr. Kidd stopped putting estrogen in the lake, conditions went back to normal ("A poison pill; pollutant," 2008).

In 1996, Snyder, who was mentioned earlier, was working on his doctorate in ecological toxicology in Las Vegas while he studied a strange occurrence in a local lake called Lake Mead. In this lake, male carp were turning into females. The Southern Nevada Water Authority found in 2000 that natural and synthetic chemicals in the lake are deforming the fish and making them incapable of reproduction ("Prozac in the Water," 2006).

In the 1990s, fishermen in Great Britain that downstream from water treatment plants there were an unnatural amount of female fish. Around the same time, alligators and frogs affected by pesticides started developing characteristics previously exclusive to females of the species. According to this article, feminized fish have been found in countless major bodies water, including the Washington, D.C. part of the Potomac River and in the Los Angeles area of the Pacific Ocean ("Prozac in the Water," 2006). Chemicals put into bodies of water affect animal endocrine systems by changing the hormones they produce. This negatively affects their reproduction, growth, and development ("Prozac in the Water," 2006).

Through Synder's research and testing, he has found that sewage treatment plants that clean water are leaving chemicals and medicines such as codeine, Prozac, Valium, common antibiotics, insect repellents, and endocrine disruptors such as estrogen. All of these pollutants have been linked to the feminization of the carp, bass, and razorback suckers in Lake Mead ("Prozac in the Water," 2006).

Research Plan

A. Researchable Question

The goal of this project is to look for an effective yet practical method of removing estrogen from water using filtration materials. The goal is to find the best method so that estrogen can be removed from water, making it safer to drink for people at a home level.

B. Hypothesis

The hypothesis is that using a filter made of Graphitized Carbon will be the most effective and practical method overall.

C. Procedure

Water concentrated with 300ng/mL of Estradiol and Ethynylestradiol to samples of distilled water will be used with the assistance of an EPA lab in North Chelmsford. Based on my research of methods of water filtration, various methods will be used on the estrogen concentrated water to test the effectiveness of each one at removing estrogen from the water. The method that removes the most estrogen will be deemed the most effective. Speed, price, and practicality will also be factored into the result.

Variables: For removing estrogen from the water, the independent variable would be the amount of estrogen put into the water. Effectiveness of the purification methods cannot be controlled.

Controls: Water samples must be isolated so that they are not affected more by other outside environmental forces. All of the testing will be done in a lab, so any chemicals or worked with will be safely contained any supervised by trained scientists and myself.

Methodology

To remove estrogen from water, nine separate filter cartridges (8 cm) were filled and packed tightly with 0.55g of graphitized carbon black, 2g of Brita filter material, 1g of hydromatrix, 0.5g of Oasis HLB, 2g of carbon, 0.3g Varian Bondesil-PSA, 0.2g SPME C18, 3g of Ottawa sand, 0.6g MCX Oasis, and 0.6g WCX Oasis. Filter cartridges were attached to a vacuum device (Supelco Visiprep D-L). 50 mL estrogen concentrated water (300ng/mL estrogen estradiol and ethynylestradiol) was poured into each filter. If needed, the vacuum was used to suck the water through the filters. The chromatography device (HPLC 1100) was used to measure the amount of estradiol and ethynylestradiol in the filtered water samples by separating and measuring the concentrations of the different compounds present.

Results

Table 1. Filtration Test 1 (Estradiol)

Filter Material	Estradiol Added ng/mL	Estradiol Removed ng/mL	Percentage Removed %
Hydromatrix	300	62	20.7
Brita	300	295.4	98.5
Carbon (coarse)	300	297.6	99.2
GCB	300	299.8	99.9
SPME Fibres	300	6.8	2.3
PSA	300	15.9	5.3
Ottawa Sand	300	5.1	1.7

The data was collected by using the HP 1100 and depicts estradiol added, removed, and percentage removed by each filtration material.

Table 2. Filtration Test 2 (Estradiol)

Filter Material	Estradiol Added ng/mL	Estradiol Removed ng/mL	Percentage Removed %
Hydromatrix	300	59.5	19.8
Brita	300	222.9	74.3
Carbon (Coarse)	300	297.3	99.1
GCB	300	300	100
SPME Fibres	300	29.4	9.8
PSA	300	15.8	5.3
Ottawa Sand	300	60.2	20.1

The data was collected by using the HP 1100 and depicts estradiol added, removed, and percentage removed by each filtration material.

Table 3. Filtration Test 3 (Estradiol)

Filtration Material	Estradiol Added ng/mL	Estradiol Removed ng/mL	Percentage Removed %
Hydromatrix	300	6.9	2.3
Brita	300	180.8	60.3
Carbon (Coarse)	300	282.4	94.1
GCB	300	295.9	98.6
SPME Fibres	300	11.2	3.7
PSA	300	26.1	8.7
Ottawa Sand	300	5.7	1.9

The data was collected by using the HP 1100 and depicts estradiol added, removed, and percentage removed by each filtration material.

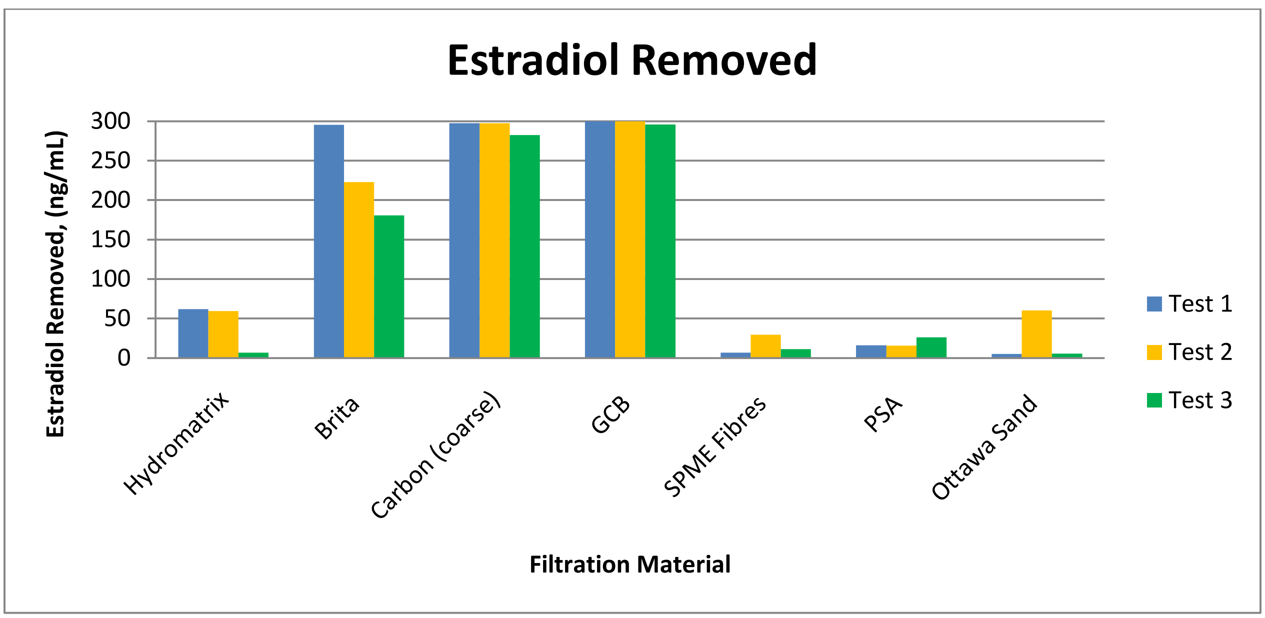

Figure 1. Estradiol removed. The graph compares the amount of estradiol removed by each filtration method. It also compares tests 1 through 3 based on the amount of estradiol removed by each material.

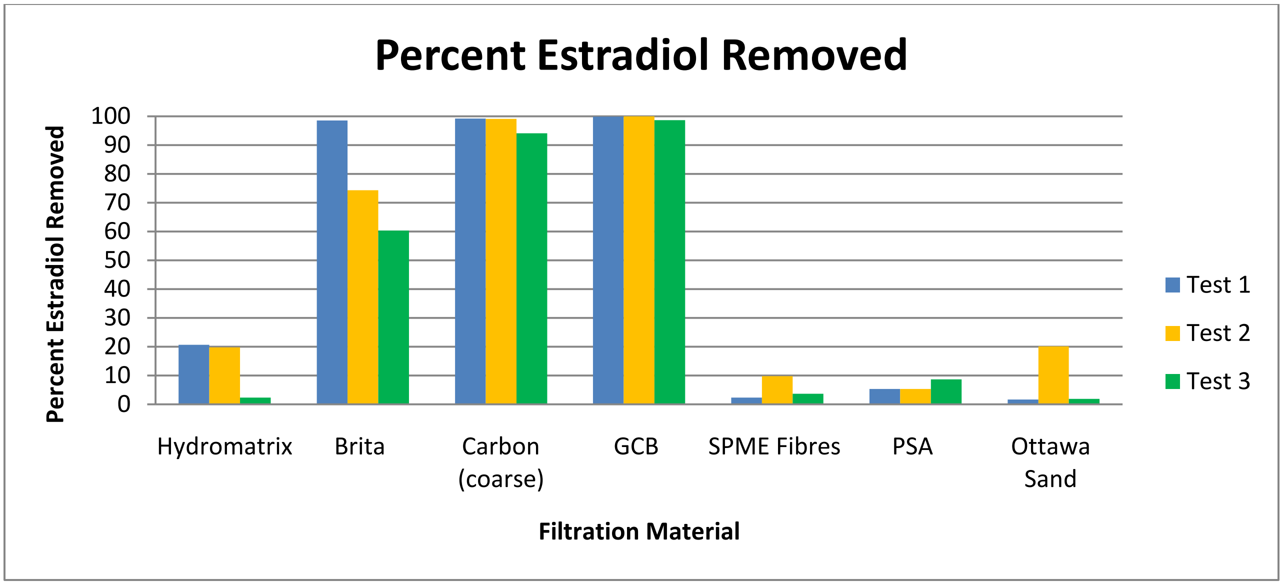

Figure 2. Percent estradiol removed. The graph compares the percentages of estradiol removed by each filtration method. It also compares tests 1 through 3 based on the percentage of estradiol removed by each material.

Table 4. Filtration Test 1 (Ethynylestradiol)

Filter Material	**Ethynylestradiol Added ng/mL**	**Ethynylestradiol Removed** ng/mL	**Percentage Removed %**
Hydromatrix	300	56	18.7
Brita	300	292.2	97.4
Carbon (coarse)	300	296.8	98.9
GCB	300	300	100
SPME Fibres	300	11	3.7
PSA	300	25.1	8.4
Ottawa Sand	300	12.4	4.1

The data was collected by using the HP 1100 and depicts ethynylestradiol added, removed, and percentage removed be each filtration material.

Table 5. Filtration Test 2 (Ethynylestradiol)

Filter Material	Ethynylestradiol Added ng/mL	Ethynylestradiol Removed ng/mL	Percentage Removed %
Hydromatrix	300	60.7	20.2
Brita	300	199.2	66.4
Carbon (Coarse)	300	297.7	99.2
GCB	300	300	100
SPME Fibres	300	36.7	12.2
PSA	300	30.3	10.1
Ottawa Sand	300	57.4	19.1

The data was collected by using the HP 1100 and depicts ethynylestradiol added, removed, and percentage removed be each filtration material.

Table 6. Filtration Test 3 (Ethynylestradiol)

Filtration Material	Ethynylestradiol Added ng/mL	Ethynylestradiol Removed ng/mL	Percentage Removed %
Hydromatrix	300	11.5	3.8
Brita	300	165.9	55.3
Carbon (Coarse)	300	274.3	91.4
GCB	300	295.5	98.5
SPME Fibres	300	15.4	5.1
PSA	300	45.4	15.4
Ottawa Sand	300	11.9	4

The data was collected by using the HP 1100 and depicts ethynylestradiol added, removed, and percentage removed be each filtration material.

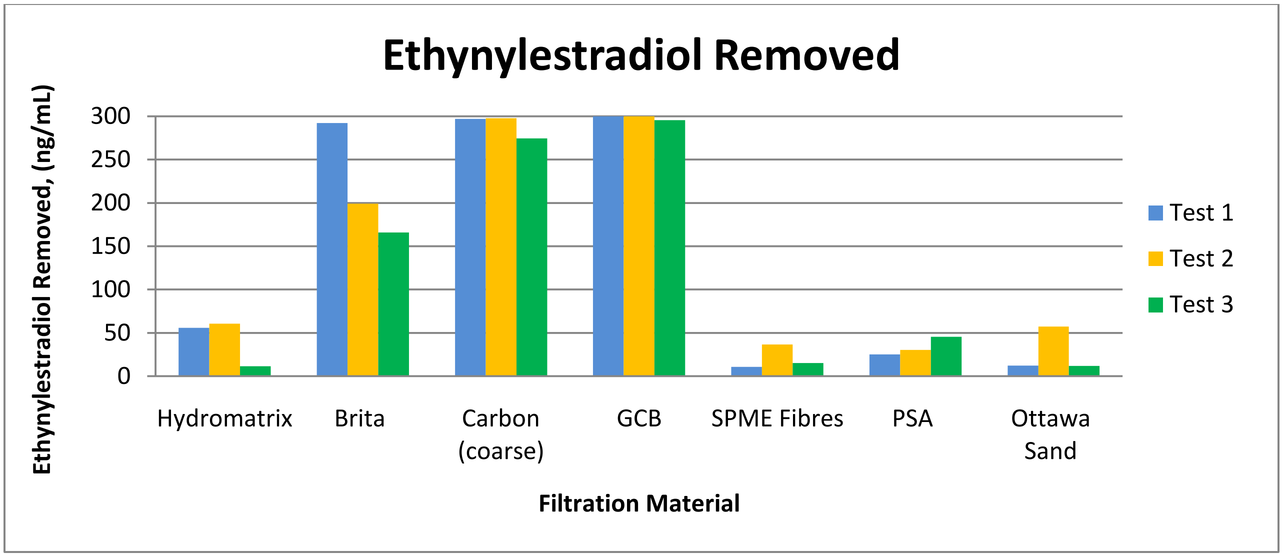

Figure 3. Ethynylestradiol removed. The graph compares the amount of ethynylestradiol removed by each filtration method. It also compares tests 1 through 3 based on the amount ethynylestradiol removed by each material.

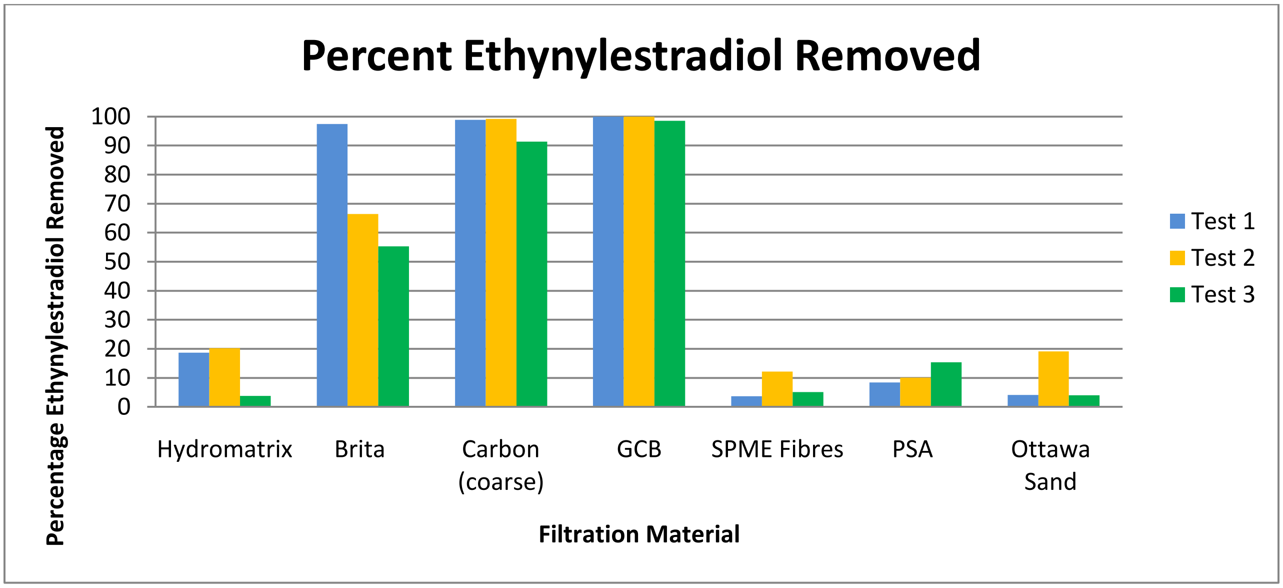

Figure 4. Percent Ethynylestradiol Removed. The graph compares the percentages of ethynylestradiol removed by each filtration method. It also compares tests 1 through 3 based on the percentage of ethynylestradiol removed by each material.

Analysis and Discussion

Overall, the data collected came out relatively consistent. The hydromatrix took out on average a total of 42.8 ng/mL of estradiol, or roughly 14.3%. It also removed an average of 42.7 ng/mL of ethynylestradiol, or roughly 14.2%. Therefore, the hydromatrix was not very effective at removing the estrogen, but was able to remove compounds equally well.

The Brita filter removed an average of 233 ng/mL of estradiol, or roughly 77.7%. It also removed an average of 219.1 ng/mL of ethynylestradiol, or roughly 73%. Something to consider is that when the water vacuum was used in test 2, the Brtia filter worked less effectively. This is most likely because the Brita material is designed for a slow drip filtration, not a suction-aided method.

The coarse carbon was mainly effective, removing an average of 292.4 ng/mL of estradiol, or roughly 97.5%, from the water. It also removed an average of 289.6 ng/mL of ethynylestradiol, or roughly 96.5%, from the water. The coarse carbon worked effectively and allowed the water to flow through the material quickly. However, unlike material like the hydromatix material, it was able to remove a large amount of the estrogen compounds.

The most effective filtration method, GCB (graphitized carbon black), removed an average of 298.6 ng/mL of estradiol, or roughly 99.5% percent. The GCB also removed an average of 298.5 ng/mL of ethynylestradiol, or roughly 99.5%. The averages are almost equal for the removal of both types of estrogen.

The SPME Fibres, PSA, and Ottawa Sand had negligible effects on removing the estrogen compounds from the water.

The data is mostly consistent throughout. The only lapse or non-similar data occurred with the Brita filter. This was most likely due to the fact that the material was not being used at the Brita company had formulated it to work. However, in order for all the materials to be tested on under the same conditions, the vacuum had to also be applied to the Brita filter material.

Conclusions

After analyzing and thinking about the data, the conclusion was reached that GCB (graphitized carbon black) is the most efficient filtration material at removing the estrogen compounds estradiol and ethynylestradiol from water. Therefore, the hypothesis was correct. The finer ground particles of the GCB led to it being the most effective. Aside from the coarse carbon, the other materials could not remove enough estrogen to be considered effective filtration methods. The Oasis products that were tested are negligible also because they are chemically formulated to absolutely purify water of every pollutant. Therefore, they were guaranteed to reach percentages of 100% removed. Also, these Oasis products are very expensive to obtain, and not at all practical to use. The GCB is even more impressive because on three occasions it matched the effectiveness of the Oasis products. So, although it had a slower flow rate, most likely due to the small cartridge it was in, it is still the most effective and practical filtration material.

Limitations and Assumptions

It was assumed that the best materials to purify water would be filtering materials. The estrogen compounds used (estradiol and ethynylesradiol) are similar to the estrogens that pollute our water supply. Estradiol is a natural estrogen, and ethynylestradiol is an estrogen normally found in birth control pills. A vacuum was used to control the time during which the water was pulled through the filters. Also, the estrogen concentration in the water was created to both replicate the small amounts in the environment, and to be great enough to be easy to measure in the water. Seeing as data was collected by a machine, the only sources for error would be very minor human errors involving exact measurements, exact times, or exact concentrations of estrogen.

Applications and Future Experiments

The work shows that estrogen can be removed from water in multiple ways very efficiently. Therefore, this shows that water treatment plants could be working with these methods to further improve the safeness and quality of our public water supply. The work presents practical uses for estrogen-removing filtration devices. These filters can be used in a similar fashion to a Britta water filter in order to make a home filtrations system that can be used by families to purify their tap water. The prototype must be improved in both efficiency (how much estrogen it can remove from the water) and practicality (speed and size of the device). Further research can be done for more filtration materials to see if there are better materials to use. Also, filtration materials can be mixed and combined to see if a multiple materials can work better together than alone.

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